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Proceedings—Pinyon-Juniper Conference

Reno, NV, January 13-16, 1986

Compiler:

RICHARD L. EVERETT, Project Leader, Intermountain Research Station, Forest Service, U.S. Department of Agriculture

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FOREWORD

The Pinyon and Juniper Woodland Formation occurs over large acreages from Mexico to Canada and from California to Texas. The vegetation type is poorly understood, inadequately defined, and often misused. Significant management problems are identifying and classifying woodland sites, understanding woodland ecology, and proper management for sustained resource productivity. Land managers and scientists alike recognized the need to improve our understanding of woodlands and their management.

An interagency steering committee was formed to develop a state-of-the-art management guide for woodlands. The approach selected was to hold a West-wide pinyon and juniper conference to gather the required information, develop a management guide from the conference papers, and hold field workshops utilizing the management guide. To that end, this conference proceedings brings together current research and management perspectives on pinyon and juniper woodlands. Session topics were selected by the steering committee to provide the required scientific and management base for practical and ecologically sound management guidelines. Session chairmen selected by the committee solicited the speakers for their own sessions as they saw fit. The success of the conference was largely due to the efforts of the session chairmen and their invited speakers.

This proceedings provides information on woodland paleobotany, inventory and classification, synecology, silvics and silviculture, fire response, economics, plant-water relations, woodland conversion, range management, wildlife, woodland hydrology, and nutrient cycling. Paleobotany papers provide us with a perspective of where we are now in relation to the previous natural expansion, contraction, and movement of the Pinyon and Juniper Woodland Formation independent of human influence. Several general session papers allow us to evaluate the current human role in the woodland ecosystem. Inventory and classification provide a reference point to evaluate the current extent of the resource and its varying productivity potentials. Papers on synecology, fire response, and silvics provide insight into woodland successional processes and stand development. Woodland conversion, wildlife, range management, silviculture, and economic papers evaluate management alternatives and the required inputs for utilizing and maintaining wood and forage resources. The nutrient cycling papers define biotic and abiotic nutrient pools and the cycling processes in natural and disturbed systems. Woodland hydrology and plant-water relation papers discuss hydrologic models, water harvesting, the erosion process, and water use by trees and competing species.

Much information was provided by the conference. Difficult questions were asked by Native Americans about current overuse of woodland resources. Our own watchdog scientists asked us to be careful to separate fact from fable in the scientific literature.

A well-deserved thank you is extended to the interagency steering committee:

Richard Bassett, USDA Forest Service
Fred Gifford, University of Nevada/Reno
Leonard DeBano, USDA Forest Service
Jim Hagihara, USDI Bureau of Land Management
William Davis, USDA Forest Service
Steve McDonald, USDA Forest Service

the session chairmen:

Synecology	Paul Tueller, University of Nevada/Reno
Paleobotany	Julio Betancourt, University of Arizona
Fire	Henry A. Wright, Texas Tech University
Economics	Lawrence Garrett, Northern Arizona University
Inventory and Classification	James S. Hagihara, USDI Bureau of Land Management
Silvics and Silviculture	Milo Larson, USDA Forest Service
Woodland Conversion	Earl F. Aldon, USDA Forest Service
Nutrient Cycling	Jeffrey M. Klopatek, Arizona State University
Plant Water Relations	Lee E. Eddleman, Oregon State University
Range Management	Rex D. Pieper, New Mexico State University
Woodland Hydrology	Fred Gifford, University of Nevada/Reno
Woodland Wildlife	Donald A. Klebenow, University of Nevada/Reno

and to the University of Nevada, the host organization for the conference.

RICHARD L. EVERETT
Chairman, Conference Steering Committee

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General Session

MULTI-RESOURCE MANAGEMENT OF PINYON-JUNIPER WOODLANDS

Robert E. Buckman and Gale L. Wolters

ABSTRACT: Pinyon-juniper woodlands occupy more than 47 million acres and are the most extensive forest type in many western States. In the past, woodlands were often ignored or converted to grasslands. The Forest Service is involved in the inventory, management, and research of pinyon-juniper woodlands. Forest Survey crews are documenting woodland resources on BLM and National Forest lands. An administrative study on the Tonopah Ranger District, in the Great Basin, was one of the first attempts at multiple-use management of the woodland. Research is examining the basic ecology of the woodland and developing new and improved management techniques. Woodland response to fire, tree harvesting, and mining activity has been documented. Woodland management strategies are being developed to utilize multiple-cash crops from forage, pine nuts, Christmas trees, and fuelwood while maintaining site quality and productivity for future generations.

INTRODUCTION

Pinyon-juniper woodlands occupy over 47 million acres in the Western United States, primarily in Nevada, Utah, Arizona, New Mexico, and Colorado. Extensive stands also occur in California and Texas, and a few stands are in southern Idaho, southeastern Oregon, southern Wyoming, and the western tip of Oklahoma. The woodlands occur predominantly on foothills, low mountains, mesas, and plateaus at elevations generally from 4,000 to 8,000 feet.

The pinyon-juniper type tolerates a wide range of environmental extremes. The mean minimum monthly temperature can vary from 14 °F in January to 95 °F in July. Frost-free growing season averages 120 days. Cloudy days are rare and relative humidity is extremely low, resulting in very high potential evapotranspiration. Average annual precipitation varies from 10 to 20 inches. Storms tend to be infrequent but can be intense, contributing to rapid runoff.

Soils where pinyon-juniper grow are derived from a variety of parent materials and are typically well drained with low to medium fertility. Limited vegetative cover and a high proportion of bare soil contribute to unstable soil conditions. The erodible nature of unstable soil in combination with intense rates of precipitation contributes to a high rate of sediment yield.

Paper presented at the Pinyon-Juniper Conference, Reno, NV, January 13-16, 1986.

Robert E. Buckman, Deputy Chief-Research (retired), Gale L. Wolters, Range Scientist, Forest Environment Research, Forest Service, U.S. Department of Agriculture, Washington, DC

HISTORICAL USES AND VALUES

The pinyon-juniper type has been used by man for as long as 20,000 years; it first served the Indians, then the Spanish. Indians inhabited these woodlands probably because of the agreeable climate, plentiful supply of wood for cooking, heating, and building, a source of berries and nuts for food, and perhaps because it was a habitat for turkey, deer, and other wild animals. The Spanish followed essentially the same pattern of use. Besides depending on junipers and pinyons for fuel and building material, they used the trees for posts in fencing their livestock.

Southwestern settlers continued to have a high regard for the pinyon-juniper type; the pinyon was their traditional Christmas tree, pinyon and juniper foliage was used for decorations on special occasions, and the wood was cherished for fuel. During the 19th century, vast areas of pinyon-juniper woodland around mining towns and other settlements were clearcut for mine props, fuelwood, and railroad ties. Most stands were high-graded, leaving residual stands of poorly formed trees and inferior species. The few remaining virgin stands were confined to remote areas and to poor sites. During the last 100 years pinyon and juniper stands have expanded greatly. Trees have encroached into areas that were formerly open grassland and tree density has increased on areas that have historically supported pinyon and juniper stands.

The understory vegetation component of pinyon-juniper woodlands has been extensively grazed by livestock for more than a century, and some parts have been grazed for as long as four centuries. All too often, grazing was continuous and excessive, resulting in unsatisfactory range condition on more than 50 percent of the type. Grazing on most of the pinyon-juniper ranges has been brought under management, and the type typically provides 2.4 million animal unit months of grazing annually, but recovery of the range has been slow.

Water is a limited resource in pinyon-juniper woodlands. The annual yield is estimated to be 4.2 million acre feet. Due to the scarce nature of water throughout the arid Southwest, it is an extremely valuable commodity. Unfortunately, soils are quite erosive; sediment yield is estimated to be 5 million tons annually.

The pinyon-juniper woodland also provides seasonal to yearlong habitat for over 150 vertebrate species of wildlife, with birds and small mammals being the most abundant. Only a few species are closely associated with the woodland--pinyon mouse, pinyon jay, and the gray flycatcher are perhaps the most dependent. The type provides seasonal habitat for a number of game and nongame species, and a few of the most common or spectacular winter residents are turkey, mule deer, and Rocky Mountain elk.

Hunting, operation of off-road vehicles, the experience of solitude, and the gathering of nuts and firewood are growing forms of recreation provided by the pinyon-juniper woodlands. Annual recreational use was recently estimated at approximately 1.5 million visitor days.

Prior to settlement of the Southwest by European man, pinyon-juniper stands were more open and largely confined to rocky ridges and shallow soils. Due to the combination of overgrazing, exclusion of fire, and perhaps changes in climate, pinyon-juniper not only encroached on the grasslands, but the original stands of trees also became more dense. Once trees became established on an area, they influenced species composition and growth of understory plants far beyond the limits of their crowns.

EARLY RESEARCH

Most of the pinyon-juniper type has been exploited without regard for sustained productivity for various lengths of time and for numerous reasons. Research was initiated early in the 20th century to improve range condition, soil stabilization, and forage production in pinyon-juniper woodlands. These investigations consisted primarily of attempts to convert pinyon and juniper stands to grassland (type conversion). Stands have been chained, cabled, clearcut, crushed, sprayed and burned, and then seeded to grass in an effort to increase forage production. Native, exotic, and improved grasses were frequently seeded with varying degrees of success.

Soil moisture is probably the limiting factor in revegetation of pinyon-juniper lands. Cultural practices that concentrate and conserve soil moisture usually provide a greater degree of seedling success. As a result, practices that provide a protective mulch on the soil surface are important to seedling establishment, as is selection of plant species based on their environmental tolerances.

Research suggests that there is little opportunity for increasing water yield in this type except in basins with volcanic soils. Here, chemical killing of the pinyon-juniper overstory and leaving the dead trees standing may result in increased water yields. Even then this increase can be expected about 1 out of every 2 years when precipitation equals or exceeds the winter average. To make this treatment economically feasible, a land manager must consider the benefits to other resources, such as additional forage, soil stability, esthetics, or wildlife habitat. Pinyon-juniper woodland is one of the most arid forest cover types in the world. Production is low per unit of land area, even under management strategies designed to maximize single resource outputs, and intensive management that enhances only a single resource is generally not cost effective. Thus, researchers and land managers must consider management costs in terms of land stewardship and productivity of multiple-resource outputs.

Conversion of dense woodlands followed by artificial seeding of grasses and forbs can improve deer forage under certain conditions. Where tree clearing is done for deer, it should be confined to areas of dense, extensive woodland where former small openings have been invaded by trees. The cleared areas should also be kept small. Excessive type conversion of pinyon-juniper can damage deer habitat and reduce deer populations and hunting success. Populations of some wildlife species will suffer as a result of partial removal of the tree stands, while other species will benefit from a reduction in arboreal cover.

Substantial amounts of wood have been harvested from the pinyon-juniper type, but until recently very little thought was given to managing the trees for sustained wood production. Limited information suggests fuelwood growth of fully stocked pinyon-juniper stands may range up to 30 ft^3/acre/year. Site quality and stand stocking influence the rate of biomass accumulation, as in the more productive forest types, and the basal area growth of fully stocked stands appears to be a good index of site quality.

Tree growth and yield throughout the pinyon-juniper type could be improved by application of stand improvement practices used commonly in other forest types. For example, harvest cuts should remove trees that have poor form, that are infested by disease, or that are not expected to survive until the next harvest; seed from superior growing stock should be used in stand regeneration, and trees should be harvested only on sites that can be regenerated. Logger's choice should no longer be the prevailing practice.

MEETING CHANGING DEMANDS

The demand for arid land resources is dynamic and there has been a dramatic change in the demand for renewable and nonrenewable resources from pinyon-juniper woodlands since the early 1970's. The demand is becoming more acute for clean air and water, inexpensive forage, wildlife habitat, quality recreational experience, and trees and wood products such as chips, posts, cordwood, nuts, and Christmas trees. Our knowledge required for management of this diverse ecosystem, however, is not complete.

The outlook for providing technical information needed by land managers is not optimistic. Opportunities for conducting research with Federal funding are severely constrained and limited

funding will most likely continue. For example, pinyon-juniper research within the Forest Service is restricted to six locations. Funding from timber, water, range, wildlife, fire, economics, and forest survey supported our pinyon-juniper research activities in fiscal year 1985 and, combined, our total pinyon-juniper research program was about $1 million.

In addition to the Forest Service's research program, the Agricultural Research Service, Soil Conservation Service, Bureau of Land Management, and possibly other Federal agencies, support research and development activities directly and indirectly applicable to the pinyon-juniper type. We suspect the total research and development commitment by other Federal agencies may be larger than the Forest Service pinyon-juniper research program. Perhaps the largest and most aggressive pinyon-juniper research program is that conducted by the western universities and State Agricultural Experiment Stations. Although dated and incomplete, the Current Research Information System listed slightly over $1 million in pinyon-juniper research by State Agricultural Experiment Stations and land-grant institutions in fiscal year 1984. Still, the total research effort from all sources devoted to the pinyon-juniper ecosystem is inadequate when the extent, complexity, and potential value of all resources are considered

AN INTERNATIONAL PERSPECTIVE

We believe, too, that there is much to be gained by sharing information worldwide. Environments similar to those that sustain the pinyon-juniper ecosystem occur on every continent in the world and provide opportunity to exchange technical information and enhance understanding through international cooperation and development. For example, the November 1984 USDA Memorandum of Understanding with the Ministry of Agriculture and Water Resources in Mexico provides opportunity to cooperate in many activities directly applicable to pinyon-juniper ecosystems. The International Union of Forestry Research Organizations also provides opportunity for sharing information worldwide as does the Scientific and Technical Exchange Program managed by the USDA Office of International Cooperation and Development.

The Forest Service participates annually in numerous exchange visits with foreign countries. In addition, we have extrapolated and exchanged information on arid shrubland seeding techniques, seed mixtures, and equipment and management recommendations internationally, and we have received, improved, and exchanged plant materials internationally for use in arid environments. Many fruitful avenues for exchange of technical information remain unexplored.

FUTURE INFORMATION NEEDS

The reason for this conference is more than a sharing of the state-of-knowledge about pinyon-juniper ecosystems. Equal or perhaps more important objectives are to (1) develop a proceedings which will serve as a technology transfer tool and (2) schedule field workshops to ensure the information is applied by land managers. From a scientific perspective the proceedings will serve as background for future research planning. Overall, the conference, the proceedings, and the field workshops will draw attention to the multitude of resources that comprise the pinyon-juniper woodland.

We are convinced that a resource of this extent and complexity holds many values, some of which we are only vaguely aware of now. It is likely to be shortsighted to manage for maximization of a single or a few selected resources. Rather, stewardship--conservation of all renewable and nonrenewable resources and protection of inherent site productivity--is more likely the appropriate management objective on pinyon-juniper lands, as on most of the Nation's wildlands.

In regard to future research needs, we believe a renewed emphasis on basic ecological studies--both autecological and synecological research--is necessary. Research on basic ecological processes in pinyon-juniper and associated arid land ecosystems is likely to yield highly useful, new information just as it has on other wildland ecosystems in recent years. Also needed are new innovative approaches, methods, and techniques to study ecological processes in arid lands.

We believe it is imperative to develop a better understanding of multiple-resource interrelationships on pinyon-juniper and associated arid lands. If we can quantify and describe resource relationships, cost-effective management practices that enhance multiple-resource outputs can be developed. A better understanding of resource relationships also is a requirement for conflict resolution.

We believe the research needs of pinyon-juniper and similar ecosystems must be viewed, packaged, and articulated through the same process used on other predominantly publicly owned forest lands--that they be treated as multiple-resource lands. Granted, forage and grazing by domestic livestock has been the predominant historical use, but these lands provide a large variety of resources and likewise the research program must reflect a multifunctional, multidisciplinary approach. Throughout the remainder of this conference we will learn more about the multiple resources on pinyon-juniper woodlands. We must use this knowledge to build sound research programs that will in turn provide information needed to manage these ecosystems.

We have made tremendous progress since the last pinyon-juniper conference nearly a decade ago. Scientists at this pinyon-juniper conference have a tremendous opportunity to directly influence the future value of this extensive resource. The combined knowledge and wisdom resulting from this conference will serve as a framework for the future of arid shrublands.

MULTI-RESOURCE MANAGEMENT OF PINYON-JUNIPER WOODLANDS:

TIMES HAVE CHANGED, BUT DO WE KNOW IT?

David P. Tidwell

ABSTRACT: Pinyon-juniper woodland occupies about 60 million acres in the western United States. In the past 3 decades agencies focused a great deal of attention on converting areas of pinyon-juniper woodland to more productive sites for increased livestock forage, improved big game habitat, and improved watershed conditions. Several methods to accomplish the restoration were used with varying degrees of success, i.e., manipulation of livestock grazing, mechancial removal of trees, and chemical treatment. The most common and effective, was mechancial treatment accompanied by the introduction of grasses or a mixture of grass, forbs, and shrubs. In the 1970's, environmentalists challenged the use of mechanical treatment because of its drastic effect on the environment. Costs became restrictive. More recently, greater attention has been directed to the production of woodland products such as firewood, Christmas trees and pinyon nuts. There is a continuing need to selectively restore depleted pinyon-juniper woodlands to more productive sites, however we must consider all resource values produced on the site. The land manager is encouraged to look at innovative ways to achieve these objectives.

INTRODUCTION

For as long as most of us have been aware of the pinyon-juniper woodland type, we have looked upon the aggressive juniper and the scrubby pinyon as weeds in need of eradication. For many years, the pinyon-juniper was considered an indicator of range abuse resulting from improper livestock management.

The traditional plan of action was to break-out the D-8's and the Ely Chain, the fuzees and later the heli-torch. Tear out the pinyon-juniper, burn it and seed it to grass to create livestock forage and wildlife habitat.

Now, that's not a goal to be ashamed of. Hundreds of thousands of acres of underproducing rangeland has been transformed into highly productive grazing land.

Paper presented at the Pinyon-Juniper Conference, Reno, NV, January 13-16, 1986.

David P. Tidwell is Special Assistant to the Director, Bureau of Land Management, U.S. Department of the Interior, Washington, DC.

But haven't we overlooked something? We've been mangling and burning the most valuable parts of the pinyon-juniper ecosystem -- wood products. Thirty years ago, the demand for firewood was limited to those few people who lived in and near the pinyon-juniper woodland. The settlement of the West was moving fast, but adequate supplies of firewood and fence posts existed within easy reach of population centers. Most preferred the easy to reach, easy to cut pines and firs on the high, lush slopes. Except for Christmas trees and pinenuts, the dry, scrubby pinyon-juniper were usually ignored.

Then came the energy crisis. Every new home had a fireplace and/or a woodheater. The demand for fuelwood soared. The pinyons and junipers were gradually discovered to be excellent firewood.

But upon close examination, the pinyon-juniper ecosystem produces far more than firewood. A complete array of multiple-use values are to be found. I'll describe those more specifically in a moment.

The revelation that the pinyon-juniper type is not just a king-sized weed patch creates some exciting opportunities.

Innovative management approaches are required to economically utilize products from pinyon-juniper woodland. Until better, more lucrative markets are developed for pinyon and juniper products, creative marketing, harvesting and processing methods must be devised which will allow commercial operators to make a profit.

We live in a changing society in an era of energy awareness. The demand for resources from pinyon-juniper woodlands will increase. I look forward to the papers which have been prepared for this Pinyon-Juniper Concerence for some of the creative management ideas that will help the Bureau of Land Management best utilize the multiple resources from the pinyon-juniper type.

MULTIPLE-USE DIVERSITY IN THE WOODLAND

The pinyon-juniper ecosystem encompasses some 60 million acres under Bureau of Land Management administration in the West. The range of the various species of junipers extends from coast-to-coast, from Canada to Mexico.

There are a number of common perceptions of pinyon-juniper woodlands that need examination. Terms like static, slow production, veritable wastelands don't hold water.

The pinyon-juniper types produce little of useful or economic value and must be eradicated or rehabilitated through intensive infusions of machinery, manpower and money.

As we now look at this ecosystem aren't such activities wasting useful and valuable resources?

Since Jim Hagihara first asked me to participate in this Conference, I have been looking for some examples of pinyon-juniper woodland management that might be interesting to you and that might also demonstrate some innovation or creativity.

I have discovered that there are a multitude of values, uses and products which industry and the American public receives from the pinyon-juniper ecosystem. They include:

1. Firewood
2. Fence Posts
3. Speciality Wood Products
4. Chips
5. Christmas Trees
6. Pinenuts
7. Wildlife Habitat
8. Livestock Forage
9. Wild Horse and Burro Habitat
10. Watershed Stability
11. Public Recreation

The demand for woodland products has increased dramatically over the last few years. The Special Public Domain Forestry Evaluation conducted by the Washington Office in 1981-82 pointed out that the public demand for wood products may be great enough to generate an income which exceeds the cost of management. The report recommended a more positive approach to woodland management through the development of policy and goals at the same level of guidance for commercial forest land.

In 1982, a policy statement was developed for management of Bureau woodlands. The statement says:

> It is the policy of the Bureau of Land Management to optimize benefits from the management of woodlands under its jurisdiction by incorporating principles of multiple use and environmental quality in a program which accomplishes the following:
>
> - Recognizes woodlands as distinct ecosystems to be managed and perpetuated for the production of multiple-resource values. These values include wood products, forage, wildlife habitat, recreation uses, watershed protection and minerals.
>
> - Develops and maintains an extensive inventory and classification of public woodlands. This information will be used to determine productive capacities and to ensure an orderly harvest of the woodland products.
>
> - Strives for a program that achieves a positive benefit/cost ratio and obtains a fair market value for the woodland products.
>
> - Facilitates the management of other resources and public use through sound management practices.

The Bureau's woodlands are being inventoried to determine their acreage, condition and productivity. These woodlands are being further classified as available or nonavailable for woodland product harvest. It is the Bureau's policy to manage the available woodlands under principles of sustained yield, maintaining an allowable harvest to provide a permanent source of woodland products for future generations. It is additionally the Bureau's policy to encourage the public to salvage wood and other forest products that have historically been lost through such actions as chaining, rights-of-way clearing and burning.

THREE MANAGEMENT EXAMPLES

I have examined three areas which include BLM lands that are each being managed under a somewhat different philosphy, but to varying degrees reflect a drift from traditional, wasteful, exploitive techniques to strategies that recognize existing multiple-use and attempt, with some degree of creativity, to manage within the pinyon-juniper ecosystem for an optimum of values.

The first has been producing a sustained yield of products for more than 30 years. The second for about 15 years, and the third a newcomer, so to speak, with the management philosophy evolving toward ecosystem integrity over the past 5 years.

The first area I'll discuss is just down the road about 5 to 10 miles east of Carson City, Nevada. It's an area called Brunswick Canyon. Some of the area was chained a long time ago, but has re-grown. This unit has supplied much of the Carson City/Reno metropolitan area with Christmas trees and firewood on a sustained-yield basis for more than 30 years and is still going strong. It has been under an intensive woodland management plan for 3 years. In addition to the wood products, the unit has produced a stable or increasing supply of forage for cattle, sheep, mule deer and a large herd of wild horses.

Records on a 25,000 acre tract under sustained-yield management show that the unit is producing 5,000 cords of fuelwood and more than 15,000 Christmas trees annually.

Revenues over the past 3 years have been $142,389.00, with costs for the same period totalling $145,400.00. For all practical purposes the unit is paying its way with saleable products. The other values are a bonus.

The second area in the Taos Resource Area in northwestern New Mexico on intermingled private, State and Section 15 BLM land combines the

multiple-use, sustained yield policy with a creative cooperative management approach with the lessee. The lessee, Don Berryman, is the majority landholder in the unit and sells wood products (mainly pinyon firewood) from his private land. He has a commercial firewood permit from BLM on his leased land. After the first year when he worked closely with the Bureau foresters in laying out and marking the sale, Mr. Berryman now marks, sells and supervises the BLM sales himself, along with his private sales. BLM checks the sales at the end of the season for compliance. Mr. Berryman's self-imposed standards are higher and more conservative then BLM's standards.

Mr. Berryman does not attempt to alter the sites, but merely harvests the woodland to release sub-dominant trees and to allow easier access to woodcutters, hunters and his saddlehorses when he gather's his cattle.

He is careful not to remove a volume of trees that would reduce cover for wildlife. His goal is to provide a sustained yield of wood products while maintaining optimum cover for wildlife, shade for livestock, access through the woodland sites and preserving the natural landscape.

Deer and elk populations are growing rapidly on Mr. Berryman's operation because of his exceptional stewardship program. His livestock operation and innovative range management has brought him national recognition.

While Mr. Berryman's program on Federal lands is a relatively modest one, the principles can be more broadly applied. The Federal share of his wood product operation is as follows:

Purchases:	100 cords firewood per year @ $15.00 per cord	
	Revenue	$1,500.00 per year
Administrative Cost to the U.S. Government		
5 man days per year		$ 550.00 per year
Net return to the Government		$ 950.00 per year

But compare this to the conventional way of doing business when BLM does not delegate the sale administration:

Purchases:	100 cords firewood per year @ $15.00 per cord	
	Revenue	$1,500.00 per year
Administrative Cost to the U.S. Government		
5 man weeks per year		$2,750.00 per year
Net return to the Government		*$1,250.00 per year

(*NOTE: LOSS OF $1,250.00 per year)

During the past 5 years, the Government has saved $11,000.00 in administrative costs and returned a profit of $4,750.00 to the U.S. Treasury as well as a result of the innovative cooperative management program being carried out with Mr. Berryman.

Another bonus is that Mr. Berryman scatters and breaks the slash by walking D-4 tracklayer over it. He also re-seeds the area to BLM specifications, all at his own expense.

The third area is in the Owyhee Resource Area in southwestern Idaho. Until 4 or 5 years ago, western juniper was considered a loser, to be chained, burned or otherwise eradicated. There was modest firewood use, but at insufficient levels to justify infusions of intensive woodland management. The focus was to prescribe burn and re-seed for livestock and wildlife forage.

Beginning in 1980 or 1981, significant blocks of juniper have been harvested by commercial woodcutters. To date, more than 100,000 acres have been harvested by southwestern Idaho residents.

The economic return is becoming attractive. The Boise District is now placing units of western juniper under a multiple-use, sustained-yield management plan. No longer is the philosophy of site conversion dominant.

The Boise District, as are most other BLM administrative units, it looking for innovative strategies of pinyon-juniper woodland sale administration, slash management and plan compliance.

BLM looks to this workshop and the proceedings which emerge from it for answers to the questions I have posed and many others which I have not.

CONCLUSIONS

The diversity of the pinyon-juniper ecosystem must be recognized by the agencies. Commercial and public utilization of pinyon-juniper wood products can and should replace traditional methods for removing excess biomass.

Conversion of the pinyon-juniper woodlands to grasslands will no longer be the primary management goal. Instead, long-term strategies which lead to sustained yields of many products and values must be devised and implemented.

The forestry profession must take the pinyon-juniper woodlands more seriously! Forest Products Utilization Specialists must team up with industry to develop new uses for pinyon-juniper products.

CHALLENGES

Foresters need to take a new look at the pinyon-juniper type as a productive, sustained yield unit.

Range Managers must revise their thinking as well. A thriving durable ecosystem can be developed which can produce surprising harvests of wood products, wildlife, Christmas trees, wild horses and burros, livestock and scenic beauty in perpetuity. It isn't a theory. It's being done.

In these days of austere Federal budgets, agencies must take advantage of the management expertise of private operators in sharing the burden of project planning, layout and administration. Profit margins are often too small, resource values too low to justify intensive sale administration. Participative management by responsible commercial purchasers as is taking place in New Mexico can save agencies scarce dollars without sacrificing the quality of management.

The BLM needs to sit down with commercial operators and jointly devise innovative ways of reducing harvesting and administrative costs on pinyon-juniper woodlands.

Perhaps, if the objective is to remove biomass, instead of BLM paying for chaining and burning, a cost-share contract arrangement could be developed that would significantly reduce agency costs while reducing the private operator's costs of operation to the point where his venture is profitable. Both parties would gain.

As our 1982 policy outlines, the Bureau of Land Management has changed its approach to pinyon-juniper management. More and more, the pinyon-juniper type is being recognized as a productive ecosystem, worth the investment of multiple-use management resources on a sustained yield basis.

But we need help. We need to be creative. We need to team up with the private sector to devise better, more economical ways of doing business.

There is a need for applied research on the pinyon-juniper ecosystem. Some of you here are providing that. We need to hear from you.

If you look at the agenda for the next 4 days, I'm sure the answers to many of our questions will be presented right here in Reno. BLM's management is looking to this Conference to provide some of the solutions to our management and research questions.

I commend Rich Everett, Jim Hagihara and the others of you that planned this timely and much needed Conference. I look forward to learning a great deal over the next few days.

CLIMAX OR ALTERNATIVE STEADY STATES IN WOODLAND ECOLOGY

Donald A. Jameson

ABSTRACT: Higher elevation areas of the pinyon-juniper woodland are climax forest and the usual concepts of (linear) plant succession apply. However, the more interesting ecological questions concern those areas where the time between regeneration events is longer than the life span of the established trees. In either case, there are years of above average precipitation that are not quite adequate for regeneration; these years may become adequate for regeneration if much of the competing vegetation is removed. Rather than linear succession, a more useful concept in pinyon-juniper dynamics seems to be that of alternative steady states. A cusp catastrophe model is suggested as a convenient way of visualizing the effects of fire, grazing, and climatic changes on woodland vegetation.

INTRODUCTION

The pinyon-juniper woodland has been often studied and frequently reviewed by several investigators. West (1984) and Shinn (1980) have assembled and synthesized much of this information, and their excellent reviews will be used here to provide the background ecological information needed in this discussion. Information on tree control problems has been drawn mostly from Arnold and others (1964) and Jameson (1971). The original research cited by West (1984), along with his references to bibliographies and other reviews, offers access to the bulk of the relevant literature on the pinyon-juniper type, and only selected articles will be cited here.

As pointed out by West, nearly all of the pinyon-juniper woodland has been heavily grazed by livestock, some for over 400 years. For much of the vegetation type, grazing use was probably most intense from 1880 to 1920; livestock numbers have generally been reduced since that time. There is no doubt that livestock grazing has been responsible for at least some of the profound changes that have occurred in the pinyon-juniper woodland during this century. Other factors, such as weather and fire, have also been an influence (Burkhardt and Tisdale 1976). However, structure of older stands, paleoecological studies, and dendrochronological records have also indicated that major changes in climate and resultant vegetation have certainly not been restricted to this century. Major changes in climate and geographic distribution of the pinyon-juniper woodland have been commonplace over past millenia.

The evidence for fire as an impact is in some cases very strong; evidence of fires of nearly all ages is commonplace throughout the woodland, both in recent centuries and earlier. West (among others) points out that pre-Columbian woodlands were likely more open "largely because of fairly frequent fires, some of which were due to Amerinds." However, a computer simulation model prepared by Samuels and Betancourt (1982) points out that, in local areas of high human population density, harvest of pinyon-juniper for fuelwood alone would have been sufficient to decimate the surrounding stands as early as 950 to 1150 A.D. Nineteenth century modern man may have also heavily harvested pinyon-juniper stands, especially near mining towns.

In spite of the rather clear evidence for fires as a widespread and important factor in the pinyon-juniper type, there are two pieces of counter-evidence about fire as a universal factor: (1) alligator juniper, a sprouting species, has had almost exactly the same successional pattern as the nonsprouting species (Jameson and Johnsen 1964), and (2) anyone who has actually tried to control the tree species in the woodland realizes that getting a fire to burn, let alone kill trees, requires a set of rather unusual conditions. It is also clear to those who have tried to control pinyon and juniper by mechanical means that keeping the trees from reinvading an old woodland area is no small feat. On the other hand, those who have attempted to plant these species, particularly the juniper species, would be tempted to avow that they are not adapted to the woodland type.

There is no doubt that disturbance by grazing, fires, and climatic shifts have all contributed to changes in density of trees within the pinyon-juniper woodland, and to changes in geographical distribution as well. In some cases, the changes that have occurred seem to be explainable by rather elementary cause-effect relationships. In other cases, very unusual forces would be necessary for some of the changes to have occurred, and overly facile explanations of the phenomena seem to fall far short.

Paper presented at the Pinyon-Juniper Conference, Reno, NV, January 13-16, 1986.

Donald A. Jameson is Professor, Department of Range Science, Colorado State University, Fort Collins, CO.

EFFECTS OF CLIMATE, FIRE AND GRAZING

Much of the literature on the woodland indicates that it was converted rather readily to grassland by natural or pre-Columbian man-caused fires and, once these fires occurred, the burned area remained tree-free or at a lower tree density for considerable lengths of time. However, the same species have been extremely difficult to control by mechanical or chemical means, or by fires that are caused by modern man, and the tree species quickly reinvade areas (unless the investigator is trying to establish trees) where control has been attempted. How can a single explanatory model handle such contradictory evidence? The factors of climate, fire, and grazing will be discussed here, first separately, then pairwise, then altogether, to see if at least some reasonably consistent conceptual picture can be drawn.

Climate

Climate, by definition, is the average of weather events over a period of years. However, some major changes of vegetation have been triggered by weather events of two consecutive years. For example, the noted "1919 reproduction" of ponderosa pine in Arizona resulted from, among perhaps other things, rather unusual weather in 1918 and 1919. How many years of unusually high rainfall qualify for a change in climate is not the point, but it is important to realize that changes in precipitation, over long periods as well as short periods, are commonplace. It seems to be universally true in a semiarid situation, such as these woodlands, that higher precipitation will result in easier (or more frequent) tree establishment and in denser stands. In an ecosystem such as the pinyon-juniper woodland, where climatic controls on tree establishment are critical, major shifts in vegetation density and distribution can occur as a result.

There is an important relationship between the frequency of weather events and the longevity of trees. If during the life span of trees there are several weather events leading to regeneration, a continuing tree stand should result. On the other hand, if a stand of trees dies before the appropriate weather events leading to regeneration occur, the area of land will only be occupied by trees intermittently.

Fire

Fire kills trees (at least nonsprouting fire susceptible trees). However, consider which pinyon-juniper stands are most likely to burn: (1) dense mature stands (often those located just below the ponderosa pine type), and (2) stands of small scattered trees with abundant herbaceous fuel between the trees. Stands of moderate tree density where competition from trees reduces the herbaceous fuel, and the trees themselves are too widely spaced to carry a fire, are exceedingly difficult to burn. Even stands of small scattered trees with blue grama as the major understory species (which is the case in much of northern Arizona, New Mexico, and southern Colorado) probably do not have enough fuel that fires, if they occur, could cause much damage to the trees. In northern Arizona, test fires in scattered stands of young juniper trees only killed the trees that had a collection of Russian thistle (not a pre-Columbian species) under the tree (Jameson 1962).

Grazing

As pointed out by West (1984), nearly all of the pinyon-juniper type has been grazed, and most of the type has been grazed heavily. There is no doubt that grazing heavy enough to be destructive to the herbaceous vegetation creates a site that is more favorable for tree establishment than is the case in an ungrazed area.

Climate And Fire

The upper elevational ranges of the pinyon-juniper type that have the most mesic climate also have the densest tree stands and greatest amount of woody fuel. Even in sparse stands, where the fuel to carry the fire must come from the herbaceous vegetation, a high rainfall year may be required to produce enough fuel for a successful fire. Thus there is a seeming paradox; although low precipitation in the year of the fire is undoubtedly necessary, those stands that have developed under the most mesic climate are the most susceptible to fire. In the more xeric stands those years following higher precipitation are the more favorable years for fire. More effort is required to have a successful fire in the more xeric stands than in the more mesic stands, and more effort is required to have a successful fire following a dry year than following a wet year.

Climate And Grazing

Grazing and wet years have a synergistic effect on tree establishment; destructive grazing followed by two wet years (the first for seed production, the second for establishment) is a favorable combination for tree establishment. Tree establishment in the pinyon-juniper type probably also requires an adequate population of birds or rodents to scarify and disperse the seed. With infrequent weather events favorable to tree establishment, heavy grazing can serve to increase the number of these events that will lead to tree establishment.

Fire And Grazing

Grazing, by removing herbaceous fuel, can significantly reduce the probability of fire. Protection from grazing can result in an accumulation of fuel and thus increase the chances of fire. However, herbaceous fuels do not accumulate to a great extent in the pinyon-juniper type except in the more mesic areas, so not too much emphasis should be placed on accumulation of herbaceous fuels.

Climate, Fire, And Grazing

In stands developed under mesic conditions, a shift from woodland to grassland as a result of fire is relatively easy. If, following the fire, the mesic conditions still pertain, the shift back to woodland is also relatively easy, particularly if facilitated by heavy grazing. However, if more xeric conditions exist following the fire, reestablishment of the tree species will not readily occur. Absence of grazing will further reduce the rate of pinyon-juniper regeneration.

In stands developed under xeric conditions, a shift from woodland to grassland as a result of fire is relatively difficult. If, following the fire, the xeric conditions still pertain, the shift back to woodland will also be difficult.

Because of these differences, a concept that encompasses the range of observed phenomena will allow a "smooth" woodland to grassland (or grassland to woodland) transition under mesic conditions, but will require more "force" or more unusual events to make the transition in either direction under more xeric conditions.

A CONCEPTUAL MODEL

A model to incorporate the above phenomena would not have jumps or discontinuities under mesic conditions, but would have discontinuities under xeric conditions. In addition, the pathway from woodland to grassland under xeric conditions probably would have more trees under a neutral fire/grazing "force" than would exist during a grassland to woodland transition with the same fire/grazing neutrality.

A cusp catastrophe model seems to fit the observed phenomena for pinyon-juniper succession (fig. 1). In this model, the amount of trees is the response; along the same axis the amount of grass is inverse to the amount of trees. There are two control axes; one represents climate or weather, and the other the fire/grazing "force". On this latter axis, fire is inverse to grazing, that is, grazing promotes woodland and fire promotes grassland. For present day woodland management concepts, "wood harvest" could be an alias for "fire".

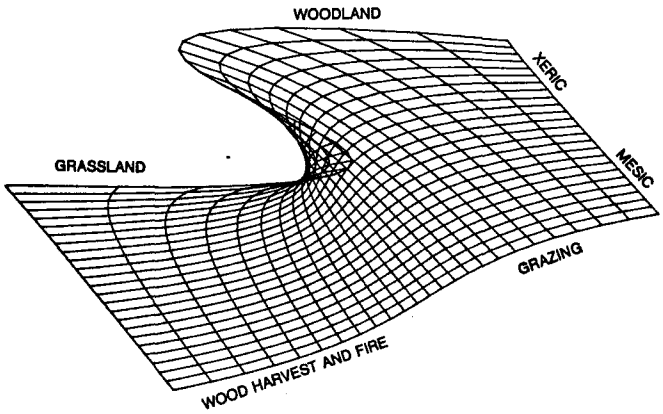


Figure 1.--A cusp catastrophe representation of pinyon-juniper woodland changes resulting from climatic or weather shifts and fire/grazing effects.

Organizing information around any model has certain implications about how the phenomena are expected to behave, and the model of figure 1 is no exception. Along the front or "smooth" side of the figure, the drawing represents the concept that, in more mesic zones, it is possible to make a smooth transition from woodland to grassland, or vice versa, with only minor forces applied. Since regeneration events occur fairly often and the tree stand can be maintained by new plant establishment, the natural transition from woodland to grassland in these areas is probably due primarily to fire. On a relative scale, fire can occur fairly readily. The transition from grassland to woodland is also a common event, and little (or perhaps even no) grazing is needed to promote regeneration.

Under more xeric conditions, however, regeneration and fire events are rare and require a greater "force" or energy level to occur. Weather events leading to regeneration with a full stand of herbaceous species are uncommon and reduction of the competing vegetation by grazing (or some other means) must be more severe for regeneration to occur. Fire events also require more energy of some kind in order to occur. In a purely natural situation this may mean that fire years are more unusual; in a managed situation this may mean that more cultural energy is required for control by fire (or control by any other means as well). Since tree growth is slow and regeneration is

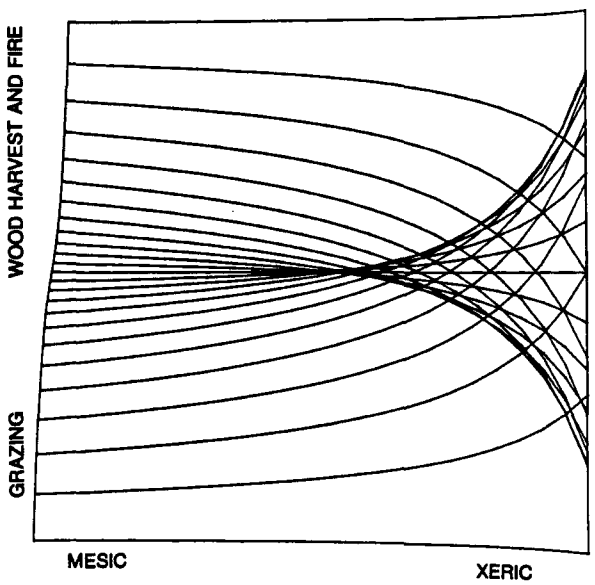


Figure 2.--An overhead view of figure 1. Lines represent the path of plant communities during a change from mesic (left) to xeric (right) conditions. Overlapping lines indicate the "bifurcation" where the pathways move into the folded area of figure 1.

rare, the Samuels and Betancourt (1982) hypothesis that harvesting alone could deplete a stand would be most appropriate under these conditions.

The back (folded) edge of figure 1 represents three of the four properties of a catastrophe model listed by Jones (1977):

1. Bimodality: the system tends to be either in a woodland state or in a grassland state; intermediate values of trees cannot be reached directly along the fire/grazing axis and tend not to occur.
2. Discontinuity (catastrophe): as the controlling factor (fire/grazing) moves toward either extreme, a point is reached where the response can no longer move smoothly, the jump to a different level at this discontinuity is what gives catastrophe theory its name.
3. Hysteresis: The path that the tree/grass response must make as the fire/grass control moves to the right is different than the response as the control moves to the left.

The fourth property of a cusp catastrophe, divergence, is represented in a movement from the front edge toward the back edge of figure 1. A small difference in tree/grass status under mesic conditions can result in development of woodland on one hand or development of grassland on the other hand as the system moves from mesic to xeric into the folded area of figure 1. The area where the pathways split is call a "bifurcation". This effect is shown in figure 2, a topographic representation of the surface of figure 1.

It is perhaps this view that most completely explains how woodland happens to occur under climatic or weather conditions which obviously would not foster the establishment of woodland, yet the woodland is persistent once it is established.

As pointed out by Jones (1977), the general cusp catastrophe model does not require that the maximum "force" for tree/grass (or grass/tree) conversion must necessarily occur under the most xeric conditions. As far as the mathematical model is concerned, the zone of maximum force or energy required to result in a change could be redrawn to show this occurrence at any point along the mesic/xeric axis. In other words, figure 1 could have two smooth edges with the fold in the middle of the figure.

MECHANISTIC MODELS

It should be emphasized that the model described above is only conceptual. In fact, the surface for the figures was generated from:

$$-(x^3 + qx + p) = 0$$

where:
x is the tree/grass response,
q is the control along the weather (climate) axis, and
p is the control along the fire/grazing axis.

Obviously this equation does not represent any ecological reality, but is the simplest mathematical form that will generate the desired surface (Fararo 1978, Jones 1977, Zeeman 1976). The ecological mechanisms involved would appear to include probabilities of weather events required for tree establishment and fires; grazing as a control mechanism for reducing the competition from herbaceous species; and the effect of fires or wood harvesting on tree mortality, particularly in the more xeric parts of the woodland ecosystem. A second level of mechanisms probably will be necessary to include studies of root growth and water uptake of tree seedlings and competing vegetation. In fact, McMurtrie and Wolf (1983), Noy-Meir (1982), Walker and Noy-Meir (1982) and Walker and others (1981) have presented models of about the appropriate level of mechanism to demonstrate at least the first three catastrophe properties listed above.

Although the equation used to generate the figures in this report is not related mechanistically to ecology, it is hypothesized that any model that adequately represents the successional behavior in the pinyon-juniper woodland will have similar properties. The model also has some other interesting properties in addition to those mentioned previously. Note that in the zone between the edges of the fold in figure 1, the equation gives three solutions for tree/grass response. However, for a given tree/grass response and position along the weather (or climate) axis, there is a single fire/grazing input. Thus it may be possible to reconstruct from ecological evidence the causes leading to a particular tree/grass mixture, but, because of the three solutions for a given input, it may not be possible to predict what the response will be without knowing the history of the stand.

MANAGEMENT IMPLICATIONS AND FURTHER RESEARCH

Regardless of whether or not the ecological mechanisms of pinyon-juniper succession are understood, the conceptual model presented here has at least some general implications for management and further research. It is clear that if woodland regeneration with a high probability of success is desired, only the more mesic portions of the type present real possiblities. Increased probability of regeneration can be achieved by increased grazing and protection from fire in these areas. On the other hand, management of these areas as grassland seems to be ecologically foolish because of the high probability of tree reinvasion. Earlier studies (Jameson 1971) have also demonstrated that, economically, the more dense stands are least desirable for conversion to grassland.

The more xeric parts of the woodland do not offer very good opportunities for wood fiber management, at least if regeneration is an issue. In these areas, the probability of tree regeneration is so low that a program that requires regeneration to be successful cannot be recommended. On the other hand, conversion to grassland in these areas could well be expected to have long-term effects

because, barring major climatic shifts, tree regeneration is infrequent. In much of the more xeric parts of the woodlands, tree control by fire is unlikely, unless there is a dense stand that has been established under more mesic conditions.

Thus the conceptual model seems to offer general, but only general, guidelines for management policy. Clarification of the general policy with application to specific sites will require a great deal more research on the mechanisms of tree establishment as influenced by weather and grazing.

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STAND STRUCTURE AND FUNCTION OF PINYON-JUNIPER WOODLANDS

Frank Ronco, Jr.

ABSTRACT: A keynote address, with broad coverage, on pinyon-juniper woodlands discusses factors influencing stand structure. Productivity of woodlands with regard to the overstory, undergrowth, and animal life, and tree and undergrowth relationships are covered, especially with regard to management implications. Productivity is correlated in general terms with stand dynamics and succession.

INTRODUCTION

Webster's Collegiate Dictionary defines a keynote address as one "designed to present the issues of primary interest to an assembly and often to arouse unity and enthusiasm." Your presence at this conference has already demonstrated a measure of enthusiasm. Similarly, your presence further suggests a degree of unity in the need for gaining a better understanding of the management of pinyon-juniper woodlands, even though our goals and their means of achievement may differ greatly. Since we are united and enthusiastic, the primary purpose of this presentation is the introduction of subjects of interest, not only those that will be covered in detail by participants of this conference, but, hopefully, others that might provide the theme for future gatherings of this kind. The approach I adopted was to address current woodland knowledge at a point between elementary distribution patterns and the specific processes or species' interactions.

Woodland structure, which in this presentation also includes species composition, can be expected to be quite variable. Similarly, a wide variety of functions may be associated with pinyon-juniper woodlands. The differences in structure and function result from a number of factors, including historical use and the widespread geographical and elevational distribution and associated climatological variation of the type throughout the West.

STRUCTURE

The climate, although generally characterized as semiarid and locally as dry subhumid (Thornthwaite 1948), can be further classified into a number of subdivisions based on temperature and moisture distributions and amounts (Springfield 1976). These subclimates exhibit temperature and moisture regimes that range from warm to cold, and vary from being uniformly moist throughout the year to having either dry summers or winters. Mean annual temperature varies from 40° to 61° F, with the frost-free period ranging from 90 to 205 days. Precipitation can be as little as 10 inches at low elevations to as much as 27 inches at higher elevations (West and others 1974; Clary and others 1974; Sellers and Hill 1974).

Vegetation over the range of woodlands reflects these climatic differences. Three major species of pines are represented--pinyon (Pinus edulis Engelm.), singleleaf pinyon (Pinus monophylla Torr. and Frem.), and Mexican pinyon (Pinus cembroides Zucc.) (Little 1971). Some taxonomists, however, believe that the pine found along the international boundary between Mexico and the United States is not Pinus cembroides var. bicolor Little (Little 1979). Instead, they consider it to be a separate species--border pinyon (Pinus discolor Bailey & Hawksw.) (Bailey and Hawksworth 1983, 1979). Juniper associates are more numerous, of which the most important are one-seed (Juniperus monosperma (Engelm.) Sarg.), Utah (Juniperus osteosperma (Torr.) Little), alligator (Juniperus deppeana Steud.), Rocky Mountain (Juniperus scopulorum Sarg.), and redberry (Juniperus erythrocarpa Cory) (West 1984; Lanner 1975). The undergrowth composition varies greatly, depending on the region and site (West and others 1975). It may consist of herbs or shrubs, or a mixture in some instances. In the northern range of woodlands, the shrub layer is composed of such species as big sagebrush (Artemesia tridentata Nutt.), bitterbrush (Purshia tridentata (Pursh) DC), and Gambel oak (Quercus gambelii Nutt.) (West and others 1975; Erdman and others 1969). Similarly, shrubs may be an important component of the undergrowth in chaparral woodlands of central and southeastern Arizona and southern New Mexico (Medina 1985; Moir 1979; Pieper 1977). The shrub layer is characteristically a mixture of evergreen, sclerophyll species including point-leaf manzanita (Arctostaphylos pungens H.B.K.), wavyleaf oak (Quercus grisea Liebm.), skunk-bush (Rhus trilobata Nutt.), and blue yucca (Yucca baccata Torr.). The herbaceous component of the undergrowth includes a number of different forbs and warm- or cool-season graminoids occurring in various combinations, depending on the particular site. Mosses, lichens, or other cryptogams may also be present. A given stand usually contains only a few plant species, but because of the wide distribution of the type, the total flora

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Frank Ronco, Jr. is Research Forester, Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Flagstaff, AZ.

associated with woodlands is quite varied (West and others 1975; Aro 1971; Potter 1957; Rasmussen 1941).

Pinyon-juniper woodlands consist of relatively few tree species, but stands exhibit considerable diversity in appearance and composition (Aro 1971). Some stands have closed canopies of a single tree species, with little or no understory vegetation; seldom, however, do pure stands cover large acreages (Howell 1940). Other stands, in contrast, are open, with widely scattered junipers, pines, or both, interspersed among grasses and shrubs. The woodland type is normally all-aged in the Southwest, and sample stands exhibit the typical inversed J-shaped diameter distribution curve when plotted against number of trees (Howell 1940). Similarly, some stands in the Great Basin also appear to be all-aged (Blackburn and Tueller 1970). Even-aged stands of pure pinyon, however, may become established on favorable sites in the Southwest after clearcutting (Howell 1940). Presumably, similar conditions exist in the Great Basin.

At lower elevations of the woodland range, pinyons tend to be bushy with sprawling crowns, whereas at the higher, wetter sites, trees reach their tallest heights and tend to be single-stemmed (Howell 1941). On these sites, pinyons and Rocky Mountain juniper may reach heights of about 50 feet and diameters of about 30 inches. Some junipers are characteristically multistemmed, but others, such as Rocky Mountain, have a single straight trunk.

Although not typically considered a part of structure, soil organisms cannot be overlooked as an important and integral component. Similarly, if we consider woodland structure in its broadest context, perhaps fauna should also be included as part of structure. Although more transitory than plants, animal life plays a vital role in the overall productivity of woodlands (Furniss and Carolin 1977; Frischknecht 1975; Little 1965; Rasmussen 1941). The impact of diverse life forms, such as insects and big game, cannot be overlooked.

Historical use since colonization has had an impact on stand structure throughout the woodland zone. Utilization by early homesteaders followed a similar pattern in the Southwest and in the Great Basin with regard to grazing activities and domestic consumption of woodland products such as fuel, posts, and nuts. However, use in the Southwest began in the early 1600's following Spanish colonization, whereas in the Great Basin, settlement was deferred until the mid-1800's. As a consequence, grazing probably had a differential impact on plant community development between the two regions. Because of the generally overgrazed conditions in either region, grass cover in woodland stands was weakened to the extent that it afforded little, if any, competition to tree seedlings. Furthermore, such stands of grass could no longer carry fire. Subsequently, trees not only encroached on grasslands, but original stands of trees increased in density (Parker 1945). However, the earlier introduction of grazing into the Southwest provided trees with nearly 300 more years of increased competitive advantage over undergrowth species. Consequently, stands in the Southwest are likely to be older, denser, and exhibit a wider range of age classes than stands elsewhere.

Similarly, a major difference in commercial use of woodlands existed between the two regions before the turn of the century. Except for heavy cutting in some localized areas to provide fuel for military installations (Moir 1985) and railroad ties, structural timbers, and limited amounts of fuel for the early mining industry (Medina 1985), large acreages were not cleared in the Southwest (Barger and Ffolliott 1972). In contrast, vast areas were clearcut in the Great Basin during the famous Nevada mining boom during the latter part of the 19th century to provide wood for kilns producing the charcoal so vital to the ore-smeltering process (Young and Budy 1979). Under these conditions of use, herbaceous plant communities in the Great Basin had an ecological advantage over woodland trees with regard to their development.

Because of the abusive practices in the past, a great proportion of existing plant communities, particularly in the Great Basin and to a lesser extent in the Southwest, are neither climax nor near-climax. Instead, they exhibit various features that are characteristic of the lower seral stages in the successional pathway.

While human activities have greatly altered or eliminated woodland areas, they have also benefited woodland establishment. Considerable evidence has accumulated to show that woodlands, especially those dominated by singleleaf pinyon, are invading areas outside their historic limits (Tausch and others 1981; Shinn 1980; Blackburn and Tueller 1970; Arnold and others 1964; Johnsen 1962; Cottam and Stewart 1940). In the Southwest, junipers are often the first trees to become established, and may be followed over time by pinyons, where a suitable environment exists (Woodbury 1947). Furthermore, tree density appears to be increasing in some stands that existed prior to the invasion period. Woodland expansion since the time of settlement has been attributed to several factors, including control of fires, reduced grass competition because of livestock grazing, and possible climatic changes. It has also been suggested that tree expansion may be related to reduced competition from understory vegetation resulting from the allelopathic influence of tree litter (Jameson 1970a, 1966), and to increased populations of seed-dispersing birds and mammals (Salomonson 1978; Wander Wall and Balda 1977).

FUNCTION

The pinyon-juniper woodlands can serve many functions, being limited only by the number of different objectives held by individual managers. However, any given function of a stand may be limited by the existing stand structure. A function could be extremely narrow, like providing

the obligate habitat for the pinyon mouse and pinyon jay (Frischknecht 1975), or extremely broad, like filling a gap in the overall scheme of ecosystem relationships. The specific function of woodlands may be somewhere in between these wide limits. For example, they may afford a place of recreation. Woodlands also function as do other biospheres, whether temperate evergreen forests or tropical rain forests, in providing a mechanism for the atmospheric exchange of carbon dioxide and oxygen. If one believes that forage production is the main reason for woodland existence, then the expansion of woodlands can be considered to be an undesirable function. Yet, to the woodcutter, this expansion is a normal function of woodlands.

This divergence of viewpoints regarding utilization, however, exemplifies, for all practical purposes, what I believe is the most important function of woodlands--their inherent productivity. This productivity may be primary, consisting of long-term biomass storage in the overstory, or more transitory energy storage in the undergrowth. Secondary productivity is also a function of woodlands, and its most important aspect probably consists of livestock and big-game husbandry. Such meat production comprises a major link in a food chain associated with woodlands, one that is related to humans and large predators.

Overstory Productivity

Tree growth is extremely variable over the woodland range. It can be as low as the equivalent of one fence post per acre per year (Myers 1962) to as much as 45.6 cubic feet per acre per year in overmature, dense pinyon stands in western Nevada (Reveal 1944). Gross annual increment on sample plots in the Southwest averages about 9.5 cubic feet per acre (Howell 1940), whereas annual increment of cordwood in the Great Basin approaches 17 cubic feet per acre (Meeuwig and Bassett 1983).

Tree volumes are not only difficult to measure because of the growth habit of woodland species, but can vary more than 300 percent for trees of the same diameter (Howell 1941). There is less variation in well-formed trees, however, and the gross volume of a representative pinyon with a basal diameter of 12 inches and 25 feet tall is 7.7 cubic feet, measured to a 4-inch top (Clendenen 1979).

Woodland volumes vary considerably, depending on species composition and density. In northern New Mexico and Arizona, mixed stands will contain cordwood volumes ranging from 0.8 to 25 cords per acre (Howell 1941), whereas in the Great Basin, volumes may reach 28 cords per acre (Meeuwig 1983). The low volumes in woodlands are a reflection of the small trees generally associated with this type. The average tree in many New Mexico stands is only 6 inches in diameter at ground line and about 9 feet tall (Howell 1941).

Undergrowth Productivity

Productivity of the undergrowth may be even more variable than that exhibited by the overstory, particularly since the undergrowth is inversely influenced by tree cover (Everett and Sharrow 1985; Jameson 1967). For example, in a sample of fully stocked stands stretching across central Nevada, herbaceous cover averaged a sparse 3.4 percent with a representation of only 73 species (Everett and Koniak 1981). In Arizona, herbage yields were only 50 pounds per acre where the canopy cover was 80 percent (Jameson and Reid 1965). Similar low cover and taxa numbers have also been reported elsewhere (Tueller and others 1979; St. Andre and others 1965). With such low densities of potential forage plants, it is little wonder that carrying capacity of woodlands has been estimated at over 40 acres per animal unit month in some areas (Everett and Sharrow 1985).

Although currently little is known about specific undergrowth reponses following tree harvest, several studies indicate that forage production and carrying capacity generally can be increased following tree removal (Everett and Sharrow 1985; Clary 1974; Aro 1971). The increase in forage production, however, can be extremely variable, ranging from little or no response to a 30-fold increase (Clary and Jameson 1981; Clary and others 1974; Aro 1971; Arnold and others 1964). Soil, climate, season and time of treatment, and plant composition are some of the factors accounting for the variation. Aside from increases in quantity of the undergrowth following tree harvesting, improved nutritional quality of the forage would benefit livestock and, especially, selective feeders such as deer (Everett and Sharrow 1985).

Although several factors, including shade, rainfall interception, tree litter, and phytotoxic root exudates, can account for reduced undergrowth production under tree canopies (Jameson 1970b, 1966), competition for soil moisture also appears to be an important consideration (Jeppesen 1978; Gifford and Shaw 1973; Skau 1964; Johnsen 1962). An individual tree exerts an influence on the undergrowth composition and growth even beyond its canopy. Competition for available soil moisture is greater in openings than under canopies because of the extension of tree roots into the interspaces (Jameson 1970b; Arnold 1964).

Precipitation in the woodland zones of the Great Basin and the Southwest does not appear sufficient to adequately support both tree and herbaceous vegetation. As discussed above, the reduced productivity associated with higher tree densities and the subsequent increase in the undergrowth following tree removal tends to support this conclusion.

Because of greater tree dominance resulting from expansion of woodlands and increasing stocking densities within existing stands, the amount of undergrowth in woodlands has declined drastically since the early 1900's (Tausch and others 1981; Blackburn and Tueller 1970). Furthermore, there appears to be a disproportionate effect on forage production, which may be more than 80 percent less

under a canopy than on treeless areas when the tree density approaches only 50 percent (Arnold and others 1964).

The practice of large-scale clearing of pinyon-juniper woodlands by chaining, cabling, and bulldozing, which began in the early 1940's, appears to have lost favor in recent years as a major means of increasing forage in the Southwest. The decline has occurred for a number of reasons, including an increased demand for trees as fuel, concerns of wildlife managers about the impact of clearing on small- as well as big-game animals, questions voiced by the public on esthetics, and an increased awareness of the overall importance and potential value of the sum of all woodland resources. About 3 million acres had been cleared in the West by 1964 (Terrel and Spillet 1975), but annual acreages being treated were already declining at that time (Cotner 1963).

Another rationale offered in support of early efforts at large-scale conversion of the woodland type was the expectation of increased water production. However, clearcutting in the pinyon-juniper woodlands, in contrast to harvesting in the more mesic spruce-fir and mixed conifer forests, has not proved to be an effective means for increasing water yields in the Southwest (Clary and others 1974; Collings and Myrick 1966). This failure to provide more water also tended to deemphasize the need for large-scale clearing operations.

The low water yield following cutting in woodlands of the Southwest should not be surprising because of the semiarid climate. Rainfall is limited to about 10 to 25 inches (Springfield 1976; West and others 1975; Woodbury 1947), and evapotranspiration is high. For example, a mean annual evapotranspiration rate of 17 inches has been reported, which is equivalent to 94 percent of the mean annual precipation (Baker 1982). Although water yield may not be an important function of woodlands, many stands have the potential for onsite improvement of water use efficiency (Gifford 1975).

Overstory removal for increasing forage production can be a viable management alternative, but its benefits must be balanced with overall management objectives. Furthermore, all potential woodland resources must be considered in planning. An integrated approach towards managing the pinyon-juniper woodlands appears to be more prevalent recently, at least in the Southwest.

TEMPORAL CHANGES IN STRUCTURE AND FUNCTION

Productivity, as expected, is related to stand development over time. Following removal of the overstory, whether by wildfire, harvesting, or destruction by chaining or cabling, a stand retrogresses to some point in the successional pathway. Different models illustrating succession following destructive fires have been developed for pinyon-juniper woodlands (Barney and Frischknecht 1974; Erdman 1970; Arnold and others 1964). Although varying somewhat in detail, each model exhibits a generalized successional sequence characterized by the following stages (Arnold and others 1964): (1) bare soil and dead standing trees; (2) annual plants; (3) annual and perennial forbs; (4) perennial forbs, grasses, and half-shrubs; (5) shrubs or perennial grasses, depending on the specific site; and finally (6) the climax woodland. Depending on the degree of disturbance and the floristic composition and developmental stage of the undergrowth at the time of disturbance, the actual successional pathway on any given site will, of course, vary. In fact, it appears that any successional stage, except the climax, can be induced immediately following fire (Everett and Ward 1984).

Regeneration

Establishment of a new woodland stand can take place in a relatively short time, or it may extend over a long period, depending on the kind and degree of disturbance. Where disturbance is not too severe, as in some chaining operations, many small pinyons and junipers survive as advanced reproduction and, responding to release, will subsequently reforest the site in about 15 years or less (Tausch and Tueller 1977). In one case in New Mexico, for example, density on a cabled area was 80 percent of that on the control 20 years after treatment (Rippel and others 1983).

Where disturbance is more severe and regeneration is dependent on seed, the start of a new stand may be considerably delayed for several reasons. The primary cause for delay is unfavorable climatic conditions that hinder natural regeneration (Little 1965). Seedlings of pines and junipers are usually found under the protective crown cover of existing trees and shrubs, and rarely in openings exposed to full solar radiation (Meeuwig and Bassett 1983). Secondly, rodents and corvid species of birds reduce available seed sources by consuming or hoarding tremendous quantities of seed (Vander Wall and Balda 1977). On the other hand, the hoarding and caching habit of these animals probably ensures pinyon regeneration, but in a haphazard and unpredictable manner. Similarly, small mammals and birds also assist regeneration of junipers through the scarifying action on seed coats as berries pass through the digestive system (Johnsen 1962; Parker 1945). The final reason that could account for possible delays in woodland reestablishment is seed characteristics. The large, wingless pine and juniper seeds are not wind-disseminated, and probably are dispersed only a few feet beyond the tree crown by wind, gravity, or water movement.[1] Consequently, establishment of regeneration across large openings is neither very rapid nor very predictable.

Tree seed germination probably continues throughout all successional stages; but, at those periods when grass cover is heavy, tree seedlings probably cannot compete well for limited soil

[1] Unpublished data on file, Rocky Mountain Forest and Range Experiment Station, Forestry Sciences Laboratory, Flagstaff, AZ.

moisture after seed germination (Aro 1971; Woodbury 1947).

Establishment

Tree establishment appears to become significant during the shrub stage. Although no single description of succession would be applicable everywhere, studies indicate that the shrub stage becomes prominent about 12 years after disturbance by fire (Barney and Frischknecht 1974). Often this stage consists of sagebrush, which is a common associate in many woodlands. Trees begin to regenerate in the shrub community, but establishment of a new woodland proceeds slowly at first. Stand density does not increase appreciably until 45 years after a disturbance, but at about 90 years trees completely dominate the site. The first tree species to regenerate the shrub community is probably dependent, to a great extent, on available seed sources because the establishment capability of pinyons and junipers appears similar. Either can precede the other on disturbed sites, depending on the particular circumstances. In areas where junipers comprise the successional stage because of the scarcity of pinyon, the rate at which pinyon tends to become established depends on available seed sources and suitable microenvironments (Woodbury 1947).

As trees reach about 60-70 years of age, forage productivity declines rapidly as the number and vigor of undergrowth species are reduced by competition from tree roots for available soil moisture (West 1984). Usually, the undergrowth declines faster than would be indicated by changes in the overstory.

Senescence

Little is known about the history of woodland stands during their senescent stage, primarily because of the lack of suitable study areas. In contrast to the large tracts of old-age, virgin stands available for study in other forest types, equivalent areas are not available in the pinyon-juniper woodlands because of their past history of use. Also, although there are probably a greater number of older stands in the Southwest than in the Great Basin, some approaching 500 years of age (Howell 1940), most woodland stands, especially in the Great Basin, appear to be relatively young (West and others 1975; Blackburn and Tueller 1970; Arnold and others 1964). In one study in the Great Basin, for example, trees on about half of the stands were less than 125 years old (Tausch and others 1981). The lack of large, dead snags also is an indication of young stand age.

Because junipers and pinyons are long lived, the absence of old trees and the young age-class distribution, especially in the Great Basin, reflects heavy and prolonged use of existing stands and the invasion of previously treeless areas. Dominant pinyons are often 400 years old and have been known to reach 800 to 1,000 years of age. Junipers are similarly long lived (Little 1965).

SILVICULTURE OF WOODLANDS

Although silvicultural methods have not been tested in pinyon-juniper woodlands, recommendations have been made based on limited knowledge of the silvical characteristics of pinyons and junipers. Selection, seed tree, and patch clearcutting systems have been proposed (Meeuwig and Bassett 1983). The system actually used will depend on management objectives. However, it must be kept in mind that these systems have been developed for tree species that rely on wind for seed dispersal. The large, wingless pinyon and juniper seeds will probably require that the traditional systems be modified.

The selection system has been recommended as the best harvesting method where the management objective is wood production because (1) it provides a suitable microenvironment for germination and establishment, (2) it maintains continual overstory cover, and (3) it assures adequate growing stock levels (Meeuwig and Bassett 1983). Because pinyon-juniper stands exhibit site dominance at basal areas of about 40 square feet per acre, this level of stocking is recommended (Meeuwig and Bassett 1983).

Actually, a modified selection system might be the most desirable and, perhaps, the only feasible means to ensure full stocking of woodlands in a reasonable period of time where the distance between residual trees is great. In this proposed modification, seedlings must already be established under a tree crown before the tree is harvested. Otherwise, regeneration of a new stand might not be successful because the large, wingless seeds from residual trees would not be dispersed into the opening created by cutting. The procedures in this modification more closely resemble those that would apply to tolerant trees, for which individual tree selection is most suitable.

Multiple-use silviculture has not been developed for the pinyon-juniper woodlands. However, limited information indicates that patch clearcutting would increase livestock forage and provide the cover and food requirements for wildlife, especially big game (Terrel and Spillet 1975).

MANAGEMENT DIRECTION

Before concluding this address, I would like to present briefly my perceptions of the direction to be taken in the future to prudently manage pinyon-juniper woodlands. Whether we consider woodlands to cover 43 or 80 million acres (West and others 1975), they constitute a valuable resource and should not be summarily dismissed simply because they may be classified as noncommerical forest land.

There are some who favor eradication of the woodlands, others who advocate that nothing be done, and still others whose desires would lie somewhere in between these two widely divergent goals. As with other forest types, conflicts will surely exist among the various demands for woodland resources. These demands may involve somewhat intangible uses, such as esthetics and recreation, or the more substantive kind dealing with wood fiber, water, nuts, or forage for big game or livestock. Balancing the demand for these resources among the various pressure groups will certainly be a challenge for land managers. Their task would be difficult enough if the only consideration were the ecological and physiological requirements of the plants, especially when so much more information is needed to fill critical gaps in our status of knowledge about woodlands. When the biological needs of plant communities are coupled with social, economic, and political considerations of the people, it is not surprising that our land managers are faced with a formidable task.

Managers most certainly will face further complications as a result of potential changes in management direction as the needs of society change with time. Such changes in management direction were emphasized by a recent experience. A colleague and I had the good fortune of spending 2 weeks this past summer with Dr. Elbert L. Little, retired Chief Dendrologist with the USDA Forest Service. We visited experimental plots in the pinyon-juniper woodlands in Arizona and New Mexico that Dr. Little established in the late 1930's, early in his career. Dr. Little reflected that these early studies were initiated to increase woodland productivity of nuts and wood products, especially fuelwood and fence posts. The development of a natural gas distribution system during this period essentially eliminated the demand for fuelwood, and subsequently, the need for research. But, witness the clamor for wood today as a result of the high cost of fossil fuels.

Less drastic changes in utilization occurred where nut production was concerned, and what was a viable management direction in the 1930's still appears applicable today. Although the commercial nut harvest declined considerably from a peak production of 8 million pounds in 1936 (Little 1941), there appears to be a steady demand today. In the Southwest, indications are that the commercial harvest may be about 1 million pounds yearly, whereas recent reports suggest that 200,000 pounds may be gathered annually in the Great Basin (Everett 1985). In addition, recreational picking of nuts by the urban dweller will probably raise the total harvest to some extent.

Earlier, I mentioned management direction. However, the remark was not meant to imply that such direction would be specific. Rather, it should be interpreted only in the broadest sense. As a research administrator--and scientist when time permits--it would be presumptuous of me to tell a Forest Service District Ranger or an Area Manager in the Bureau of Land Management what utilization should be made of land areas under his or her jurisdiction. However, as a member of the scientific community, I believe that it is our responsibility to provide accurate information about the woodlands. This information, in the form of guidelines that are based on sound research, hopefully will assist land managers in the decision-making process.

Regardless of the treatment applied to woodlands as a result of management decisions made today, it is important that we maintain the inherent productivity of the woodlands. Changes in management direction are certain to take place because, historically, what we find to be acceptable and appropriate management today, often is outmoded tomorrow. However, if the ability of woodlands to produce is not drastically altered, managers should have sufficient flexibility to accommodate any future directional changes.

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ENERGY CRISIS IN 19TH CENTURY GREAT BASIN WOODLANDS

James A. Young and Jerry D. Budy

ABSTRACT: The pinyon/juniper woodlands of the Great Basin were a vital source of wood products for the mining industry from the 1860's to the 1920's. Pinyon and juniper were cut extensively for fuelwood and/or the production of charcoal, the only available fuel or energy source for the smelters of central Nevada. Firewood and fence posts for ranches were also important uses of pinyon and juniper. Deforestation by cutting and wildfire continued unabated until the 1920's and 1930's, when fossil fuels, wood substitutes, and fire control combined to decrease use of this vegetation type.

INTRODUCTION

The vestiges of a once-flourishing wood products industry haunt the current managers of the pinyon-juniper woodlands. Land managers, users, and environmentalists alike suffer from lack of historical perspective when they contend with management practices in pinyon/ juniper woodlands. The modern energy crisis has also impacted pinyon/juniper woodlands as they are cut for fuel wood. The past and present harvesting of woody biomass for energy sources in the semiarid Great Basin provides a western North American model for similar utilization in developing countries that exceeds the potential of their environments and leads to deforestation and often desertification.

The pinyon/juniper woodlands of the Great Basin are unique in how they relate to other types of vegetation. In the Rocky Mountains and the Southwest usually a forest of pine (often Pinus ponderosa) is located above the pinyon/juniper zone. In the central Great Basin, a mountain brush community occupies this site. The species composition of shrubs, forbs, and grasses in this community suggests a forest, but the trees are absent. In the Southwest, pinyon/juniper communities often merge with oak (Quercus) woodlands. Oaks are absent from Nevada with the lower edge of the pinyon/juniper zone merging with Artemisia plant communities. Thus the central Great Basin was unique among nineteenth century mining areas where energy was a problem. Other southwestern regions had some forest resources besides the pinyon and juniper available for use.

The mountain crest of the highest ranges of the Great Basin support five-needled pines, of which bristlecone (Pinus longaeva) and limber pine (Pinus flexilis) are best known. Although the sparse forests were generally remote and limited in area, they were still heavily cut to supply mines with structural timbers and lumber. The summit of Prospect Peak, near Eureka, was reported to have been covered with bristlecone before the demand for mine timbers resulted in the removal of most trees (Sargent 1879). Limber pine was the most valuable timber tree of the central Great Basin, because it was large and more widespread than the bristlecones. It was the only tree of the region that was sawed into lumber.

MINING IN THE WEST-CENTRAL GREAT BASIN

The mining era in Nevada was ushered in by discovery of the silver-rich Comstock Lode in 1859 and subsequent developments during the 1860's (Elliot 1973). As the mining district on the Comstock grew in size, the supply of firewood seldom met the demand. The pinyon and juniper in the Virginia Range were removed in an ever-expanding circle. In 1864, for example, several hundred American laborers were constantly cutting and hauling firewood from nearby woodlands. Chinese laborers followed the wood cutters, pulling up the brush, stumps, and roots from the overcut hills. It was a common experience for boys growing up on the Comstock to spend their after-school hours searching mine dumps for discarded wooden candle boxes to feed the family heating stove (Galloway 1947). When 6 feet of snow covered the roads during the winter of 1866-1867, a cord of wood cost from $40 to $50. An estimated 120,000 cords of firewood were used in the district in 1866 (Lord 1883). The scant supply of pinyon and juniper on the neighboring hills was rapidly exhausted, and wood cutters moved to the eastern slopes of the Sierra Nevada, some 20 miles from the mines.

Although the pine-fir forest of the eastside Sierra assured an abundant supply of timber and fuel, transportation to the mines was expensive. The construction and maintenance of mountain roads became so costly that natural waterways were used wherever possible to move logs down to the mills in the valley below Virginia City. Because of the limited number and size of waterways, water transportation was not satisfactory until the 1870's when the V-flume

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James A. Young is a Range Scientist, Agricultural Research Service, USDA; Jerry D. Budy is an Assistant Professor of Forestry, Range, Wildlife, and Forestry Division, College of Agric., Univ. of Nevada, Reno, NV

was developed and proven to be practical. Then sawmills were erected in the mountains, and cordwood and timbers were transported down the flumes from the Sierra. More than 700 cords or 500,000 feet of mining timbers were transported down the Carson and Tahoe Lumber Company's flume daily (DeQuille 1889). Spring floods on the Carson River also were used for transporting wood. More than 150,000 cords of wood were floated down the Carson in a typical season.

Although the adjacent Sierra slope fulfilled much of the Comstock's demand for wood products, its use of pinyon and juniper was still extensive. The Comstock is located on the edge of these woodlands in the Great Basin. Utah juniper extends north of the Comstock, but singleleaf pinyon occurs south of a line running diagonally across Nevada, from Virginia City to the Idaho-Utah-Nevada corner (Beeson 1974). Mining operations along the Comstock Lode from the early 1860's until well into the present century drew upon this adjacent wood resource. As a result, more than 190,000 acres of second-growth pinyon-juniper woodland now cover Douglas, Ormsby, and southernmost Washoe Counties (Wilson 1941).

Use of wood in subsequent mining strikes and boomtowns in western Nevada and eastern California (for example, Aurora and Bodie) more or less followed the same pattern: transportation of fuelwood and timber from the adjacent Sierra Nevada and secondary reliance on the pinyon-juniper woodlands, especially for firewood.

MINING IN CENTRAL NEVADA

In 1862 a former Pony Express rider who was cutting wood discovered silver ore in the Toiyabe Range, 175 miles east of Virginia City. This new find, around which grew the town of Austin and the Reese River Mining District, brought the wood energy crisis into sharp focus. Central Nevada was too far removed from the Sierra Nevada for the transportation of huge quantities of fuel. The pinyon-juniper woodlands alone had to sustain the mining industry.

In contrast to the free-milling ores on the Comstock, the Reese River ores were called refractory or rebellious (Oberbillig 1967). The Reese River ores were dry crushed and roasted with salt before amalgamation. Although dry crushing was a terrible health hazard to the millworkers, it saved the cost of drying the crushed ore before roasting and prevented losses from oxidation of wet ore. The salt was harvested from playas in the desert valleys.

During the 1860's the Reese River mills used reverberatory furnaces in which the ore was heated on hearths and roasted, with the flame passing across the top of the bed of ore. These furnaces took 7 hours to roast each charge of ore, consumed salt amounting to 8 or 10 percent of the ore volume, and burned a cord of wood per ton of capacity (Rossiter 1870). There was only one source of fuel for roasting the ore, and that was the pinyon-juniper woodlands. Roughly, 60 percent of the expense of milling ore was for fuelwood.

The efficiency of roasting was greatly improved by the development in 1869 of a new furnace by C.A. Stetefeldt. The principle of this furnace is that finely ground silver and salt are completely chloridized when they fall against a current of hot air. The Stetefeldt furnace became the standard roasting mechanism for the central Great Basin until all amalgamation processes were replaced by the cyanide process early in the twentieth century (Oberbillig 1967).

Only one-third as much wood was required with the Stetefeldt furnace as compared to earlier furnaces, and the labor requirement was greatly reduced. The technology developed on the Reese River Mining District provided the model for all of central Nevada for the next three decades.

CHARCOAL PRODUCTION

Despite savings in wood with the new technology, the energy source became very expensive once stands of pinyon and juniper adjacent to the mills were cut. There was no water transportation available in the arid mountains, so costs were reduced by carbonizing the raw wood to charcoal before transport to the mills.

The production of charcoal had a long history in Europe. Charcoal from oak and willow was burned in California from the early 1850's onward. During the 1860's and 1870's several million bushels of charcoal were produced annually in the northeastern United States for use in the manufacture of iron (Hough 1878). By carbonizing wood through controlled combustion, it was possible to obtain a fairly high-energy-value fuel with a 60 percent savings in volume and an 80 percent savings in weight over raw cordwood.

Making charcoal from wood is essentially the process of partially burning the wood. The degree to which the wood is burned is controlled by regulating the amount of air admitted. Heat generated by burning the wood distills combustible vapors, which arise from wood surrounding the burning zone. The heat caused by the burning of these gases distills more gas from surrounding wood, and the zone of distillation moves progressively through the pile. Enough air is admitted to burn the gases, but not enough to burn the carbon residue, which is charcoal. If the burning process is correctly done, the result is good charcoal, relatively free from volatile or vaporous material (Anon. 1943).

Cutting singleleaf pinyon or Utah juniper for fuelwood is a miserable job. Mature pinyon and juniper trees seldom exceed 30 to 35 feet in height and 20 inches in diameter at the base. In addition to their small size, both species usually have poor growth form. Opengrown trees are often multistemmed and exceedingly bushy.

Both species lack natural pruning and thus retain branches right down to the ground. These characteristics make pinyon and juniper difficult to fell and buck into cordwood. We estimate that cutting a cord of pinyon wood requires at least two to three times as much labor as cutting a cord of ponderosa pine.

Pinyon logs were cut and allowed to dry before they were burned in earth-covered pits. The term charcoal pit is misleading. Although in the finished kiln the wood was completely covered with soil, the base was usually located at the soil surface. In construction of the pit, a center chimney was made, either by driving three poles into the ground and keeping them separated or by building a triangular crib of wood in the center. The chimney was packed to part of its height with dry grass, twigs, or other loose combustible material. This material was used to start the fire. The chimney served as a support for the pile of wood and as a flue to aid the draft and carry off smoke. The charge of wood was piled around the central chimney, standing on end and leaning slightly toward the center. Top layers were put on flat, so that the kiln was dome shaped.

The entire mound, except for the central opening at the top, was covered with grass and pine needles to a depth of 3 to 5 inches. This fine organic material was topped with 2 to 5 inches of clay soil; sandy soils would not provide the correct seal. Care was taken to make the soil layer as airtight as possible. Small openings were left around the bottom for draft. The size of these holes was varied or controlled by putting in or taking out soil.

Management of the burning process required considerable skill. The kiln was lighted through the central chimney. After the fire was well started, the draft was reduced. Burning conditions were judged by the color of the smoke. The kiln had to be watched night and day, and wet clay was kept on hand to repair any cracks. A 100-cord pit kiln probably required from 3 weeks to a month to burn.

When it was judged that all wood in the kiln had been completely burned, all openings were closed. The cooling process required a week to 10 days for large kilns. Opening the cooled kiln was a dangerous operation, best carried out when the wind was still. Unless it was completely cold, the kiln was always in danger of igniting the charcoal during the opening process.

Utah juniper and curlleaf mountain mahogany (Cercocarpus ledifolius) were also converted to charcoal. These species require higher temperatures for conversion to charcoal than can be obtained with ground pits. So that the proper control over drafts could be achieved, beehive-shaped ovens were constructed from native stone (Grazeola 1969). Many perfectly symmetrical ovens remain today in isolated parts of Nevada as monuments to the back-breaking labor of a forgotten industry.

The yield of cordwood from pinyon-juniper woodlands can vary from less than 1 cord to more than 12 cords per acre. A charcoal pit produced from 2,800 to 3,300 bushels of charcoal from a supply of 100 cords of wood. Therefore, roughly 10 to 100 acres of woodland had to be cut for each pit. Probably the lower yielding woodlands were too sparse for their use to be economical. A yield of 300 bushels of charcoal per acre may have been a reasonable average.

Eureka, about 60 miles east of Austin, became important in the 1870's and 1880's. From 1869 to 1883 the Eureka District produced $60,000,000 of gold and silver and 225,000 tons of lead (Lincoln 1970). Fumes from the roasting ore were so severe that elongated stacks were run up the canyon walls and then vertically to vent the fumes from this Pittsburgh of the West. The major smelting companies were processing 750 tons of ore per day. Smelting a ton of ore required from 25 to 35 bushels of charcoal. An estimated 1.25 million bushels of charcoal were consumed at Eureka in 1880 (Anon. 1875).

The demand for charcoal was so great that deforestation became a severe problem. From our estimates of wood yield, 4,000 to 5,000 acres of woodland had to be cut annually to supply the Eureka mills. By 1874 the mountain slopes around Eureka were denuded of pinyon and juniper for a radius of 20 miles. By 1878 the average hauling distance from pit to smelter was 35 miles (Anon. 1875).

Deforestation pushed shipping costs higher until the price of charcoal topped 30 cents per bushel. A price of 35 cents per bushel would have made importation of coal by railroad feasible. The standard transportation unit was 16- to 20-mule teams pulling four wagons, hitched in tandem, and each loaded with 4 tons of stacked charcoal.

A small army of charcoal burners was required to harvest the pinyon and juniper. Most of the charcoal workers were Italian immigrants, some of whom had practiced charcoal making before coming to central Nevada (Grazeola 1969).

Although the official price for charcoal in 1879 was 25 cents per bushel at the smelter, there is evidence that some charcoal burners were receiving only 13 cents, not enough to cover production costs. The smelters and the middlemen teamsters also cheated the burners by forcing them to accept orders on local merchants rather than cash payment (Earl 1979).

On July 6, 1879, some 500 burners attended a meeting at Celso Tolli's saloon in Eureka and formed the Eureka Coalburners Protective Association. The membership agreed to withold their product unless the price was raised to 30 cents per bushel. Representatives of Eureka's two major smelting firms, who had contracts with the teamsters, let it be known that they would not pay the higher price and might close down the smelters rather than give in (Earl 1979).

On July 16 a group of 35 armed men prevented a burner from loading charcoal, and several teamsters were forced to return to Eureka with empty wagons. Sheriff Matt Kyle did nothing on that occasion, but 3 days later a similar incident led to charges of malicious mischief against five burners. Their arrests led to internal division within the association and the resignation of three leaders. New officers were elected at a meeting held on August 5, and the membership decided to stand on the 30-cent demand. Subsequent disturbances and forced unloadings in charcoal camps south of Eureka led to general uneasiness and to more arrest warrants, mostly unserved (Earl 1979).

Few were prepared for the tragic event that took place at Fish Creek, south of Eureka, on August 18. The details did not become known for several days, but apparently 100 or more Italians had confronted a party of deputies who were investigating threats against teamsters. Shooting broke out. Five Italians were killed outright and several others were injured. One deputy was slightly wounded. Many contradictory stories were told later, but the Italians seemed to be more consistent in their version than were the lawmen.

Evidence on the killings and the riot and conspiracy charges were presented to the grand jury in late August, as was the testimony of the men charged with murder. On September 25 the grand jury issued its report, which led to dismissal of charges against all parties. The report justified the use of force by Eureka authorities but did not address the fundamental issue, the burners' need for adequate compensation. Although never stated as such, the grand jury was motivated by a desire to end the whole disgraceful affair rather than string out the bitterness in a series of expensive trials.

Eureka is a well-documented, but not isolated, example of the use of pinyon-juniper woodlands. The spread of mining brought prospectors, with little and big boomtowns, to virtually every mountain range in Nevada (Paher 1970).

Miners who operated north of the pinyon-juniper distribution in the Great Basin used drastic measures to obtain energy. The Dexter Mine at Tuscarora, Nevada, used sagebrush (Artemisia tridentata) to fire boilers. Sagebrush was cut and delivered to the mine for $2.50 per "cord." The hoisting works smoked like a miniature Vesuvius and the entire area was covered with ashes (Paher 1970).

Sagebrush was a major source of fuel for settlers on the Minidoka irrigation project located in south-central Idaho. It was a mark of economic achievement when a family, trying to establish an irrigated farm in the desert reclamation project, could afford to switch from collected sagebrush to purchased juniper or lodgepole pine (Pinus contorta) as a source of fuelwood (Anon. 1924). Any attempted historic energy budget for the Great Basin probably should acknowledge the contribution of big sagebrush to the meeting of energy requirements.

Intermountain Research of Silver City, Nevada, has conducted intensive archaeological studies in the Mt. Hope area located about 20 miles northwest of Eureka, Nevada. This archaeological study located 79 sites in the Mt. Hope area that were related to charcoal production. A total of 58 soil surface kilns was found in an area of about 5,000 acres.

Hugh Shamberger (1978) provides interesting sources of information on the 19th century utilization of pinyon and juniper in the southwestern portion of the Great Basin. Quoting from the mining camp newspaper, the True Fissure of February 18, 1881, he told about hauling wood to the mills at Belleville, Mineral County, Nevada.

"The Farrington Bros. have contracts to haul all the ore, wood and charcoal for the company, Belleville being the center of operations. Their wood wagons carry eight full cords each and require ten animals to a team.---In the wood and charcoal camps they employ about 40 men, chopping and hauling wood and burning wood for charcoal."

The two Belleville Mills required 24 cords of wood per day according to Shamberger (1978) quoting from the same source.

Shamberger was fortunate in finding a series of post card photographs published in the 1880's by the Scott-Crispin Company of Belleville, Nevada. These photographs detailed the woodcutting process. This series of photographs shows pack mules being used for the initial transportation of wood. The mules moved the wood to roadheads where it was loaded on freight wagons drawn by 15 to 20 mules.

Shamberger (1978) reported on a previous in-person interview with Roger Bruffey of Pine Valley, Nevada. Mr. Bruffey had witnessed the charcoal burning in central Nevada during the 19th century. Bruffey indicated the pinyons were cut during the winter months when the sap was down and bucked into 5-foot belts for drying. During the summer the charcoal burner scraped off level places in canyon bottoms and built circular tiers of the 5-foot pinyon cord wood lengths. Usually, two tiers were stacked one atop the other, or sometimes three, with an opening in the center of the tiers running from top to bottom for a combustion chamber. Juniper branches and tops were then thatched around the outside of each tier, after the interstices betweeen the cordwood belts were plugged with small sticks and branches. Soil was then packed over the juniper thatching. Care was taken to make this outer covering of soil as airtight as possible, to keep the combustion process under control.

Each pit contained 15 to 25 cords according to Bruffey (Shamberger 1978). The pit or mound of wood was ignited by dropping coals and kindling

down the center hole. After the fire was well established the draft was reduced as much as possible. It took 30 days to reduce this amount of wood to charcoal. The charcoal maker had to watch day and night for telltale wisps of smoke indicating leakage through the sides of the mound.

The Scott-Crispin photographs published by Shamberger (1978) provided several views of nearly denuded hillsides in the background of the cutting operation. The citations presented by Shamberger provided instances of similarity and variation in the charcoal making process for singleleaf pinyon wood as compared to earlier reports for the central Great Basin.

OTHER USES OF WOOD

Despite the huge demand for charcoal in mills, the use of pinyon and juniper wood for home heating and cooking may have had an even greater effect on the total woodland environment. The denuded area around Eureka accounted for a relatively small percentage of the pinyon-juniper woodlands in the Great Basin. The 70-mile-diameter cutting circle contained roughly 2.5 million acres, of which 0.6 million acres or 24 percent was pinyon-juniper woodlands; this equals 3.4 percent of the 17.6 million acres of this vegetation type in the Great Basin. Every isolated mine and ranch had to have wood as a source of fuel and fencing. The corrals, for example, at the Walti Hot Springs in central Nevada are constructed of 3,000 juniper poles. The dirt roofs of the native stone buildings are supported by pinyon and juniper trunks. Some 50 miles of barbed wire fence is supported by juniper posts, with 260 posts per mile. The woodlands above the ranch are laced with wagon roads among the stumps left from past use. One may multiply this example by the hundreds of ranches and thousands of mining prospects to estimate the true extent of use of the pinyon-juniper woodlands.

When large ranches in the Great Basin were first fenced with barbed wire during the 1880's, those located along the Humboldt River route of the Central Pacific Railroad could buy redwood posts from California cheaper than juniper posts from the over-utilized woodlands of the Great Basin (Gordon 1880). Many ranchers employed Indian woodcutters to supply posts and wood for other purposes. Thirty Mile Charley was an enterprising Paiute resident of Montello, Nevada, who contracted with the giant ranches of the Utah Construction Company. His crews cut 3,000 to 4,000 posts per season (Bowman 1958).

The accelerated use of pinyon-juniper woodlands also brought promiscuous burning. David Griffiths, a trained scientific observer, reported in 1902 that every mountain range in the northern Great Basin showed evidence of recent wildfires. He attributed most of the fires in areas remote from railroads to criminal negligence. Many fires were set to facilitate the movement of bands of sheep.

Sheep, cattle, and horses, Griffiths noted, heavily utilized the Great Basin ranges. Domestic livestock did not eat the pinyon or juniper reproduction, but, by depleting the herbaceous understory vegetation, they indirectly favored establishment of woody plants by reducing competition and changing the fuel available for wildfires. Griffiths also mentioned that ranchers had the greatest difficulty finding sufficient wood for posts and firewood, many traveling 50 miles to cut posts (Griffiths 1902).

The extensive use of pinyon-juniper woodlands for posts and fuelwood extended well into the twentieth century. The Dangberg Livestock Company at Minden, Nevada, used first steam and later gas tractors to haul wagonloads of cordwood from the Pine Nut Range to the Carson Valley. This utilization was a factor in establishing the 65,000 acre Washoe Indian allotments in the Pine Nut Mountain range. Cordwood was in short supply in Tonopah before World War I. Wood cost from $30 to $35 per cord delivered, with teamster charges of $10 per cord for hauling from distant cutting areas and stumpage fees of $1.50 per cord to the U.S. Forest Service (Billeb 1968).

After World War I, the Great Basin gradually became dependent on fossil fuels for energy -- first the cities and towns, and then, even more slowly, the rural areas. A declining rural population also helped to lessen use of pinyon-juniper woodlands. In later years the Bureau of Land Management and the Forest Service adopted policies of complete exclusion of wildfire. Although not completely successful, these policies greatly reduced promiscuous burning and permitted reestablishment of the woodlands.

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THE PROBLEMS WITH CUSTODIAL MANAGEMENT OF PINYON-JUNIPER WOODLANDS

Jim W. Doughty

ABSTRACT: The current lack of management on pinyon-juniper woodlands may result in site degradation; increased soil erosion; depleted understory production; and stagnant, unhealthy overstory. When pinyon and juniper stands become overcrowded from lack of proper management, the trees outcompete the grasses, forbs, and shrubs for moisture and nutrients. Soon the understory is gone and the multiple uses of the resource are diminished. Soil organic matter is reduced and the soil surface is vulnerable to erosive water and wind.

Coordinated resource management and planning can provide a tool for identifying proper management alternatives that will protect resource values and prevent deterioration of pinyon-juniper woodland. There is a demand for fuelwood, fence posts, Christmas trees, pine nuts, foliage and other ornamental material, and chips for processed wood products, as well as forage for livestock and wildlife habitat.

INTRODUCTION

There is a serious situation developing in the pinyon (Pinus edulis, Pinus monophylla) and juniper (Juniperus spp.) woodlands of the West. It needs the attention of everyone concerned with multiple use and sustained yield of this important natural resource.

The consensus of those who advocate good resource management seems to be that this resource should be managed on a custodial basis. Vail and Strobel (1985) define custodial management as "managing to protect existing resource values and prevent further deterioration."

Meeuwig (1984) defines custodial management in regard to pinyon-juniper woodland as "where none of the other management alternatives such as, type conversion for wildlife or livestock; or management for sustained yield of fuelwood or other woodland products, are cost effective."

The most significant problem regarding custodial management of pinyon-juniper woodlands is that WE ARE NOT DOING IT!! Currently, custodial management of pinyon-juniper woodlands is essentially synonomous with nonmanagement. By the year 2000, if present trends continue, all but the more marginal sites for pinyon-juniper woodlands will have lost most of their understory productivity (West and others 1979).

Resource managers are charged with managing these resources to a greater degree. The Resources Conservation Act of 1977 (RCA) which directs the activities of the Soil Conservation Service indirectly addresses the concern about pinyon-juniper management in three of five listed national priorities. These are (1) improvement of range, pasture, and forest land; (2) improvement of water quality; and (3) improvement of fish and wildlife habitat. SCS is directed to assist landowners to apply and maintain systems on nonfederal lands to improve and protect the resources.

The National Forest Management Act of 1976 requires the Forest Service to evaluate the "effects of management on the permanent impairment of the productivity of the land..." The 1985 RPA Program range goal statement calls for the Forest Service to "provide forage to promote economic stability of dependent livestock producers." Most ranchers in the Great Basin are dependent upon federal rangeland for their livelihood.

The Federal Land Policy and Management Act of 1976 (FLPMA) states that the Secretary of the Interior shall manage the public lands under principles of multiple use and sustained yield. In managing the public lands the Secretary shall, by regulation or otherwise, take action necessary to prevent unnecessary or undue degradation of the lands.

Much of the productive understory has been traded for less useful tree cover during the past 100 years, and more solid tree dominance is likely. The trees are the climatic climax dominants. Without periodic fire or mechanical or herbicidal treatment, the herbaceous and shrubby species cannot be maintained (West and others 1979).

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Jim W. Doughty is the State Resource Conservationist, Soil Conservation Service, U.S. Department of Agriculture, Reno, NV.

DISCUSSION

Competition in Overstocked Stands for Nutrients and Moisture

Successional stages in the pinyon-juniper type have been described following fire in the Mesa Verde National Park in Colorado. After fire, pinyon-juniper forest returns after about 300 years (Erdman 1970).

Data collected in 1964 indicate that tree canopies may intercept a considerable amount of precipitation, creating poorer soil moisture regimes. The lack of moisture under the canopies may also be the result of depletion due to roots in that area (Erdman 1970).

When fire is eliminated, trees are eight or nine times as efficient as grass in their use of physical resources of this kind of environment (West 1978). We know that the allelopathic effect of the litter of pinyon and juniper inhibits grass growth, decomposition, and the mineralization processes essential for nutrient cycling (West 1984).

The rate of increase in tree phytomass accelerates as the size of the young trees increases. Pinyon and juniper are much more efficient users of soil moisture and nutrients than herbaceous species. They form green tissue that is photosynthetically active year-round for up to 10 years. These tissues only have to be partially replaced each year. Grasses must replace nearly all of their above-ground growth each year (West 1984).

The use of deep soil moisture in winter by heavy stands of western juniper, while most other species are dormant, has a considerable effect on most spring and summer plants in the understory during most years. This may explain why understory species are slow to reestablish in pinyon-juniper woodland and the lack of plant vigor by most species throughout the season, even under ungrazed conditions (Jeppesen 1977).

Gaither and Buckhouse (1983), in their study of infiltration rates of various vegetative communities within the Blue Mountains of Oregon, found the effects of vegetative cover, litter, and surface crusting are important. The study illustrates the need for maintaining or enhancing adequate ground cover in order to ensure optimal infiltration rates.

Each year, juniper seedlings become established in big sagebrush communities, but their influence on succession and dominance will not be apparent to land managers for another 25 to 50 years (Young and others 1981).

Trees gain competitive dominance over shrubs and herbaceous species far earlier in the sere than has been previously realized. Tree dominance exceeds that of the understory when the trees reach one-third of their climax potential. The height of the trees at this point is only about double that of the shrubs, but the understory species decline at an increasingly rapid rate as the trees rapidly grow and monopolize soil moisture (West and others 1979).

Loss of Forage for Livestock and Habitat for Wildlife

Succession has changed pinyon-juniper communities in a way detrimental to deer and livestock; that is, carrying capacity has been reduced (Tausch and others 1981).

Tausch (1980) graphically illustrated the relationship of understory cover to overstory tree crown cover in natural stands. As total tree cover increased, total understory cover decreased proportionately.

Managers generally do not notice the loss of forage production until much more aboveground tree growth and more startling losses of understory have occurred. Weight of understory, and thus available forage, is being lost at a much more rapid rate than indicated by the cover changes (West and others 1979).

Young and Evans (1981) report that western juniper communities growing on sites dominated by big sagebrush (Artemisia tridentata) are virtually fireproof and have purged their understories of almost all herbaceous and shrub vegetation. Herbage production of the herbaceous vegetation in the juniper stands on big sagebrush sites averaged less than 45 pounds per acre.

Arnold and others (1964) in northern Arizona showed an inverse relationship between tree canopy and herbage production. Production was about 600 pounds per acre with no trees, 300 pounds per acre with 20 percent canopy (fig. 1).

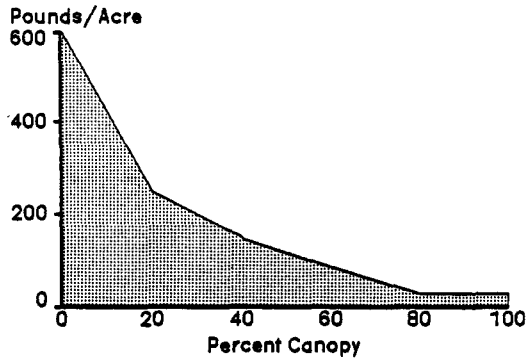


Figure 1.--Relation of air-dry herbage yield to percent canopy intercept of overstory pinyon and juniper in northern Arizona (from Arnold and others 1964).

Everett and Sharrow (1984) state the loss of understory cover and production is readily apparent as tree cover increases but the decline in soil seed reserves is not visible. As succession proceeds, the number of seedlings emerging from soil samples declines. Declining soil seed reserves are important because they decrease the initial plant response following tree release.

Loss of Organic Surface Causing Soil Erosion

Early detection of soil erosion is necessary for efficient management of rangeland watersheds. The early stages of sheet erosion profoundly affect the range, since productivity declines as fertile topsoil and humus are gradually lost. This loss can proceed undetected for years until its adverse effects on plant growth and infiltration capacity lead to the more obvious states of erosion. Once the advanced stages are reached, controlling erosion is more difficult than preventing excessive sheet erosion at the incipient stage (Meeuwig 1970).

Intuition tells us the bare interspaces between trees, due to subsurface occupancy by tree roots, make many sites within this ecosystem susceptible to wind and especially water erosion. The mound microrelief with hillocks under the trees and rills in the interspaces is an ominous indication that differential erosion is at work. Soil surfaces in the interspaces will not be covered by plants or litter as long as the trees remain. Since the trees can live at least 600 years, soils that took thousands of years to form are at risk if management does not occur. The soil is richest in nutrients near the surface. If erosion occurs, site potential is degraded (West 1984).

Plummer (1958) witnessed one terrestial rainstorm in August 1956 where 70 percent of the land area was barren openings between trees on a 20 percent slope where after 1 hour large nets of rootlets lay exposed on the ground--a striking demonstration of the need of surface cover to preserve the soil mantel.

Buckhouse and Gaither (1982) in their study of potential sediment production within vegetative communities in Oregon's Blue Mountains, found that juniper ecosystems showed potential sediment losses exceeding the losses in all other ecosystems with a rate of 1,402 pounds per acre (fig. 2).

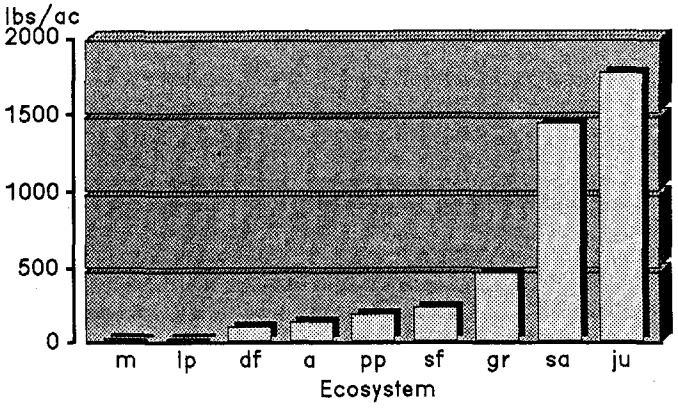


Figure 2.--Potential sediment production in nine Blue Mountain ecosystems. m=meadow, lp=lodgepole pine, df=Douglas-fir, a=alpine, pp=ponderosa pine, sf=spruce-fir, gr=grassland, sa=sagebrush, j= juniper (from Buckhouse and Gaither 1982).

Carrara and Carroll (1979) used the characteristic of great tree longevity and exposure of roots to demonstrate that soil erosion rates in at least one part of the juniper-pinyon woodland have increased over 400 percent during the past century compared to the previous three centuries. This study also suggests that erosion rates on south-facing slopes are more than twice those of north-facing slopes.

The erosion rates in this study changed from .008 inch/yr to .07 inch/yr. Although .07 inch/yr seems negligible, we must realize that at that erosion rate, 6 inches of topsoil would be removed in 85 years. This is extremely important on pinyon-juniper sites involving shallow soils and when we consider the importance of the soil surface richest in nutrients.

Even in well-managed pinyon-juniper stands, erosion could be a problem. In central Oregon, Buckhouse and Mattison (1980) found that juniper woodland with desirable understory species like Idaho fescue (Festuca idahoensis) and bluebunch wheatgrass (Agropyron spicatum) yielded the highest sediment production when compared with 10 habitat types.

Potential for Catastrophic Wildfires

If fire occurs in dense stands, it is often a fire storm that destroys every living thing. These types of fires are not historically typical (West 1984).

Hester (1952) on the Grand Mesa National Forest, in Colorado, observed under extreme conditions the fuel-sparse pinyon-juniper type will not only burn, but will "literally explode." Although the bulk of the trees remained standing after the fire, he observed that the intense heat left the ground "well cooked." He predicted that growth of any kind was bound to be slow and erosion a problem. The wind started drifting the soil before the fire was out and continued throughout the summer. Only two rainstorms occurred during the summer, but small gullies were evident by fall.

Intense fire volatilizes excessive amounts of nitrogen and other essential nutrients, destroys organic matter, disrupts soil structure, and may induce water repellency. These effects combine to subject the soil to excessive erosion and lost productivity potential. Soils from acid igneous parent materials are more prone to surface erosion than those from basic igneous materials and therefore the former soils require more conservative prescriptions for burning than would be necessary for the latter (USDA-FS 1978).

CONCLUSIONS

Substantial reduction of forage available from pinyon-juniper woodland for game and livestock has taken place. Without a major change, this

reduction will continue until all sites climatically favorable for tree survival are dominated by these more efficient plants.

Control of grazing animals will not change the successional pattern. Only practices such as prescribed burning and mechanical or chemical treatment will allow return of forage and habitat-producing conditions. These methods should be coordinated with the various land uses and the needs for utilizing wood products. For example, if forage for livestock and wildlife habitat is the primary objective, the product of the treatment to meet this objective may include firewood and fenceposts. Prescribed burning to increase forage may result in early seral stages that provide excellent areas to harvest Christmas trees and ornamental nursery stock.

There is a need for the inventory and classification of pinyon-juniper woodland to determine potential for treatment and expected response based on site characteristics.

Priority for intensified management should be placed on areas where critical erosion is taking place, causing loss of production, habitat degradation, and sedimentation.

Periodic selective harvesting, at least every 10 years, will keep the stand opened up and growing vigorously, producing high-quality trees, and give the understory a chance to sustain itself in both desirable species and growth rates.

We need a teamwork approach involving professionals and interest groups dealing with these woodlands to see if we can react to the challenge of developing better ways of manipulating the ecosystem for acceptable net economic and ecologic returns. In short, we need to begin, wherever possible, to truly manage the pinyon-juniper woodland for its multiple values and uses on a custodial basis.

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MYTHS AND FABLES AND THE PINYON-JUNIPER TYPE

Gerald F. Gifford

ABSTRACT: During the past 10 years much new and interesting information has been derived through a variety of studies within the pinyon-juniper type. However, many "facts" associated with the pinyon juniper type are in truth derived from a decade or two of storytelling which relies heavily on personal or agency opinion and often ignores available research results. Some of these myths and fables are briefly examined.

INTRODUCTION

Once upon a time (180 million years ago), in a land far, far away (northern Asia), the pines first appeared (Lanner 1981). I'm not sure when junipers came on the scene, but on a time scale involving millions of years, perhaps it doesn't matter. Of importance though is the passage of time, the evolution of the pinyon-juniper type, and the fact that pinyon and juniper trees now cover about 60 million acres of the western U.S. (West and others 1975).

This conference has reviewed many aspects of the pinyon-juniper type. I believe that everyone will agree that some very solid, substantial contributions have been made and perhaps the last decade may be looked at, in retrospect, as one of enlightenment. During this 10 years of activity, new insights have been achieved in regard to successional trends, water (including erosion) and nutrient relations, control and revegetation, and wildlife and livestock responses.

Some of the research shared this week has been ongoing for a number of years. In other situations the research has been short-term, often underfunded, and sometimes lacking in depth. Along with the research findings has come an abundance of advice, observations, gut feelings, woodland experiences, and perhaps even a few revelations. In some instances it is perhaps difficult to separate the myths and fables of the pinyon-juniper type from scientific fact.

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Gerald F. Gifford is Head, Department of Range, Wildlife and Forestry, University of Nevada, 1000 Valley Road, Reno, NV 89512.

MYTHS AND FABLES

An excellent source for mystic bits of folklore is the topic of long-term productivity within the pinyon-juniper type. Productivity is related to erosion and everyone that is anyone knows that once pinyon and juniper occupy a site, erosion is accelerated and long-term productivity is on a down-hill trend. However, there is no evidence to support this hypothesis and in fact existing limited research indicates otherwise (Gifford 1975a; Clary and others 1974). A typical example of current reasoning is as follows (West 1984b):

> Sustaining production capacity of the land over the longrun is more important than maximizing current production (Altieri et al. 1983). Thus, any public wildland manager should have maintenance of soil stability as his major criterion of success. Although evidence is indirect, we think that the present situation on most pinyon-juniper sites is degrading (Southard 1978). This is because there are usually bare interspaces between the trees that are not protected from water erosion ... Tree roots grow thoroughly underneath the interspaces well beyond their crowns, but they don't penetrate the upper few centimeters of soil that is most rich in nutrients (Charley and West 1975, Barth 1980). The tree roots do, however, through uptake of water and nutrients, contribute to the death of the herbs and shrubs that once grew over these interspaces and protected the surface soil from the erosive force of wind and water.
>
> On some soils, microphytic crusts may help substitute for lack of understory, although the importance of these is debated (Loope and Gifford 1972). Microphytic crusts do not develop well on many pinyon-juniper sites. A mounded micro-relief, with hummocks of soil protected by living tree crowns and litter... and lower elevation spots between the trees is common. These depressions in the interspaces are often connected by rills. In some cases the interspaces are already eroded down to a restrictive

> soilpan or bedrock. Bare roots of trees there reveal that the erosion has occurred recently... The situation described above seems to characterize much of the pinyon-juniper type.

West (1984b) goes on to indicate the need for additional research, but actual facts (or lack thereof) become somewhat obscured in all the storytelling.

Where are the studies relating productivity to incremental losses in soil profile? What are the actual erosion rates on pinyon-juniper sites that may experience a runoff event only once every two to perhaps five years? What are the impacts of erosion on soil nutrients, soil water holding capacity, infiltration rates or rooting depth? It can easily be hypothesized that erosion is only important in the pinyon-juniper type if it has a biologically significant impact on nutrient cycling or if it adversely affects the water holding capacity of the soil. Technology, given current economics, probably cannot afford to replace nutrients and it definitely cannot replace the water holding capacity of the soil. It is interesting to contemplate how the pinyon-juniper type has sustained itself on so many diverse landscapes over the past 5000 years or more. The response of plant communities to extreme hydrologic events hasn't been touched, yet pinyon-juniper sites everywhere have obviously experienced many potentially devastating storms, and they are still out there. Most flood control works are designed to accommodate the 50-, 100-, or perhaps the 200-year storm, yet the pinyon-juniper type has obviously been designed to withstand at least the 5000-year event. Has something changed recently? I suggest that although we see a lot of things, we understand very little.

And finally, so what if some soil is being lost? In the first place, where does the soil go? Is it being deposited at other locations on the watershed, perhaps somewhere in the riparian zone, where the end result is a greater increase in productivity than the loss in productivity initially experienced on an upland site? This questions of course the relationship or linkage of contributing parts of the watershed to the riparian zone, a question that is very important but which we have no time to discuss now. And secondly, what is the significance of any proposed productivity loss? Pretend for a moment that T-values (Soil Conservation Service tolerable levels of soil loss) are being exceeded on pinyon-juniper sites in general. You must pretend because no one knows what a correct T-value is for a pinyon-juniper site. As pointed out by Crosson and Stout (1983), the T standard is faulty because it overlooks the fact that there are alternatives to erosion control for avoiding cost increases and secondly it ignores the importance of timing the application of control measures. In the first case the philosophy is that new technologies (fertilizer, etc.) can be developed which in effect replace the productivity lost to erosion, and the issue is to select that mix of alternatives which is most cost effective in avoiding rising production costs. In the second case the standard requires that measures be applied on all land where erosion exceeds the T-value even though the consequent loss of productivity may be long deferred. Yet the present value of the loss, as indicated by Crosson and Stout (1983), may be very low in comparison with the present value of the cost of control measures. To install control measures now, as demanded by the T standard, would waste resources that could be put to more productive use elsewhere within the pinyon-juniper type. Given that avoidance of higher production costs is perhaps a better criterion than T-values for judging when erosion is excessive, the problem quickly equates to a big question mark because of the difficulty in determining production costs within the type. I'm sure the economists could outline several additional problems. Until society is willing to invest sufficiently in researching the erosion/productivity problem, a management theme-song set to music from the Twilight Zone will have to suffice.

There are other issues that are part of the myth and fable theme. Besides increased erosion, surface runoff (overland flow) is supposed to increase and groundwater recharge decrease as pinyon and juniper increase. This, despite the fact that rainfall simulator studies on a variety of pinyon-juniper sites and water budget studies on two sites generally indicate otherwise (Gifford and others 1970; Williams and others 1969; Gifford 1975b). Perhaps a lighter soil texture, as found on at least some pinyon-juniper sites, accounts for some of this. In other cases, as pinyon and juniper increase and other more palatable species decrease, then grazing patterns change. Trampling disturbance, found to be very influential in terms of reducing infiltration rates (Dadkhah and Gifford 1980), is reduced significantly, thereby allowing soils to regain maximum infiltration capacities. Again, it is very easy to hypothesize that the runoff frequency from lightly grazed pinyon-juniper stands is no greater (perhaps less?) than the runoff frequency from adjacent similar lands more fully utilized by livestock and perhaps big game. As for ground water recharge, the limited research indicates it makes little difference whether trees are present or not as nearly all water available on an annual basis is lost through evapotranspiration.

And what about wildlife? Improved wildlife habitat is often a major justification for controlling pinyon and juniper. Based on past research, some of which has been presented at this conference, I wonder if (or which?) wildlife impacts are significant in terms of whether a woodland is present or not. In many cases it would appear that impacts of pinyon-juniper control on deer use have been rather minimal, and impacts on other wildlife species have been somewhat variable. Blanket

statements are obviously out of place when discussing the relationship of wildlife to the pinyon-juniper type.

Successional changes or pinyon-juniper invasion is another interesting topic. In capsule form many range managers would again align themselves with West (1984b):

> The pinyon-juniper type ... has changed dramatically since European man came to the region (West 1984a) .... Periodic ground fires at 10-30-year intervals (Wright et al. 1979) were probably mainly responsible for restricting trees to topography that broke up the spread of fire in mid-belt woodland or in savannas before whitemen came. Livestock reduced the understory fuel load and tree-herb competition. These factors plus several lesser, concomitant and ancillary influences contributed to an explosion of tree seedling establishment in the first few decades after livestock introduction (West 1984a).

On the other hand, Lanner (1981) offers another viewpoint:

> ...While the concept of a massive, regionwide invasion is offered as justification for wholesale uprooting of pinyon and juniper trees, the validity of the invasion hypothesis remains undemonstrated and open to serious challenge.
>
> To validate the invasion hypothesis two things are essential. First, it must be shown that a given tract of land was in grass or shrubs up to the time it was settled; and second, that it later became wooded.

Because of the undocumented past, we may never know what "dramatic" changes have occurred in the pinyon-juniper type. There undoubtably have been some changes, and slide presentations such as Wayne Burkhardt presented on Monday visually document relatively recent changes. Perhaps the type has even "invaded" new territory, but whether the end process is good or bad appears to be somewhat dependent on individual perspectives. The coming or going of the pinyon-juniper type is definitely not all good nor is it all bad.

Related to community dynamics is the question of controlling pinyon and juniper. In the first place, why eliminate the trees? Does society really have a good reason? Secondly, if trees are to be eliminated, can they be utilized for anything at all? And thirdly, if the trees are eliminated, what is the end result? Both wildlife and watershed impacts appear either minimal or hard to predict, leaving other items such as improved livestock grazing to absorb the majority of the costs. It seems reasonable to suggest that before large sums of money are expended to modify a plant community that baseline data be gathered to reflect existing conditions (which may or may not support a previous bias) and then, if change is initiated, that data be collected to substantiate whether or not any of the initial objectives were met. If baseline and post-treatment evaluation monies are not available, then the project should never be approved. This equates to professional accountability.

CONCLUSION

Well, where are we with the story telling, the myths and the fables of the pinyon-juniper type? Obviously much remains to be done, many truly exciting finds are yet to be discovered. Storytelling will continue, but successional questions, alleopathy relationships, water and nutrient relations, erosion questions and wildlife and livestock relations will gradually acquire new dimensions of clarity. I look forward to the next 10 years of research.

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THE AMERICAN INDIAN RESPONSE TO THE PINYON-JUNIPER CONFERENCE

Glenn E. Wasson

ABSTRACT: The American Indian has occupied pinyon-juniper lands for eons in total harmony with Mother Earth. Values of the Indian and U.S.-European are completely different; the former emphasize living in harmony with all other living things, the latter focus on monetary rewards and technological change, with polluting side effects. By adopting the Indian method of management, pinyon-juniper lands can be restored to full productivity. Trees should not be cut, rather pine nuts should be harvested and processed into high-protein food for starving people on our planet.

INTRODUCTION

On January 13-16, 1986, the Pinyon-Juniper Conference was held in Reno, NV. The chairman of the conference, Richard L. Everett, allowed the Indian an opportunity to express his views, which understandably were not in agreement with the presentations of the previous days of conference. A major point illustrated was the difference of usage the two cultures were prescribing.

This report is to expose to readers the Indian culture. This is quite necessary, as a true intercourse or interchange between the two has never taken place. Rather, the trend has been contentious. Land bridges were invented to prove to the world that the Indian was as guilty as the dominant society in conquering this land. The land bridge was essential since ape remains have never been found in the Americas. The more that is found and written on this subject--the greater the question.

The American Indian has occupied the entire area considered in the Pinyon-Juniper Conference as written in the U.S. Indian Claims Commission cases: "Since time immemorial." Validity of this land tenure has been established from archaeological sites near Las Vegas, NV, where footwear has been dated at 30,000 years old. At another site, called the Lovelock Caves, findings have amplified the tenure of Indian occupancy. Recently, archaeological findings near Fallon, NV (Reno Gazette-Journal, Nov. 3, 1985), whose dates have not been officially published, in any event place the American Indian in this area far earlier in time than the biblical Adam, Western Civilization's concept of the first man.

The enigma of the American Indian is quantified infinitely when skull comparisons of the Cro-Magnon man, placed as the first of Homo sapiens in Europe, and the American Indian are found to be identical! (Goodman, Jeffrey. American Genesis, Summit Books.)

The archaeological sites and findings above are verified and recorded as such. In any event, there can be no doubt that the American Indian has lived and prospered in this land for eons, leaving to each following generation a land filled with clean air, clean water, and a generous supply of food, and the knowledge of how to live in harmony with all the life forms placed here by the Great Creator.

THE OTHER SIDE

"WE WILL NEVER LIVE AGAINST MOTHER EARTH AGAIN!" This was the first edict made by the survivors of the First Destruction. This Destruction is recorded on the Stone Calendar excavated near Mexico City. It was the first of the four recorded destructions, the last being the Flood.

The western Shoshone have a story of how to run from man-eating monsters, and thus live. The Smithsonian Institution has in its records the Paiute version of the Flood, narrated in 1873 by Natchez, a son of Winnemucca. Of course, these stories come from savages who could not have had a history or anything akin to a culture.

Nevertheless, all facts point to one actuality--the Indians have lived in this area for eons, and to do so have had to work, plant, and pray, to take a destroyed land and make it into a productive land. This was not an easy task. This assignment, called stewardship by some, was handed from generation to generation. In the Teachings, each life form was acknowledged as a total entity as its spirit was granted by the Great Creator just as man's was. Through this Creator-structured mode of living, the entire spectrum of ecology became a way of life. To reemphasize the point, Ecology was practiced! All tribes had and enforced laws designed to protect all life. These protective laws included the protection of our Mother Earth, one of the many children of the Great Creator of the Universe.

Paper presented at the Pinyon-Juniper Conference, Reno, NV, January 13-16, 1986.

Glenn E. Wasson is Member, Sacred Land Association, 2700 Sunkist, Susanville, CA 96130.

The Indian had come to the realization eons ago that the only thing that could be construed as "bad" on this earth was man, himself. To achieve a harmonious relationship with Mother Earth, man had to control himself, thus allowing each and every life granted by the Creator its space to live. Consequently, birth control was practiced by Indian women who used certain plants as a contraceptive. This practice was so implanted in the Indian life, that it was practiced throughout all the Indian Wars.

The ancients found and taught that there has to be a reason for life and living. Each living entity constitutes a link in the chain of life. All those seen and unseen, all who grow from the ground, all those who crawl, all those who swim, all those who walk on legs, all those who fly, are all intertwined in the chain of life. Each plays a vital role in the keeping of a strong, healthy,and living Mother Earth, who provides each and every entity with all the necessities for life.

Therefore, the cutting down of a single living tree is sacrilegious--the cutting down of a forest--UNTHINKABLE!

COMPARATIVE ANALYSIS

The preceding has been a vastly oversimplified version of life and living prior to the coming of a new culture. The Pinyon-Juniper Conference brought forth ideas and possible uses of these trees from those cultures. The issue at hand is which is the best approach to utilize these trees--the Indian method or the U.S.-European (for the lack of a better identity word) method. It is evident that comparisons have to be made to objectively evaluate the best usage method.

Backgrounds

Beginning with the U.S. Indian culture, findings indicate that it has had little or no impact from an outside source for a 5,000-year period, until the mid-1800's. The U.S.-European culture has been appreciably impacted by and/or has absorbed other cultures over the same time period.

The development of these two cultures in regard to values, time, and goals has extended into an ever-widening schism. The Pinyon-Juniper Conference showed the polarity between the two cultures. Therefore, an examination of the two points of view is needed to find out why the polarity exists.

Values

The U.S.-European side presenters tended to show a profit motive in their presentations, while the Indian side presented life. Boiled down, the question becomes dollars vs. life.

The Indian teaches the Creator did not create money. To the dismay of the U.S.-European, the Indian does not fully grasp the values placed in monetary matters. To the dismay of the Indian, the U.S.-European does not fully grasp the values placed on water, air, land, or the uprooting or breakage of the pinyon-juniper.

A values-structure antithetical may be stated:

- o The Indian has given the world 156 different foods and medicines for a healthier life for all men, with no harm to Mother Earth.
- o The U.S.-European is using a technological approach to afford man an easier life, but with great harm to Mother Earth.

Time

The two cultures view time from a totally different aspect. One writer has used the terms, linear for the U.S.-European, and cyclic for the Indian, to describe this difference. A comparison of the two shows the philosophical concept of the U.S.-European has developed into a man-oriented concept. The philosophy developed has placed man over all, therefore he is allowed by his philosophy to do with as he sees fit with no thought of the ecological consequences on or for his posterity.

The Indian philosophic concept has placed man as a part of the whole and he must protect all life to protect his own and his posterity.

The questions posed are, "Is today more important than tomorrow?" and "Who will make this judgment?"

Record Comparison

The U.S.-European past record starts with the cedars of Lebanon of biblical fame and extends to the redwoods of northern California--one is extinct and the other is near extinction. The Indian past record is with us today, for all life to enjoy in the established way.

Clearly, the comparisons of the two cultures' past records point out that one has managed its forests into extinction while the other has managed its forests into today's enjoyment.

MULTI-USE, A PLAY ON WORDS

The term multi-use will have to have a common definition. Presently, the U.S.-European uses the term to describe a finite man-oriented usage. The Indian uses the term to describe the usage as it has been for ages. This report will not attempt to change or define the term, but will adhere to the term as understood by each culture.

Proposals of the U.S.-European at the Pinyon-Juniper Conference included methods of forest clearing and converting the cleared land for multi-use purposes and possibly manufacturing products from the fallen trees. These

presentations were made by experts in their fields and professionally presented. The plans were to clear the forests, then manage the cleared ground using the term multi-use to conclude a point. Left unclear was the replacement of the pinyon-juniper or what lives would be adversely affected.

The Indian proposes no chains or change as both species are a part of the life chain. The pine nut constitutes a food staple in man's and other species of life's diet, its tar is used for waterproofing, and its dead branches provide a heat source. It has been such an ally to the Indian that dances are held in its honor. Likewise, the juniper plays an important part in life. The berries are used for medicinal purposes, the leaves and boughs are used for other therapy, and its dead branches provide a heat source. To the Indian and other species, one is a grocery tree and the other a medicine tree.

Which of these multi-uses will best suit this planet is the decision that must be reached.

DIFFERENCES IN ECOLOGICAL PRACTICES

The U.S.-European treats ecology as a branch of science concerned with the interrelationship of organisms and their environment. Colleges and courses are provided for those who wish to pursue this science. As with all science, every event or phenomenon has to be weighed, measured, etc., before full acceptance. This full acceptance has never been granted the ecologists by the powers that be, causing this branch of science to have never impacted the U.S.-European culture in a timely manner. Because of this, portions of the oceans are not life-supporting, air is being polluted, water is being polluted, lands are being kept productive via chemicals, and the planet itself is becoming overloaded with waste products (from chemical to nuclear) from manufactured items for the good of society, which are harmful to all life.

This is the legacy that the U.S.-European culture leaves to its posterity when the culture's ecologic effect is viewed in a holistic overview. The Indian treats ecology as a part of his daily life, as harmony is the goal. Each generation was granted a full life as bestowed by the Creator, and its duty was to ensure the following generation was allowed its full entitlement.

CONCLUSIONS

Historically, the U.S.-European has had to travel from place to place over the centuries because of his ecological practices. Due to the overpopulating of a land, movement became a necessity and every movement left behind a razed and overpopulated circumstance. Today there is no place to move, so space is being considered as the next "logical" step. Unfortunately, manned flights just beyond earth's atmosphere do not qualify as interstellar travel, nor do they justify the wanton destruction of life on this planet. The cultural linear-time concept prevents the U.S.-European from viewing the things he has caused, and prohibits the evaluation or the consolidation of his position.

A realistic evaluation of the U.S.-European psyche has to be made before any change can be effectuated. At present, his philosophy prevents him from self-evaluation. In his blind pursuit of a goal not yet established, he cannot see, therefore it is impossible to learn from and teach against the wanton killing and destruction he has caused. Also, in his blindness he has assumed the Creator is blind, or dead. THIS IS THE REALITY THAT ALL OTHER LIVING SPECIES ARE FACED WITH! The polarity between the two cultures was furthered by a meeting of Great Basin Indian Elders in 1968 when the following declaration was made:

> If we [mankind] go to another planet and take our filth [morals, wanton destruction, ecological practices] and ruin that planet, then we are nothing but a bad cancer in this Universe and we should be destroyed!

The culture comparisons show the Indian method is far more beneficial for this planet and all living species therein. Since this is the only planet man has to live on, something has to be done by man himself, posthaste, to ensure its livability for future generations.

RETURN TO NORMAL

The past 150 years do not constitute a tick (timewise) in the age of this pinyon-juniper area. It is not too late to bring these forests back into full production--and it is up to man to do so.

The comparisons in this report point out conclusively that there is only one method to manage the forests, that being the Indian method. The seeming obstacle at this point in time is economics. Solid reasoning is the way to overcome this seeming obstacle.

In the fairly recent past, people were taught to eat potatoes, tomatoes, etc. The same people can also be taught the food value of the pine nut. Using the algebraic sequence of "if-then," the postulate may be stated:

> If the pinenut has been the staple of the Indians' diet for eons, then it is possible the pinenut can be a food source for all mankind.

The harvesting by Indians would provide jobs and fulfill their cultural ties to Mother Earth. As in the past, the nut would be ground into a flour for transportation purposes. The shells and pitch could have additional value. This flour could provide a high-protein food for starving people all over this planet. The yields are annual with no cost to anyone. Best of all, this food source would not place a drain on existing food banks, nor would it make any new demands on present tilled lands as the entire system is in place.

From the ecological standpoint, all life would benefit. The role-modeling by Indians would change the habits of those who use the forests. This is sorely needed. The hunters who scatter their garbage, beer cans, and whiskey bottles over wide areas, besides killing every type of animal to zero-in their instruments of death--for the sheer joy of killing. The average sightseer or vacationer who keep their houses, yards, and automobiles in a spotless condition, but run wild when in the forest and think nothing of strewing the Earth with tin cans, plastics, diapers, etc., dirtying the land and water that other life forms must use for their life. These are just some of the abuses our Mother must face on a daily basis.

All of these acts of ignorance can be changed. First, by role-modeling and then through the holistic application of ecology that has been in practice in this country for ages, through an educational process which should begin at home and be furthered through each and every year of formal education. The change would not be immediately visible, but in a relatively short time-span this Earth could be brought back into the condition the Great Creator placed it here--clean and full of Good Spirits.

Synecology

Chaired by:

Paul T. Tueller, Professor, Department of Range, Wildlife, and Forestry, University of Nevada—Reno

SUCCESSIONAL PATTERNS IN PINYON-JUNIPER WOODLANDS

Neil E. West and Nicholas S. Van Pelt

ABSTRACT: Managers and students of pinyon-juniper woodlands must have information on how these ecosystems respond through time to human and natural influences. We document the importance of plant succession and describe six kinds of change that operate within present-day woodlands. Our purpose is to broaden thinking on woodland dynamics and to suggest how intervention and research can be designed to give more definitive outcomes, answers, and predictions. Many more successional sequences need to be obtained, using a variety of techniques, starting points, and disturbance regimes.

INTRODUCTION

Ecosystem, landscape, or vegetation change is a prominent theme uniting many of the paper topics in this volume. That is, we are not considering pinyon-juniper woodlands just as they are today, but as they have been and might become. It is relatively easy to form a static picture of woodlands--number of trees or volume of fuelwood per acre, and so forth--but far more challenging and useful to explore the histories, dynamics, and potentials of these ecosystems. For example, we have learned that woodlands are extensively present today where, only a few thousand years ago, there were none (Thompson, this volume). Conversely, pinyon and juniper have disappeared from lowlands where they formed vast stands (Van Devender, this volume). These are changes on immense geographic and temporal scales, but they are linked to processes over shorter distances and timespans that we can observe and comprehend in the present. This paper will examine a phenomenon--plant succession--arising from such processes in contemporary woodlands.

Our purpose is to assist land managers and other researchers in understanding how a knowledge of succession can benefit them, to discern regularities, and to review and suggest methods of detecting patterns. We will propose a flexible definition of succession, present a scheme for labelling varieties of change occurring in the type, and consider how these are illustrated at particular places and times in the literature. In so doing, we will at least touch upon 10 or so themes found in other conference papers.

Paper presented at the Pinyon-Juniper Conference, Reno, NV, January 13-16, 1986.

Neil E. West is Professor, Department of Range Science, Utah State University, Logan; Nicholas S. Van Pelt is Graduate Research Assistant, Department of Range Science, Utah State University, Logan.

For example, vegetation and site classification, understory response to tree removal, and the consequences of custodial management are just three topics for which some consideration of succession is essential.

Our review has led us to the conviction that those concerned with the use and betterment of woodlands have three elementary choices: one, they can take the limited number of successional sequences already published as a guide to all their actions; two, they can simply wait until consequences of past and current actions manifest themselves, with no expectations of what will happen; or three, they can employ a battery of hypotheses and techniques to portray more sequences and to anticipate what woodlands will do with or without our intervention. Our discussion is premised on the superiority of the third alternative. If we take this "activist" route, we will need to know not just what has happened, but why. Furthermore, we must rapidly generate and analyze possibilities and outcomes, signifying that modeling should complement our field data.

PERTINENT WOODLAND CHARACTERISTICS

At the outset, we should list several "system-wide" properties or conditions that would influence succession, making patterns from one locality and time either more or less generalizable to other portions of the woodland type. These statements reflect our greater familiarity with Great Basin and northern Colorado Plateau expressions of pinyon-juniper vegetation.

Over their huge extent, woodlands occupy radically different effective environments for plant growth. One of the primary "drivers" of vegetation change--climate--is quite variable both within a given place and between places. Soils and landforms are likewise heterogeneous, but are believed (Everett 1985) to be not as influential as climate and unusual weather in controlling macropatterns and the rate of succession.

Within the entire type, or even any sizeable subregion, there is a huge pool of arboreal, shrubby, herbaceous, and nonvascular plant species which can potentially participate in succession. These species do not exist in unvarying or stereotypical relationships to each other, hence they play flexible roles in the successional drama. Modern man has profoundly influenced the set of "actors" by introducing or extirpating plant and animal species.

Woodland successional behavior today is unquestionably influenced by large-scale paleohistorical and historical events and trends. What we see happening on even a limited plot of ground cannot be fully understood without reference to larger forces. We know that Great Basin woodlands are yet rebounding from pluvial displacements and the deforestations of the last century (Hattori and Thompson, this volume). Pinyon and juniper trees still occupy much less land than they are capable of growing and reproducing upon under current climates.

Many woodlands exhibit very low dynamism, or scant evidence of change from year to year or over longer periods. Indeed, some appear to be among the most static of all western ecosystems, for example in comparison to subalpine forests or semidesert grasslands. While such impressions are not wholly correct even for the more arid versions of the type (Jameson 1965; Treshow and Allan 1979), we are nonetheless dealing with an entity whose successional activity requires patient, close observation. The long lifespans and time to maturity of the trees mean that they are subject to much environmental fluctuation and potentially many disturbances from the time a bare site is colonized until a tall woodland appears.

Over millions of acres where tree dominance is very strong and little understory remains, it is tempting to regard the vegetation as "climax"--the end of succession. Although the influx of new species may be negligible in such situations, the trees retain their dynamism. They will still be growing at constant or increasing rates, without offsetting mortality (Meeuwig and Budy 1979), and heavily drawing resources from the interspaces. Erdman (1970) found that even quite old woodlands on the Mesa Verde, Colorado, do not have the stable (self-perpetuating) age structure required for a true climax. These examples signify that the true endpoints of long successions have not yet been attained, and that great vegetational dynamism continues even though species turnover has ceased.

We confront present-day woodlands that have sustained pervasive impacts like grazing for over one hundred years or, throughout much of the Southwest, much longer periods. True relict areas, except on very broken topography or low-producing sites, are scarce. It is accordingly difficult to find and study successional sequences that are wholly natural; most reflect human agency to some degree, and the specific effects can be quite hard to reconstruct. Whether certain changes now evident in woodlands are natural or man-caused is very much an issue requiring new methods and data for resolution (Betancourt, this volume).

The woodland type overlaps the sagebrush, semidesert and plains grasslands, mountain brush, and ponderosa pine ecosystems, among others. Pinyon-juniper communities are thus far from being entirely discrete systems. Their successional patterns cannot be considered in isolation from what we know about other vegetation the type adjoins and with which it shares species, soil taxa, and climatic patterns. The fluidity of vegetation formations is a universal conclusion from paleoecological work, as well.

DEFINITIONS

Succession is usually not explicitly defined in studies purporting to deal with it. However, it has become an extremely inclusive term, one which should be qualified in most contexts. Goodall (1977: 310) asserted that succession "denotes an ill-defined set of dynamic changes in the specific composition of a biotic community, which are in some sense sequential or progressive, often involving the replacement of a dominant life-form by another, larger one." He concluded, "It is probably best to regard 'succession' as having no conceptional content differentiating it from dynamic change in general." However, Goodall (1977) also felt that predictability, if not directionality, was a feature of the traditional notion of succession, and that observable changes in one instance should be generalizable--fit a pattern--to be relevant. That is, random change should not be regarded as succession.

Zedler (1982: 429) simply felt that succession should "be synonymous with change in species composition." All other changes should be considered vegetation development, even shifts in relative abundance among a set of species growing together. This is probably an overly restrictive definition, just as the equation of succession with dynamism is excessively general. A middle-of-the-road approach is preferable, calling succession the result of several kinds of change that cause the composition, stature, functioning, and appearance of vegetation to shift over periods of years to decades, and which are at least somewhat orderly. should still strive to distinguish varieties of succession and what is clearly not successional change.

"Stage" is a term closely coupled with succession, and implies that we can recognize its progression, much as points can reflect an underlying trend (fig. 1). Indeed, use of the word to represent a point along a sequence, in the same way that otherwise continuous vegetation is "typed out" on the landscape, is almost essential to communication. We thus define "successional stage" as a more or less distinct segment along a continuum, denoted by the prevalence of particular species, life forms, propagule reserves (Koniak and Everett 1982), or stages of maturity (for example, sapling). "Sere" is a closely associated, common term covering the progression of stages on a given site. "Seral" species, stands, and vegetation are those present at and characteristic of stages short of climax; that is, transitory.

Spatially, woodland succession may be manifest on a few square yards or over a square mile or more, and studied at these extremes or on tracts, transects, or plots of intermediate size. A flexible definition of the spatial, as well as temporal, scale of succession is therefore better than any arbitrary delimitation of where and for how long it should be studied. However, regional displacements or advances of vegetation spanning thousands of years (woodland to creosotebush, for example) are not encompassed by the term succession.

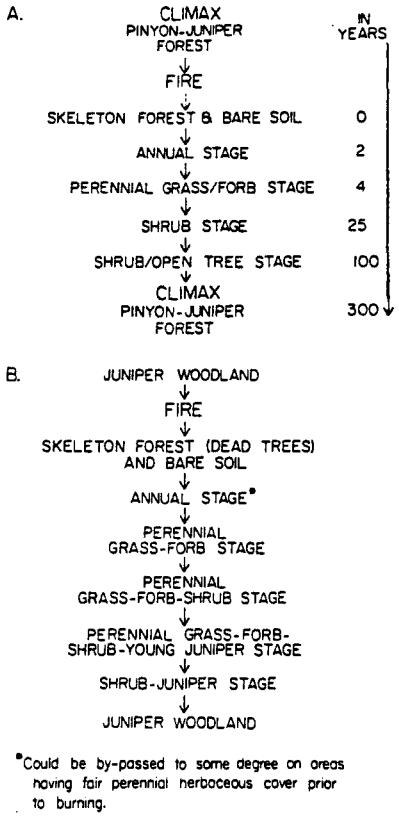


Figure 1.--Two sequences of secondary succession in pinyon-juniper woodlands, showing the stages observed and (top) approximately how long after a disturbance they appear. A=southwestern Colorado after Erdman (1970); B=western Utah from Barney and Frischknecht (1974).

THE IMPORTANCE OF UNDERSTANDING SUCCESSION

Any level of real interest in and commitment to woodlands implies a need to know their history and a curiosity about their possible futures. Of course, how far backward or forward our interest reaches depends upon our objectives, patience, resources for study, and other considerations. We see four primary justifications for seeking to better understand succession in managed and unmanaged woodlands. "Secondary" justifications pertain more to specific planning needs, and examples of both kinds will be given.

One, the mix of successional stages or states on the land determines the mix of goods and values obtainable. Unbroken tracts of dense woodland produce little besides wood fiber and other tree products, whereas the same area seeded to crested wheatgrass supplies little besides cattle forage. With a combination of these two states, "forest" and "pasture", products diversify. This becomes even more so with the addition of other identifiable states (sapling pinyon for Christmas trees, for example). Multiple use is thus scarcely conceivable without a combination of states. The challenge is to attain a mix or mosaic that accords with the land-use plan and to maintain it although every subdivision or "patch" is advancing or reverting to another state or stage.

Two, expectations about the presence and outcome of successional causes or mechanisms are implicit in, or built into, all silvicultural and range-management prescriptions. The clearer the acknowledgment of this by writers and users of such plans, the smaller will be the discrepancy between prediction and outcome.

Three, a view of succession is also implicit in vegetation classification schemes and, again, an awareness of governing assumptions is crucial. If we believe that woodland vegetation and sites are classifiable over their enormous extent into a moderate number of units, we are supposing that (1) species groups from many, many starting points will over time converge into fewer, consistently recognizable states, and (2) convergent vegetation will faithfully reflect the characteristics of the site. Furthermore, we may also assume that land units classified the same will respond similarly to disturbance or improvement, and that climax stands are satisfactory referents. In short, our perspectives on plant succession and vegetation classification are not inseparable, and must be reconciled.

Four, we have troubling indications that a large proportion of the woodland type is going along undesirable successional pathways toward tree superdominance. This could lead to grave erosion, depletion of seed pools, extinction of understory plants, the threat of firestorms, and site degradation (Carrara and Carroll 1979). We need to know where and why this is occurring, and to devise ways to divert or reverse such trajectories. Certainly the trends now evident contradict the prevalent idea that succession is always "good", leading to stabler, more valuable communities.

As mentioned, a knowledge of succession assists management in a number of specific applications. We may be able to provide confident answers to questions like:

How will forage plants, or for that matter weeds, respond to partial or complete removal of the tree overstory? What patterns of tree regeneration will ensue after patch-cutting for fuelwood?

How will the abundance of particular bird or small-mammal species be influenced by successional stages (which are denoted not only by plant species present, but by their arrangement and vertical structure)? If a known percentage of an area of dense woodland must be converted to a perennial grass/forb stage for deer numbers to increase, how long will such a stage persist?

Thus, we see how the land manager is compelled, on at least part of the landscape, to retard or encourage succession in directions that further the objectives of his land-use plan. He will not, however, reach his goals or avoid criticisms from his clientele if he cannot anticipate what will happen if he institutes an action. Similarly, he must be able to recognize danger signals accompanying the course of unimpeded succession.

STUDIES AND DEBATES ON SUCCESSION AND ITS CAUSES

Vegetation change is universal and seemingly regular enough that people have sought a theory or governing theme to account for the patterns we observe both casually and scientifically. Hence, we inherit many schemes, generalizations, and analogies, the legacy of innumerable attempts at explanation. We will next briefly review some major ideas abounding in the literature of succession (which Roberts (in preparation) has called "extensive, diffuse, and acrimonious").

The earliest "classical" notions about succession held that predictability is brought about by some species modifying a "new" habitat to make it more fit for other species. Hence, there would be "relays" of sets of species until the habitat was dominated by one which is not replaced, constituting a climax or single, stable endpoint (fig. 2, top). Succession was considered orderly, progressive, and clearly understandable in terms of the interactions of species first present or arriving later.

The monoclimax view was modified after a recognition that more than one endpoint of succession could prevail over a region or vegetation formation. Thus, the polyclimax school (Cooper 1926) proposed that relatively permanent features of habitat, such as soils and topography, led to a distinctive climax for that location and all others like it. Nonetheless, a linear, deterministic course of succession was still envisaged (fig. 2, middle). The polyclimax concept is the one which best accords with most land managers' idea of succession in relation to site and time.

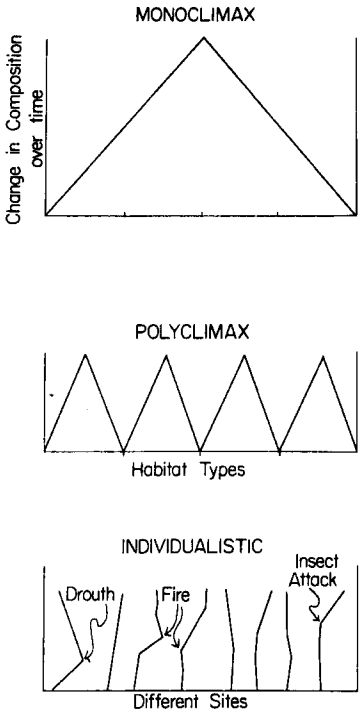


Figure 2.--Pictorialization of three major notions of succession and trend toward climax. Suggested by Bruce McCune.

So many exceptions to these two models have been pointed out that they cannot be considered sufficient for all circumstances. However, they remain influential (in range-management and ecology texts, for example), predisposing us to see regularity, harmony, and even purpose in vegetation change.

The most contemporary view (supported by the largest number of examples from diverse ecosystems) recognizes that each site can develop its own pathway and climax, both formed by the peculiar combination of forces impinging upon it. The species pool available to contribute to succession is not regarded as a constant. There are many possible avenues which, although tending to resemble each other with the passage of time, rarely converge (fig. 2, bottom). Outside forces are continually diverting sequences, such that particular stages are only more or less probable, not inevitable. Interspecific mechanisms are liable to be overridden

With their reliance on interspecific interactions to drive succession, the first two models assume the prevalence of certain causes. Connell and Slatyer (1977) have formalized these mechanisms, the terms for which are widely used. Facilitation means that the sequence of species present is governed by the process of "reaction", whereby later species can only become established after habitat preparation by precursors. The sequence ends when the reaction process stops.

Connell and Slatyer's second or tolerance model means that early species neither pave the way for nor inhibit later species. Instead, the sere is determined solely by life-history characteristics of the participating species. This model was explicitly posed against facilitation, as an alternative explanation for the same observed pattern.

These authors' third or inhibition model suggests that early colonizers either suppress the invasion of later species or strongly limit their growth and survival. Later arrivals will only be successful when the "pioneers" die, releasing space and resources. Where this model is valid, then the initial floristic makeup after a disturbance is especially important in molding the subsequent pathway.

The nature of the climax, or presumed endpoint of succession, has been loudly debated for over 80 years. Some have shown that no trend toward stability through self-replacement of dominant species may be evident even after decades (McCune and Allen 1985), whereas others claim that change can become negligible after certain species prevail and reproduce in sufficient numbers. Whatever the merits of either view, it seems prudent to retain climax as a working definition of a possible (but hardly inevitable) result of succession. McCune and Allen (1985: 382) regard it as "simply a state of relatively stable composition that develops in the absence of major disturbance."

Current thinking on succession, while hardly unified or theory-grounded, nonetheless includes important areas of general agreement. Also, while exceptions to old generalities continue to accumulate, some workers (Roberts, in preparation) point out that early writings still have much to offer and should

not be dismissed. Overall, the debate on succession has been tempered by the evidence that patterns and outcomes are quite system-conditional (say, for warm deserts), and that causes and stages apparent in one ecosystem may be inoperative or subdued in others. If disturbances or the macroenvironment are severe, there may be no grounds for invoking an interspecific "mechanism" of replacement. On the other hand, classical "reaction" can certainly be critical when tall-statured plants mediate the biophysical medium of small ones to their benefit or detriment. That is, casting shade and depositing litter are inevitable consequences of a tree's growth.

METHODS OF STUDYING SUCCESSION

Scienists would obtain a perfect view of succession if they traced the birth, growth, and death of every plant on a plot of ground from the time of a disturbance until a defined endpoint or until something came along to interrupt the pattern. Gaining such a view, however, would require both the observational patience and continuity to identify every plant and to watch what happens for many years--perhaps hundreds. It would also require recognizing a stable outcome. Together, such preconditions may be impossible to meet, and the degree of resulting detail would be greatly in excess of needs. We could lose sight of patterns detectable by studying segments of a sere, only some of the individuals, or a number of seres simultaneously.

The reason we have any notion of succession over the long haul is that scientists have employed other, albeit indirect means of gathering data. Our truly direct studies have been largely limited to the early stages of secondary woodland succession. We may briefly consider the feasible methods as falling into four categories, depending on our desired perspective relative to the present:

1. Retrospective--what pathway did plants take to produce the communities we see now. This family of approaches includes chronosequences (arrays of neighboring plots with vegetation of different ages) and age-structure analyses. Succession is inferred, not directly observed.

2. Direct, short term--what patterns are evident if we watch succession from a known starting point for a few years onward. For example, species presences and abundances are recorded before, just after, and for three years following a fire.

3. Direct, long term--succession is described as it unfolds over an indefinite period. Such approaches, while superior, require committed investigators, stable budgets, protection of study sites from intrusion, and uniformity of measurement from visit to visit.

4. Prospective or predictive--past patterns, direct evidence, and assumptions or arbitrary values are used to anticipate what course succession will take in the future. Predictions may be in verbal, diagrammatic, or equation form, and in advanced work today they are generally computer simulation outputs or model consequences.

These approaches are in no way mutually exclusive, and the greatest and most reliable insights will come from using all four in studies of a given area, management problem, or span of time.

SUCCESSION AND OTHER TYPES OF CHANGE IN WOODLANDS

To distinguish varieties of succession, and to discuss nonsuccessional change as well, we have chosen to use terms in Lewis' (1982) detailed classification of ecological change. His scheme is hierarchical, fosters considerable precision of meaning, and permits the use of modifiers indicating the source of change.

Our discussion will concentrate on the recent and contemporary time scales, since changes over geologic and prehistoric spans are well addressed elsewhere in this volume. However, readers may consider which of Lewis' categories are operative if very long-term trends bring about large-scale displacements or invasions of pinyon, juniper, and associated species. For example, the severe oscillations of a drying climate might decimate lowland pinyon stands, giving more xerophytic forms an advantage.

Noncyclic replacement change is just the replacement of an individual plant by another of the same species; that is, population turnover. There is a scarcity of data on this topic for woodlands, and addressing it would require demographic approaches. To the extent that this kind of change prevails in a given situation, succession in the sense of species substitution is not occurring. In fact, a true climax would be maintained by precisely this process. Noncyclic replacement would possibly govern the numerous, troubling instances of stasis or lack of dynamism in pioneer or ruderal stages. Clary (1971) describes a clearing in which there was no progress away from a weedy stage even after more than a decade. Noncyclic replacement also may control stagnated semidesert-shrub and woodland communities.

Cyclic intracommunity change appears as a mosaic within the same community. It results when occupation of microsites shifts among species, but the displaced ones may return. Overall, the stand composition remains much the same despite such "fine-grained" turnover. Studies in Nevada (for example, Everett and Sharrow 1985) document how this sort of change may operate, driven by shifts in microsite proportions accompanying tree-crown expansion or tree removal. As crowns expand, the understory is "enhanced" or "debilitated", depending on the species involved and its original proximity to the tree stem. This type of change is successional, but is not necessarily directional in terms of the whole stand if tree mortality balances crown and rhizosphere expansion.

If oak (Floyd 1982), sagebrush, or other tree "nurse" species occupy the woodland interspaces, there would be shifting of tree-stem locations

over decades. As these trees grew, the understory about them would rearrange itself. Upon death or removal of the trees, microsuccessions would commence. However, the cyclic, perpetual nature of this scenario is speculative at present, necessitating extensions of recent work like that of Everett and others (1983).

Intercommunity cycles are a kind of change whereby one type of community repeatedly changes to another expression and back again. For example, juniper woodland and savanna may alternate under regular fire return periods (fig. 3). The cycle would be distorted or broken if fire frequencies increased (maintaining a pure grassland), or if the removal of fire led to a thickened, largely inflammable woodland. There is good evidence that fire-driven intercommunity cycles were widely prevalent in pinyon-juniper during presettlement times (Barney and Frischknecht 1974; Rogers 1982; Tausch, in preparation).

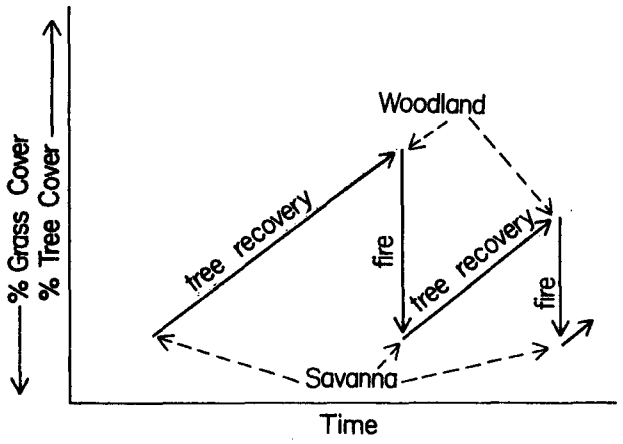


Figure 3.--A depiction of how periodic wildfire maintained a productive intercommunity cycle alternating between thickening toward woodland and a savanna condition.

Fluctuation includes a range of phenomena short of replacement, such as year-to-year differences in the density of an annual herb, tree-ring widths, or herbage production. The parameters of interest fluctuate about a mean value, with or without long-term trend. They may exhibit serial correlation, or extended spans of abnormal values. We can assume that woodland fluctuations are overwhelmingly climate-driven, but grazing, diffuse competition, and release of site resources complicate the interannual effects on a plant or population of plants.

There are almost no community-wide studies of fluctuation, with the pollution-baseline study by Treshow and Allan (1979) an instructive exception. These authors found marked fluctuations in their dry Utah woodlands: least in the trees, more in the shrubs, and greatest in the herbaceous annuals. The many tree-ring studies of pinyon (Tausch and and Tueller 1977) chronicle growth variations, but they rarely relate them to contemporaneous successional changes. If fluctuation exceeds the tolerance of the trees, as apparently occurred during the droughts of the late 1500's (Erdman 1970), the resulting mortality can provoke other, more lasting types of change, such as regression.

Change toward some permanent state is the second major division in Lewis' (1982) outline, and includes all of what is conventionally regarded as succession. We may consider directional change to be from less complex to more complex vegetation as species accumulate and interactions increase. Change in the opposite direction can be regarded, with qualification, as regression or simplification. If the former, progression, is due to the effect of the community on the habitat it is termed "autogenic".

If we start with previously unvegetated or very drastically disturbed parent material or soil, autogenic progression would be equated with primary succession. If the site has been previously vegetated, the postdisturbance path is called secondary succession because spores, seeds, and remnant plants are present. If the influence or agent of change comes from outside the community, but is natural, it is termed "allogenic". A human-caused sequence is termed "induced". These are not mutually exclusive categories. For example, a woodland could be affected by both cattle and drought, with grazing and soil-moisture stress placing some species at a double disadvantage in autogenic interactions. Most changes in vegetation stem from all three, intermixed or confounded sources.

Knowledge of primary succession is pertinent when revegetation of mine spoils is necessary, or when the slow colonization of naturally eroded surfaces is studied. Overburden, especially stored topsoil, will rarely be devoid of propagules, so there is some immediate potential for succession to occur. However, many mining and construction scars within the type have exposed hostile substrates upon which there is little or no sign of woodland recovery even after many years. There is still much to learn and apply in primary-succession contexts. Pinyon-juniper woodlands are quite congruent with terrain underlain by coal, oil shale, minerals, and tar sands.

A growth of pinyon or juniper or both is often observed on highly exposed or erodible soils without evidence that the trees were preceded by the more typical or "zonal" stages of the surrounding country (Woodbury 1933; and fig. 4). Probably far fewer species than normal can grow on such sites, limiting the pool of participants in succession. In fact, pinyon and juniper appear to be among the most adaptable species when unaltered substrates are considered. Gifford (1984) found that containerized Pinus edulis and Juniperus osteosperma seedlings survived about as well on raw mine spoil as on top-soiled plots near Farmington, New Mexico. We have observed J. osteosperma and some pinyon (P. edulis and P. monophylla) on cinder cones and lava flows of fairly recent age in western Utah.

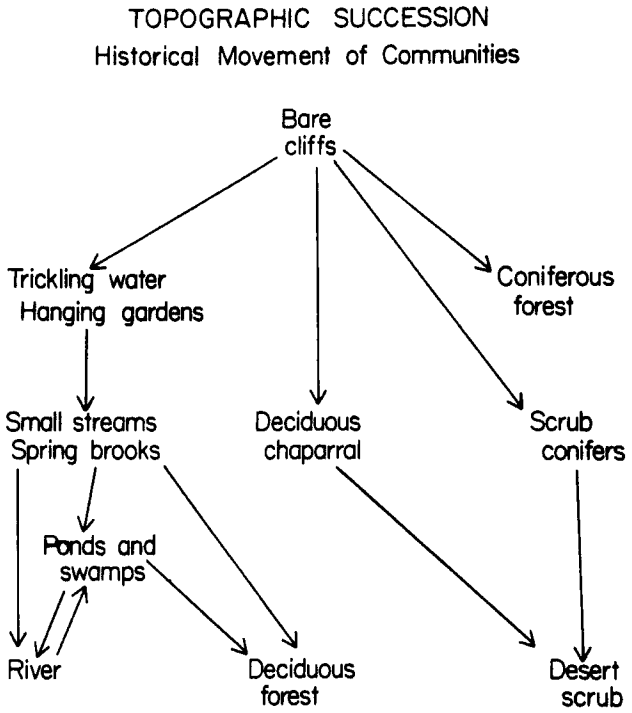


Figure 4.--Successional pathways (generalized and very long-term) in Zion Canyon, Utah, showing a direct progression from raw substrates to a woodland. From Woodbury (1933).

Secondary succession in woodlands has been studied indirectly after several types of disturbance. For example, Erdman (1970) on the Colorado Plateau, and Barney and Frischknecht (1974), Everett and Ward (1984), and Koniak (1983) in the Great Basin have studied chronosequences or postburn seres arising from wildfire. The resulting patterns, as indicated by chronosequences, tend to be rather similar (see fig. 1). Erdman's (1970) and Koniak's (1983) data on comparability of slope, exposures, and soils are more complete than most. Furthermore, Erdman supplies abundant plant community structure data indicating that species diversity is highest early in the sere and declines as the tree cover becomes more complete.

Stager's (1977) and Koniak's (1983) studies each involved a wide range of sites. Koniak explained why Stager encountered such enormous variation in response. What recovered was influenced both by the seral status of the vegetation when it burned and by site factors. Because of the "initial floristics" effect, annual and perennial forbs increased most where the woodland vegetation was early seral before burning. Shrubs and annual grasses dominated after mid-seral stands were ignited. Trees, shrubs, and perennial grasses were prevalent after late seral stands were burned. North and east slopes generally supported greater cover and occurrence of shrubs, perennial grasses, and perennial forbs after wildfire, whereas south and west slopes tended to support the highest cover of annual forbs and annual grasses. After-cutting responses are likely to be similarly formed by initial floristics, seed pools, aspect, opening size, and the dispersion of residues (such as slash).

Regression is a less straightforward or neatly diagrammable category of change than progression. It can be conditionally regarded as "reverse" succession, but not precisely equated with a trajectory back through the stages evident leading toward a climax. Many regression sequences (and causes) are speculative, and far fewer studies of them have been performed. For one thing, graphic regression chronosequences are hard to come by.

We choose to equate regression with deleterious or destabilizing change, largely synonymous with trend away from a desirable condition. Climate change, leading to decimation of trees followed by their replacement with hardier vegetation, would promote allogenic regression. Less subtle agents like sulphur-dioxide pollution or pinyon sawfly infestations would also qualify.

Repeated hot fires, volatilization of nutrients, ground disturbance, and severe grazing or browsing would constitute a set of reinforcing regression causes. An illustrative, widespread result would be a savanna-like juniper overstory (or no trees), and a sward of Bromus tectorum or other weedy annuals. Such communities would be depauperate in species (including microflora), incapable of progressing because of frequent disturbance and voided seed pools, and in danger of regressing still further. Fuelwood overexploitation could eradicate the best tree genotypes, break down microphytic crusts, aggravate weed invasions, and even lead to extinction of the woodland (fig. 5; and Samuels and Betancourt (1982)).

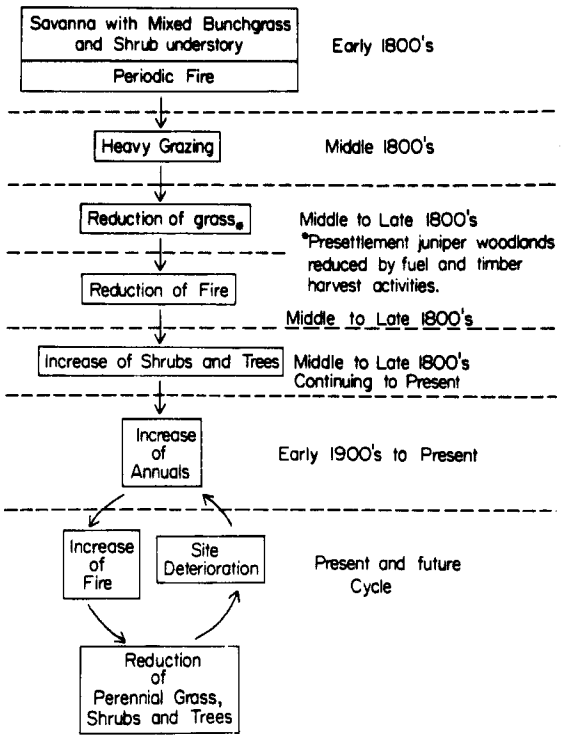


Figure 5.--A summarization of current understanding of the factors leading to regression in Great Basin pinyon-juniper woodlands. Modified from Rogers (1982).

DISCUSSION AND RECOMMENDATIONS

We have shown that there are five important kinds of vegetational change besides succession as we usually mean it: as progression. Directional replacement change--comparable to succession-- in turn has several facets. Whether cyclic, random, progressive, or regressive, changes in woodlands have multiple causes, manifestations, and implications for planning. Two or more kinds of change can occur simultaneously, one within the other (for instance, strong fluctuation about a downward trend). Patterns at moderate space and time scales (square yards, acres, years, and decades) connect reciprocally with regional woodland advances and retreats over acres, miles, centuries, and millenia (Neilson, this volume; and fig. 6). Having recognized the value of Lewis' (1982) "dynamic of dynamics", we can choose which kinds of change to retard or hasten.

Intracommunity change will occur when we intervene at small scales, for instance through the selective removal of crop trees and the patchwise release of site resources for lesser vegetation (including tree regeneration). The process can promote a "fine-grained" community pattern, akin to that resulting from selection cutting, wherein microsuccessions are in close juxtaposition and underway at the same time.

Intercommunity cyclic patterns are integral to much of what we do with woodlands and alternative communities on the same soils. Periodic retreatment or "weeding" of type conversions to remove small trees

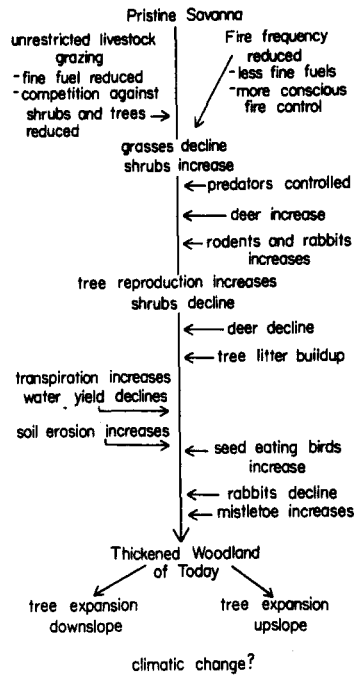


Figure 6.--The complex of factors that might be connected to the historic transition of savanna into thickened pinyon-juniper woodland and to expansion of trees into adjacent zones. Note linkages between stand-level influences and landscape transformation.

involves arresting a progression in order to retain the land in forage production. Through specification of a retreatment schedule on biologic or economic grounds, we are setting the cycle length. Prescribed-fire and let burn regimes are similar ways to maintain this manner of change.

Fluctuation is controllable to a degree, if we wish to reduce stress on particular groups of plants. For example, thinning of pinyon stands would release trees, accelerating growth on their stems and making it more uniform from year to year. Otherwise, volume growth during especially dry years could be negligible. Pinyon nut crops may fluctuate less if certain stress-reducing cultural practices like irrigation or fertilization are applied with care.

Inducing rapid progressions toward managed steady states or alternative climaxes (Jameson, this volume) will remain our foremost interest in bettering pinyon-juniper. We may also wish to skip a stage of succession, to commence the process at a stage after the first (pioneer) one, or to tightly control the initial species composition. Or, the goal may be to protract succession--defer the arrival of a stage--by thoroughly removing residual plants. At any rate, managers are inevitably concerned with considerable timespans if their interest lies in the growth of mature trees and stands from seedlings to nut trees, fuelwood crops, or juniper posts.

Regression change will rarely be an objective. On the contrary, managers should be alert to the risks of site and vegetation decline from air pollution, pathogen outbreaks, heavy foot or vehicle traffic, and weed infestations. Regression--with much historical momentum behind it--is not easily foretold or remedied.

We saw that broad, reasonably predictable or linear successions described for a subregion are locally modified by weather (Koniak 1983), grazing (Barney and Frischknecht 1974), soil microphytes (Everett 1985), and topography, especially slope aspect. New depictions of sequences should therefore acknowledge the proximate conditions under which they were made. Management plans should similarly recognize sources of response variation or shortfall that would push the "standard" local sequence toward greater or lesser predictability.

Because trees can dominate woodland sites so strongly, particularly in the summer-dry Great Basin, they "channel" or confine succession late in the sere, forcing a marked degree of convergence. In fact, a monoclimax view (fig. 2, top) could plausibly apply to large sections of the type where tree biomass has aggraded (built up) without interruption. Everett (1985) points out that this simplification masks the potential for very different understory and reseeding responses once the trees are removed. In short, the successional possibilities throughout much of the type are far greater if trees are sparse or absent.

Our review leads us to conclude that, whatever the mechanisms, models, or pathways at work, outcomes of succession are probabilistic, not assured or

or foregone. Everett (1985) rightly advocates that subdivisions of the woodland ecosystem be regarded as "most probable plant communities" having confidence limits around their typifying compositional and functional values.

Students and managers of pinyon-juniper woodlands throughout the West need to obtain many more successional sequences, through a combination of methods. They should specify predictions or hypotheses in advance, to evaluate the state of knowledge to date. Studies should not be confined to directional or supposedly progressive change, because there are other possibilities and "problem" woodlands may behave in unprecedented ways.

Methodologically, chronosequence-based approaches will probably continue to head the list of choices, for several compelling reasons (including the need for timely, if approximate, answers). All such studies must, however, disclose assumptions, be explicit about how plots were matched (with similarity indices, for example), and provide replication of plots representing each stage.

Stand reconstructions have been underutilized. Despite the assumptions and effort they require, this family of methods yields insights obtainable in no other way. They are equally suitable for mensurational research (Meeuwig and Budy 1979). Oliver (1982) supplies an excellent guide to the possible approaches, which are not limited to tree-ring analyses. He recommends that the development of present-day, desirable stand structures be investigated so that the silviculture of current young stands can be directed to achieve them in the future. Reconstructions can inform us about disturbance types and severities (for example, through fire histories), and about past periods of little or substantial tree establishment or mortality (Tausch, in preparation).

Modeling could offer tremendous assistance in successional research, but its routine application to woodlands is mostly constrained by a lack of data. However, alternatives less sophisticated than computer simulations could be taken with knowledge on hand. An outstanding model type is Noble and Slatyer's (1980: 6) "vital attributes" approach. Vital attributes are the characteristics of a species that are central to its role in vegetation replacement sequences. The most important of them are:

1. "The method of arrival or persistence of the species during and after a disturbance."

2. "The ability to establish and grow to maturity in the developing community."

3. "The time taken for the species to reach critical life stages."

This scheme, which produces simple diagrams, can be used with available natural-history and silvical information to assess the response of pinyon, juniper, and any other tree species to disturbances of varying kinds and frequencies. Application of the method to other coniferous forests has shown that codominant species strongly diverge in behavior and community status when disturbances occur at anomalous intervals. Plausible modeling results could be all-pinyon or all-juniper, or open stands of both, in situations where (with no disturbance) the two species would form dense woodlands in about equal proportions.

Rather than assuming the operation or prevalence of any particular successional mechanisms in pinyon-juniper woodlands, it would be helpful to test hypotheses about them. Specifically, it would be good to have more conclusive evidence on facilitation (nurse plants, for example), "relays", the varieties of competition, alternation of pinyon and juniper (Fox 1977), and much more. Only by describing mechanisms as clearly as we can (well exemplified by Everett and others (1983)), will managers be consistently able to exclude, imitate, or introduce them.

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INFLUENCE OF TOPOGRAPHIC FEATURES ON PINYON-JUNIPER VEGETATION IN SOUTH-CENTRAL NEW MEXICO

Rex D. Pieper and Gordon A. Lymbery

ABSTRACT: Pinyon-juniper vegetation occupies all topographic positions in the mountain foothills of the Southwest and Great Basin. The pinyon pines tend to be more important at higher elevations than the juniper species, but are often subdominant in other situations. In south-central New Mexico Juniperus monosperma tends to have higher densities and canopy cover on northeast exposures and lowest values on the more xeric southwest slopes. Densities of Juniperus monosperma were higher on steep slopes than on gentle slopes. Pinus edulis is somewhat more abundant on north slopes but is not influenced by slope steepness. Understory species appeared to be more sensitive to topographic variables than the tree species. Rhus trilobata exhibited greatest densities and canopy cover on the steepest slopes, but does not respond to aspect. Quercus undulata also has highest densities on slopes above 20%. Opuntia imbricata seems to thrive on gentle south-facing slopes.

INTRODUCTION

Pinyon-juniper vegetation occurs widely in foothill areas of the Southwest. However, since other environmental factors are influenced by topography, it seems logical that there would be vegetational variations correlated with topographical variables. Generally the environment is more mesic on north slopes and more xeric on south slopes. Conditions generally also become more mesic with elevation.

The topographic variables considered in this paper are elevation, aspect, slope position, and slope steepness. While the major emphasis will be on situations in south-central New Mexico, other relevant literature is also included since there are few studies in New Mexico. Such analyses will also provide a broader basis for comparative studies.

ELEVATION AND SLOPE STEEPNESS

Pinyon-juniper vegetation generally occurs at elevations from 4,500 to 7,500 ft (1500 to 2500 m) in the Southwest (Springfield 1976) and at slightly higher elevations in the Great Basin (Tueller and others 1979). In most cases there is a general increase in canopy cover and density of trees with increasing elevation (Tueller and others 1979; Perez 1978; Whittaker and Niering 1965). In many cases a more mesic forest (usually ponderosa pine [Pinus ponderosa] type) occurs above the pinyon-juniper vegetation. In typical pinyon-juniper vegetation, there appears little doubt that Colorado pinyon (Pinus edulis or single-leaf pinyon (P. monophylla) increases with elevation while single-seed juniper (Juniperus monosperma), Utah juniper (J. osteosperma) and Rocky Mountain juniper (J. scopulorum) decreases (fig. 1). On the eastern side of the Rocky Mountains, pinyon and juniper cover were nearly equal at about 7500 ft. (2500 m) where they graded into ponderosa pine forests at higher elevations (Woodin and Lindsey 1954). In the Great Basin, canopy cover of single-leaf pinyon and juniper was equal at about 6200 ft. (2050 m) (fig. 1, Tueller and others 1979). The one exception to these patterns was in the Guadalupe Mountains in Southwestern New Mexico where importance values of single-seed juniper on flat sites were greater at elevations ranging from 4200-4800 ft. (1400-1600 m) than at 5000 to 5200 ft. (1650-1750 m) (Gehlbach 1967). These patterns probably reflect the relatively xeric nature of juniper compared to the mesic adaptation of pinyon.

In other areas of the Southwest the situation is probably somewhat more complex, with other tree species present in the woodland communities. In oak-pine communities of Southwestern Arizona and the Sierra Madre of Northern Mexico total tree cover increased with elevation, but canopy values of both Mexican pinyon (Pinus cembroides) and Alligator juniper (Juniperus deppeana) exhibited highest cover at intermediate elevations (fig. 2). In both these situations, the oak-pine woodlands graded into ponderosa pine and mixed conifer forests at higher elevations (Gehlbach 1967; Perez 1978; Wallmo 1955; Whittaker and Niering 1965). The Colorado pinyon-alligator juniper habitat type apparently requires more mesic conditions than the Colorado pinyon-single-seed juniper habitat type. Presumably alligator does not become an important component of the woodland until elevation reaches 6750 ft. (2250 m) (Kennedy 1983). Apparently shifting competitive relationships were responsible for these differences.

Few studies have reported the relationship between understory shrub cover and elevation. Perez (1978) and Whittaker and Niering (1965) reported a general decrease in cover of shrubs in southeastern Arizona and the Sierra Madra occidental in northern Mexico.

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Rex D. Pieper is Professor of Range Science, Department of Animal and Range Sciences, New Mexico State University, Las Cruces, NM 88003. Gordon A. Lymbery is Range Management Consultant, Elko, NV.

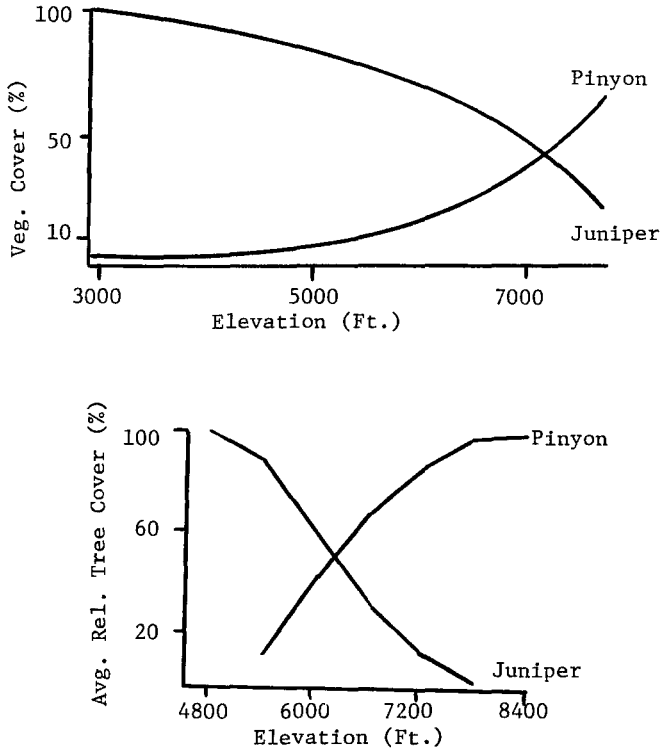


Figure 1.--Cover of pinyon pine and juniper species in relation to elevation in New Mexico (top, from Woodin and Lindsey 1954) and Nevada (bottom, from Tueller and others 1979).

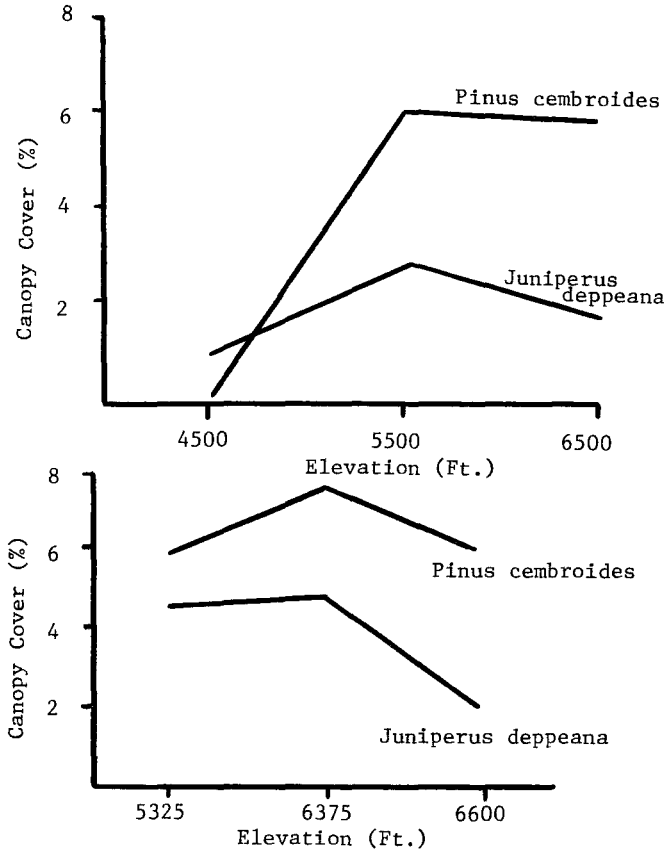


Figure 2.--Cover of alligator juniper (Juniperus deppeana) and Mexican pine (Pinus cembroides) in relation to elevation in Southeastern Arizona (top, from Whittaker and Niering 1965) and northern Mexico (bottom, from Perez 1979).

For example the cover of skunkbush (Rhus trilobata) declined from 0.46% at 5300 ft. (1775 m) to only 0.24% at 6600 ft. (2200 m) in northern Mexico (Perez 1978).

ASPECT AND SLOPE STEEPNESS

One of the most striking features of western mountain ranges is the contrast in vegetational composition between north and south slopes. Northern slopes are more mesic than southern slopes and often exhibit dense stands of trees compared to shrubby vegetation or grasslands on the south slopes. Even at lower elevations, aspect has a major influence on vegetational patterns (Jenny 1980; Klemmedson 1964).

Pinyon-juniper vegetation appears to occur on all aspects, and any differences in composition and size are subtle. In the Great Basin, Tueller and others (1979) found a slight elevation by exposure interaction for some of the tree species. Juniper species tended to exhibit slightly higher cover values on south and east exposures at high elevations. On north and west exposures single-leaf pinyon had higher composition at lower elevations (in spite of the general trend of increasing pinyon cover with elevation). In the Sacramento Mountains of south-central New Mexico a detailed analysis of aspect influences on tree species indicated that the relationships were very complicated (Lymbery and Pieper 1983). Canopy cover of single-seed juniper and alligator juniper did not differ among the different aspects (table 1). Colorado pinyon (Pinus edulis), on the other hand, exhibited higher cover values on northern exposures, but mainly on the steepest slopes.

Tree densities appeared to be more sensitive to aspect and slope steepness than did cover, but several interactions were also significant. One-seed juniper densities were greater on the mesic northeast, northwest and southeast exposures and lowest on the xeric southwestern exposures (table 2). This preference for north exposures was also true for alligator juniper in Mexico (Perez 1978). However, there was no difference on gentle slopes. Although there were no significant main effects of slope steepness or aspect on pinyon pine, several interactions were significant (table 2). Pinyon densities were highest on steep slopes with no differences on more gentle slopes. Alligator juniper was not very abundant in the area, and did not respond to aspect or slope steepness (tables 1 and 2). Pronounced aspect preferences were also exhibited between oak woodlands and pinyon-juniper woodlands in the Peloncillo Mountains in southwest New Mexico (Moir 1979).

Table 1.--Canopy cover (%) of tree species on different slope and aspect classes (From Lymbery and Pieper 1983)

Aspect Class	% Slope 0-10	11-20	21-30	31-40	Avg.
			One-seed Juniper		
NE	13.09	16.61	35.33	18.36	21.35
SE	17.63	31.65	18.10	18.92	18.96
SW	22.63	8.46	15.29	7.14	13.38
NW	17.67	17.12	17.38	18.86	17.76
AVG.	17.69	18.96	21.53	15.82	
			Alligator Juniper		
NE	2.99	5.70	0	.66	2.33
SE	.94	6.11	1.08	4.30	3.10
SW	5.31	5.60	0	10.69	5.40
NW	0	0	85.98	2.15	.75
AVG.	2.31	4.35	48.45	4.45	
			Colorado Pinyon*		
NE	13.73^{AB}_{a}	28.07^{B}_{a}	21.21^{AB}_{a}	2.95^{A}_{a}	16.40
SE	17.79^{A}_{a}	7.19^{A}_{a}	4.70^{A}_{a}	8.49^{A}_{ab}	9.55
SW	6.12^{A}_{a}	6.89^{A}_{a}	12.47^{A}_{a}	7.83^{A}_{ab}	8.33
NW	4.75^{A}_{a}	11.72^{AB}_{a}	8.29^{AB}_{a}	25.83^{B}_{b}	12.66
AVG.	10.60	13.48	11.67	11.18	

*Means in the same row followed by the same capital letter are not significantly different ($P \leq .05$). Means in the same column followed by the same lower case letter are not significantly different ($P \leq .05$).

Table 2.--Density (no/ha) of tree species on different slope and aspect classes (From Lymbery and Pieper 1983)

Aspect Class	% Slope 0-10	11-20	21-30	31-40	Avg.
			One-seed Juniper*		
NE	197.6^{A}_{a}	$469.3^{A}_{a}{}_{b}$	1148.55^{B}_{b}	481.65^{A}_{a}	574.28_{b}
SE	185.25^{A}_{a}	778.05^{B}_{b}	271.7^{A}_{a}	127.69^{A}_{a}	340.61_{ab}
SW	172.9^{A}_{a}	74.1^{A}_{a}	395.2^{A}_{a}	111.15^{A}_{a}	188.46_{a}
NW	131.65^{A}_{a}	$555.25^{A}_{a}{}_{b}$	329.25^{A}_{a}	502.15^{A}_{a}	379.89_{ab}
AVG.	171.67^{A}	469.3^{B}	535.99^{B}	305.54^{AB}	
			Alligator Juniper		
NE	16.30^{A}_{a}	65.95^{A}_{a}	0^{A}_{a}	8.15^{A}_{a}	22.60_{a}
SE	8.15_{a}	37.05^{A}_{a}	8.15^{A}_{a}	16.30^{A}_{a}	17.49_{a}
SW	69.95^{A}_{a}	32.85^{A}_{a}	0^{A}_{a}	45.20^{A}_{a}	35.82_{a}
NW	0^{A}_{a}	0^{A}_{a}	28.90^{A}_{a}	53.50^{A}_{a}	20.58_{a}
AVG.	22.65^{A}	33.96^{A}	9.27^{A}	30.88^{A}	
			Colorado Pinyon		
NE	94.60^{A}_{a}	341.68^{AB}_{a}	448.79^{B}_{b}	123.5^{A}_{a}	251.9
SE	140.05^{A}_{a}	123.5^{A}_{a}	94.60^{A}_{a}	185.25^{A}_{a}	135.9
SW	106.95^{A}_{a}	181.05^{A}_{a}	218.10^{A}_{ab}	255.15^{A}_{ab}	190.2
NW	106.95^{A}_{a}	407.55^{AB}_{a}	135.85^{A}_{ab}	514.50^{B}_{b}	291.2
AVG.	112.4^{A}	263.55^{AB}	224.28^{AB}	269.72^{B}	

*Means in the same row followed by the same captial letter are not significantly different within species ($P \leq .05$). Means in the same column followed by the same lower case letter are not significantly different within species ($P \leq .05$).

Two shrubby species, walkingstick cholla (Opuntia imbricata) and skunkbush (Rhus trilobata) showed opposite response to topography in the Sacramento Mountains of New Mexico (Lymbery and Pieper 1983). Walkingstick cholla densities were highest on nearly level south-facing sites. Skunkbush had greatest densities and cover on steep north-facing exposures. Wavy-leaf oak (Quercus undulata) was another abundant shrub in the area. Canopy cover for this species was greatest on steep slopes, but did not appear to be greatly influenced by exposure.

SLOPE POSITION

Position on the slope has been shown to be important for several forest situations: southern pine and hardwoods (Della-Bianca and Olson 1961), scarlet and black oak forests (Doolittle 1967), ponderosa pine forest (Myers and Van Deusen 1960), and upland oak forests (Trimble and Weitzman 1956). However, studies in the Sacramento Mountains in New Mexico revealed no significant influence of slope position on pinyon or juniper trees or shrubs (Lymbery and Pieper 1983). These slopes were relatively short, usually less than 500 m, and apparently did not influence environmental factors sufficiently to impact the vegetation. If slopes were long enough to change elevations, then slope position would probably influence vegetation along the gradients.

An evaluation of the effect of aspect, slope, and slope position on composition and basal cover of grass and forb species showed that only the aspect by slope steepness exerted an influence, and then only on grass basal cover. Grass basal cover was greatest on southern exposures.

CONCLUSIONS

Elevation appears to be the most important topographic feature influencing stand structure and tree size in pinyon-juniper vegetation. Woodlands with pinyon pines dominant occur at higher elevations and those with juniper as dominants at lower elevations. Aspect appears to be confounded with other variables and is difficult to isolate as an independent variable. There is a tendency for mesic species to occupy northern exposures at higher elevations and xeric species the southern exposures at lower elevations. Interactions among topographic and other abiotic variables make precise interpretations difficult. The general trends revealed in these studies can be useful in establishing management plans (particularly harvest levels) for pinyon-juniper woodlands.

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THE SIGNIFICANCE OF VARIABILIITY IN CONE PRODUCTION IN *PINUS EDULIS*

Mary E. Floyd

ABSTRACT: Three studies are presented which investigate the relative contribution of exogenous and endogenous variables in reproductive variability in *Pinus edulis*. Female cone production is reduced on south-facing canyon walls in Utah. The reduction is not correlated with increased internal moisture stress. Endogenous oscillations in reproductive effort are suggested by tree ring studies. The cost of female cone production is partially, but not entirely, offset by cone photosynthesis.

INTRODUCTION

Pinyons exhibit several fascinating patterns in their reproductive efforts. Masting, the phenomenon of large cone crops followed by 3-5 years of low cone production, has been well documented in *Pinus edulis* (Forcella 1981; Little 1943-46). Fluctuations in reproduction entrain over large geographic areas, yet reproductive effort varies between trees of different ages (Floyd 1983) and in different microhabitats within a population. This paper describes four on-going studies designed to analyze the significance of reproductive variability in pinyon. The goal of the investigation is a comprehensive, detailed theory accounting for the observed patterns. The theory will be formulated in a computer simulation model that can be used to test hypotheses relating exogenous and endogenous factors in reproduction of *Pinus edulis* (Floyd and Richardson 1984).

Pinyons are not unique among trees in their ability to produce large cone crops at periodic, non-annual, intervals; forest trees which mast include other species of *Pinus* (Linhart and others 1979), other conifers (Boe 1954), and deciduous species within *Carya*, *Betula*, *Fraxinus* and *Quercus* (Silvertown 1980). The masting phenomenon in *P. edulis* has been statistically correlated with low temperatures in late summer during the year of cone initiation (Forcella 1981). Predation by the cone beetle *Conopthorus edulis* and the pinyon cone moth *Eucosma bobana* are cited as the selection agents responsible for the "erratic" cycles (Forcella 1980,1978).

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The author is Assistant Professor of Biology, Wheaton College, Norton, MA.

The ultimate selective pressures which might account for the evolution of masting are often clear; the proximate mechanisms responsible for masting (and reproductive fluctuations in general) are not well understood. Certainly, carbohydrates must reach a critical threshold before reproduction is possible. The proportion of reserve and current photosynthates allocated to growth, reproduction, and other functions varies with species and throughout the lifespan of one individual. Only a complete shifting from growth to reproduction will allow maximum reproductive effort (Cohen 1971), so a compromise must be reached in terms of resource allocation. Vegetative growth is often reduced in trees during large reproductive events (Gross 1972; Kramer and Kozlowski 1979; Linhart and others 1979).

Stress or fluctuating environments may alter the natural tendency of growth-reproductive competition. Trees in variable environments may respond to stresses by immediately decreasing reproduction and increasing vegetative growth, which in the long run, maximizes reproductive efficiency. Often stresses such as drought and fire cause growth reduction and increased seed production, presumably by stimulating a shift in internal resources (Wolgast and Zeide 1983). Moisture stress is the documented cause of sex shifts toward a predominance of the male function in *Atriplex canescenes* (McArthur and Freeman 1982). Male flowers are often presumed to be the less expensive means of reproducing, hence are maintained when the parent cannot "afford" female inflorescences (Willson 1983).

Pinyons provide an excellent opportunity for a study of reproductive variability and its consequences. The masting behavior, as well as age and site-related reproductive shifts, indicate that inconsistency is adaptive. The widespread geographic distribution of *P. edulis* provides a diversity of habitat types within which one can compare the reproductive pattern. The studies in this paper investigate the hypothesis that reproductive shifts will occur in pinyon pine when particularly stressful (dry) microhabitats are encountered, and that the shift is due to increased moisture tension. The hypothesis is suggested by the notion that female reproduction is costly, and cannot be maintained under drought conditions, and that control of reproduction is endogenous. Specifically, the following questions will be addressed:

1) Is there a shift in reproduction in marginal habitats? Does the shift correlate with internal moisture stress?

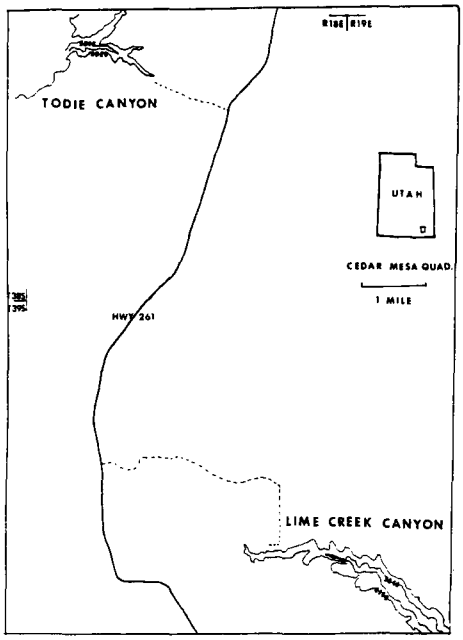


Figure 1.--Location of study areas Todie Canyon and Lime Creek Canyon in San Juan County, UT.

2) Is female more costly than male reproduction, or do female cones contribute to their own maintenance by producing photosynthates?
3) Is there evidence that periodic bursts of reproduction are accompanied by periodic growth reductions, and that endogenous mechanisms control reproductive effort?

METHODS AND RESULTS

Study 1: Shifts in Reproduction in Stressful Habitats

Two canyon systems, Todie Canyon and Lime Creek Canyon on Cedar Mesa, Utah were selected for this study (fig. 1). Each system, growing on Cedar Mesa sandstone, had well developed south-facing walls which provided intensive daily exposure and could be deemed "stressful" relative to north-facing slopes and bottomlands. The bottomland of each canyon served as "control".

Data collected for each tree in these two systems included diameter at ground level, height, distance to nearest neighbor, number of branch tips with male strobili, number of female strobili and 2-nd year cones, slope, and soil characteristics (moisture, texture, depth under crown) (table 1). Sample sizes consisted of 300 trees in Todie Canyon and 150 in Lime Creek Canyon. Care was taken to include nearly identical diameter ranges in each exposure. The study was done in 1984 and repeated in 1985 in Todie Canyon; Lime Creek Canyon was studied in 1985 only. In general, south-facing slopes had less soil build-up and, in Todie Canyon, soil moisture was significantly lower on the south slope. Todie Canyon slopes with southern exposures were the steepest; in Lime Creek, benches layered the southern exposure, creating microhabitats of less severe slope and greater soil depth.

Pinyons did not mast in the general Cedar Mesa area during 1984 but a large cone crop was present in 1985. The reproductive trends of nearby mesa areas did not extend into the canyons. In neither of the canyon systems were cones present in appreciable numbers in either 1984 or 1985. In table 2, counts of reproductive structures are summarized, and a comparison is made of south-facing, north-facing, and bottomland habitats.

In both canyons the trees occupying south-facing slopes produced signficantly fewer female cones

Table 1.--Characterization of study areas and tree characteristics in Todie Canyon and Lime Creek Canyon, UT.

	Todie Canyon			Lime Creek Canyon		
	South-facing Slope	North-facing Slope	Bottomland	South-facing Slope	North-facing Slope	Bottomland
Soil depth (m)	0.15 ± 0.17	0.20 ± 0.14	0.32 ± 0.82*	0.15 ± 0.15	0.24 ± 0.20	0.37 ± .01*
Soil moisture (pmc)	1.70 ± 2.26	3.81 ± 1.95	3.97 ± 2.69*	0.60 ± 0.33	0.41 ± 0.12	0.69 ± 0.18
Slope (%)	44.58 ± 42.28	41.98 ± 13.82	18.57 ± 22.66*	34.12 ± 3.08	46.55 ± 2.09	14.62 ± 1.90
Density $\frac{\text{trees}}{100\ m^2}$	7.0	29.9	11.7	12.5	32.3	18.9 *
Tree Height (m)	4.70 ± 9.75	6.44 ± 13.51	4.39 ± 1.60	2.57 ± 0.21	2.95 ± 0.24	6.03 ± 0.42
Tree Diameter (cm)	22.99 ± 11.60	17.30 ± 9.69	22.26 ± 10.34	21.38 ± 1.63	13.14 ± 1.09	26.43 ± 1.91
Tree ring width (mm)	0.70 ± 0.49	1.43 ± 0.84	1.09 ± 0.29*	.24 ± .17	.43 ± .20	.60 ± .38*

*indicates significant differences between three exposures ($p<.05$)

Table 2.--The number of male strobili and female cones in Todie Canyon and Lime Creek Canyon, UT. Numbers are mean ± standard devisions for 100 trees in Todie Canyon and 50 trees in Lime Creek Canyon

		Exposure		
		S-facing	N-facing	Bottomland
Todie Canyon				
Male strobili	(1984)	321.5 ± 550.3*	206.3 ± 254.2*	485.0 ± 991.9
	(1985)	497.8 ± 867.4	537.4 ± 603.9	533.3 ± 959.7
Female cones	(1984)	2.8 ± 9.1	11.2 ± 19.0	134.3 ± 891.2
	(1985)	0.3 ± 0.9	5.5 ± 21.6	28.5 ± 46.9°
Lime Creek Canyon				
Male strobili	(1985)	243.9 ± 58.1	144.3 ± 25.8	354.1 ± 69.1°
Female cones	(1985)	0.6 ± 0.4**	3.0 ± 1.8	6.6 ± 2.8

*Sign. difference between adjacent exposures $p < .01$
°Sign. difference between all exposures $p < .001$
**Sign. difference between South and Bottomland $p < .04$.

than did those on north-slopes or bottomlands. The 1984 Todie Canyon data were verified in 1985. Male strobili production did not show a consistent trend: in Todie Canyon (1984) and Lime Creek Canyon (1985), the production of male strobili was greater in bottomland than other exposures yet higher on southern than northern exposures. This trend was not repeated in Todie in 1985.

The hypothesis that moisture stress is controlling the ability to produce or maintain female strobili was tested. When female cone production is lower, more negative xylem pressures are expected. Measurements were taken of internal moisture stress with a PMS Pressure Bomb apparatus on a sample (n=12) of trees from each exposure (north, south, and bottomland) at pre-dawn (6 am), noon and 5 pm. Samples were taken at breast height from the north side of the tree. The pressure bomb readings are summarized in table 3. Because of collection dates, the magnitude of moisture stress differs between the two studies. Neither set of readings clearly support the hypothesis that moisture stress is controlling sex expression. However, the pre-dawn data set in Todie Canyon is suggestive, as south-facing trees had significantly lower (more negative) pressure readings at this time. However, by noon, the readings were similar across exposures, which may indicate stomatal closure. Southern exposure trees had the least change in pressure throughout the day. The pattern of pressure measurements from north-facing and bottomland trees is nearly identical.

Lime Creek pressure readings were lowest on north and south facing slopes, compared to the control group, at pre-dawn. However, as the day proceeded, no difference in moisture stress was detected among the sites.

The data do not support the proposed hypothesis. However, the trend of lower pre-dawn readings on exposed slopes may prove to be significant. Ritchie and Hinkley (1975) point out that pre-dawn measurements are the most critical as they represent the adjustments the tree makes to its moisture environment during the night. Stomatal closure during the day, which responds to light intensity, moisture stress, and many other environmental variables, may allow for all trees to obtain the same level of tolerable moisture stress. More data are required to determine the physiological signficance of this pre-dawn tendency.

Table 3.--The xylem pressure of pinyon trees as determined with PMS Pressure Chamber, at three times of the indicated day. Number is mean ± standard deviation of 12 sampled trees. C = control; S = south-facing; N = north-facing

Time + Exposure	Pressure (bars)	
	Lime Creek (7/18/85)	Todie Canyon 6/15/85)
Pre-dawn : C	11.15 ± 2.05	8.87 ± 2.08
Pre-dawn : S	16.32 ± 3.78	12.10 ± 3.69
Pre-dawn : N	16.18 ± 4.87	11.00 ± 2.19
Noon : C	31.14 ± 4.54	13.44 ± 3.24
Noon : S	27.00 ± 2.61	13.40 ± 4.47
Noon : N	30.57 ± 5.56	10.68 ± 3.39
5 pm : C	20.41 ± 3.09	16.35 ± 2.30
5 pm : S	21.66 ± 1.82	20.07 ± 4.23
5 pm : N	21.77 ± 2.51	20.3 ± 2.98

Table 4.--The growth of pinyon cones during the final growing season. Number represents (cone length) x (cone width)

Treatment	Change in cone dimensions	Sample Size
Bagged cones	+2.07 ± 0.71	27
Control	+3.71 ± 1.21	20

T-test indicates sign. reduction in growth
$p = <.0001$

Study 2: Reproductive Structures as "Sinks"

Pinyons are photosynthetic in the outermost layer of the woody cone. Do they therefore contribute significantly to their own maintenance by providing photosynthates for developing seeds and other tissues? If so, the potential drain of supporting cones for 2 1/2 years would be offset. This hypothesis was tested in two ways.

1) In May, 1985, 2-nd year cones were covered with black, cotton bags which prevented penetration of light. Each cone was paired with an uncovered cone on the same branch or, if this was not possible, in a nearby position on the same tree. The length and width of each cone was measured with micro-calipers before the bags were positioned and again on August 22 after most of the cone growth was completed. Growth was decreased significantly ($p=.0001$) by the treatment (table 4). Sample sizes were reduced by the unfortunate loss of cones to Dioryctria infestation. Nonetheless, these data support the hypothesis that cones contribute photosynthates, and offset support costs.

2) Chlorophyll was extracted from five 2-nd year cones every 10 days throughout the final growing season (May-Sept, 1985). Extraction was done with DMSO according to Hiscox and Israelstam (1979). A DU-6 spectrophotometer was used to determine absorption spectra. The amount of chlorophyll was calculated per volume of cone.

In table 5, the amount of chlorophyll per cone volume is given. If cones were indeed "sinks", we would expect that the amount of chlorophyll/cone-volume might decrease during rapid second-year growth, because surface area/volume is continually reduced. However, the amount of chlorophyll/cone-volume remains essentially the same throughout the growing season. This does not indicate that the amount of photosynthate is sufficient enough to maintain the cone and seeds. It does however allude to the fact that whatever that contribution is, it remains steady as the cone grows. When coupled with the previous experiment, indications are that this may be a substantial contribution. To test this claim, photosynthates could be radioactively labeled, enabling direct measurements of cone respiration and photosynthesis.

Study 3: Is There Evidence for Endogenous Control of Resources in Pinyon?

Increment cores were collected from trees at a study area near Breen, Colorado, approximately 20 miles southwest of Durango. Fifteen cores were analyzed as follows: the width of annual rings was measured for the period 1953-1983 and false or missing rings were accounted for by cross-dating (shown in figure 2A for one of the sampled cores). To eliminate the effect of exogenous variables such as precipitation on ring size, the annual precipitation for nearby Durango, CO was regressed on ring width for the 1953-1983 period (data were obtained from the Durango NOAA weather station). The detrended residuals (fig. 2B) represent the fluctuations in ring sizes not accounted for by rainfall, and were examined for the presence of cyclical fluctuations in width that might be due to resource shifting away from vegetative growth. Cycles of 3-5 year periodicities (the documented time between pinyon masting years) were of particular interest. Autocorrelation analyses were performed to determine whether such fluctuations remain or are enhanced when the random effects of precipitation were removed. If indeed the ring width depressions are due to an endogenous oscillation, removal of the random effects of precipitation would enhance evidence of the oscillation, and in the same year, a greater positive autocorrelation would be detected. Figures 2C and 2D support this hypothesis, as do the analyses for 14 of the 15 cores analyzed. An endogenous drain on resources, with approximately a 3-year periodicity is suggested by this preliminary study.

Table 5.--The chlorophyll content of 2-year-old pinyon cones collected during the final growing season. Each number is the mean of five cone samples

Collection Date	Chlorophyll content (g/10cc cone)
5-28	1.1687
6-9	2.024
6-19	1.8020
6-29	2.069
7-9	1.5065
7-18	1.2441
7-29	1.4842
8-11	1.4203
8-19	2.728
8-26	2.209
9-8	3.0728
9-16	4.0972

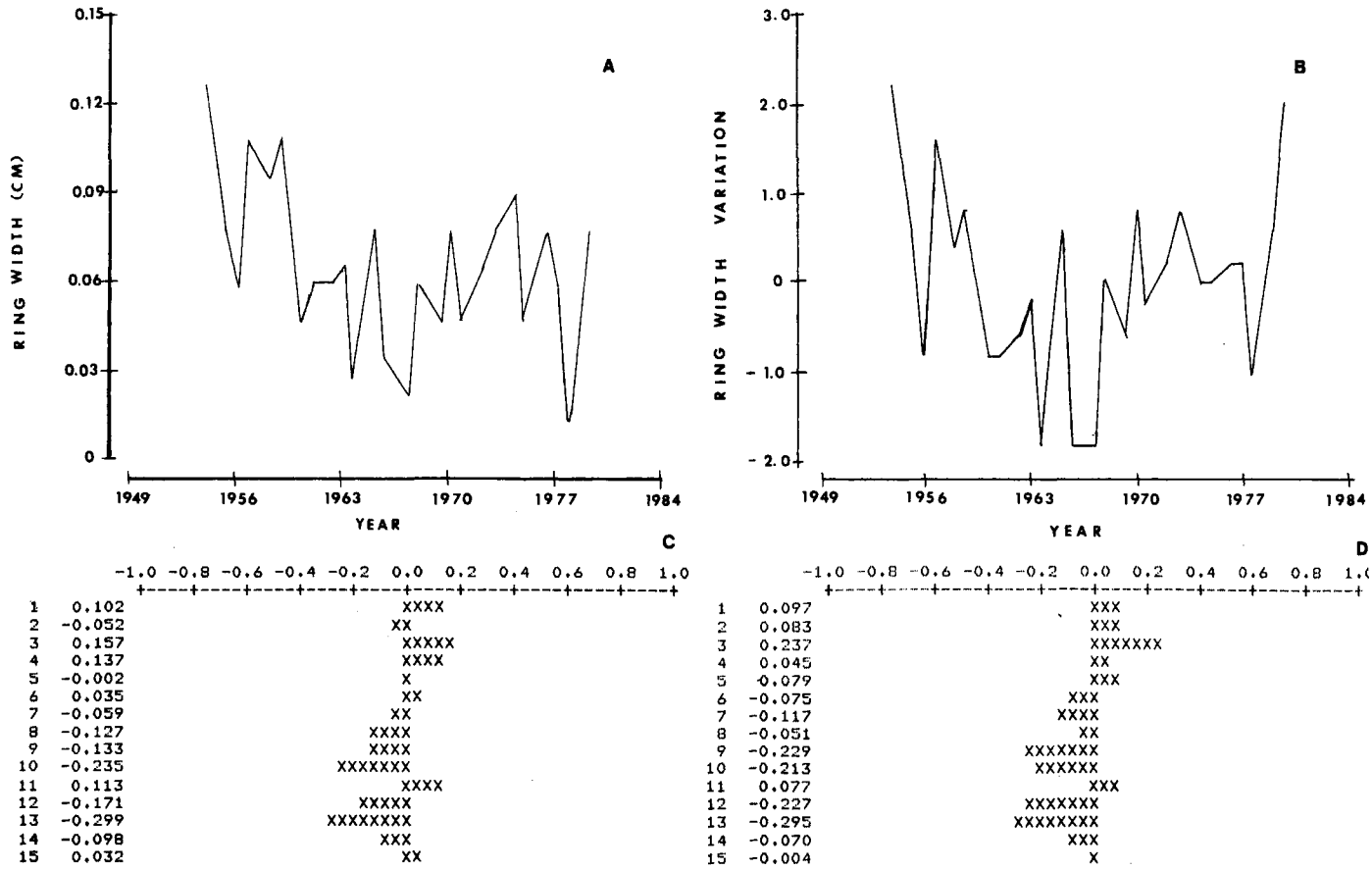


Figure 2.--(A) Annual width of growth rings, (B) variation in ring width not explained by annual precipitation, (C) autocorrelation analysis of detrended data, (D) autocorrelation analysis of residuals shown in (B).

DISCUSSION

The direction of sexual expression in pinyon changes depending on the microhabitat. On south-facing slopes of "slickrock" canyons, maleness tends to predominate. A similar situation is documented in the arid shrublands of Utah: in several monoecious (Freeman and others 1981) and dioecious (Freeman and others 1976) species, xeric sites are populated with male plants while females are restricted to mesic sites. Dioecious trees in the dry steppe of Lower Volga, Russia, sort themselves out with male trees on xeric sites. These males show greater growth and developmental rates than female trees (Lysova and Khizhnyak 1975). Ponderosa pines that produce large cone crops grow more slowly and have smaller diameters than those which are less prolific (Linhart and others 1979). Yet, pinyons fit neither of these patterns. On the driest sites, growth, as indicated by annual ring width, is retarded (table 1), as is the female function. It does not, therefore, appear that the shift to male function from monecy is sufficient to allow normal vegetative growth in stressful sites. Nor is it conclusive that moisture stress is the only exogenous factor involved in the allocation of resources, as no significant difference between internal moisture stress readings were detected except at pre-dawn.

Soil texture and moisture characteristics differed across sites, with surface soils drier and sandier on southern exposures. It is, however, questionable if these soil characteristics define the actual moisture available to the south-facing tree whose roots are embedded in cracks and fissures in sandstone. In the bottomland sites, soil build-up is appreciable, and it is unlikely that the roots reach sandstone parent material. The north-facing slope fits somewhere between the two substrate extremes, as soil accumulations are significantly greater than south-facing slopes, yet the underlying sandstone is likely within the reach of the deeper roots.

If, in fact, the potential moisture contribution from the substrate is different on the south-facing slopes, and internal moisture tensions are not, there must be a compensating mechanism operating. This hypothetical compensating mechanism could account for both reduced growth and allotment of resources primarily to the male function. Female pinyon cones require 2 1/2 years to mature, and may represent a significant drain on the tree. The compensating mechanism may preclude allocation to female functions.

This proposed mechanism leads us to focus on the internal workings of the pinyon tree. What evidence is there from core samples that endogenous control of female reproduction occurs,

or that it represents a signficant sink to internal resources? The preliminary evidence for the occurance of endogenous fluctuations in resources occur is strong: autocorrelation analyses show enhancement of 3-5 year cycles in ring width when the random effects of precipitation on growth are removed. This study is now being verified (Richardson and Floyd in preparation).

Female reproductive structures, which are generally showy and less ephemeral than their male counterparts, are often considered expensive and draining to the plant. Bazaaz and others (1979) point out that female inflorescences and fruits which photosythesize contribute to the plant's total carbon pool reducing the cost. Pinyon cones take several years to mature, in contrast to one season for male strobili, yet they are photosythetic throughout this time. The two studies presented here indicate that 1) chlorophyll production keeps up proportionately with the rapid growth of cones in the second growing season, and 2) if the cone photosynthesis is blocked, cone growth is significantly retarded. Direct measures of photosynthesis and respiration of pinyon cones have not been made. These data are needed to determine if the chlorophyll provides carbon to a degree which might compensate for cone respiration and allow for accumulation of seed products. Dickmann and Kozlowski (1970) have done such studies on P. resinosa and concluded that the cones are sustained by photosynthates from adjacent one and two-year old needles, and not by cone photosynthates. In addition, my studies of annual ring growth show a periodic decrease in growth that correlates with reproductive effort. Clearly, cones do photosynthesize, but during a mast year the drain is excessive and probably cannot be compensated effectively by cone photosynthesis.

CONCLUSIONS

Pinyons growing on south-facing slopes of slickrock canyons rarely produce female cones. It is hypothesized that the cause of shifting to male function is moisture stress, which induces a drain on internal resources, preventing the production and maintenance of the relatively expensive female cones. Measurements of internal moisture stress do not strongly support the hypothesis; they indicate that xylem tensions of south-facing trees are not signficantly different than control and north-facing trees, with the possible exception of pre-dawn tension. The potential contribution by cones to their maintenance was investigated; a) cone chlorophyll/cone-volume remains steady during the final growth season, indicating a constant photosynthetic contribution, and b) if photosythesis is blocked, growth is reduced. These data indicate a potential reduction of reproductive costs. However, periodic reductions in ring width are documented which suggest costs in terms of lost growth resulting from large scale female cone production and an endogenous control of reproduction. I concluded that reproductive costs are partially, but not entirely, offset by cone contributions and that relatively low xylem tensions are not the "cue" controlling the shifting to male function in south-facing trees.

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PINYON TREES (PINUS EDULIS) REMEASURED AFTER 47 YEARS

Elbert L. Little, Jr.

ABSTRACT: Growth of pinyon (Pinus edulis Engelm.) is extremely slow, according to remeasurement by the same person in 1985 of trees in two plots in New Mexico established in 1938. The 47-year study yields information also on mortality, regeneration, and management.

INTRODUCTION

In 1985 I had the opportunity to examine again some trees of pinyon (Pinus edulis Engelm.) in two plots in New Mexico that I established in 1938. Remeasurement by the same person after 47 years confirms that growth is extremely slow. This study planned for other purposes and discontinued after 1941 yields information on other subjects, such as mortality, regeneration, and changes in land management.

There have been changes in objectives of land management during the half century. In 1938 the most valuable products of pinyon trees were the large edible seeds, or pinyon nuts. Afterwards on large areas the pinyon-juniper woodlands were eradicated or destroyed and converted to grasslands. More recently the increased demand for pinyon fuelwood has led to management of some woodlands for fuelwood harvest on a rotation of 80 or more years. Thus, within a half century, the land uses have shifted from pinyon nuts to grassland to fuelwood. Future uses should be considered in land management planning.

Research Project Of 1937-1941

A research project on the pinyon-juniper woodland was begun in 1937 by the former Southwestern Forest and Range Experiment Station, of the Forest Service, United States Department of Agriculture, with headquarters at Tucson, Arizona. I was assigned to that project from September 1937 to December 1941 as assistant forest ecologist (later associate). However, work was interrupted in World War II and afterwards was discontinued. Several studies, as well as suggestions for future research, were published (Little 1965, 1977).

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Research Associate, Dept. of Botany, Smithsonian Institution, Washington, DC 20560. Chief dendrologist (retired), USDA Forest Service.

Reestablishment in recent years by the U.S. Forest Service of the research project in the pinyon-juniper woodlands of the Southwest led to review of my earlier, interrupted studies. An effort was made to locate pinyon trees that I tagged for experiments in November 1938.

EXPERIMENT OF PRUNING AND CULTIVATING PINYON TREES

This experiment of pruning and cultivating pinyon trees was established in November 1938, with the assistance of labor from Civilian Conservation Corps. The object was to determine whether pinyon nut production could be increased by these treatments. Natural mature stands of pinyon-juniper woodlands on nearly level lands within National Forests were chosen. The design was simple. Trees were selected in sets, consisting of 4 trees of about the same size, shape, and cone production. There were 5 sets of average to large trees and 2 sets of small trees, a total of 28 trees. A brass tag with embossed number on a nail 2 1/2 in long was added at height of 4 1/2 ft (dbh) on the south side of each tree. Notes and measurements were recorded.

Treatments were assigned at random: (1) control (untreated); (2) pruned; (3) cultivated; (4) pruned and cultivated. Pruning consisted of removing all green branches and limbs within 4 ft of the ground. Cultivation involved spading, turning over, and breaking up the soil within a radius of 10 ft of the trunk to a depth of 6 in. Then the soil was smoothed over with a rake, and small ditch was left at the outside ring. This experiment was repeated at three locations or plots, which were studied last in November 1941.

Walnut Canyon Pinyon Plot

Walnut Canyon Pinyon Plot is on the Coconino National Forest at about 6,900 ft altitude in Sec. 31, T. 21 N, R 9 E, 12 mi E of Flagstaff, Coconino County, in northern Arizona. As the main plot, it was located near my base at the Fort Valley Experimental Forest 9 mi NW of Flagstaff. The pinyon-juniper woodland on a nearly level sandstone outcrop here was a dense stand of pinyon (Pinus edulis) near the upper altitudinal limit. Utah juniper (Juniperus osteosperma) and one-seed juniper (J. monosperma) were uncommon. A 5-acre plot was fenced, and the fence has been maintained. However, the trees of this experiment were outside and were destroyed or eradicated when the area of many thousand acres was converted to grassland in the early 1960's. When I returned in May 1968, the area

was barren and had been burned. By October 1985 it had recovered slightly but still was a grassland. Incidentally, the plot fenced in 1938 containing protected trees now serves for other pinyon studies. The untreated fenceposts of Utah juniper are still in good condition, though some wood stays have been replaced.

Glorieta Mesa Pinyon Plot

Glorieta Mesa Pinyon Plot, originally 9.6 acres fenced, is on the Santa Fe National Forest in sec. 10, T 13 N, R 12 E, on Glorieta Mesa at about 7,500 ft altitude. It is west along the road between Rowe and Rincon 14 mi S of Pecos and about 26 mi directly SE of Santa Fe, San Miguel County, in northern New Mexico.

The plot is located on the nearly level extensive top of Glorieta Mesa. The mesa is composed of almost horizontal sedimentary strata capped by sandstone. The soil is a deep loam at least 2 ft deep, mostly clay loam with small amounts of sand and small gravel, without boulders and rocks at the surface. Vegetation in 1938 varied from grass land or parks of blue grama to dense stands of pinyon-juniper woodland averaging 15-20 ft in height. Pinyon (Pinus edulis) was the dominant species. Rocky Mountain juniper (Juniperus scopulorum) was scattered, and one-seed juniper (J. monosperma) was rare. Dead junipers had been cut for fuel, and some live junipers had been removed for fenceposts.

An unexpected result was the appearance of annual weeds under all 14 trees cultivated and 2 others. Observations were made in Sept. 1941, almost 3 years after treatment and following high seasonal rainfall. Most of the 14 had many weeds, others few. These weeds 1-2 ft or more in height included Chenopodium (3 spp.), Descurainia, and Agropyron. The source of the weed seeds is uncertain, whether wind dispersal or old buried seeds or partly both.

This area was visited next on Oct. 13, 1981. The surrounding pinyon-juniper woodland over an area of several thousand acres had been destroyed and converted to grassland. Three sides of the fence around the plot had been removed, and a drift fence had been extended along the fourth side. Fortunately, the trees of the experiment were left, except for several removed by fuelwood cutters. Incidentally the remaining untreated juniper fenceposts were still in good condition.

The measurements of pinyon trees at Glorieta Mesa Pinyon Plot after 47 years were made on July 23 and Oct. 9, 1985. Also, each tree found was photographed. Measurements in 1938 and 1985 are summarized here:

Ave. height of 19 trees, 1985, 20.5 ft; 1938, 16.2 ft
Ave. increase in height in 47 years, 4.3 ft
Ave. increase in height per year,.09 ft or 1.1 in
Ave. crown spread, 1985, 23.8 ft; 1938, 17.5 ft
Ave. increase in crown spread in 47 years, 6.3 ft
Ave. increase in crown spread per year, .13 ft or 1.6 in
Ave. diameter at ground, 1985, 14.7 in; 1938, 11.6 in
Ave. diameter at breast height, 1985, 10.2 in; 1938, 7.4 in
Ave. increase in dbh in 47 years, 2.8 in
Ave. increase in dbh per year, .06 in or 1 in 16.8 years
Annual growth rings of wood, about 33 in 1 inch of radius

The 9 trees not surviving in 1985 were accounted for as follows:

Died naturally, afterwards cut for fuel, 2
Stumps found, cut for fuel, 3
Not found, probably cut for fuel, 4

This area of woodland along a road and surrounded by large areas converted to grassland has been readily accessible to wood cutters. Mortality from natural causes apparently was low. A minor use was removal of small pinyons for transplanting, as indicated by the deep hole left by the core of roots and soil removed. Regeneration apparently was good. Several small pinyons were observed in the opening where one tree had died.

Mayhill Pinyon Plot

Mayhill Pinyon Plot, unfenced, is on the Lincoln National Forest in SE 1/4 sec. 1, T 17 S, R 15 E, altitude about 7,000 ft, about 7 mi directly SE of Mayhill Ranger Station and 35 mi directly E of Alamogordo, Otero County, in southeastern New Mexico. It was established in November 1938 and reexamined on Oct. 10-11, 1985.

The plot is located on a small flat area on top of a ridge bordered by canyons. Bedrock is limestone in almost horizontal ledges. The soil is a shallow rocky loam with numerous boulders and flat outcrops of bedrock. Vegetation in 1938 was an open pinyon-juniper woodland with the dominant species Pinus edulis and alligator juniper (Juniperus deppeana) and the scattered large trees about 15-25 ft high. There had been considerable cutting of large, mostly dead junipers.

In 1985 the surrounding woodland had not been converted to grassland and was relatively undisturbed. However, there had been some cutting of juniper fuelwood.

Only 3 of the 28 trees in the experiment of pruning and cultivating were found alive after 47 years. A summary of measurements follows:

Ave. height in 1985, 17.3 ft; 1938, 13.3 ft
Ave. increase in height in 47 years, 4.0 ft
Ave. increase in height per year, .085 ft or 1.0 in
Ave. crown spread, 1985, 14.2 ft; 1938, 12.2 ft
Ave. increase in crown spread in 47 years, 2.0 ft
Ave. increase in crown spread per year, .042 ft or .5 in
Ave. diameter at breast height, 1985, 6.4 in

The remaining 25 trees not surviving in 1985 were located by position, pruning, or a few by tags. They were accounted for as follows:

Standing dead trunks or snags, 4
Dead fallen trunks, 19
  Windthrow, 10
  Not windthrow, 9
Not found, 2

Thus, mortality was relatively high. Also, windthrow, apparently was a main cause of death. Uprooted dead trunks mostly pointed eastward. As these trunks had lost bark and were weathered, the time of death was estimated at roughly 10-20 years ago. A tornado might have been the explanation. This site on top of a ridge perhaps was exposed. The 3 surviving trees were at the northwest edge of the plot.

In another study, a ditching experiment, 20 paired pinyon trees, large to small, were tagged. One of each pair was ditched; that is, a ditch 6 in deep at a 10-ft radius was dug around the tree with dam on outside, to conserve water that would have been lost in runoff. On Oct. 10-11, 1985, only 1 living tagged tree was found.

The remaining 19 trees not surviving in 1985 were accounted for as follows:

Dead fallen trunks, mostly from windthrow, 12
Stump found, cut for fuel, 1
Not found, 6

At Mayhill, mortality was high, mostly from windthrow. Also, regeneration was low. Small pinyons were absent or few in the open areas around the many uprooted trunks.

Increment borings made near the base of trunks of of the 4 trees found at Mayhill in 1985 confirmed the extremely slow rate of growth. Further studies are planned, including determination of ages of the surviving trees at both Mayhill and Glorieta Mesa plots. Information on ages with growth rate will be useful in preparation of site indexes for pinyon.

USES OF WOOD

Some trees of this experiment on National Forests were cut for fuelwood, and dead trunks were salvaged also. These thinning operations apparently reduced competition, further opened the open stands, and favored growth of the remaining trees. Also, some juniper was cut for fenceposts. After nearly a half century the fenced plots at Walnut Canyon and Glorieta Mesa are in good condition and the fenceposts of untreated juniper still durable. Thus, under multiple use, wood products are of economic importance on some areas.

CHANGES IN LAND MANAGEMENT

The changes in objectives of land management during the 47-period, as shown in these three plots on National Forests, have been great. Several thousand acres around the Walnut Canyon and Glorieta Mesa Plots were converted to grassland by destruction of the trees. The trees of the experiments at Walnut Canyon, being unfenced, were destroyed, while those at Glorieta Mesa were saved by the fence, afterwards removed. In recent years, as noted on these plots, some trees have been cut for fuelwood and junipers also for fenceposts. Some areas are being managed for fuelwood.

DISCUSSION

It was an unusual experience for the same person to remeasure the same trees that he had tagged 47 years earlier. Most trees retained their brass tags on nails. Thus, expansion of the trunk in radius was less than the length of the nail originally exposed. However, some of the small-headed nails probably shed their tags and were covered by the expanding bark. Persistence of tags confirmed the extremely slow growth in all characters measured.

From this study there are questions about the average height of pinyon trees in a mature stand. The stands selected at the three plots appeared to be representative and mature. For example, at Glorieta Mesa most tagged trees were of average to large size, though 8 of the 28 were small, and 15 of the 19 still living in 1985 were average to large. The 8 trees that did not survive were of similar size, not the largest and oldest. The entire stand continued to increase in height. Perhaps the stand in 1938 was immature. Is the stand in 1985 also immmature? Will the average and large trees of the stand continue to grow at the same rate and for how long? Indefinitely? At Mayhill the 3 surviving trees of the 28 showed a similar average increase in height. Was and is this stand also immature? When will these stands stop height growth? Or will the oldest and tallest trees gradually die from natural causes? If immature, at what size and age do these stands become mature and begin to decline? Why should the trees die?

Questions about mortalitiy and causes of death are raised. The Mayhill plot shows that windthrow may be a factor, at least rarely and locally. Slight porcupine damage was observed, and damage from insects and diseases apparently has been minor.

ADDITIONAL COMMENTS

Additional statements, some widely accepted, may be summarized here. They are based also upon other experience over a half century, including ing eight years of field work in Arizona and New Mexico.

Pinyon-juniper woodlands merit increased attention in research and management, because of their vast extent, which compensates for their low productivity. In these marginal lands productivity is limited by the relatively low precipitation and may be increased by measures to conserve and distribute water more effectively.

One of the first steps in management of pinyon-juniper woodlands is to locate and restore deteriorated lands, for example, those with accelerated soil erosion or overgrazing. A quick preliminary survey may help to prevent further damage.

Large areas can be maintained in more or less natural and stable condition under custodial management at low cost with some production. Even where not cost effective, public ownership should prevent deterioration.

Like other wild lands, the pinyon-juniper woodlands should be managed as renewable natural resources under sustained yield for the greatest number in the long run. They should be managed for multiple uses, including water and soils, wood, forage, wildlife, and recreation. However, on some sites, one use may be most important. Obviously, cooperation between research workers and land managers is essential. Management plans should be flexible and subject to revision with changing times. For example, in the Southwest, solar energy before many years should reduce the consumption of fuelwood.

As in other wild lands, the better woodland sites gradually can be made more productive through research and intensive management. Increased productivity will provide both increased employment for local residents and more useful products for an expanding population.

Much improvement can be expected through forest genetics or tree breeding programs, though progress may be slow. Wherever artifical regeneration is adopted, selected seeds or other propagating material should be used. Foresters and other land managers in their field work should constantly look for superior or plus trees and obtain seeds or other propagating material for testing. Much can be accomplished in limited time by selection, for example, pinyon trees with good form, high cone production, large nuts, etc. Likewise, junipers with rapid growth and good form for fenceposts and wood products. Hybridization of natives and exotics, though slow, has possibilities.

Promising exotics should be tested. For example, desirable aggressive species that might spread naturally after introduction.

Valleys and riparian sites merit special attention. Because of their greater moisture, they can be more productive with lowland species and perhaps some cultivation. The two species of native walnuts (Juglans) in the Southwest might be improved for both cabinetwood and nuts.

Finally, it may be noted that the native species pinyon (Pinus edulis) and singleleaf pinyon (P. monophylla) are sufficiently distinct in characters and distribution to merit separate treatment in both research and management. Likewise, the pinyon-juniper woodlands with several combinations of juniper species should be treated differently.

CONCLUSIONS

Growth of pinyon (Pinus edulis Engelm.) is extremely slow, according to remeasurement after 47 years of trees at two plots in New Mexico. Objectives in land management of pinyon-juniper woodlands have changed from pinyon nuts to grassland to fuelwood. Incidentally, untreated juniper poles make good fenceposts still durable after almost a half century.

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Credit for field assistance in 1985 is due several foresters of the U.S. Forest Service, including Frank Ronco, Jr., Gerald J. Gottfried, Larry Beagle, John Dalton, Stanley W. Stroup, Dennis Watkins, and James Bates. In 1938-1941 many members of the Civilian Conservation Corps provided needed support.

SUMMARY

Growth of pinyon (Pinus edulis Engelm.) is extremely slow, according to remeasurement by the same person in 1985 after 47 years of trees in two plots in natural stands of pinyon-juniper woodlands in New Mexico established in 1938. At each plot 28 trees were measured in an experiment to determine whether pinyon nut production could be increased by pruning and cultivating. However, the work was discontinued after World War II. At Glorieta Mesa Pinyon Plot about 26 mi SE of Santa Fe the 19 surviving trees in 1985 had these average measurements: Ave. height increased from 16.2 ft to 20.5 ft, or 4.3 ft in 47 years, or per year .09 ft or 1.1 in. Ave. dbh increased from 7.4 in to 10.2 in, or 2.8 in in 47 years, or 1 in in 16.8 years. Of the remaining 9 trees not surviving, 2 died naturally, 2 were cut for fuel, and 4 not found probably were cut for fuel. At Mayhill Pinyon Plot 35 mi E of Alamogordo the 3 surviving trees had similar growth rates. The remaining 25 trees included 4 standing dead trunks, 19 dead fallen trunks (10 windthrow), and 2 not found. Objectives in land management of pinyon-juniper woodlands have changed from pinyon nuts to grassland to fuelwood.

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ROOTING PATTERNS IN THE PINYON-JUNIPER WOODLAND

Teralene S. Foxx and Gail D. Tierney

ABSTRACT: An extensive bibliographical study documenting rooting patterns of native and introduced plants of the Western United States resulted in a computerized data base of over 1000 different rooting depth citations. From that data base, average rooting depths and frequencies were determined as related to species, habit, soil type, geographic region, root type, family, root depth to shoot height ratios, and root depth to root lateral ratios. Annual grasses were found to root within 1 m of the soil surface. Median rooting depth of other life forms was 2.0 m with a maximum rooting depth of 61 m. The various life forms had the following median and maximum rooting depths: annual forbs (median of 0.6 m, maximum of 3.0 m), biennial forms (0.8 m, 1.5 m), perennial grasses (1.1 m, 8.2 m), perennial forbs (1.1 m, 39.0 m), subshrubs and vines (1.2 m, 6.4 m), shrubs (2 m, 17.0 m), and trees (1.6 m, 61 m). In addition to the bibliographic study, 21 species common to the pinyon-juniper woodland were excavated from soils derived from volcanic tuff in northern New Mexico. Rooting patterns and gross morphology were examined. Perennial forbs and grasses occurred within the first 30 cm of the soil surface. Roots of the overstory trees were traced to depths of 6 m and roots of shrubs to depths of 1.8 to 2.6 m.

INTRODUCTION

At Los Alamos National Laboratory, our primary interest in rooting depths of plants stems from regulations regarding low-level nuclear waste disposal (Nuclear Regulatory Commission 1982; Environmental Protection Agency 1983). The current method for disposing of low-level radioactive waste is shallow land burial. Burial trenches range in depth from 5-6 meters. These trenches are usually filled within 1 m of the surface with waste, backfilled, and capped with up to 70-90 cm of soil and 10-30 cm of topsoil.

Nuclear Regulatory Commission (1982) and Environmental Protection Agency (1983) standards for design and remedial action of disposal sites and/or mill tailings require designs to prevent intrusion or disruption for 100 years or more. Substantial earth cover could be penetrated by roots of native and introduced plants. In fact, investigations into the control and isolation of buried wastes and mill tailings have shown that deep-rooted plants may provide a pathway for the release of buried toxic materials into the biosphere (Dahlman and others 1976; Whicker 1976; Dreesen and Marple 1980; Hakonson and others 1981; Romney and Davis 1972; Sharitz and others 1975). Studies at Los Alamos National Laboratory have been conducted to determine how engineering of the trench cap and placement of biobarriers can prevent intrusion (Hakonson and others 1982).

In addition to the problem of intrusion and possible transport of hazardous materials to the surface, plant roots are important to prevention of seepage or percolation below the trench cover. Plants, through transpiration, have an effect on the water balance within the rooting zone. If evapotranspiration is maximized, seepage into the water table can be prevented eliminating a major source of transport of hazardous materials into the ecosystem. Presently at Los Alamos, studies are being conducted to determine the biological and environmental factors influencing these rates (Rodgers and others 1984). To determine long-term changes, models such as BIOTRAN and CREAMS (Gallegos and others 1983; Knisel 1980) are being used to predict plant-soil interactions and water-balance. Studies on rooting depths and rooting patterns are important to modeling contaminant transport through time.

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Teralene S. Foxx, Staff Member, and Gail D. Tierney, Collaborator, are plant ecologists at Los Alamos National Laboratory, Division of Health, Safety, and Environment, Group HSE-8, Los Alamos, New Mexico 87544.

To determine the best trench cap design through model simulation and basic research, two considerations are important: the prevention of intrusion of roots through the trench cap and the manipulation of the water balance within the overburden to prevent seepage and percolation. With these two criteria in mind, studies were done to determine the maximum rooting depth and the rooting ecology of plants known to invade low-level waste sites at Los Alamos National Laboratory. The intention was to develop and verify model simulations for various climatic regimes and native plant combinations for reclamation within the pinyon-juniper woodland where most of the waste sites are situated at Los Alamos.

In the rooting depth study, we were most interested in the potential for plants to disrupt a trench cap, how deeply different species root, and the likelihood of plants penetrating depths greater than 1 m where they would come into contact with waste material. This study was not meant to be physiological but instead descriptive and, when possible, quantitative. The field study, by necessity, was descriptive because excavation of roots is time consuming and laborious, making removal of enough plants for statistical analysis difficult.

DESCRIPTION OF THE STUDY AREA

Los Alamos National Laboratory is located on a plateau forming a table-like extension at the base of the Jemez Mountains in northcentral New Mexico. The Jemez Mountains are volcanic in origin, with soils derived from basalt and tuff. Climate is semiarid continental with cold winters and moderately warm summers. Elevational gradient for the study area ranges from 1642 m at the Rio Grande to 3344 m at the top of the highest peak in the Jemez range. Six different plant communities have been identified and reported (Foxx and Tierney 1980, 1984c, 1985). These include juniper grassland, pinyon-juniper woodland, ponderosa pine, mixed conifer, spruce-fir forests, and subalpine meadows. The pinyon-juniper woodland falls into two minor elevation units--one from approximately 1642 m to 1915 m on the upper edge of the Pajarito Plateau escarpment, and the other from 1915 m up to the ecotone with the ponderosa pine forest, which varies with exposure and slope from 2128 m to 2219 m. Barnes (1983) defined three habitat types within the woodlands: (1) Juniperus monosperma/Bouteloua curtipendula habitat type (one-seed juniper/side-oats grama), (2) Pinus edulis, Juniperus monosperma/Bouteloua gracilis habitat type (pinyon, one-seed juniper/blue grama), and (3) Pinus edulis, Juniperus monosperma/Muhlenbergia montana habitat type (pinyon, one-seed juniper/mountain mulhy).

METHODS

In 1981-1982, an extensive bibliographic study was undertaken to reference rooting depths of native and crop plants that occur within the United States. Most references were limited to studies done within states west of the Mississippi. Presently, the data base resulting from this literature search contains over 1000 different rooting citations (Foxx and Tierney 1984a,b).

Each paper referenced in the data base was examined for rooting depth information from field studies. Also included were observations, water-table depth information, and some tracer studies. Artificial plantings and lysimeter studies were excluded because of uncertainties in the comparability of the experimental and field data. Data base fields were defined as: family, species, common name, root depth, root lateral extension, root type, shoot height, life form, substrate, and geographic location and reference (Foxx and Tierney 1984b).

Once the computerized data base was created, it was searched for parameters such as rooting depth as related to life form, substrate, geographic location, and specific species. Cumulative percentage rooting frequencies were calculated when there were eight or more citations.

The field study involved excavation of species known to grow and invade low-level waste disposal sites at Los Alamos (Tierney and Foxx 1982). Twenty-one species were excavated (3 trees, 9 shrubs, 5 perennial forbs, 1 biennial forb, 2 annual forbs, 1 perennial grass) (Tierney and Foxx, In press 1985). A backhoe was used to dig a trench about 1.5 m wide and 3 m long in several locations. Excavations were seldom more than 3 m deep because of possibility of cave-ins in the alluvial soils. The remainder of the excavation of plant roots was done with hand tools. Care was taken to excavate the stoutest roots to the longest extent possible. Sometimes the entire length of the root was excavated intact but more often the root was broken at the bottom of the trench. For that reason formulae were developed to predict possible lengths (Tierney and Foxx 1982).

After the largest roots had been uncovered or delineated, the entire plant was photographed, and the rough dimensions

of its root system measured to the nearest 5 cm.

DATA ANALYSIS

For this presentation, rooting depths of plants as related to life form (tree, shrub, forb, grass) were examined from the data base, disregarding the influence of substrate, geographic location, or root type. These other analyses can be found in Foxx and Tierney 1984a and b. Information was collated for the plants that are known to occur in the pinyon-juniper woodlands of Northern New Mexico. Finally, this information was compared to field excavation data.

Depths as Related to Life Form

General observations by researchers, such as Weaver (1915, 1919, 1926, 1958), Meinzer (1927), Cannon (1911) and Cannon (1960) indicate that roots of herbaceous perennials, trees, and shrubs can penetrate to great depths if water is available. They have also observed that annuals root to the limit of the depth of seasonal rain penetration.

The computerized data base contained information for 40 evergreen trees, 107 deciduous trees, 87 shrubs, 370 perennial forbs, 36 subshrubs, 305 perennial grasses, 8 annual grasses, 9 biennial forbs, 81 annual forbs, and 4 vines. Average rooting depths and ranges of rooting depths for each of the life forms are found in table 1. The average rooting depths for all plants recorded in the data base was 190 cm with a range of 2 to 6096 cm.

In addition cumulative percent frequency for the 1012 plants was calculated (figure 1). Seventy-five percent of all plants rooted within 183 cm and 40% within the first meter. The median rooting depths are 122 cm. Only 6% of all specimens studied rooted deeper than 457 cm.

The cumulative rooting depth frequencies of the nine life forms for the five selected depths of 91, 183, 274, 366, and 456 cm (table 2). The shallowest rooting life form was an annual grass. All other life forms rooted deeper than 91 cm. On a percent basis, shrubs root the deepest, followed by deciduous and evergreen trees.

Rooting Depth of Plants of the Pinyon-Juniper Woodland

The data base was then searched for information on individual plant species known to inhabit the pinyon-juniper woodlands of New Mexico (Foxx and Tierney 1985; Barnes 1983; Martin and Hutchins 1981) (table 3). Again, geographic regions, root types, and substrate were ignored in the search parameters. Cumulative frequency (%) of rooting depths of 10 forbs and 9 grass species was calculated (tables 4, 5). Three forb species have roots at depths greater than 457 cm, gayfeather, goldenweed, and alfalfa. Alfalfa has been reported to depths of 39 m in the roof of a mine tunnel in Nevada (Meinzer 1927). Other researchers (cited in Meinzer 1927) have reported roots of older plants to depths of over 19 m. In deep prairie soils, alfalfa has been reported to root deeper than 6 m (Weaver 1926).

Three of the 12 grasses found in woodlands and recorded in the data base had rooting depths of greater than 457 cm. They included blue grama, dropseed, and side-oats grama. Alkali sacaton (Sporobolus arioides) has been reported

Table 1.--Average root depth for ten life forms

Life Form	Data Base	Average (cm)	Sigma (cm)	Range (cm)
Evergreen trees	40	336	954	10-6096
Deciduous trees	107	332	451	73-3000
"All" trees	147	334	611	10-6096
Shrub	87	350	350	15-1737
"All plants	1012	190	330	2-6096
Perennial forbs	370	170	250	2-3932
"All" perennials	675	160	200	2-3932
Subshrubs	36	140	100	51- 640
Perennial grasses	305	140	90	5- 823
Annual grasses (native)	8	52	41	5- 110
Biennial forbs	9	107	38	53- 152
Annual forbs	81	80	80	4- 300
Vines	4	168	78	102- 280

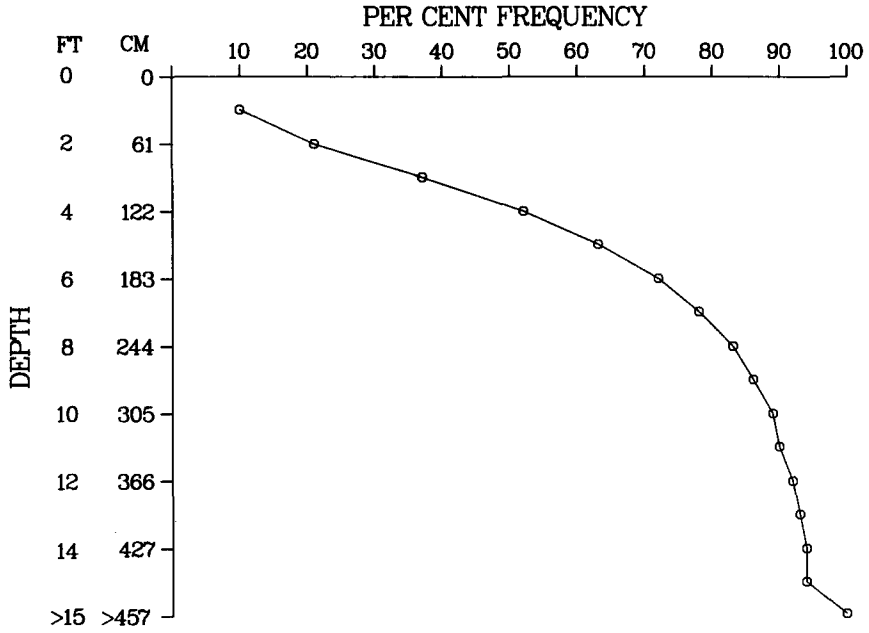


Figure 1.--Cumulative percentage frequency of rooting depth for 1012 vascular plants.

Table 2.--Cumulative rooting depth frequencies (%) for nine life forms at selected depths

Life Form	91 cm	183 cm	274 cm	366 cm	457 cm
Annual grasses	75	--	--	--	--
Biennial forbs	65	100	--	--	--
Annual forbs	65	88	97	100	--
Perennial forbs	42	71	85	93	97
Subshrubs	41	85	96	96	96
Perennial grasses	40	79	94	99	99
Evergreen trees	33	80	86	86	86
Deciduous trees	7	52	70	78	80
Shrubs	10	47	60	72	77

to root to depths of 823 cm based on water table data (Meinzer 1927). Tomanek and Albertson (1957) excavated roots of blue grama and side-oats grams to depths of 400 cm. Three-awn and downy chess were the deepest rooting annual grass species.

Field Studies

The information from the data base was compared to field studies (Tierney and Foxx, In press). Table 6 shows a comparison of the rooting depths of 21 species excavated at Los Alamos with the literature values.

Trees.--Because of the nature of the study, only small trees were excavated (3 m). We did, however, supplement the excavation information with observations of rooting depths, in large trenches (over 6 m deep) being prepared for burial of waste. Ponderosa pine roots were observed in road cuts, along arroyos, and tree fall areas as well as data from excavations.

In alluvial soils, roots of pinyons 17.0 cm diameter breast height (DBH) were traced 130 cm in depth. Ponderosa pine 10 cm DBH, on the other hand, went to 160 cm. Field observations showed ponderosa pine roots of even very large trees to be primarily in the upper 3 m of soil. This species, however, has been reported to root to depths of 25 m (Cannon 1960). Plants growing in shallow soils had well developed lateral roots that follow cracks in tuff. At Los Alamos in excavated trenches, roots

Table 3.--Rooting depths of plants of the pinon-juniper woodland (shallowest to deepest)

Species	Common Name	No. In Data Base	Avg. (cm)	Range (cm)
Graminoides				
Agrostis alba	redtop	1	--	15
Agropyron trachycaulum	slender wheatgrass	1	--	25
Koeleria cristata	Junegrass	17	58	30-76
Bromus tectorum	downy chess	2	70	30-110
Festuca spp.	fescue	19	78	5-152
Carex spp.	carex	14	89	35-183
Oryzopsis hymenoides	Indian ricegrass	2	84	45-122
Poa spp.	bluegrass	9	88	35-213
Muhlenbergia montana	mountain muhly	7	91	20-135
Sporobolus cryptandrus	sand dropseed	4	97	91-122
Bouteloua hirsuta	hairy grama	4	103	46-137
Aristida spp.	three-awn	8	108	76-152
Stipa comata	needle-and-thread	10	110	63-168
Bouteloua gracilis	bluegrama	29	119	38-396
Agropyron smithii	western wheatgrass	17	148	68-314
Andropogon scoparius	little bluestem	10	165	71-274
Agropyron desertorum	crested wheat	1	--	183
Andropogon gerardii	big bluestem	16	196	18-135
Bromus inermis	bromegrass	3	198	169-229
Bouteloua curtipendula	side-oats grama	6	222	76-396
Forbs				
Allium cernuum	wild onion	1	--	15
Castilleja spp	Indian paintbrush	2	28	25-30
Antennaria spp.	pussytoes	--	79	36-152
Mentzelia spp.	blazing star	3	58	11-152
Achillea spp.	yarrow	5	63	14-183
Salsola kali	Russian thistle	1	--	67
Arenaria spp.	sandwort	3	77	38-117
Antennaria parvifolia	pussytoes	3	40	36-48
Vicia spp.	vetch	2	80	20-140
Amaranthus spp.	pigweed	3	100	10-240
Hymenoxys richardsonnii	pinque	1	--	90
Solanum elaeagnifolium	horse-nettle	7	93	15-152
Senecio spp.	groundsel	6	94	20-154
Artemisia frigida	estafiata, wormwood	15	104	46-244
Gaillardia spp.	blanketflower	2	103	76-130
Potentilla spp.	cinquefoil	3	110	10-240
Ratibida spp.	coneflower	3	112	46-183
Yucca spp.	yucca	7	112	30-213
Grindelia spp.	gumweed	5	115	43-185
Chenopodium album	lamb's quarters	1	---	119
Cucurbita foetidissima	coyote melon	1	--	122
Penstemon spp.	beardstongue	7	129	36-305
Melilotus spp.	sweetclover	3	130	85-152
Aster spp.	aster	5	154	15-335
Eriogonum spp.	buckwheat	9	165	64-305
Petalostemum spp.	prairie clover	4	166	85-213
Geranium spp.	geranium	2	180	86-274
Lupinus spp.	lupine	4	182	168-240
Artemisia dracunculus	false terragon	1	--	213
Kochia scoparia	summer cypress	1	--	200
Oenothera spp.	evening primrose	5	209	53-305
Lithospermum spp.	puccoon	6	220	183-305
Sphaeralcea spp.	globe mallow	5	262	80-396
Gaura spp.	gaura	2	252	76-427
Soladago spp.	goldenrod	9	255	107-335
Chrysopsis villosa	goldenaster	5	275	130-396
Haplopappus spp.	goldenweed	6	287	107-518
Liatris punctata	gayfeather	6	308	120-479

(con)

Table 3 (con)

Species	Common Name	No. In Data Base	Avg. (cm)	Range (cm)
Glycyrriza spp.	wild licorice	3	395	360-428
Medicago sativa	alfalfa	13	690	38-3900
Subshrub				
Gutierrezia spp.	snakeweed	10	122	51-244
Shrubs				
Fallugia paradoxa	Apache plume	2	115	60-140
Cercocarpus montanus	mountain mahogany	4	113	40-152
Quercus gambelii	Gambel's oak	2	238	80-396
Artemisia tridentata	big sagebrush	9	248	110-914
Chrysothamnus nauseosus	chamisa (rabbitbrush)	5	293	100-457
Rosa spp.	wild rose	5	391	91-640
Atriplex canescens	four-wing saltbush	3	392	110-762
Trees				
Ulmus pumila	elm	1	127	127
Pinus ponderosa	ponderosa pine	1	447	10-2438
Pinus edulis	pinon pine	1	---	640
Juniperus monosperma	one-seed juniper	3	2438	579-6096

Table 4.--Cumulative frequency (%) of rooting depths of forbs

Forb	Root Depth 91	183	274	366	457	>457
Yucca	57	71	100	--	--	--
Cinquefoil	57	85	100	--	--	--
Wormwood	53	92	100	--	--	--
Buckwheat	22	66	88	100	--	--
Goldenrod	0	30	40	100	--	--
Beardstongue	57	86	86	100	--	--
Puccoon	0	34	67	100	--	--
Alfalfa	17	41	57	57	57	100
Goldenweed	0	50	67	84	84	100
Gayfeather	0	17	50	65	83	100

Table 5.--Cumulative frequency (%) of rooting depths of grasses

Grass	Root Depth 91	183	274	366	457
Junegrass	100	--	--	--	--
Bluegrass	72	100	--	--	--
Fescue	64	100	--	--	--
Three-awn	50	100	--	--	--
Needle-and-thread	40	100	--	--	--
Mountain muhly	15	58	100	--	--
Wheatgrass	18	77	95	100	--
Dropseed	37	75	75	85	100
Side oats grama	17	50	67	83	100

Table 6.--Comparison of Rooting Depths of Species with Literature values found by Foxx and others (1984a,b)

Common Name and Scientific Name	Excavated Depths (cm)	Literature Values Average (cm)	Literature Values Range (cm)
pinyon pine *Pinus edulis*	110,130,640	---	---
ponderosa pine, *Pinus ponderosa*	160,150	447	10-2438
one-seed juniper, *Juniperus monosperma*	170,640	2438	579-6096
chamisa, *Chrysothamnus nauseosus*	140,180,210	147	100-457
Squawberry, *Rhus trilobata*	210,230	---	---
Apache plume, *Fallugia paradoxa*	170,290,260	---	---
mountain mahogany, *Cercocarpus montanus*	50	113	40-152
wax currant, *Ribes cereum*	80,290	---	---
New Mexico locust, *Robinia neomexicana*	140,100	---	---
Oak, *Quercus* spp.	150,175,320	238	80-396
four-wing saltbush, *Atriplex canescens*	185,220	314	80-762
big sagebrush, *Artemisia tridentata*	130,180	248	110-914
snakeweed, *Gutierrezia sarothrae*	24,34,32	122	51-244
narrowleaf yucca, *Yucca angustissima*	20,20	113	40-152
prickly pear, *Opuntia polyacantha*	8,10,28	77	2-366
lupine, *Lupinus caudatus*	200	182	168-240
pinque, *Hymenoxys richardsonii*	23,25	---	90
mullein, *Verbascum thapsus*	28,42	---	---
lamb's quarters, *Chenopodium fremontii*	30	---	---
sunflower, *Helianthus petiolaris*	45	---	69
Blue grama, *Bouteloua gracilis*	53,58	119	38-396

of pinyon and juniper were traced in cracks in the tuff to depths of 6.4 m. The literature values indicated most trees to root to between 91-123 cm from the surface. Deciduous trees root somewhat deeper than evergreens.

Shrubs.--Four distinct rooting patterns were observed in the nine shrubs excavated. Apache plume and chamisa (fig. 2a) had well developed taproots that descended directly downward to depths of 2 or more meters. The oaks and New Mexico locust had rather distinct taproots with laterals forming sprouts. (fig. 2b). Four-wing saltbush and sagebrush had numerous small roots in the upper soil surface with larger lateral roots descending from the caudex (fig. 2c). Squawbush, mountain mahogany, and currant had large stem clump bases from which rather stout lateral roots emerged (fig. 2d). In alluvial soils these descended downward to depths of 100-320 cm. In shallow soils underlain by tuff, the roots penetrated to the depth of the bedrock, then grew at right angles until encountering a crack, and then descended downward.

The data base contained information on 87 different shrub specimens with an average rooting depth of 350 cm. The medium rooting depth was 195 cm, but over 20% of the specimens recorded rooted to depths greater than 457 cm. Woodbury (in Meinzer 1927) reported roots of big sagebrush to depths of over 9 m. We found sagebrush to root to approximately 2 m in alluvial soils and most other species to less than 3 m.

Forbs.--At Los Alamos five perennial forbs were excavated and roots traced: pinque, estafiata, snakeweed, yucca, and lupine. Although yucca is rhizomatous, it was included in the studies because it often invades disturbed areas in the pinyon-juniper woodland. Whole plants of pinque, estafiata, and snakeweed were excavated and were found to root to depths of 25 cm. Lupine, however, rooted to depths of greater than 2 m. The root of the lupine was a distinct tap root that descended rapidly, whereas the roots of the other two perennial species were a single taproot with a number of laterals. The yucca was found to root to 30 cm. Numerous sprouts formed other plants from the rhizome.

Perennial forbs comprised the largest number of entries in the data base (370). Average rooting depths were 170 cm with a range from 2 to 3920 cm. Again, the greatest depths were reported for plants with roots penetrating mine tunnels. The common alfalfa (Medicago sativa) is one of the deepest rooting perennial forbs. At Los Alamos, the deepest rooting perennial forb excavated was lupine. Interestingly, rooting depths of three families were compared in the data base, legumes (Fabaceae) rooted the deepest, then composites (Asteraceae), and grasses (Poaceae) the shallowest (Foxx and Tierney 1984a). Legumes are often used for reclamation or invade disturbed ground.

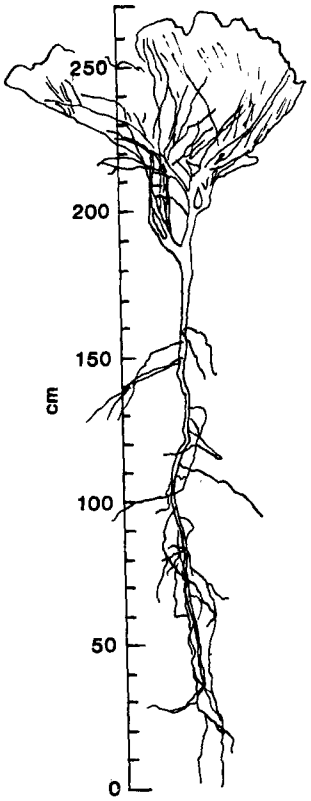
The highest frequency of rooting depths for perennial forbs was 92 cm. Median rooting depth of 114 cm was found. Only 4% of all occurrences rooted deeper than 457 cm.

Biennial forbs.--At Los Alamos we excavated only one biennial species, mullein. This weedy plant can grow to a height of 7 feet. Our specimens were approximately 3 feet tall and rooted to depths of 40 cm in alluvial soils. This root depth was below the average and median rooting depths for the nine biennial forbs in the computerized data base. The average rooting depth for those nine plants was 107 cm with a range of 53 to 152 cm. The common sweet clover was the most deeply rooted biennial genus. The highest rooting frequencies occur from 91 to 152 cm. Median rooting depth is 76 cm. No specimens rooted deeper than 152 cm.

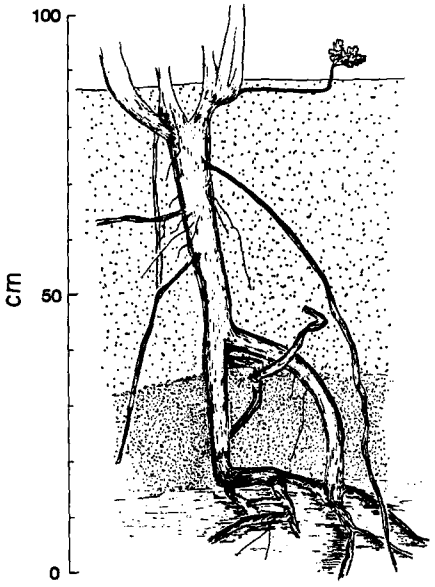
Annual forbs.--Two annual forbs, lamb's quarters and sunflower, were excavated. The roots of these species were traced to depths of 45 and 30 cm, respectively. At 30 cm, the roots of the lamb's quarters turned at a right angle and may have gone much deeper. The average rooting depth for the 81 annual forbs recorded in the computerized data base was 80 cm, with a median rooting depth of 61 cm. The highest rooting frequency was 123 cm. There were no annual forbs that rooted deeper than 305 cm recorded in the data base.

Grasses.--The most common perennial grass of the pinyon-juniper woodland in northern New Mexico is blue grama. It was excavated in alluvial soils and roots were measured to 58 cm. No annual grasses were excavated.

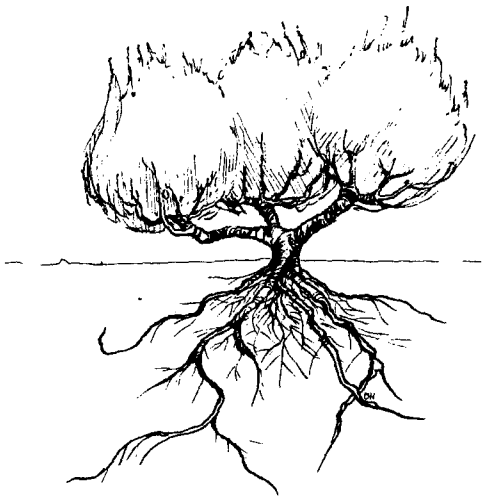
On an average, the perennial grasses recorded in the data base were found to root to a depth of 140 cm with a range of 5 to 823 cm, whereas the average rooting depth of annual grasses was 52 cm.



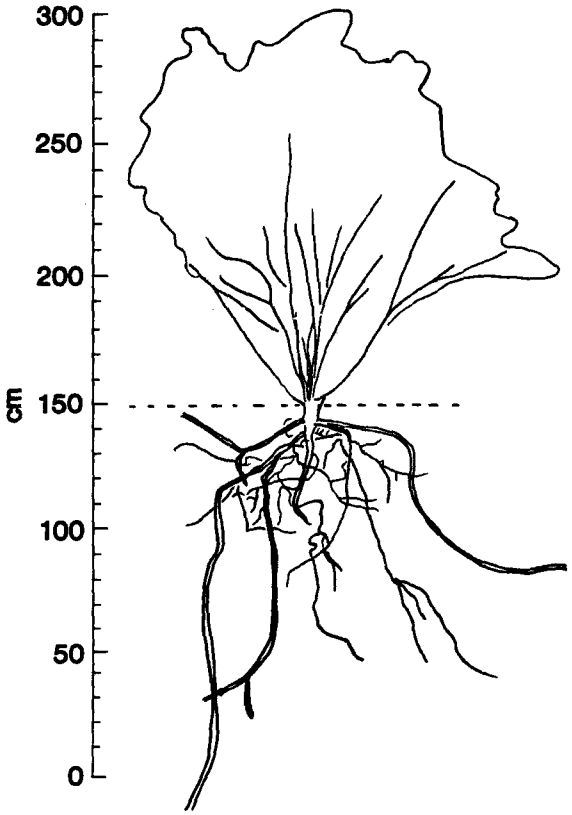
a. chamisa



b. Gambel's oak



c. sagebrush



d. squawbush

Figure 2.--Rooting patterns of shrubs in the pinyon-juniper woodland.

CONCLUSIONS

Examination of the computerized data base of rooting depths of species found in various soils in the states west of the Mississippi showed that the annual grass roots were found entirely within 1 m of the soils surface. Median rooting depths of other life forms were 2.0 m, with maximum rooting depths of 61 m. The other life forms had the following median and maximum rooting depths: annual forbs (median of 0.6 m, maximum of 3.0 m); biennial forbs (0.8 m, 1.5 m); perennial grasses (1.1 m, 8.2 m); perennial forbs (1.1 m, 39 m); subshrubs and vines (1.2 m, 6.4 m); trees (1.6 m, 1.5 m); shrubs (2 m, 17 m).

Field excavations of 21 species found within the pinyon-juniper woodland showed that roots of pinyon pine and one-seed juniper could extend to depths of 6 m in fractures in tuff. Roots of shrubs were the most varied, some with distinct deeply rooting taproots and others with more extensive root systems to the surface. In all cases, even in alluvial soils the rooting depths of species found in these volcanic soils were somewhat shallower than those means found from the collated literature values.

This study emphasizes the importance of the engineering of a trench cap on waste sites to accommodate the rooting patterns of planted and successional species. The data base suggests that most plants root to levels below 1 m and 90% of all the specimens examined root to depths of 2 m. Because the present overburdens are generally only 1 m deep, penetration of roots into the waste zone is certain if biobarriers are not employed. In trench cap design, the data base can be predictive in suggesting which plants may be appropriate to reclamation of sites where rooting depths are important. In addition, the data base can be useful in determining the possible rooting patterns of successional species in various plant communities, including the pinyon-juniper woodlands found throughout the western United States and eliminate time intensive excavations. The study provided some basic information needed for model development and simulation.

Information on the physiology of roots at various depths is important to an understanding of the influence of plants to the water balance and contaminant transport of waste sites in any plant community. Such information was not within the scope of this study and needs further investigation.

ACKNOWLEDGMENTS

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SUCCESSIONAL CHANGES IN COMMUNITY STRUCTURE OF PINYON-JUNIPER WOODLANDS ON NORTH-CENTRAL ARIZONA

James A. Tress, Jr. and Jeffrey M. Klopatek

ABSTRACT: Five pinyon-juniper woodland communities representing different successional stages were studied in north-central Arizona. The postfire successional communities ranged from 7 to 90 years in age, while the mature community was greater than 300 years old. This paper documents the changes in community structure associated with this sere, including density-diameter distributions, diversity (H', J', and species richness) and crown cover. An estimate of successional rate, based upon community similarity indices and a computer simulation of pinyon-juniper succession is presented.

INTRODUCTION

Knowledge of successional processes is fundamental to obtaining the silvicultural understanding necessary to meet the increasing fuelwood demands being placed upon pinyon-juniper woodlands (Gottfried 1984). Arnold and others (1964) first reported the successional patterns of the pinyon-juniper woodlands in the southwestern United States. Everett and Ward (1984) have demonstrated, through the use of controlled burns, the importance of Egler's (1954) initial floristics concept in determining the composition of the early stages of succession.

This paper documents the dynamics of pinyon-juniper succession in north-central Arizona with emphasis placed upon changes in community structure. An estimate of the rate of succession and the results of a deterministic computer simulation are presented.

SITE DESCRIPTIONS

The temporal nature of the sere was described using spatially distinct seral stages. [For the limitations of this approach see McCune and Allen (1985) and MacMahon (1980).] Only sites under the influence of similar abiotic regimes were studied. Limiting the region from which the sites were selected, while necessary, limited the applicability of the study geographically. This is particularly true of systems which experience as broad a range of climatic conditions as do the pinyon-juniper woodlands of the western United States (West 1984).

Five communities in north-central Arizona, representing different stages of secondary succession, were selected. The sites lie between mean January isotherms of -4 and -1 °C and mean July isotherms of 18 and 21 °C. The selected sites also occur between the 38 and 50 cm precipitation isopleths (Sellers and Hill 1974). Soils on the sites are derived from the same parent material, Kaibab limestone (Moore and others 1960), and are primarily lithic ustocrepts and udic haplustalfs (Anonymous 1980; R. Jorgenson per. com.). The sites are approximately 1950 m in elevation.

The amount of time since the last disturbance by fire for four of these communities ranged from 7 to 90 years. The fifth community studied, the mature community, appears to have been free from major disturbance for more than 300 years. All ages were determined using the open literature, Forest Service fire records, or by analysis of tree core and snag cross sections (Erdman 1970).

The disturbance history of the Cosnino site (app. 65 old in 1984) is unique (in contrast to that known for the other sites). The first recorded fire on this site occurred in 1885 and the northeast portion was burned again in the early 1920's. Both the southwest portion of the original burn and the northeast portion (twice disturbed) were sampled by Arnold and others (1964) in 1954 and were approximately 70 and 35 years old, respectively. After 1954 the southwest portion of the original burn was either chained or pushed and no further sampling was done on that part. The northeast portion was again sampled in 1984 and was approximately 65 years old at that time.

METHODS

Community composition was determined using a combination of 1-m^2 quadrats and the point centered quarter method (Cottam and Curtis 1956). Grasses, forbs, and any shrub less than 0.3-m tall were sampled using 1-m^2 quadrats. The point centered quarter method was used to determine the density and crown cover for both shrubs (> 0.3 m)

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James A. Tress, Jr. is a Graduate Student and Jeffrey M. Klopatek is an Assistant Professor, Department of Botany and Microbiology, Arizona State University, Tempe, AZ.

and tree species. All nomenclature follows Lehr (1978). Two perpendicular crown diameters and the height were measured for each tree and shrub sampled. The diameter at collar height (10 to 20 cm above the ground) was measured for pinyons (Pinus edulis Engelm.) and diameter breast height (dbh) was determined for each of the main stems for junipers (Juniperus osteosperma (Torr.) Little). Main stem diameters were than converted to an adjusted diameter (equivalent to the dbh of a tree with one stem of equal cross-sectional area) (Meeuwig and Budy 1981).

Density-diameter curves were determined for the Dillman, Cosnino, and mature communities. Species diversity was determined using the Shannon-Wiener diversity index (H'), species richness, and equitability (J') (Pielou 1966). Motyka's modified Sorenson index was used to calculate community similarity indices (CSI) based upon life-form using the mature community as the reference and crown cover as the index of importance (Chambers and Brown 1983) for the four successional communities.

Due to differences in sampling technique not all of the data collected from each site are comparable. In particular, estimates of grass cover, made in 1954, were based upon basal intercept (Arnold and others 1964) while those reported in this study were based upon crown intercept. Additionally, the 90-year-old site was sampled at a later date than the others using the line-intercept method (Canfield 1941). Because of these differences these sites could not be used in all of the analyses (diversity and density-diameter distributions).

The programming language DYNAMO (Pugh 1983), was used to model this system based upon hypothesized biotic interactions. A chi-squared test was used to compare model output to the data used in its calibration (Woodfield per. com.). For a more complete description of the methodologies used in data acquisition and modeling see Tress (1986).

RESULTS AND DISCUSSION

Vegetational Description

Figure 1 shows the change in cover of the four life-forms studied. Of these four, forbs is the most insignificant (based upon crown cover), ranging from a low of 0.34 percent on the 65-year-old burn to a high of 1.87 percent on the 35-year-old burn. The dominant grass on all of the sites studied was blue gramma (Bouteloua gracilis (HBK) lag. ex Steud.). On the 7-year-old site grass cover was 0.34 percent, while maximum grass cover, for all of the sites studied, was 25.02 percent on the 90-year-old site. On the mature community grass cover was 8.37 percent.

Broom snakeweed (Gutierrezia sarothrae (Pursh) Britt. & Busby.) was the dominant shrub on the 7-year-old site comprising approximately 90 percent of the total shrub cover (8.84 percent). Rubber rabbitbrush (Chysothamnus nauseosus (Pall.) Britt.) was the dominant shrub on the 35- and 65-year-old sites. Shrub cover for these sites was 22.03 and 10.1 percent, respectively. The 90-year-old and mature communities were dominated by Fremont's barberry (Berberis Fremontii Torr.). Total shrub cover on these sites was 18.03 and 0.35 percent, respectively.

Shrub crown cover reported for the twice-disturbed, 35-year-old community, 0.10 percent, (Arnold and others 1964) is much lower than that reported for the once-disturbed, 35-year-old community in this study, though the dominant species, rubber rabbitbrush, is the same. The 70-year-old site sampled by Arnold and others (1964) is similar to the 65-year-old (twice-disturbed) site reported in this study; shrub crown cover for these two sites was 12.6 and 10.1 percent, respectively. Given the differences in disturbance regime associated with these two sites and the disparity in shrub cover reported for 35-year-old sites which have experienced different disturbance regimes, the similarity between the reported crown covers is remarkable.

Tree regeneration on the 7-year-old site was limited to a few individuals in the drainages avoided during sampling. Crown cover for the tree life-form on the 35-year-old site was 1.77 percent, and on the mature site was 34.78 percent. Arnold and others (1964) reported tree life-form crown cover values ranging from 31.7 to 43.28 percent for several mature pinyon-juniper communities in northern Arizona.

Trees are the dominant life-form within mature pinyon-juniper woodland communities and have the greatest biotic influence upon community composition (West 1984; Arnold and others 1964). Density-diameter distributions of both species and life-form are reported to better understand their ecesis and development.

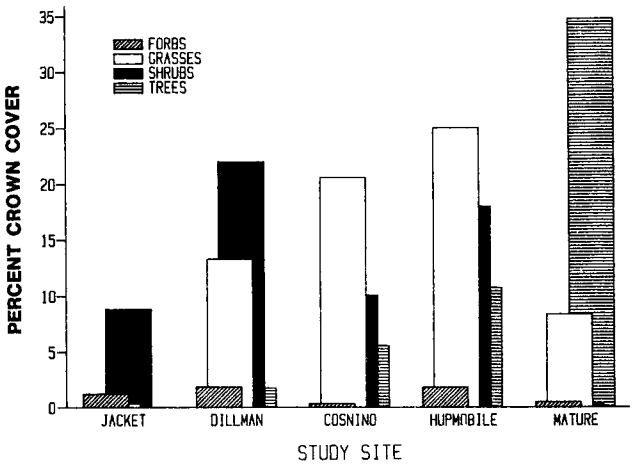


Figure 1.--Crown cover by life-form for postfire successional communities and the mature community.

Density-diameter distributions for all-aged stands approximate a rotated, sigmoid curve due to the differential recruitment of trees from one size class to the next (Goff and West 1975; West and others 1981). Mortality is high and growth rate slow in the smaller size classes. Recruitment to the canopy increases the growth rate and decreases the mortality rate, thus decreasing the slope of the curve. The larger size classes exhibit an increase in slope due to a decrease in growth rate and an increase in mortality associated with senescence (Goff and West 1975).

Density-diameter curves by species and site are shown in figure 2. On the 35-year-old site, species dominance reverses for the two size classes (0 to 10.16 and 10.17 to 20.32 cm) represented. Pinyons are the dominant species in the smaller size class while junipers are the dominant species in the larger class. The reversal in dominance is even more apparent if the densities by sapling and mature size classes (as sampled) are examined (table 1).

Pinyons were the dominant species in all of the classes represented on the 65-year-old burn. The overall shape of the curves for pinyons and junipers are approximately the same (fig. 2).

Density-diameter curves for junipers on the mature site approximate the rotated sigmoid curve indicative of an all-aged stand (Goff and West 1975). Junipers deviate from the expected curve in that the slope from class 1 to class 2 is not as steep (fig. 2). The pinyon density-diameter distribution is more complex; classes 3 and 4 have a higher density than the other four classes represented. The decrease in density from class 4 to 5 is precipitous, bringing pinyon densities down to the levels reported for junipers in class 5.

The increase in pinyon density in classes 3 and 4 on the mature community and class 2 on the 65-year-old community deviate from the expected

Table 1.--Tree density by species, size class and site (no/ha)

Species and size	Site			
	Jacket	Dillman	Cosnino	Mature
Pinus edulis				
sapling	0	32	28	28
mature	0	4	63	202
sub-total	0	36	91	230
Juniperus osteosperma				
sapling	0	4	19	27
mature	0	29	29	165
sub-total	0	33	48	192
TOTAL	0	69	139	422

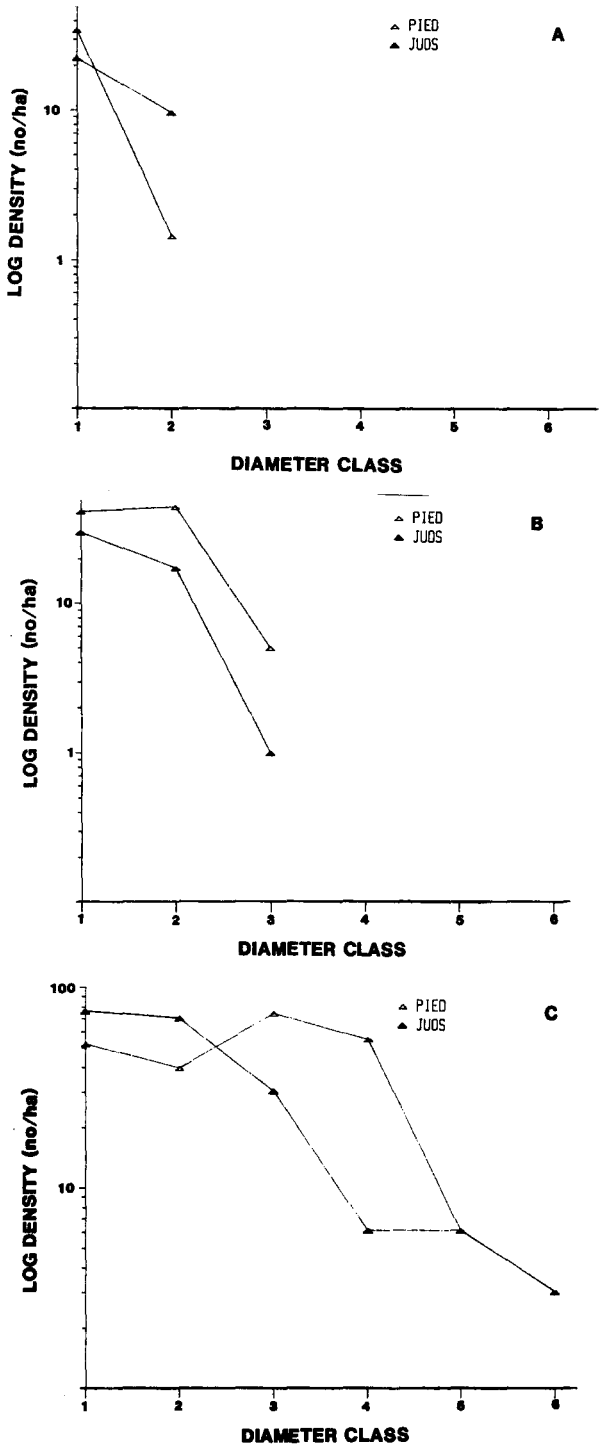


Figure 2.--Species density-diameter distributions: A = Dillman site, B = Cosnino site, and C = mature site.

curve for all-aged stands, and are indicative of regeneration cycles (Goff and West 1975). There are a number of factors which contribute to the episodic reproduction of Pinus edulis indicated by this pattern (fig. 2). The interaction of these factors [unfavorable climate, a large seed

crop every 5 years, infertility of the seed, and predation (Tueller and Clark 1975)] is the probable cause for the lack of a monotonic decrease in the density-diameter distribution. One possible explanation for the shallow slope reported for the smaller size classes of junipers would be as follows: First, selection occurred prior to individuals reaching the minimum size criteria (.5-in height) of the sampling design (Tress 1986). Secondly, upon reaching this minimum size the canopy acted in a way which ameliorated the harsh climatic conditions associated with this woodland. While this explanation is speculative it does point out the need for increased research concerning pinyon and juniper germination and establishment particularly in light of the increasing demands for fuelwood being placed upon these woodlands.

Species Diversity

Shannon-Wiener diversity indices as well as equitability (J') and species richness are listed in table 2. Diversity for the 65-year-old site is reported but not used in our comparisons due to its unique disturbance history. All of the indices of diversity exhibited a low-high-low temporal pattern. The greatest diversity (for all measures) occurred on the 35-year-old site; Shannon-Wiener index, equitability, and species richness were 1.52, 0.48, and 23, respectively. The increase in H' from the 7- to the 35-year-old community is primarily caused by the increase in the species richness (from n=10 to n=23). Though the increase in equitability played a role, the relative magnitude of the changes in species richness and equitability suggest that species richness was the primary factor involved. The relative magnitude of the changes in species richness and equitability from the 35 year old to the mature site suggests that the decrease in equitability is the primary cause for the decrease in H'.

Successional Rate

Calculating the linear rate of change for community similarity indices (table 3) provided a means of estimating successional rates for these woodlands. A linear regression [Community

Table 2.--Diversity indices for perennial species = Shannon Wiener (H'), Species richness, and equitability (J')

Site	Diversity	Equitability	Richness
Jacket	0.93	0.43	10
Dillman	1.52	0.48	23
Cosnino	1.37	0.46	20
Mature	1.11	0.39	17

Table 3.--Community similarity indices based upon crown cover, using the mature community as the reference community

Site	CSI
Jacket	4
Dillman	26
Cosnino	36
Hupmobile	41
Mature	100

Similarity Index (CSI) as a function time] was used to determine this rate of change and was based upon 0, 7-, 35-, and 90-year-old sites (r^2=0.94; F=28.3, $p < 0.05$). Based upon the results of that regression approximately 215 years would be required for the pinyon-juniper woodlands studied to recover following a disturbance by fire.

There are several inherent limitations associated with this method of determining successional rates. The first is the assumption that the change in CSI through time is linear. While our data suggested a linear response from 0 to 90 years, the long-lived nature of the dominant species may alter the shape of the CSI curve. Secondly, different community attributes change at different rates. The accumulation of wood (indicated as a percentage of the mature communities x-sectional area/ha) is slower than the change in crown cover or density (indicated as a percent of the mature communities values for cover and density) (table 4). Therefore, estimated rates of succession based upon crown cover will underestimate the rate of recovery associated with other measures of community physiognomy (wood accumulation).

Model Results

Figure 3 represents 230 years of model output. Table 5 contains the results of the chi-square test for each life-form. The shrub life-form was the only life-form for which model output did not agree with the field observations (x^2=30.07: $p < .005$). Two of the seven study sites [five from our research and two from Arnold and others (1964)] account for this significant difference -- the twice-disturbed, 35-year-old site studied by Arnold and others (1964) and the 90-year-old site. On the twice-disturbed, 35-year-old site shrub cover was much less than what the model predicted while on the 90-year-old site it was higher.

Disturbance history accounts for the differences between the predicted 35-year shrub response and what was actually reported by Arnold and others. When this community was resampled in 1954, it was described as a grassland-dominated community (Arnold and others 1964). Assuming that this

Table 4.--Comparison of the tree life-form based upon density, crown cover and the sum of basal area and breast height area (SBB) presented as a fraction of their respective value reported for the mature community

Site	Density	Crowncover	SBB
Jacket	0	0	0
Dillman	0.17	0.05	0.16
Cosnino	0.33	0.16	0.09

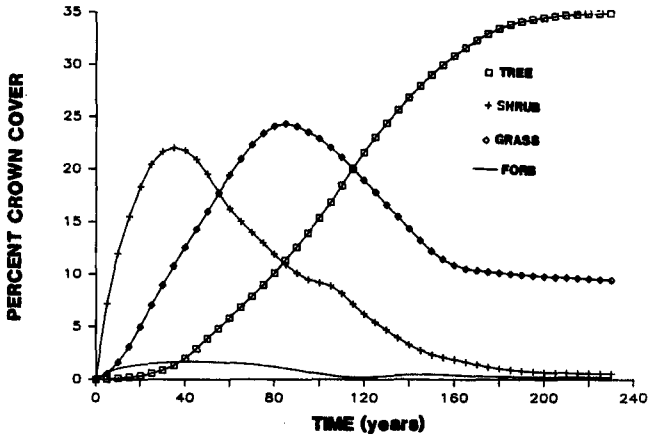


Figure 3.--230 years of pinyon-juniper succession.

site was similar to the 35-year-old Dillman site at the time of the second burn, it would have been dominated by shrubs, have had a fairly substantial grass cover, and the trees would have been sparsely distributed. After the second burn the grasses may have had a competitive advantage due to their ability to reproduce vegetatively from root crowns, which would have enabled them to recover faster following the second disturbance than did the shrubs.

On the 90-year-old site, shrub cover was much higher than what was predicted by the model (18.03 vs 10.09 percent). This was primarily due to the dominance of this community by, longer lived shrub species such as Fremonts barbary and salt bush (Atriplex canescens (Pursh) Nutt.). Everett and Koniak (1981) have suggested that rabbitbrush disappears more rapidly than other shrubs as competition from pinyons and junipers increases. Thus, if established, longer lived shrub species will significantly modify the middle portions of the sere.

SUMMARY

Five pinyon-juniper woodland communities, representing different successional ages, in north-central Arizona were studied. The length of the sere, based upon the crown cover of perennial species, was estimated to be 215 years. other measures of community physiognomy (wood accumulation) suggest that 215 years may underestimate the amount of time required for a community once disturbed to become "equivalent" to a mature community. All of the calculated measures of diversity (H', J', and species richness) exhibit the low-high-low pattern described by Margalef (1968). Density-diameter distributions for the mature community failed to follow the rotated sigmoid shape hypothesized for all-aged stands (Goff and West 1975). This deviation is primarily due to the episodic reproductive events associated with pinyons. A computer simulation of pinyon-juniper successional dynamics accurately depicted those dynamics for all but the shrub life-form. The primary cause of the deviation for the shrub life-form was a difference in the disturbance regime experienced by that particular community.

Table 5.--Chi-square test of model output vs. the field observations used to construct the model. 2_x = double disturbance regime experienced at the Cosnino site

Life form	Fire age (yrs)							
	7	35	35 (2x)	65 (2x)	70	90	220	Chi-square
Tree	0.07	0.12	0.43	0.24	0.99	0.28	26E-5	2.13
Shrub	0.05	72E-6	21.87	1.70	0.13	6.25	0.08	30.08*
Grass	0.38	0.59	--	0.01	--	0.04	0.14	1.16
Forb	1.21	0.02	--	0.93	--	1.03	0.4	3.59

* significant ($p < 0.005$)

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MORPHOLOGICAL VARIATION/PRECIPITATION RELATIONSHIPS OF GREAT BASIN SINGLE-NEEDLED PINYON

Robin J. Tausch and Neil E. West

ABSTRACT: The selection of ecotypes is important for improved production and management of the common and economically important conifers. Because of limited past commercial interest, little information on ecotypic variability is available for pinyon. Variation in selected morphological characters of pinyon was investigated at eight sites across the northern Great Basin. One site near a weather station (Lehman Creek, Nevada) allowed the annual variation in the selected characters to be correlated with precipitation. Annual increment in stem length, annual needle length, and annual percentage of double needled fascicles were significantly positively correlated with one or both of two precipitation measures. Needle length, in particular, could be used as a phytometer of the environmental conditions of the preceeding decade. Individual trees on the Lehman Creek site significantly differed in the magnitude of their responses to variations in precipitation. Trees on all sites that showed a higher average incidence of paired needles also generally had larger annual increments in stem growth, longer needles and a denser crown than other trees on the same site. Patterns in the variation in morphological characters between sites were consistent with the patterns in annual variation for the Lehman Creek site. Sites with better growth also had a higher frequency of trees with both a blue-glaucous coloration and greater than 5 percent double needled fascicles. Further study may improve selection of pinyon trees for fuelwood and Christmas trees.

INTRODUCTION

Pinyon-juniper (Pinus monophylla-Juniperus osteosperma) woodlands are an important forest type representing over 17 percent of the Great Basin (>48,000 mi^2, Tueller and others 1979). In most areas of the Great Basin it is the predominant forest cover type. Areas occupied by these woodlands have grown in economic importance, particularly from increasing demand and use as a source for fuelwood resulting from rising fossil fuel costs (Young and Budy 1979; Sammuels and Betancourt 1982; Meeuwig and Cooper 1981). This increased consumption has created shortages (Gray and others 1982). Fence posts, Christmas trees, and other products are also increasing in importance with Christmas tree shortages occurring in some areas. Because little commercial interest previously existed, limited information on the growth characteristics of pinyon or their variation from location to location exists (Samuels and Betancourt 1982; Meeuwig and Cooper 1981). This has led to affected National Forests and BLM districts formulating fuelwood and other harvest policies on an ad hoc basis (Carey 1980).

During recent synecological studies of pinyon-juniper woodlands (West and others 1978, 1979; Tueller and others 1979; Tausch and others 1981; Tausch and West 1986), localized populations of single-needle pinyon were observed in the Great Basin that appeared to be growing faster and had different morphological characters than trees in surrounding areas. These populations could be distinguished by tree shape, vigor, needle color, and on closer inspection, the presence of fascicles with paired needles. Distinguishing characteristics were often sufficiently pronounced to make recognition possible as much as a third of a kilometer away. Although these populations appear to comprise only a small portion of the total woodland area, they may represent important sources of propagules for improved fuelwood and Christmas tree production.

Pinyon trees in the Great Basin with paired needles present have a scattered occurrence. They are found along the eastern boundary of the Great Basin where the range of single needle pinyon meets that of true or two-needle pinyon (Pinus edulis) and hybrids are generally known to occur (Erdman 1970; Lanner and Hutchinson 1972; Lanner 1974, 1981). Non-hybrid occurrences are known, such as in the New York Mountains of California where Trombulak and Cody (1980) found that pinyon trees with two needled fascicles were higher in elevation and separated from pinyon with single needled fascicles. Although rarer than trees with predominantly one or two needled fascicles, they found trees with varying numbers of one and two needled fascicles in intermediate locations. The proportion of two needled fascicles was found to be significantly correlated with elevation and apparently with cooler, moister conditions. Trombulak and Cody (1980) suggested that the existence of pinyon

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Robin J. Tausch is Assistant Professor, Department of Range, Wildlife, and Forestry, University of Nevada Reno 89512; Neil E. West is Professor, Range Science Department, Utah State University, Logan, Utah 84322.

with mixed one and two needled fascicles in otherwise monotypic stands indicated some developmental plasticity in needle number in direct response to environmental pressure. Their recorded frequency distribution also indicated that two distinct forms of pinyon could be present.

Pinyon exhibited similar characteristics on the sites for this study. These sites were generally located in the northern Great Basin near the northern limits of its distribution. The sites appear to have better soil moisture conditions than are present in the surrounding woodlands.

Close examination of the faster growing trees on such sites revealed that many morphological characters, including those discusssed by Trombulak and Cody (1980), also varied from year to year on an individual tree. This indicated the possibility of yearly variation that could be used to investigate the developmental plasticity hypothesized by Trombulak and Cody (1980). The climatic variable of concentration for this investigation is precipitation.

METHODS

Eight sites scattered across the northern Great Basin were sampled during September, 1974, for this initial investigation (fig. 1, table 1). One of these sites (Lehman Creek, Nevada) was used for direct climatic studies. It was located about 400 meters from the weather station at Lehman Caves National Monument.

Each of the eight sites was located within a pinyon population exhibiting the distinguishing characteristics. The tree appearing to have the highest occurrence of fascicles with double needles was used as the center tree of each plot. The presence of double needles was the focus because of ease in field recognition. Sampling was done within expanding concentric rings about the center tree until at least one of each of the six size-age-form classes described by Blackburn and Tueller (1970) that were present was included. Plots were positioned to remain on the same slope, aspect, and topographic position of the center tree.

One branch was collected from the outer portions of the midpoint of the crown on each aspect and one from the top, for a total of five limbs per tree. Each branch was collected to include at least one year's stem growth behind the oldest needle-bearing stem section. Sections of annual

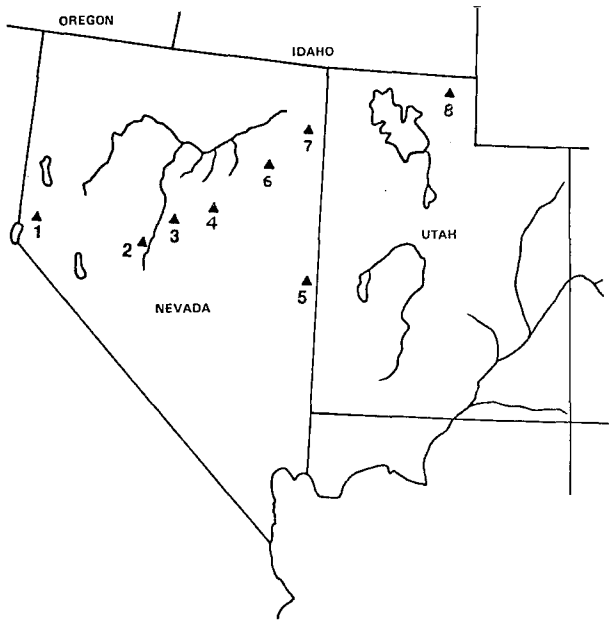


Figure 1.--Map of the locations of the sample sites listed in table 1.

Table 1.--Tree sample sizes and averages of the seven sampled morphological characters for the sampled sites. Site locations are shown in figure 1

Plot number and location	Number of trees sampled	Percent of trees with Chroma 2	Percent of trees with ≥5% double needles	Average stem length (mm)	Average needle length (mm)	Average percent double needles	Average resin canal number	Average cone width (mm)
1. Gieger Lookout	5	20.0	20.0	33.6	36.8	2.8	3.8	61.4
2. Elkhorn Summit	11	36.4	54.6	36.9	37.7	6.2	3.3	64.2
3. Bob Scott Summit	13	15.4	30.8	35.3	34.1	7.6	3.1	65.0
4. Garden Pass	9	55.6	33.0	34.1	35.3	2.7	4.2	62.4
5. Lehman Creek	10	40.0	40.0	34.9	35.5	6.2	3.3	66.0
6. Valley Mountains	9	11.1	11.1	22.9	32.9	0.9	3.4	66.2
7. Independence Summit	6	0.0	0.0	24.5	32.8	2.5	4.0	70.3
8. Dry Curtis Creek	21	47.6	23.8	35.7	37.3	4.8	3.4	64.6

growth were determined on each branch by locating the terminal bud-scale scars (Ewers and Schmid 1981). All annual sections containing needles were numbered beginning with the current year's growth and measured for length.

All the fascicles on each annual stem increment were counted and the percent of double needles computed. Average needle length and resin canal number were determined from a random selection of 10 needles from each annual stem section. Resin canal number, also linked to morphological variation (Lanner 1974), was determined from a cross-section at the center of each needle.

Ten cones were collected from each sample tree bearing them. The number of trees with cones ranged from three to six per site. Two diameters were measured on each cone, the widest and the width perpendicular to the widest, and averaged for cone width. All sampled variables were averaged by tree and site.

The percent of the sampled trees on each site with greater than or equal to 5 percent double needled fascicles was determined as was the percent of sampled trees on each site with a fresh foliage chroma 2 on a "5-GY" Munsell Color Chart. The latter measurement indicates the frequency of the blue-glaucous coloration associated with sites with the faster growing trees.

Monthly precipitation totals were obtained for the 10 years previous to sampling on the Lehman Caves National Monument. Determining annual precipitation by summing the monthly precipitation for July through the previous August was found to have the highest correlations with the sampled morphologic characters. During and subsequent to the data collections reported elsewhere (West and others 1978; Tueller and others 1979; Tausch and others 1981), the completion of tree growth, observed as the cessation of needle elongation, was generally completed by the end of July or early August. Most of the precipitation at Lehman Caves National Monument came during the late fall, winter, and spring. The moisture affecting the growth and annual variation in the sampled morphological characters appears to be that available for growth each year. Because growth in any one year can be influenced by the previous year's as well as the current year's precipitation (LaMarche 1974), the sum of the previous two years precipitation, beginning from July of each year, was also used.

On the Lehman Creek site, correlation coefficients and regression equations were computed between the possible pairs of the sampled morphological characters and the two precipitation variables. Linear correlation coefficients were also computed between the annual variation of the possible pairs of sampled morphological characters on the remaining sites. Overall plot averages for each of the sampled morphological characters were used to compute correlation coefficients for site to site variation.

RESULTS AND DISCUSSION

Over the eight years of available morphologic data for the Lehman Creek sample, the average annual stem length, needle length, and percent double needles were correlated with each other at the 10 percent level (table 2).

Three of the 10 sample trees on the Lehman Creek site had distinctly higher average percentage double needles over the 10 years of data. These differences were significant by T-test analysis ($T=4.9$, $P \leq 0.01$). For these three trees, the relationship between stem length and percent double needles was significant (table 3).

Table 2.--Correlation coefficients between the average annual values of three morphological characters of pinyon and two measures of precipitation from the Lehman Creek sample site. Pinyon data were computed using the branches from all the trees

	(1) Stem length	(2) Needle length	(3) Percent double needles	(3) August through July precip.	(4) 2 Year precip. sum
(1)	1.0	0.70#	0.65#	0.63	0.73*
(2)		1.0	0.69#	0.96**	0.59
(3)			1.0	0.77*	0.60

\# = $P \leq 0.10$
* = $P \leq 0.05$
** = $P \leq 0.01$

Table 3.--Correlation coefficients between the average annual values of three morphological characters of pinyon and two measures of precipitation from the Lehman Creek sample site. Pinyon data were computed using the branches from the three trees with the highest percentage of double needles

	(1) Stem length	(2) Needle length	(3) Percent double needles	(4) August through July precip.	(5) 2 Year precip. sum
(1)	1.0	0.69#	0.75*	0.72*	0.85**
(2)		1.0	0.70#	0.97**	0.66#
(3)			1.0	0.80*	0.67#

\# = $P \leq 0.10$
* = $P \leq 0.05$
** = $P \leq 0.01$

Annual precipitation at Lehman Creek was significantly correlated with the annual average percent double needles for both the full tree sample and for the three trees with a higher percentage of double needles (fig. 2). The latter three trees had both a higher overall percent double needles and a greater increase with increasing precipitation. A strongly divergent point below the regression line in both analyses represents a year (1969) that had the warmest and second driest spring of the eight years of weather records.

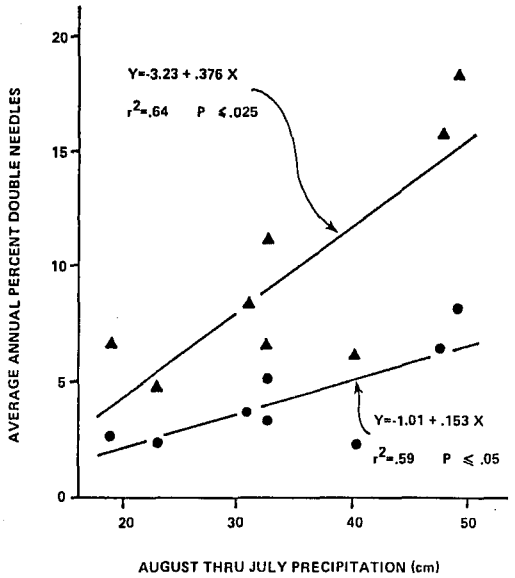


Figure 2.--Regression analyses for the relationship between the August through July precipitation at Lehman Creek and the average annual percent double needles from all the sampled trees (●) and from the branches of the three trees with the highest average percent double needles (▲).

Average annual needle length at Lehman Creek was highly significantly correlated with the August through July precipitation (table 2). Regression analyses indicated the relationship was curvilinear (fig. 3).

The curvilinear relationship implies an approach to an upper limit to needle length. The three trees with the highest average percent double needles also had longer needles and a greater increase in needle length with increasing precipitation (fig. 3).

The correlation of stem length with the two year precipitation sum was higher for the three trees with the highest double needle percentage than for the full data set. Annual stem increment on the latter three trees was longer and increased more with increasing precipitation than on the other sample trees (fig. 4). The annual variation in resin canal numbers at Lehman Creek was not significantly correlated with any of the other variables. Analyses of the morphological characteristics on the remaining plots provided similar results.

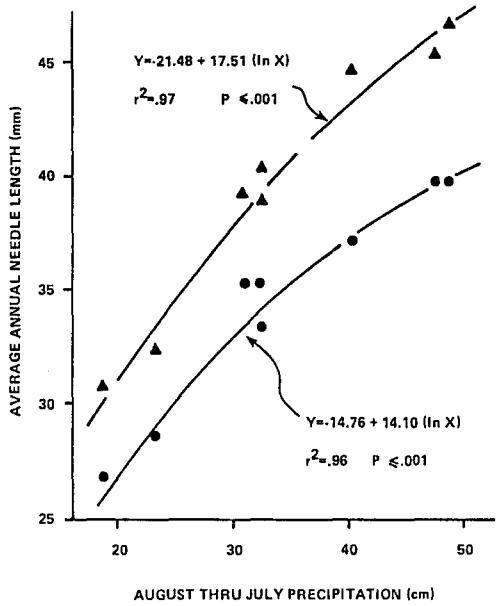


Figure 3.--Regression analyses for the relationship between August through July precipitation at Lehman Creek and the average annual needle length computed from the branches of all the sampled trees (●) and from the branches of the three trees with the highest average percent double needles (▲).

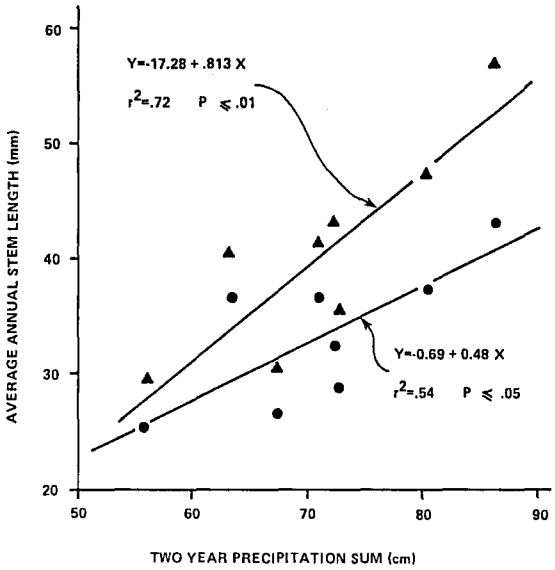


Figure 4.--Regression analyses for the relationship between the two year precipitation sum at Lehman Creek and the average annual stem increment computed from the branches of all the sampled trees (●) and from the branches of the three trees with the highest average percent double needles (▲).

The overall average of each morphological character for each site potentially reflects the average of the climatic conditions on each plot for the period of available data. Consistencies

also provide an indirect check on the Lehman Creek results over a wider geographic area. This was investigated using correlation coefficients betweeen all the possible pairs of the average site values. The significant correlations of average needle length and percent double needles with average stem length over the sampled sites (table 4) duplicated the previously discussed patterns of annual variation on a single site.

Average stem length was also significantly correlated with the percent of trees on a site with chroma 2 and with the percent of trees with 5 percent or more double needled fascicles. The sampled morphological characters appear to fluctuate in synchrony from site to site, supporting the possible extrapolation of the Lehman Creek results over a wider region.

Average needle length was significantly negatively correlated with cone width, indicating a possible trend of having larger cones on drier sites than those on moister sites. A correlation of needle length with the percentage of trees on a sites with chroma 2 and with 5 percent or more double needled fascicles was present at the 10 percent level. This reduced correlation of needle length compared to stem increment appears to indicate a longer term moisture control on these characters. A higher frequency of trees with a more blue-green than yellow-green foliage, combined with a denser foliage (resulting from the more vigorous needle growth) was the primary character that made the sampled sites recognizable from a distance.

The highest correlation coefficient between the average resin canal number and any of the other morphological characters over the sampled sites was a negative correlation ($P \leq 0.10$) with average percent double needles. Annual variation in the percentage of fascicles with double needles was, on the average, eight times greater than the variation in the average resin canal number. This higher variation was generally reflected in higher correlation values between percent double needles and the other variables. Resin canal numbers were apparently less variable over the range of climatic variation covered by the sampled trees.

CONCLUSIONS

The growth characteristics of annual stem length, needle length, and percentage of double-needled fascicles all had significant positive correlations with the annual precipitation received prior to the completion of each year's growth. This apparent plasticity in development is consistent with the results of Trombulak and Cody (1980) for percent double needled fascicles of single-needled pinyon on the New York Mountains. Individual trees within a plot also differed in the magnitude of their response. Trees growing side by side, under what appeared to be identical abiotic conditions, often had both morphological and growth rate differences. Trees that had high values for one character, such as annual stem increment, usually had high values for others as well. Growth rates in annual stem increment in adjacent trees differed by as much as 20 percent.

The close correlation between needle length and annual precipitation indicates that the trees on a site carry an 8 to 12+ year record of relative precipitation. This could be of use as a phytometer for a relative measure of variation in environmental conditions on a site. It could also be used for determining the precipitation cycles necessary for good seed production years and for optimum seedling establishment for restocking harvested areas. Overall, the consistency of the differing levels of response to precipitation between individuals within a

Table 4.--Correlation coefficients between all possible pairs of six morphological characters of pinyon at all eight sample sites listed in table 1

	Stem length	Needle length	Percent double needles	Resin canal number	Cone width	Percent of trees with Chroma 2 color	Percent of trees with $\geq$5% double needles
Stem length	1.0	0.81*	0.76*	-0.31	-0.50	0.72*	0.82*
Needle length		1.0	0.40	-0.14	-0.72*	0.70#	0.67#
Percent double needles			1.0	-0.70#	0.13	0.28	0.69#
Resin canal number				1.0	-0.24	0.03	-0.44
Cone width					1.0	-0.64#	-0.43
Percent of trees with a Chroma 2 color						1.0	0.69

\# = $P \leq 0.10$
* = $P \leq 0.05$
** = $P \leq 0.01$

plot indicates potential field recognizable ecotypic variation in single-needled pinyon that could be used for increasing its fuelwood and Christmas tree production.

Similar patterns were evident in the differences between the average values of the morphological characteristics on the individual sites. Plots which had trees with a higher average stem length also had a higher average needle length, a higher percentage of fascicles with double needles, and a higher percentage of trees with a chroma 2 foliage color and 5 percent or greater doubled needled fascicles. The largest cones generally occurred on the plots with the smallest average stem and needle lengths. The consistency of the differences in pinyon morphology between sites may have potential implications for management of the woodlands and associated vegetation.

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Paleobotany

Chaired by:

Julio L. Betancourt, Paleoecologist, U.S. Geological Survey, Research Project Office, Tucson, AZ

ON THE INTERFACE BETWEEN CURRENT ECOLOGICAL STUDIES AND THE PALEOBOTANY OF PINYON-JUNIPER WOODLANDS

Ronald P. Neilson

ABSTRACT: Recent invasions by pinyon-juniper woodlands into neighboring ecosystems raise difficult questions for land managers. A complete understanding of the causes of these invasions has remained elusive. However, recent advances in the fields of paleobotany, ecology and climatology allow new syntheses which may hold promise for understanding these difficult problems.

INTRODUCTION

The pinyon-juniper woodlands, or pygmy forests, of the west are among the most widespread vegetation types on the continent. Their ecology and taxonomic characteristics have been widely reviewed elsewhere (including this conference) and will not be extensively treated here. The pressures of recent population growth in the west have put enormous, often conflicting demands on all natural resources of this vast region. Increased demands on P-J woodlands for fuelwood, recreation and wildlife habitat argue for their protection. By contrast the same population growth demands more grazing lands. The two demands are in opposition. This is particularly apparent as a result of recent invasions by P-J woodlands into neigboring plant communities. Invasions have apparently occurred both down and up in elevation and north in latitude (West and others 1975).

The subject of expansions and contractions of the woodlands on both historic and pre-historic time scales and the interplay of different causal factors is sufficiently encompassing to form the focal point of this discussion. The study of the dynamics of P-J woodlands on historic time scales is primarily the province of foresters and other ecologists; while, study of the pre-historic dynamics of the woodlands is accomplished by the paleobotanists. In general, the two fields, modern ecology and paleobotany, have evolved with a large measure of isolation from each other. Paleobotanists usually seek explanations for migrational movements over long time spans in terms of climatic change.

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Ronald P. Neilson is Environmental Scientist, Environmental Studies Laboratory, University of Utah Research Institute, Salt Lake City, UT, 84108.

Presumably, the species that we study in their current ecological contexts are essentially the same taxonomic entities being studied from the late-Pleistocene and Holocene fossil record. The question being asked in both cases is the same. What controls the migrations of these species?

The current theories on the causes of migrational advances include fire supression, overgrazing and to a lesser extent climatic change. Although there is little doubt that overgrazing and fire supression have affected migrational patterns, debate continues on the role of climatic change, or variation, in the species' migrations on the time span of a few human generations. While paleobotanists view climatic change as the dominant controlling factor with secondary effects from competition, fire, etc., modern ecologists tend to concentrate on the perturbations of man. This implies the assumption that in modern times the climate has been essentially constant. Recently, however, paleobotanists have pondered the effects of past perturbations of man, specifically fuelwood harvest and burning; while, climatologists and ecologists have begun to appreciate the nonrandom variability in our modern climate system.

These different perspectives are a natural result of the vastly different time scales of study by the two groups. Yet, as with the fabled blind men and their elephant, the modern ecologists and paleobotanists are studying different aspects of the same entity, P-J woodlands, and same phenomena, migrational dynamics. Migrational dynamics are now and have always been dependent on the processes controlling births and deaths. Migrational advances require births, that is, the establishment of new individuals in previously unoccupied environments. Modern studies have adequately demonstrated that this is a complex process in which many aspects of the environment must be just right on a very short time scale if all is to be successful. Processes of mortality can be equally swift as with severe frost, drought and fire, or can be more prolonged if a shift in the background climate produces gradual declines or enhances the incidence of disease.

Independent progress on at least three different frontiers of science, i.e. climatology, paleobotany and physiological plant ecology, is beginning to provide a more clear picture of the full complexity of migrational dynamics of P-J woodlands. In climatology we are beginning to understand the vagaries of the weather from a deterministic perspective.

Since the weather can control many of the processess of births and deaths, an understanding of local weather patterns in relation to global warming and cooling trends allows the bridging of short and long time scales from weather variability to climatic change. In paleobotany, the study of macrofossils from packrat middens has provided considerable detail of individual species distributions and community associations at well defined points in space and time. Physiological ecology provides the link between migrational dynamics, past and present, and climatic change or weather variability, past and present. Syntheses of knowledge from the three fields of climatology, paleobotany and physiological ecology have been few. I hope that this discussion will underscore the need for such combined efforts.

The question of invasions of surrounding plant communities by P-J woodlands spawns a number of corollary questions. For example, why does a single physiognomic type exist across such a diverse array of climatic types? How resilient are the woodlands to both natural and man-caused disturbance? What is the relative stability of the community associations within the pygmy forests? And, what is the taxonomic status of given populations of pinyons and junipers?

Since we know that populations and species have moved considerable distances in the last 20,000 years, all of these questions require some degree of time depth to comprehend the intimate relation between climatic controls and biotic responses. Different community associations have come and gone through geologic time allowing some understanding of their relative stabilities. On both historic and pre-historic time scales man has apparently been a factor in the fire history, wood utilization and perhaps local decimation of the pygmy forests. The uncertain taxonomic status of some local populations of pinyons and junipers requires knowledge of both the present and the past geographic distributions of the species. For example, was it physically possible for a given population of a species to hold relictual status or does the fossil evidence argue against such past distributions? These questions also require a considerable knowledge of the comparative physiology of the different species both within and between genera, a knowledge base that simply does not exist in any great quantity.

BIOGEOGRAPHY

That pinyon-juniper woodlands span such a diverse array of climatic types was underscored when Mitchell (1976) published maps of the climatic gradients of the West. These maps are based on air mass characteristics and surface air streams. Regional climates range in seasonal precipitation patterns from winter-wet/summer-dry to biseasonal to winter-dry/summer-wet in a general gradient from the Northwest to the southern Rockies and Chihuahuan desert regions. Likewise, the physiognomic type traverses a range of temperature regimes from southern Canada (juniper only) to central Mexico. Few common denominators are apparent from this diverse array of climates. Perhaps the only generality that can be made is that the pygmy forest, as the type is frequently known, seems to be a result of regional moisture deficiencies, regardless of the seasonality of the moisture. Apparently, a given amount of moisture can only support a given biomass. Growth rates are severely hindered by high evaporative demands, depleting the little moisture that does reach these forests. Pinyons and junipers are known for their slow growth (Tueller and Clark 1975). Apart from a general lack of moisture, the climatic regimes occupied by P-J woodlands are quite distinct. The air mass gradients separating these different climatic regimes may well have provided the necessary barriers to gene flow which produced the taxonomic variety within the two genera. Details of specific distributional patterns, when cast in the light of Mitchell's gradients, are quite revealing (Lanner 1975; Little 1971).

Western juniper (Juniperus occidentalis) is confined to a region primarily north of the polar front gradient in eastern Oregon on relatively high-elevation desert scrub plateaus or mountains and in relatively high elevations along the Sierra Nevada. Its occurrence in the rain shadow of the Cascades is not too surprising; however, the species' scant occurrence in Idaho is somewhat of an enigma. Again, Mitchell's (1976) work, which indicates strong westerly surface winds in winter across the Snake River Plateau with a weaker southerly flow immediately to the south in Nevada, suggests an answer. California juniper (J. californica), a close relative of western juniper, occurs primarily south of the polar front gradient in the dry mountainous regions of California and Baja, but in some proximity to the eastern extent of summer humidity along the west coast of the continent.

Utah juniper (J. osteosperma) is found primarily south of the polar front gradient in the central Great Basin, primarily in piedmont or high plateau situations. This species appears to be confined to a winter-wet/summer-dry climate. That is, it lies outside the penetration of summer moisture into the continental margin from the west and primarily outside of the average extent of the Arizona Monsoon. Rocky Mountain juniper (J. scopulorum) is a Rocky Mountain inhabitant coursing from southern Canada (with apparent relicts on Vancouver Island, B.C.), where it commonly occurs on high plateaus (Adams 1983), down the mountain axis moving ever higher on the mountain. At the polar front gradient, essentially the southern Wyoming border, the species appears to take a stepwise increase in elevation (personal observation) and continues at higher elevations to the southern Rocky Mountains. One seed juniper (J. monosperma), red berry juniper (J. erythrocarpa) and alligator juniper (J. deppeana) all appear to be confined to the region of summer rains, the Arizona Monsoon.

The pinyons possess similarly constrained distributions. Singleleaf pinyon (Pinus monophylla) is confined to the central Great Basin in a similar pattern to Utah juniper. Colorado pinyon (P. edulis), a two-needle species, is primarily confined to the Colorado Plateaus and appears to be under the control of both the polar

front and Arizona Monsoon gradients as described for Gambel oak (Neilson and Wullstein 1983).

This appears to be a biseasonal rainfall species. A close relative of this pine, P. remota, another two-needle pinyon, is currently confined to local habitats in west and central Texas. It, too, appears to be a biseasonal rainfall species (Van Devender, this volume). Mexican pinyon (P. cembroides), a three-needle species, occurs primarily south of 32° N latitude in the Sierra Madre Occidental, a predominantly summer rainfall regime. Interestingly, Parry pine (P. quadrifolia), a four-needle pinyon, of apparent hybrid origin, and Sierra Juarez pinyon (P. juarezensis), a five-needle pinyon (Lanner 1974), both occur at the conjunction of two summer moisture gradients, the influx of Pacific moisture into the continental margin and the Arizona Monsoon from both the Gulf of California and the Gulf of Mexico. These species may also be confined to the maritime temperature regime.

Needle number in pinyons appears to follow a gradient of summer moisture. One possible explanation of this may simply be that incremental shifts in the surface to volume ratio of the leaves, which would impinge on the water use efficiency, are selected by steep climatic gradients. Similarly, shifts in the quantity of leaf resin ducts may be physiologically related to regional shifts in climate. It is quite convenient that the numbers of needles, stomatal rows and resin ducts are among the most consistent taxonomic characters used to distinguish pinyon species (Lanner and Van Devender 1974).

If the current relation between air mass gradients and the distributions of pinyons and junipers is one of cause and effect, then past distributions should reflect past positions of air mass gradients. The past and present positions of these gradients are constrained by the topography, ice sheets and the physics of the atmosphere. For example, P. edulis, which is primarily confined to the Colorado Plateaus, is circumscribed by the subtropical jetstream during much of the Arizona Monsoon period. During the last glacial maximum, P. edulis was apparently confined to the current limits of the northern Chihuahuan Desert in New Mexico (Van Devender and others 1984). It is likely that the subtropical jet stream and, hence, the Arizona Monsoon were similarly confined. Thus, current questions of the taxonomic status of specific populations might be resolved with a knowledge of past constraints on species distributions as revealed independently by the fossil record and from our knowledge of possible past climatic scenarios (Thompson and Mead 1982; Wells 1983).

The more we know about the comparative physiology of the species, the greater will be our understanding of their regional climatic controls and their taxonomic relations. As pointed out by Thompson and Hattori (1983) "There is little information available on the climatic and environmental parameters that control the geographic and elevational ranges of most western plants".

CLIMATIC AND BIOTIC CONTROLS

Given a knowledge of the current physiological relation between species distributions and air mass gradients, as well as the distributions of the species through geologic time, accurate reconstructions of past climate and inferences on competitive (and facilitative) interactions can be made. For example, asynchronous movements of ecologically overlapping species hints at competitive constraints on migrational advances of P. edulis by P. ponderosa (Betancourt 1984). Conversely, independent reconstructions of past climate (e.g. through tree ring analyses) provide independent confirmation of our knowledge of the limits of tolerance of species (LaMarche 1973).

Investigations of correlations between species' ranges and air mass gradients for two southwestern oaks (Neilson and Wullstein 1983) allowed a general, but testable, reconstruction of past plant communities at specific points in space and time. The fossil record appears to support the general features of this model (Cole 1982). On the other hand, a full test of the model will require the filling in of some deficiencies in the fossil record. Specific regions and specific time frames might be targets for future fossil hunting.

In the statement of the model, Colorado pinyon was considered to be roughly equivalent, ecologically, to Gambel oak (the primary difference being an ability for the oak to reproduce asexually). Thus, the past distribution of Colorado pinyon should be consistent with the inferred dynamics of the atmospheric gradients during the late Pleistocene and Holocene. This appears to be the case. However, as previously mentioned, competition from Ponderosa pine might have retarded the advance of P. edulis onto the Colorado Plateaus to some time after the expansion of summer rains (Betancourt personal communication).

How, specifically, might atmospheric gradients control plant migrations? The positions and steepness of both the polar front and subtropical gradients (i.e., the Arizona Monsoon) covary in a deterministic fashion as a function of global warming and cooling trends (Neilson and Wullstein 1983). During cooling trends the polar front gradient steepens and may shift south, while concurrently the Arizona Monsoon gradient shifts to the south and (possibly) east. This produces the combined effects of increased winter and spring cold stress at northern boundaries followed by summer (growing season) drought stress (fig. 1). The upper elevational boundaries should shift down from the increased cold stress, while the lower elevational boundaries should shift up due to the increased summer drought stress. The "wedge" in essence shifts south during cooling trends and north during warming trends.

Let us consider whether the evidence favors such an association between air masses and P-J woodlands in the central Rockies and Great Basin regions. If the wedge concept is correct, upper elevational ecotones should rise with decreasing latitude, a function of increasing temperatures.

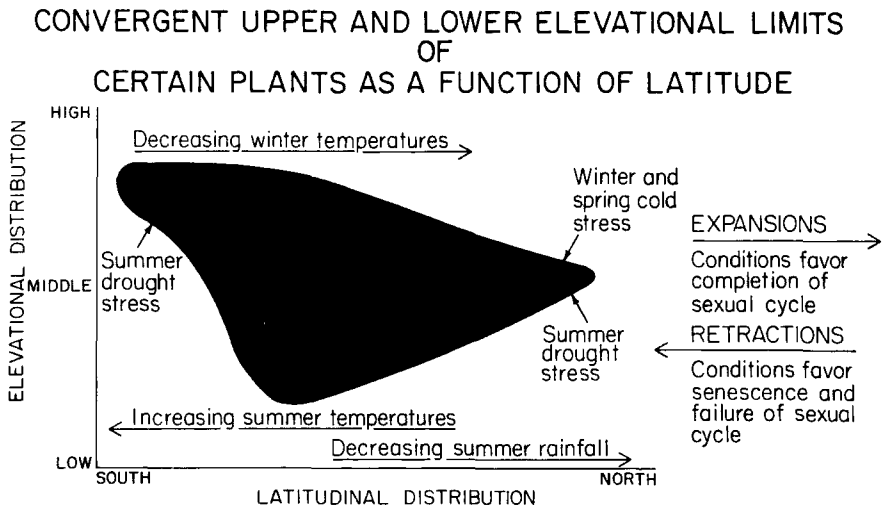


Figure 1.--Theoretical effects of the polar front and subtropical air mass gradients on the elevational and latitudinal distributions of plants in the West. (Courtesy of J. Betancourt).

The lower elevational ecotone might rise, fall or stay the same with decreasing latitude, but in any case, would not rise as fast as the upper limits. This results from increased growing season rainfall from the Arizona Monsoon, which would depress the lower elevational limits with decreasing latitude.

In the Great Basin, the base level of the topography generally rises to the north, which confounds the interpretation. West and others (1978) document the elevational distribution of the woodland along several regional transects. Their data appear to support the wedge hypothesis, notwithstanding the shift in topography. They also document a higher elevational zonation pattern on smaller mountain masses. This may result from less summer rainfall on smaller mountain masses. Wells and Berger (1967) also document an "anomalous" decline in the lower limits of the P-J woodlands with decreasing latitude in the Mohave, Colorado and southern Great Basin deserts.

Nevertheless, purely physical factors are insufficient to explain the elevational bounds of the woodland. The upper bounds of pinyon may well be constrained by competition with ponderosa pine, while the lower bounds may be constrained by competition with grasslands. However, these biological constraints would act within the general climatic constraints and should only further constrain the general features of the climatically induced distributions.

Excess logging of ponderosa pine could release the upper elevational constraints on the woodland, while overgrazing could release the lower elevational constraints. Suppression of natural fire might enhance the establishment of woodlands in grasslands, but this should operate to some extent throughout the elevational range. It is difficult to envision a fully regional synchrony of all these man-caused perturbations, which would be necessary to explain the regional scale of invasions. West and others (1975) do acknowledge that increased warmth and rainfall during the period 1850-1940 were contributory to the P-J expansion.

The north-south shift of the climatic wedge appear to have operated from the late Pleistocene to the present. Over the course of the last 500 years th globe was dominated by a cool period termed the "little ice age". The first major global warming since the inception of the little ice age was that commencing since about 1900. The polar front gradient became less steep and the Arizona Monsoon shifted north (Neilson and Wullstein 1983). These changes alone should have produced expansions of the P-J communities up, down and north, beginning sometime early in this century, in clear juxtaposition with the period of the most serious overgrazing. Similar interactions between climati change and the intervention of man have been proposed to explain shifts from grassland to shrubland in the Southwest (Neilson in press). Th expansion of P-J woodland might simply have been enhanced by the intervention of man, including the suppression of fire. Also, most lightning-caused fires arise from convective storms, the distribution of which is controlled by air mass gradients and is subject to modulation by global climatic oscillations. With regard to the timing of recent invasions, it must be remembered that pinyons and junipers tend to be very slow growing plants. Their first appearance in old photographs may postdate their establishment by up to 30 years. Thus, expansions observed in the 1940's could have begun in the early part of the century, during the global warming trend. We are seeing these trees grow during a global cooling trend, bu their establishment might well have been linked to the global warming trend. Again, this is parsimonious with the fossil record, which indicates pinyons and junipers expanding up and north in the Great Basin during the Holocene Warming. The question remains as to the direct physiological and demographic linkages between the woodland and the atmosphere. Each species being specifically associated with the complex atmospheric gradients should be behaving according to the dynamics of those gradients. This can be tested, but has not been.

There are, however, interesting observations which hint at a direct relation between species specific

establishment processes and the weather associated with specific air masses. For example, Tueller and Clark (1975) note that Pinus monophylla masts every 2-3 years, while P. edulis masts approximately every 5 years. P. monophylla is closely associated with the polar front jet stream which exhibits a 2-3 year oscillation known as the Quasi-biennial Oscillation (Wallace and Gutzler 1981). P. edulis is closely associated the sub-tropical jet stream which exhibits a 3-5 year oscillation known as the Southern Oscillation (Horel and Wallace 1981). These relationships are only suggestive, but could be tested. Once seed is produced, seedlings must become established, for a successful invasion. Arnold and others (1964) related successful establishment to years of above average moisture.

These observations, collectively, suggest strong links between the demographics of P-J woodlands and specific air masses. Most ecologists and paleobotanists agree that there is a strong dependence on summer rains for the establishment of all pinyons.

Differences in physiology and needle number appear to modulate the degree of dependency on summer rains by the different species.

Pinus edulis, for example, appears to require abundant summer rainfall for establishment and lies generally within the bounds of the Arizona Monsoon. However, P. edulis does not appear to be as tightly constrained by the air mass gradient as do Juniperus monosperma and J. erythrocarpa. In a comparison of the drought physiology of P. edulis and J. monosperma Barnes and Cunningham (in preparation) found that the juniper was more sensitive to summer drought, thus providing a mechanistic hypothesis for their differences in distribution. Much more such comparative physiology is needed.

Critical holes in the fossil record are also apparent from this perspective. Little is known of the dynamics of these woodlands during the mid-Holocene Thermal Maximum, particularly in their upper elevational and northern limits. During this period the wedge should have shifted north with an increase in summer rains and a decrease in winter and spring cold stress. Did the woodlands exist farther north than at present? The fossil record of Danger Cave, Utah, is frequently cited as evidence against a mid-Holocene "Altithermal." This is not surprising. On the basis of atmospheric dynamics the Arizona Monsoon should have exhibited an enormous shift along the axis of the Wasatch escarpments, but go virtually undetected only a few miles west in the Great Basin, the location of Danger Cave (Harper and Alder 1972). Elevationally controlled fossil sequences from the northern Great Basin and Wasatch Mountains are badly needed to resolve these questions. Likewise, mid-Holocene middens should be collected from the regions in southern Idaho that are currently under invasion by juniper. Perhaps the woodland was there during the mid-Holocene!

How resilient are the present woodlands under the use of man? The fossil record in conjunction with dendrochronology provides some indication. Climate appears insufficient to explain the decimation of the woodland in Chaco canyon at the termination of the Anasazi occupation (Betancourt and others 1983). Overpopulation with overuse appears to be a more viable explanation. However, climatic change might have hindered the re-vegetation of the region.

The interplay of climatic variation, fire and grazing must be considered. In the absence of overgrazing, P-J woodlands might be much slower to invade neighboring grasslands, as a result of grass and tree seedling competition. Remove the grasses and that vegetation favored for establishment will become established. It must be emphasized that overgrazing alone is not sufficient to explain an expansion of forest. Amenable climatic conditons must also be present. Although natural fires might hinder seedling establishment, while their suppression might promote invasions, a suitable climate for establishment must still be present.

In summary, paleobotanists are compiling considerable documentation of pre-historic plant migrations. A consensus is growing that individual species do respond uniquely to climatic change. Observed shifts through time in both the physical location and species composition of plant communities are allowing more and more detailed reconstructions of past climates. A growing appreciation for the relations between weather and climate is facilitating these efforts. Currently, these reconstructions are primarily limited by our lack of knowledge of the direct effects of weather on plant distributions. This is a task for modern ecologists and physiologists. Increases in our knowledge of physiological tolerances and requirements of plants in relation to air mass properties would considerably enhance the interpretation of the fossil record. Finally, a greater understanding of the fossil record would cycle back into a greater understanding of present community dynamics. These disparate sources of knowledge must be synthesized for a thorough understanding of the biology of these unique woodlands. Sound management practices are ultimately based on a knowledge of fundamental causes of ecosystem dynamics.

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LATE QUATERNARY HISTORY OF PINYON-JUNIPER-OAK WOODLANDS DOMINATED BY PINUS REMOTA AND PINUS EDULIS

Thomas R. Van Devender

ABSTRACT: Ancient packrat middens record thriving Late Wisconsin pinyon-juniper-oak woodlands in the present Chihuahuan Desert. The range of Pinus remota was from the southern Chihuahuan Desert, Mexico (25°56'N) to the Hueco Mountains, east of El Paso, Texas (31°54'N). At 610-680 m elevation in Big Bend National Park (29°13'N), P. remota was common in the Late Wisconsin (11,000-22,000 B.P.) but declined or disappeared in the Middle Wisconsin (22,000->36,000 B.P.) with a modest increase in its lower elevational limit. Both P. remota and P. edulis were identified in the Hueco Mountains midden sequence which documents pinyon-juniper-oak woodland from 42,000-10,720 B.P. in the northern Chihuahuan Desert. In the Holocene, the range of P. remota first retreated from the Chihuahuan Desert proper soon after 11,000 B.P. to the southern Edwards Plateau, and later was fragmented into its modern relict stands. At the same time Pinus cembroides probably expanded to dominate modern woodlands in the Chisos and Davis mountains. The Late Wisconsin range of Pinus edulis was probably restricted to a small area in south-central New Mexico and adjacent Texas (32-33°N). In the Holocene, P. edulis expanded from this Ice Age refugium onto the Colorado Plateaus and into the Rocky Mountains finally reaching its northern limit in Colorado (40°50'N) in the last few centuries. The composition of pinyon-juniper-oak woodlands has varied continuously as individual dominants responded differentially to climatic changes.

INTRODUCTION

The Chihuahuan Desert is the interior, continental arid area centered on the Mexican Plateau and bounded by the Sierra Madre del Sur to the south, the Sierra Madre Occidental and Oriental on the sides and the Rocky Mountains to the north. Most of the area is relatively arid with at least 60 percent of the annual rainfall in the summer and an increasingly tropical climate to the south. The rockshelters and crevices in the characteristic limestone sierras are excellent for the preservation of ancient packrat (Neotoma) middens and their abundant, well-preserved plant macrofossils. Pinyons and their woodland and desertscrub associates have a rich fossil record to the lowest elevations in the Chihuahuan Desert for the last 42,000 years in the last glacial age, the Wisconsin (fig. 1; Wells 1966; Lanner and Van Devender 1981).

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Thomas R. Van Devender is Research Scientist at the Arizona-Sonora Desert Museum, Route 9, Box 900, Tucson, AZ 85743.

BOLSON DE MAPIMI

The Bolson de Mapimi is a large area of internally drained lake basins in the southern Chihuahuan Desert that is mostly above 1200 m elevation. Packrat midden samples radiocarbon dated at 12,830 and 11,730 B.P. (radiocarbon years before 1950) from the southwestern Bolson de Mapimi near Bermejillo, Durango (25°56'N; 1250 m), contained Pinus remota (papershell pinyon), juniper, and a rich assortment of Chihuahuan succulents including Agave lechuguilla (lechuguilla) and Opuntia rufida (blind prickly pear; Van Devender and Burgess in press). A sample dated at 12,700 B.P. from Puerto de Ventanillas, just to the east in Coahuila (26°03'N; 1370 m), contained a more xeric assemblage dominated by succulents in association with Juniperus cf. erythrocarpa (redberry juniper) and J. cf. saltillensis (Saltillo juniper) but without pinyon. New samples from the Cuatro Cienegas Basin in central Coahuila (26°39'N; 930 m) contain a two-needle pinyon (probably P. remota) and juniper, at 12,850 and 12,360 B.P. The new samples provide evidence refuting the conclusion based on pollen analyses from spring deposits that the ice age climates had little effect on the slope vegetation on the mountains surrounding Cuatro Cienegas (Meyer 1973).

TRANS-PECOS TEXAS

The Trans-Pecos subdivision of the Chihuahuan Desert in general extends along the Rio Grande from El Paso, Texas, to beyond Big Bend National Park. Wells (1966) reported a general expansion of woodlands with P. remota, juniper and oaks into the lowlands of the Big Bend. Fourteen middens from near Rio Grande Village (29°11-16'N; 610-760 m) document a Late Wisconsin woodland dominated by P. remota, Juniperus sp., and Quercus hinckleyi (Hinckley oak) in association with Agave lechuguilla and Koeberlinia spinosa (allthorn) between 21,830 and 11,470 B.P. (Van Devender in press). Quercus hinckleyi is presently endemic to two populations (El Solitario and Shafter) north of the Park well below pinyon or juniper. Koeberlinia spinosa is most common today in grasslands at 1220-1520 m elevation. Middle Wisconsin samples older than 22,000 B.P. from Rio Grande Village are more xeric with pinyon less common or absent, and more desert-grassland plants. Pinyon middens from higher elevations suggest that this only reflects a modest upward shift of the lower elevational limit of P. remota (Wells 1966). Eleven middens from Maravillas Canyon Cave 40 km north of Rio Grande Village (29°33'N; 610 m) again record a pinyon-juniper-oak woodland with P. remota and Juniperus sp. but with Quercus pungens (sandpaper oak; Van Devender in press; Wells 1966). Quercus pungens is a widespread

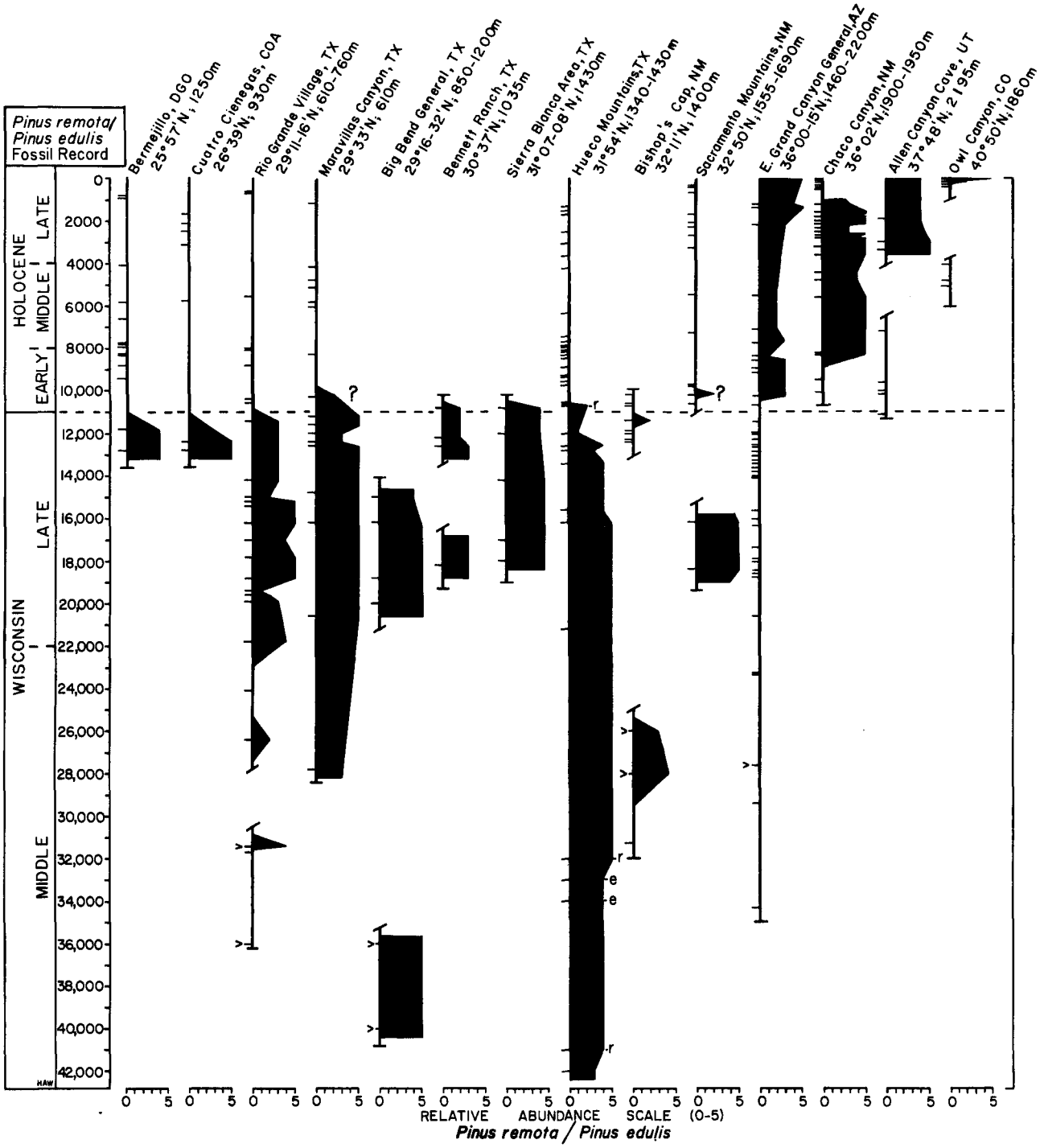


Figure 1.--Relative abundances of Pinus remota and P. edulis from packrat midden chronosequences along a latitudinal gradient from Durango, Mexico, to northern Colorado. Data from Maravillas Canyon and Big Bend General from Van Devender (in press) and Wells (1966). In Hueco Mountains, e = Pinus edulis and r = P. remota after Lanner and Van Devender (1981). Bishop's Cap data from Thompson and others (1981). Sacramento Mountains data from Van Devender and others (1984). Grand Canyon records from Cole (1981). Chaco Canyon records provided by J. L. Betancourt. Allen Canyon Cave data from Betancourt (1984). Length of baseline indicates length of midden coverage for each area. Marks on the baseline are for radiocarbon dates. > = infinite date; ? = questionable record.

oak that often grows on limestone and reaches relatively low elevations. Some of the juniper material appears to be J. pinchotti (Pinchott juniper), a small shrub juniper that can be common in desert-grassland above 1280 m.

Most of the Trans-Pecos appears to have been covered by pinyon-juniper-oak woodland without a xeric juniper-oak woodland zoned below it. The only packrat midden assemblage older than 11,000 B.P. from the Big Bend that lacks pinyon is a sample from Santa Elena Canyon (29°09'N; 670 m) dated at 13,690 B.P. (Lanner and Van Devender 1981). Pinus remota apparently disappeared from the lowlands of the Chihuahuan Desert proper about 11,000 B.P. at the end of the Wisconsin. The pollen record from the Devil's Mouth Site, 185 km east of Maravillas Canyon, suggests that P. remota remained common on the southern Edwards Plateau for several thousand years in the Early Holocene (Bryant 1968).

Nine middens from Bennett Ranch (30°37'N; 1035 m) and the Streeruwitz Hills-Quitman Mountains area (31°07'N; 1430 m) record similar woodlands with P. remota, Juniperus sp., and Quercus pungens between 18,190 and 10,910 B.P. in areas that now support Chihuahuan desertscrub (fig. 1; Lanner and Van Devender 1981). The most extensive pinyon records from the northern Chihuahuan Desert are from the Hueco Mountains east of El Paso (31°54'N; 1340-1430 m). Eighteen middens containing woodland assemblages record pinyon, Juniperus sp., and Quercus pungens from 42,000 to 10,720 B.P. Both P. remota and P. edulis (Colorado pinyon) were identified by Lanner and Van Devender (1981). In the Late Wisconsin Pinus remota extended its range about 300 km to the northwest where it intermingled with P. edulis in its glacial refugium (Van Devender and others 1984). The species are closely related and probably should be considered as interglacial varieties. Agave lechuguilla apparently arrived in the Hueco Mountains in the Late Holocene less than 5000 years ago and did not associate with the ice age pinyons.

The fossil records of Pinus edulis from south-central New Mexico are less detailed. Samples from Shelter Cave on Bishop's Cap (32°11'N; 1400 m) containing P. edulis and juniper but without oak yielded dates of 11,330, >26,000, and >28,000 B.P. (Thompson and others 1980). However, five additional samples dated at 31,250 and 12,430-11,850 B.P. lacked pinyon suggesting the site was relatively dry. Full-glacial samples from the Sacramento Mountains (32°50'N; 1555 m) dated at 18,315 and 16,260 B.P. contain abundant P. edulis with J scopulorum (Rocky Mountain juniper) and J. cf. monosperma (oneseed juniper). A few needles of Pseudotsuga menziesii (Douglas fir) in the samples suggest that the lower edge of mixed-conifer forest was not far above. Juniperus deppeana (alligator juniper) apparently has dispersed into the area in the Holocene and now dominates middle-elevation woodlands.

A sample dated at 14,920 B.P. from the San Andres Mountains, New Mexico (33°11'N; 1710 m) contained a mixed-conifer forest assemblage with Pseudotsuga menziesii, Picea pungens (blue spruce), and Pinus ponderosa (ponderosa pine; Van Devender and Toolin 1983). A xeric juniper woodland with Juniperus cf. monosperma was apparently zoned directly below mixed-conifer forest without intervening ponderosa pine forest or pinyon-juniper woodland. The study area may have been north of the Late Wisconsin range of P. edulis (Van Devender and others 1984). Pinus edulis was also absent from Early Holocene samples in the area suggesting that it did not disperse into the present pinyon-juniper woodland from lower elevations but directly into its present elevational zone.

NORTHERN AREAS

Cole (1981) found that Pinus edulis arrived in the eastern Grand Canyon, Arizona (36°00-15'N; 1460-2200 m) by 10,290 B.P. in the Early Holocene soon after the retreat of the mixed-conifer forest dominated by Pseudotsuga menziesii, Pinus flexilis (limber pine), and Picea sp. (spruce). Juniperus osteosperma (Utah juniper), the Holocene and present dominant, was also present with J. scopulorum and J. communis (dwarf juniper) in the Wisconsin forests. Today P. edulis dominates much of the eastern Grand Canyon but is replaced by P. monophylla (singleleaf pinyon) to the west (Lanner 1974). Hybrids with both one and two needles occur in intermediate areas. Two Early Holocene middens from Lee Canyon above the gorge of the Little Colorado River on the Colorado Plateaus just east of the Grand Canyon (35°52'N; 1890 m) are of interest because they record a woodland with J. osteosperma without pinyon in an area presently supporting a woodland dominated by P. edulis. Apparently Colorado pinyon arrived at the site sometime after 8410 B.P.

Late Wisconsin pinyon records from the western Grand Canyon are a two-needle sample dated at 16,580 B.P. from Peach Springs wash (35°43'N; 1300 m; Van Devender and Spaulding 1979) and a one and two-needle sample dated at 12,650 B.P. from the Rampart Cave area (36°09'N; 635 m; Phillips 1977). The Peach Springs Wash trees may represent an independent derivation of the two-needle condition from P. monophylla similar to that proposed for the New York Mountains pinyons, California (Lanner 1974). If the fossils are verified as P. edulis, there may have been a narrow, relict population in central Arizona below the Mogollon Rim mixed-conifer forest and above P. monophylla woodland/chaparral.

In an extensive midden series from Chaco Canyon in the San Juan Basin of northwestern New Mexico (36°02'N; 1865-1980 m), Pinus edulis appeared by 8300 B.P. and, with Juniperus monosperma, dominated the local woodlands for much of the Holocene (Betancourt and others 1983). Colorado pinyon drops out of the sequence between 1230 and 520 B.P. during the local peak of Anasazi cultural activity. Apparently the pinyon fell to Anasazi wood cutters and has not recovered in 800 years.

Betancourt (1984) analyzed packrat midden series from two caves on the Colorado Plateaus in southeastern Utah. At Allen Canyon Cave (37°48'N; 2195 m) Pinus edulis only arrived between 7200 and 3400 B.P. and still lives at the site. Juniperus osteosperma and J. scopulorum appeared in the record at 7200 B.P. At Fishmouth Cave P. edulis appeared in a single sample at 3740 B.P. even though the site

is below its present lower limit. Juniperus osteosperma apparently replaced J. scopulorum by 9700 B.P. The timing of the arrival of P. edulis into the western Rocky Mountains and its ecological interactions with P. ponderosa need additional study.

DISCUSSION

During the last glacial period the areal extent and geographic distributions of pinyon-juniper woodlands and of pinyon species were very different than today. The range of Pinus remota was greatly expanded to the northwest throughout Trans-Pecos Texas while that of P. edulis was contracted into a small area in south-central New Mexico and adjacent Texas (Van Devender and others 1984). In the Holocene, P. remota contracted to small relict populations to the southeast and on mountaintops in northeastern Mexico (Bailey and Hawksworth 1979) separating the two pinyons by 300 kilometers. Pinus cembroides (Mexican pinyon) expanded to dominate woodlands in the Davis and Chisos mountains. Pinus edulis expanded from its glacial refugium near its present southern limit onto the Colorado Plateaus. By the Late Holocene, it was well into the western Rocky Mountains in Colorado and Utah although the details of its dispersal are not well known. The isolated northernmost P. edulis population at Owl Canyon, Colorado (40°50'N; 1860 m) on the east side of the Rocky Mountains appears to have become established less than 500 years ago (Betancourt and others in preparation) suggesting that the northern edge of its range may not have reached equilibrium.

In several of the Chihuahuan Desert study areas, the Wisconsin pinyon-juniper-oak woodland was relatively stable for periods of 10,000-20,000 years when the woody dominants are considered (Van Devender in press). However, when other plants (succulents, herbs, grasses) are included, the community composition becomes less stable and a general equilibrium state of all plants is probably never reached. Because northward migrations of similar magnitude and timing for common pinyon-juniper woodland dominants (Pinus edulis, Juniperus monosperma, J. osteosperma) have resulted in large areas with similar vegetation types, pinyon-juniper woodland appears to be more of a cohesive evolutionary unit than is actually the case. Juniperus deppeana, a common associate of P. edulis in much of the southern pinyon-juniper woodlands, may have dispersed northward from the Sierra Madre in the Holocene. The northern limit of Quercus pungens, the Wisconsin associate of P. edulis in the Hueco Mountains, did not expand greatly to the north in the Holocene. Quercus grisea (grey oak) or Q. undulata (wavyleaf oak) presently associate with P. edulis in much of New Mexico. Quercus hinckleyi, the codominant in low-elevation Wisconsin woodlands in the Big Bend of Texas, is now a rare endemic in Chihuahuan desertscrub well below woodland. Juniperus pinchotti and Koeberlinia spinosa are now more characteristic of desert-grassland than woodland. Apparently, the composition of pinyon-juniper woodland has varied continuously as the ranges of its dominants shifted differentially due to fluctuating climates.

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SYSTEMATICS AND DISTRIBUTION OF PINYONS IN THE LATE QUATERNARY

Philip V. Wells

ABSTRACT: The wide prevalence of pinyon-juniper woodlands at very low elevations in the hot-desert provinces of the Southwest is well established by a quarter-century of paleobotanical studies on Neotoma (wood rat) middens, ^{14}C-dated back to the last glacial. The PJ type has shifted upward some 1,000-1,500 m in elevation and has extended northward into the Great Basin and Rocky Mountains some 6° of latitude (640 km), mainly during early Holocene. In spite of these shifts (no doubt previously reiterated during glacial/interglacial cycles), there is consistency as to taxon of pinyon pine recorded (as exquisitely preserved fossils in Pleistocene middens) at low-desert elevations and the nearest living pinyon surviving on higher mountains of each desert province. The first examples in the northern Mohave Desert of Pinus monophylla and in the Chihuahuan Desert of P. remota have been augmented in the Sonoran Desert (c. Baja California: P. quadrifolia; se. California and s. Arizona: P. edulis fallax) and northernmost Chihuahuan Desert: P. edulis. Thus, the PJ type is a very ancient set of plant communities of remarkable stability despite its migrational history.

INTRODUCTION

The principal morphological characters that distinguish species in subsection Cembroides (pinyon pines) of Pinus are in the leaves and seeds, parts that are exquisitely and abundantly preserved in Pleistocene Neotoma (wood rat) middens throughout much of the Southwest (Wells 1966, 1969, 1976, 1979, 1983; Wells and Berger 1967; Wells and Hunziker 1976; Van Devender and Spaulding 1979; Lanner and Van Devender 1974, 1981). Since, furthermore, the extant species of pinyon pines have largely allopatric or parapatric distributions of wide geographic extent and the various taxa occupy climatically distinctive regions, the pinyon group has great paleoecological potential. One of the goals of the present paper is to document the reality of a much more complex morphological/geographic pattern in the pinyon group than is commonly recognized. A more incisive taxonomic discrimination among the pinyons is also essential to a proper understanding of the community and management ecology of the highly heterogeneous "PJ type" that presently extends from the Great Basin (to 42°N) to Baja California and from the Colorado Plateau and Rocky Mountains to the Sonoran and Chihuahuan Deserts and southward in the mountains of Mexico to Jalisco and Puebla (to 18°N). The focus of the paper will be on the consequences of greater taxonomic complexity for ecological (especially paleoecological) interpretations of the PJ type.

Less than 20 years ago, only four pinyon species were recognized from the United States, and these were distinguished primarily on the basis of number of leaves per fascicle, according to the simplistic formulation: one needle = Pinus monophylla Torr. & Frem. (chiefly Great Basin); two needles = P. edulus Engelm. (Colorado Plateau - southern Rockies); three needles = P. cembroides Zucc. (mountains of Mexico and adjacent U.S.); and four needles = P. quadrifolia Parl. (Peninsular Ranges of Baja California and southern California). Five needles per fascicle were also (more recently) known in two localized endemics from Mexico: P. culminicola Andresen & Beaman and P. maximartinezii Rzedowski; thus, the pinyons also have the ancestral number five that is so constantly prevalent among the white pine group to which subsection Cembroides belongs. The pinyon group is unique in Pinus in having a complete evolutionary reduction series from five to one needle per fascicle; the possible implication that this is a linear series with only one taxon at each needle-number step can be discounted. Careful taxonomic work in the past 20 years (Little 1966, 1968; Bailey 1979 and unpublished) has established the existence of well-marked, additional taxa with one, two, and three needles per fascicle (fallax, remota, and discolor, respectively), all occurring in the United States and two in northern Mexico; there is also an undescribed species of single-leaved pinyon that is very distinctive (to be published in 1986) and yet another three-needled pinyon (P. johannis Robert), the latter restricted to several mountains in the Chihuahuan Desert of Mexico.

Since these newer taxa await treatment in standard manuals and floras, they are not widely known and therefore not generally accepted. This situation is unfortunate for community ecology of the PJ type, but it is deplorable from the standpoint of paleoecology. The numerous pinyon taxa have ecologically different distributions today, occupying climatically disparate regions or sorting out on elevation gradients into different plant communities. Hence, the paleobiogeography of pinyons (evidenced in the Quaternary macrofossil

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Philip V. Wells is Professor of Botany at the University of Kansas, Lawrence, KS 66045.

record) affords excellent insights into Quaternary climatic patterns in western North America, and recognition of all identifiable taxa is indeed essential to proper evaluation of the paleoecology.

SINGLE-LEAF PINYONS: ECOLOGY AND HISTORY

In making any paleoecological interpretation, it is always necessary to consider the possibility that the fossil taxon may have differed in its ecological physiology from the morphologically similar extant taxon. Ecotypic differentiation has been well documented in numerous groups of plants, including conifers. A cautious interpretation is especially necessary if the putative extant taxon occurs over an extensive geographic range with a wide array of existing climates (for example, all single-leaved pinyons, arbitrarily lumped as one taxon, "P. monophylla"). Obviously, any geographically segregated, taxonomic subdivision, e.g., the Arizona single-leaf pinyon (fallax) of a wide-ranging, broadly defined group ("monophylla") should be gratefully recognized when the morphological distinctions are apparent in the fossil material, as this greatly reduces the scope of geographic and climatic parameters to be invoked in the paleoecological interpretation of the fossil occurrence.

In this example, recognition of the characters of fallax in the Neotoma material from southern Arizona, as originally reported (Van Devender and King 1971), radically alters the biogeographic and paleoclimatic implications, relative to the later assertion that Great Basin P. monophylla actually migrated across southern Arizona to southwestern New Mexico during the last glacial (Lanner and Van Devender 1974; Van Devender and Spaulding 1979). The extreme climatic shift implied by the latter view (increase in winter rain, great reduction in summer rain over much of southern Arizona) is invalidated by correct identification of the fossil pinyon material, which is identical to the local single-leaf pinyon of Arizona, fallax. Today, the latter taxon is much more narrowly restricted at lower elevations along the Mogollon Rim of southern Arizona (hundreds of kilometers to the southeast of Great Basin P. monophylla). The fossil evidence of fallax from much lower elevations in the Sonoran Desert of southern Arizona implies a relatively modest expansion of the now greatly contracted fallax populations downward, southward, and westward during the Wisconsinan glacial; the absence of fossil evidence of Great Basin P. monophylla in southern Arizona and even southeastern California (where fallax occurs in full-glacial Neotoma deposits: Wells 1979) refutes the hypothesis that monophylla extended an absurdly long and tenuous peninsular salient across southern Arizona.

In detail, the modern distribution of fallax is along the southwestern flank of the range of its close relative, P. edulis, but with fallax generally at lower elevations than edulis. Therefore, fallax occupies a rather long but narrow strip along the ragged southern and western edge of the high Colorado Plateau in Arizona from the western Grand Canyon south and southeast (below the long Mogollon Escarpment) to southeastern Arizona, descending to unusually low elevations for a pinyon today; fallax also occurs on outlying mountains to the west, south, and southeast (e.g., the Virgin, Hualpai, and Chemehuevi Mountains in northwestern Arizona and on the upper Virgin drainage in southwestern Utah; the Newberry Mountains in the southern tip of Nevada; and on various mountains south of the Mogollon Rim, with an extreme outlier in the Florida Mountains near Deming in southwestern New Mexico). Thus, the distribution of fallax is geographically very different from that of Great Basin monophylla; the two taxa barely meet in southwestern Utah, having discrete, allopatric ranges extending for hundreds of kilometers in divergent directions.

Throughout most of its climatically distinct range, fallax is a patchy component of the "Arizona" chaparral or "encinal", a mixture of heterogeneous semixerophytes and evergreen, broad sclerophylls. The various species of the encinal are adapted to a summer-rain regime (e.g., Arctostaphylos pungens, A. pringlei, Ceanothus greggii, Eriodictyon angustifolium, Garrya flavescens, Quercus turbinella, together with Juniperus erythrocarpa and diverse Agavaceae), assemblages alien to most of the range of Great Basin P. monophylla. Furthermore, some of these species of Arizona chaparral are documented with fallax as the only pinyon in late-Pleistocene Neotoma assemblages from low elevations in the Sonoran Desert of southern Arizona (Van Devender 1973). Since the "Submogollon" country below the Colorado Plateau (occupied by existing Arizona chaparral with fallax as the only pinyon) now has abundant summer rain (about half or more of the mean annual precipitation), there is the clear implication from the very similar assemblages in Pleistocene Neotoma middens (from much lower elevations) that southern Arizona was receiving ample summer precipitation during the last glacial.

Having shown that the single-leaf pinyon taxon fallax is very different geographically, ecologically, and paleoecologically from monophylla, how different are the two taxa morphologically? Validly named as Pinus edulis var. fallax Little (1968), the Arizona single-leaf pinyon differs from P. monophylla of the Great Basin and cismontane California (i.e., type P. monophylla of Torrey and Fremont) in at least five characters. Unlike both P. monophylla and P. edulis, which have fascicle sheaths splitting and curling up revolutely into a radially arranged rosette of scrolled segments, fallax has shorter fascicle sheaths that split into merely arching or recurving segments, and do not form a rosette of tight scrolls at the base of the single needle (this very valuable character was discovered by D. K. Bailey).

Another discrete difference is the nature of the food reserves in the abundant endosperm of the seeds. Great Basin P. monophylla has seeds with an average starch content of more than 50 percent, whereas fallax (and P. edulis) have less than 20 percent starch in their seeds; conversely, P.

monophylla has less than 25 percent fat in its starchy-tasting seeds, while the oily-tasting seeds of fallax and edulis average more than 60 percent fat (Botkin and Shires 1948). Since most pinyon species have oily seeds, starchiness of seeds is a distinctive trait for Great Basin P. monophylla.

Another unique trait of the latter is the unusually large number of stomatal bands (20-40 or more); these are rows of stomata marked by deposits of whitish wax that because of their close spacing give the foliage of Great Basin P. monophylla an intensely glaucous or "blue" (whitish-gray) appearance, not unlike that of blue spruce. In contrast, fallax averages only 10-15 stomatal bands per leaf, and the foliage has a bright green color, strikingly different from P. monophylla. In addition, the leaves of fallax are noticeably more slender (1.0-1.4 mm in diameter) than those of Great Basin P. monophylla (1.5-2.0 mm) and are also shorter as to mean and extreme lengths. More visual seed characters are shape and size: the seeds of P. monophylla (Great Basin) are narrower and taper gradually to a subacute base and average longer (15-22 mm), whereas in fallax the seeds are more round-ovoid, averaging 14-17 mm in length. Thus, fallax is amply distinct from Great Basin Pinus monophylla and P. edulis (but more closely related to the latter taxon, as noted by Little when he named fallax), and the distinctions of the leaves and seeds are visible in macrofossils from Pleistocene Neotoma deposits.

The late-Pleistocene distribution of fallax is better documented in the Neotoma record than that of monophylla. Only at relatively high elevations in the northern Mohave Desert (southernmost Great Basin) are there a few records hinting at the pleniglacial distribution of Great Basin monophylla; there are also macrofossil records from the west slope of the Sierra Nevada (Cole 1983) and the west side of the San Joaquin Valley (McKittrick asphalt beds, Mason 1944). Whereas the late-glacial/Holocene history of fallax is one of drastic contraction of range to a narrow strip of "Submogollon" country across central Arizona with outlying montane relicts, the Holocene history of the more northerly taxon monophylla is a vast expansion throughout much of the central and northeastern Great Basin, from about 36° to 42° latitude (Wells 1977, 1979, 1980, 1983).

TWO-NEEDLED PINYONS

A situation parallel to monophylla and fallax is apparent in the present and past distributions of Pinus edulis Engelm. and P. remota (Little) Bailey & Hawksworth, two-needled pinyons that are amply distinct. Again, it is the more southerly taxon, remota, that has contracted from a much wider pleniglacial range (in the lowlands of the Chihuahuan Desert) to a comparatively localized scattering of chiefly montane populations (in northeastern Mexico and the adjacent Big Bend area of west Texas). The outlying, widely disjunct population of remota to the east on the Balcones Escarpment of the Edwards Plateau (southwestern rim) descends to the extraordinarily low elevatic of 450 m. The relict nature of these outliers is shown by full to late-glacial Neotoma macrofossil records documenting the wide distribution of remota at basal elevations of the adjacent Chihuahuan Desert to the west (Wells 1966, 1974, 1979; Lanner and Van Devender 1981).

At 450 m, the Edwards Plateau population of remot is elevationally the lowest living population of any pinyon pine in the United States; indeed, any fossil record of pinyon at this elevation in the deserts of the Southwest would signify a displacement of full-glacial magnitude! The modern elevational anomaly of pinyon on the Edwards Plateau is readily explained, however, by the ample mean annual precipitation (ca. 50 cm, most of it falling in summer: May to September) and the rocky limestone outcrops that thin the dense stands of live oaks along the Balcones rim, providing open woodland habitat for remota.

In contrast to the contractional Holocene history of remota (paralleling fallax), edulis has accomplished a great expansion to the north (paralleling monophylla) from small, sparsely documented, pleniglacial refugia in the south (on the northern fringe of the Chihuahuan Desert). As in monophylla, a northward latitudinal expansion of some 6° of latitude during the Holocene is inferred from late-Pleistocene fossil records in the south and only Holocene records in the north (Wells 1977, 1979, 1980, 1983; Van Devender and others 1984), but rigorous documentation of the northward migration remains unpublished. Inasmuch as the taxonomic distinctions between edulis and remota (and cembroides) have been reaffirmed by Bailey and Hawksworth (1979), I will not reiterate the differences here except to point out that the distinctions between the remota and edulis pair are analogous to those between fallax and Great Basin monophylla, but less strikingly different than the latter pair. Details on the Quaternary history of remota and edulis are treated in other papers in this symposium.

THREE-, FOUR-, AND FIVE-NEEDLED PINYONS

Few macrofossil records have been obtained of pinyons with multiple-needled fascicles, at least partly because there has been little in the way of intensive searching for Quaternary Neotoma deposits at likely latitudes and elevations in Mexico. In southeastern Arizona, the three-needl P. discolor Bailey & Hawksworth was reported (as P. cembroides var. bicolor Little) from the Santa Catalina Mountains in Neotoma middens containing a lower-montane forest assemblage dated at ca. 14,000 yr BP (Van Devender and Spaulding 1979). Since this record is from a montane site at 1555 on Pontotoc Ridge in the Catalinas, it does not prove an incursion of discolor into the Sonoran Desert lowlands then occupied by fallax. Of cours Pinus discolor is primarily a mixed live-oak/chap arral or pine-oak woodland tree and does not form typical woodlands of the PJ type. The same is true of other multiple-needled pinyons, especiall

the five-needled P. maximartinezii and P. culminicola of Mexico; the latter occurs at the upper limit of pine-oak woodland, sometimes forming a subalpine krummholz in the Sierra Madre Oriental.

I know of only one other Pleistocene record of a multiple-needled pinyon: Pinus quadrifolia Parl., a four-needled pinyon that has left abundant macrofossils in a pleniglacial Neotoma midden (nearly 18,000 years old) from the great Idria-Pachycormus desert of central Baja California (the heart of Shreve's Sarcophyllous subdivision of the Sonoran Desert). It was accompanied then by Juniperus californica; today P. quadrifolia is more of a submontane, pine-oak woodland tree in the mountains of northern Baja California, also associating there with typical California chaparral (on the western slopes).

PINYON COMMUNITIES: PRESENT AND PAST

Only two species of pinyon pines dominate the most extensive areas of the PJ type: Pinus monophylla and P. edulis; the other pinyon taxa are components of communities for the most part very different from typical PJ. These two relatively cool-temperate species range farthest north (to 42° N) and occupy immense areas of the Great Basin, Colorado Plateau, and southern Rockies. The dominant junipers associated with these pinyons are Juniperus osteosperma in the west and J. monosperma in the southeast, the latter species occurring exclusively with P. edulis. Components of both monophylla and edulis PJ are the ubiquitous sagebrush (Artemisia tridentata) on the deeper soils and the evergreen mountain mahogany (Cercocarpus ledifolius); the edulis PJ differs in having a major development of deciduous shrubs and trees such as Cercocarpus montanus and Quercus gambelii (the "Petran chaparral").

The more recently recognized pinyon taxa, remota and fallax, have much more narrowly restricted ranges (in both an areal and ecological sense) just to the south of edulis, which they closely resemble in many characters. Neither these pinyons nor their typical associated junipers (J. pinchotii or J. ashei with remota in Texas and J. erythrocarpa with fallax in Arizona) exhibit the regional dominance seen in monophylla or edulis PJ. Rather, the conifers are components of encinal dominated by evergreen-sclerophyll trees and shrubs: live oaks and chaparral of the "Arizona"-Mexico, summer-rain type, laced with Agave, Dasylirion, and Nolina; sagebrush is conspicuously absent.

The three-needled discolor and cembroides occur at higher elevations than fallax and remota in Arizona and Texas, respectively; these lower montane elevations are dominated by live-oak woodland and J. deppeana that combine with the pinyons to form a xerophytic pine-oak woodland. Finally, the four-needled P. quadrifolia associates with J. californica in the floristically distinct live-oak woodland and chaparral of the winter-rain type in the Peninsular Ranges of Baja California and southern California, a relatively restricted area today.

The Neotoma macrofossil record documents a major shift in dominance areas among most of these geographically diverse pinyon taxa, commencing with the ecological crisis of late-Pleistocene/Holocene transition (ca. 12,000 to 8,000 years ago) and continuing through the early Holocene. There was comparative stability of dominance levels and geographic extent of pinyon species during much of the Wisconsinan glacial, prior to about 12,000 years ago, on the other hand. For tens of thousands of years, Pinus monophylla (Great Basin type) and P. edulis were apparently restricted to only a small fraction (the southern fringes) of their modern ranges (though further Neotoma work will undoubtedly increase the known areas somewhat, as these northern pinyon species are as yet sparsely documented in the fossil record).

In striking contrast, the southerly taxa, fallax and remota, had vastly greater pleniglacial ranges than they do today, primarily because they then occupied the spacious lowlands that are now the hot deserts of the northern Sonoran and Chihuahuan provinces, respectively. As the deserts expanded in the desiccating lowlands, these encinal pinyons underwent severe contraction of range to the comparatively small areas of moderate elevation that have a combination of mild winter temperatures and adequate summer rain. But the same warming and drying of climate that decimated the southerly pinyon taxa opened up immense areas of the Great Basin, Colorado Plateau, and southern Rocky Mountains to a rapid expansion of the more cool-temperate monophylla and edulis, areas of higher elevation that had been occupied for tens of thousands of years under glacial climates by cold-tolerant, subalpine conifers (e.g., bristlecone pine and Engelmann spruce in the east-central sector and limber pine and Douglas-fir in the southeastern sector of the Great Basin, the latter pair also extensive on the southern Colorado Plateau: Wells 1983).

Remarkable parallels and contrasts are seen in the spectacular northward expansion (over 6° of latitude) of monophylla in the Great Basin, northeast to southern Idaho, and of edulis over most of the Colorado Plateau and southern Rockies, vis-a-vis the drastic contraction of fallax to the Submogollon fringe of the southwestern Colorado Plateau and of remota to montane islands of the northern Chihuahuan Desert and to a tiny relict population on the Edwards Plateau of Texas.

CONCLUSIONS

The more precise and detailed systematic distinctions among taxa of pinyon pines established recently by E. L. Little and D. K. Bailey are beneficial both to the modern-day management ecology of the PJ type and to accurate interpretation of the paleoecological implications of the Quaternary macrofossil records of pinyon pines preserved in Neotoma deposits throughout the Southwest. In general, the modern distributions of pinyon taxa are consonant with their known Pleistocene distributions, but elevationally shifted as much as 1000-1500 m upward and (for the cool-temperate species, monophylla and edulis) latitudinally expanded as much as 6° northward. Coherence of the

PJ communities through the most recent glacial/interglacial (Wisconsinan/Holocene) climatic cycle is apparent in the consistency of the dominant taxa in the fossil record and in modern PJ communities. Examples of modern combinations detected in the Neotoma macrofossil record include Pinus quadrifolia with Juniperus californica in central Baja California; P. monophylla with J. osteosperma in the northern Mohave Desert; P. edulis with J. monosperma in the northern Chihuahuan Desert; and P. remota with J. pinchotii in the Big Bend area of west Texas and farther south in the Chihuahuan Desert. Also, the encinal pinyons (fallax, remota) are consistently associated through late Quaternary time with the various live oaks and other sclerophylls of their respective regions (northern Sonoran and Chihuahuan Deserts). Thus, the PJ type is a very ancient set of plant communities of remarkable stability despite their diverse expansional or contractional histories in the last 12,000 years.

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WESTERN JUNIPER IN THE HOLOCENE

Peter J. Mehringer, Jr. and Peter E. Wigand

ABSTRACT: Macrofossils from woodrat middens and lake sediments, and fossil pollen reveal prehistoric variability in relative importance of grass, sagebrush and western juniper. The spectacular historic expansion of western juniper is matched by similar events of the last 4000 years when episodes of plentiful precipitation favored its spread at lower elevation.

INTRODUCTION

Western juniper (*Juniperus occidentalis* var. *occidentalis*) (Vasek 1966) is the Intermountain Northwest's version of the Great Basin's pinyon-juniper woodlands. Widespread in the interior Pacific Northwest, western juniper characterizes the vast woodlands of central Oregon, where it may grow thickly between 500 and 2000 m on level to gently undulating topography and less densely on steep or broken ground. Its distribution coincides with dry, hot summers, cold winters, and precipitation (20 to 50 cm) that falls principally as snow in winter and rain in fall and spring (Driscoll 1964; Dealy and others 1978). Stony or gravelly substrates, overlying broken, indurated subsoil layers or fractured bedrock, support western juniper through most of its range, and it is commonly found along escarpments and on ridges. The trees reach their northern limit on dunes in central Washington (Little 1971, map 16-w).

Western junipers intermingle with ponderosa pine on the forest fringe. Stands of widely spaced trees may grow on deeper soils with big sagebrush (*Artemisia tridentata*) and bunchgrasses, on rocky ridges with low sagebrush (*A. arbuscula*), and with stiff sagebrush (*A. rigida*) on lithosols. From central Oregon to northeastern California bitterbrush (*Purshia tridentata*) is also a common understory.

Juniper's recent success at the expense of forage has fueled academic interest, practical studies, and campaigns of eradication. Photographs and tree-rings reveal that much of its current range and density stems from historic encroachment onto open grazing lands (Arno and Gruell 1983; Rogers 1982; Young and Evans 1981). Many investigators suggest that fire impedes spread of western juniper, and relate increasing juniper density to overgrazing and fire protection (Burkhardt and Tisdale 1976; Dealy and others 1978; Driscoll 1964).

Although grazing may reduce fuels for fires that would halt juniper expansion, suppression of wildfires and overgrazing--that may indeed have influenced historic juniper "invasion" of steppe--cannot explain prehistoric fluctuations in juniper's range or density. Our initial studies of radiocarbon dated assemblages of fossil pollen and macrofossils seemed to indicate that over the past few thousand years western juniper had undergone changes in range and importance greater than those witnessed since arrival of European grazing animals and decline in uncontrolled range fires (Mehringer and Wigand 1985).

The Holocene history of western juniper remains poorly understood because both fossil records and present distributions provide too few clues to its wanderings in response to late-Quaternary environmental stresses. The oldest radiocarbon dated fossils come from Kings Canyon, California, where twigs and seeds occurred in several woodrat middens dating from >45,000 to 12,500 B.P. (Cole 1983). Western juniper appears as an invader of freshly exposed margins of Pluvial Lake Lahontan, where 12,000 year old seeds and twigs come from woodrat middens from the Winnemucca Lake Basin, Nevada (Thompson 1984, table 1). It is next reported from Lava Beds National Monument by 5300 B.P. (Mehringer and Wigand 1985), and from Diamond Craters, eastern Oregon, as a single seed in lake sediments by 4800 B.P. and as remains in woodrat middens by 3100 B.P. At Connley Caves, Fort Rock Valley, Oregon, charcoal identified as juniper occurs just beneath Mazama volcanic ash (Bedwell 1973). We suspect that western juniper occurred over much of its present range before 6000 years ago.

Even incomplete data on past responses of juniper to fluctuating Holocene climates would enhance understanding of historic changes in juniper distributions. With such information we could begin to evaluate, for example, the uniqueness of historic shrub and woodland expansion, and test notions concerning the long-term integrity of species associations and role of fire in western juniper communities. Eventually, paleoecological information will allow us to reconstruct, or at least better estimate, the relationships between grass and shrub dominance, fire frequency or intensity, climate and the prehistoric distribution of western juniper in southeastern Oregon. While conducting these investigations we

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Peter J. Mehringer is professor of Anthropology and Geology, and Peter E. Wigand is a post-doctoral research associate, Department of Anthropology, Washington State University, Pullman, Washington 99164-4910

also gathered information from Lava Beds National Monument, northeastern California, where historic "invasion" of western juniper and shrubs at the expense of grass has been well-documented.

In this paper we first describe the fossil plant contents of woodrat (*Neotoma* spp.) middens from Lava Beds National Monument. These suggest that at times over the last 5300 years, western juniper and large shrub associates occupied elevational ranges and abundances that were attained again within the past 100 years in northeastern California. Secondly, we present more detailed information from the Steens Mountain region, southeastern Oregon. There fossil pollen, macrofossils and charcoal from lake sediment cores, with plant fossils from woodrat middens, allow focused speculation about the Holocene history of western juniper, and its relation to climate and to natural fire regimes.

METHODS

Woodrat middens were prepared by washing surface contaminants from stratigraphically discrete pieces of urine cemented dung and plant remains. These samples, and those from lake cores, were soaked in water until plant fragments were free and then washed through nested stainless steel sieves (8, 10, 24 and 42 mesh). After drying and sorting we identified the plant remains with our comparative collections and those in the Marion Ownbey Herbarium, Washington State University. They were then counted, dried at 40°C, cooled in a desiccator, and weighed to five places, rounded to three; .001 grams indicates a trace that may weigh less. Abundance and state of preservation of plant remains, and usefulness of the parts preserved for distinguishing particular taxa determined levels of identification. Nomenclature follows Cronquist and others (1977, 1984) or Hitchcock and Cronquist (1973).

Ten centimeter-diameter cores collected from near the center and deepest area of Fish Lake (9.3 m) and Diamond Pond (2.0 m), with a mechanically driven piston corer, were returned to cold storage at Washington State University. Sediment samples of measured volume, to which *Lycopodium* spores were added as tracers, were extracted and mounted in silicone oil. We tabulated all pollen, spores, acid resistant algae, and charcoal fragments larger than 25 microns.

The pollen sums, that average nearly 1000 grains for 92 Diamond Pond and 800 for the 104 Fish Lake samples, do not include pollen of plants whose major abundances occur mainly in or around aquatic habitats (e.g., sedges, cat-tails, bur-reed, and pond weeds), nor acid-resistant algae (e.g., *Pediastrum* and *Botryococcus*) which are many times more abundant than pollen. Because relative abundance of grass pollen could be such an important ecological indicator in the steppe of southeastern Oregon, all counts include at least 50 grass pollen to assure reasonable statistical comparisons between samples. The pollen sum (sum of the pollen of terrestrial plants) was used in calculating pollen percentages and charcoal/pollen ratios.

LAVA BEDS NATIONAL MONUMENT

Woodrat middens collected from lava tubes and rock shelters at Lava Beds National Monument, northeastern California (figs. 1, 2), furnished estimates of natural vegetation before disturbances of the past 150 years. As elsewhere in western North America, photographs and historic accounts indicate that, in places, a comparatively open grassy landscape had recently given way to shrubs and juniper. Study of seven woodrat middens showed past plant assemblages characterized by the same species that occupy the sites today (tables 1, 2). Western juniper dominated all middens and mountain-mahogany (*Cercocarpus ledifolius*) was abundant in most. The dates of these assemblages (table 1) confirm appearance of western juniper by 5300 B.P. and its presence, at least sporadically, thereafter.



Figure 1.--A lense from this large woodrat midden, in the Labyrinth Distributary lava tube, Lava Beds National Monument, contained western juniper dating to 5265±75 B.P. (M. A. Mehringer, May 12, 1983). Thus, western juniper has been present in northeastern California for at least 5300 years and the lava tube is older yet.

The Lava Beds woodrat midden fossils reveal past presence of junipers over their full present elevational range within the monument. Current distributions result from the historically documented spread of juniper from the rough lava flows at mid-elevations into areas where ponderosa pine succumbed to drought and beetles, and into grasslands recently invaded by shrubs. All locations but two (Gillem's Bluff 1280 m and Heppe Ice Cave 1615 m) are near 1500 m elevation and probably supported western juniper and some ponderosa pine 100 years ago (Martin and Johnson 1979, fig. 1). Although adjacent to ponderosa pine forest, Heppe Ice Cave is currently surrounded by dense curl-leaf mountain-mahogany and western juniper, and its two woodrat middens are dominated by these species. Fragments of pine seeds occurred in five middens (table 2).

During the last century the area around Gillem's Bluff supported a bunchgrass-sagebrush community (Johnson and Smathers 1974, fig. 5). Encroachment of juniper and native and exotic pioneer dominants, and increasing density of sagebrush since then have been attributed to heavy grazing and control of wildfires. Although a few small junipers grow near the Gillem's Bluff midden site (fig. 2), an active woodrat midden there lacks juniper. Yet, about 2200 years ago western juniper and bitterbrush (*Purshia tridentata*) occurred sufficiently near to assure their collection by woodrats when neither overgrazing nor fire suppression could account for their presence.



Figure 2.--Gillem's Bluff midden locality (rock face at base of slope) near lower elevation of recent juniper spread in Lava Beds National Monument (M. A. Mehringer, May 13, 1983).

Fossil plants from woodrat middens show that in the past western junipers occupied elevational extremes equivalent to the present. Still, it is not known if, like the present, this broad range existed at a single time. Under mid- to late-Holocene climatic differences western junipers may have shifted upward while retreating at lower elevations or vice versa; their elevational range may have broadened at both upper and lower extremes or changed in a single direction. A juniper zone, as broad as the current one, about 2000 B.P. may be indicated by radiocarbon dates from Gillem's Bluff, Paradise Alleys (4), and Heppe Ice Cave (7) middens. The dates range from 2215±80 to 1915±50 B.P. (table 1) and average 2035±40 B.P. Given rapidity of historic variations in grass, shrub and juniper dominance, an uncertainty of even 150 years is too long to establish contemporaneity of reconstructed vegetation. The Steens Mountain studies show that continuous pollen records are necessary--as complement to woodrat midden macrofossils--to reveal the timing of western juniper's prehistoric oscillations.

STEENS MOUNTAIN

Steens Mountain, southeastern Oregon, is unusual in lacking a montane coniferous forest zone (McKenzie 1982, fig. 3.8), but it is ideal for study of changing steppe vegetation. On Steens Mountain the upper limit of western juniper woodland has remained unimpeded by competition from other coniferous trees throughout the Holocene. Fossil pollen, algae, charcoal and macrofossils of cores from Wildhorse (2565 m) and Fish (2250 m) lakes in subalpine and sagebrush steppe, and from Diamond Pond (1265 m) in

Table 1.--Radiocarbon ages of woodrat middens (tables 2, 3)

Site and Elevation (meters)		^{14}C Dates (laboratory no.)		Material Dated
LAVA BEDS				
Heppe Ice Cave (7)	1615	1915±50	(WSU-2966)	dung
Heppe Ice Cave (6)	1615	1260±80	(WSU-2965)	dung
Paradise Alleys (4)	1500	2065±80	(WSU-2926)	juniper
Paradise Alleys (1)	1500	2570±80	(WSU-2834)	dung
Hercules Leg (5)	1500	4910±70	(WSU-2925)	juniper
Labyrinth Distributary (2)	1500	5265±75	(WSU-2836)	juniper
Gillem's Bluff (3)	1280	2215±80	(WSU-2916)	dung
DIAMOND CRATERS				
Graben Dome (GD-1)	1435	2390±260	(WSU-2726)	juniper
Graben Dome (GD-2)	1410	835±55	(WSU-2725)	juniper
Graben Dome (GD-3)	1410	1625±150	(WSU-2727)	juniper
Rat Amber Ridge (RA-1)	1330	3000±75	(WSU-2573)	juniper
Rat Amber Ridge (RA-2)	1330	2340±90	(WSU-2575)	juniper
Rat Amber Ridge (RA-3)	1330	2455±90	(WSU-2572)	juniper
Surprise Cave (SC-1)	1290	2800±110	(WSU-2441)	juniper
Surprise Cave (SC-2)	1290	2700±80	(WSU-2448)	dung
Surprise Cave (SC-4)	1290	2680±90	(WSU-2574)	juniper
Spattercone Cave (SP-1)	1280	2350±80	(WSU-2447)	juniper
Spattercone Cave (SP-3)	1280	2670±70	(WSU-2581)	juniper

Table 2.--Weights of macrofossils (grams) and radiocarbon ages from woodrat middens from Lava Beds

	Gillem's Bluff (3) 2215±80 B.P.	Labyrinth Distributary (2) 5265±75 B.P.	Hercules Leg (5) 4910±70 B.P.	Paradise Alley (1) 2570±80 B.P.
TREES AND SHRUBS				
Pinus cf. *ponderosa* (seeds)	.033(F)			.002(F)
Juniperus occidentalis				
twigs	.015	39.597	13.257	2.838
seeds and berries	.255(10W/5F)	3.244(102W/40F)	5.363(131W/13F)	1.657(68W/31F)
galls			.231	
Artemisia (bark)		.015		
Chrysothamnus nauseosus				
bracts				
pappi and seeds			.001	
Tetradymia glabrata (twigs)		.007		
Cercocarpus ledifolius				
leaves		.050	.054	.012
fruits		.146	.339	.467
Chamaebatiaria millefolium (leaf)				
Prunus emarginata (seeds)				.113(3W)
Prunus virginiana (seeds)	.017(2F)	.111(1W)		
Purshia tridentata				
leaves		.088	.017	
seeds		.018(1W)		
Arctostaphylos patula (seeds)				
Ceanothus sp. (seed)				
Ribes cf. *cereum* (seeds)				
Sambucus cerulea var. *cerulea* (seeds)			.001(1F)	
FORBS				
Amsinckia tesselata (nutlets)	.007(13F)			
Chenopodiineae (seeds)	.003(11W)		.001(2W)	
Collinsia parviflora (seed)				.001(1W)
Cryptantha intermedia (nutlets)	.001(1W)	.002(3W)	.001(1W)	
Cryptantha torreyana (nutlets)			.001(2W)	
Eriogonum sp. (seed)	.001(1W)			
Galium aparine (seeds)	.006(3W)			
Labiatae (seed)				
Lappula redowskii var. *redowskii* (nutlets)	.002(2W)			
Penstemon deustus (capsules)		.006		.039
Phacelia linearis (seeds)	.001(1W)	.001(1W)		.001(1W)
Phacelia ramosissima (seeds)	.002(2W)		.001(1W)	
Portulacaceae (seeds)				
cf. *Solanum* (seed)				
GRASSES				
Agropyron spicatum (spikelets)		.002(2W)		
Elymus cinereus (spikelets)	.025(12W)			
Puccinella lemmonii (spikelets)	.001(2W)			
Sitanion hystrix (spikelets)			.001(1W)	
MOSSES				
Grimmia spp.		.006	.004	

W = whole seeds, fruits or nutlets; F = seed fragments.

sagebrush-shadscale desert are precisely correlated by volcanic ashes and radiocarbon dates (Mehringer 1985, fig. 12). Additionally, woodrat middens from the lava tubes, caves and rock shelters of Diamond Craters hold plant assemblages that record the fluctuating lower limits of western juniper onto present barren basalt flows or into territory now dominated by shadscale species. We estimate the history of western juniper near its current upper and lower elevational limits by using pollen profiles from Fish Lake and Diamond Pond, as well as macrofossils from the latter and from nearby woodrat middens.

Table 2.--(continued from facing page)

Paradise Alleys	Heppe Ice Cave	
(4)	(6)	(7)
2065±80 B.P.	1260±80 B.P.	1915±50 B.P.
.216(F)	.138(F)	.003(F)
22.984	1.037	3.370
4.235(165W/17F)	.398(15W/7F)	.433(10W/11F)
.045		.013
.002	.054	.001
.001		
.005		
.201		.066
1.855	.013	.101
		.001
.004		
.030(2W)	.032(2W)	
	.012(1W/1F)	.008(1W)
.003(1W)		
.025(26W)	.004(4W)	
.001(1W)	.001(1W)	
.003(1W)		
.081	.003	.006
	.001(1W)	
.001(1W)	.001(3W)	
.001(1W)		
.003(2W)		
	.001	.015

Juniper History from Lake Cores

Steens Mountain supports a broad zone of mature western juniper woodland that in places between 1650 and 1950 m forms dense, nearly closed canopy stands. It thins considerably, however, as woodland patches approach their elevational limits--as low as 1250 m on rimrock along the Blitzen Valley and as high as 2100 m on south slopes. A few stunted, frost-damaged western junipers survive, and produce seeds and pollen, in dense mountain big sagebrush at 2270 m near Fish Lake (fig. 3) and 2310 m near Honeymoon Lake. Relatively minor climatic differences might enhance their success at this elevation.



Figure 3.--Frost-pruned western juniper marooned in a transgressive sea of sagebrush (near Fish Lake, P. J. Mehringer, September 20, 1985).

During the mid-Holocene, conditions of less effective moisture (as indicated by the grass/sagebrush pollen ratios, fig. 4), and perhaps warmer summers with longer frost-free periods, prevailed on Steens Mountain, the surrounding desert, and elsewhere in the interior Northwest and northern Great Basin (Mehringer 1985, 1986). Although we suspected that under these conditions western juniper may have grown at generally higher elevations, juniper pollen percentages from Fish Lake (fig. 5) do not support such an assumption for Steens Mountain. In fact, the largest juniper percentages (to 3.1%) occur in sediments dating to about 500 B.P.; here they do accompany an increase in sagebrush in relation to grass pollen. But, what do juniper pollen percentages tell about the presence or abundance of juniper?

According to studies of modern pollen distribution (Davis 1984; Henry 1984) in the nearest comparable settings (south-central Idaho's sagebrush-dominated terrain with *Juniperus osteosperma* and the Owyhee Uplands with *J. occidentalis*), about 7 to 20% juniper pollen indicates presence of junipers at the sites sampled. Modern pollen spectra derived from surface sediments or moss polsters from most plant communities of southeastern Oregon can be expected to contain 1 to 3% juniper pollen transported long distances. At Wildhorse Lake atop Steens Mountain, where the cold tolerant *Juniperus communis* thrives, juniper values do not exceed 4% over the last 9300 radiocarbon years; some of this juniper pollen probably reflects wind-transport from far down the mountain.

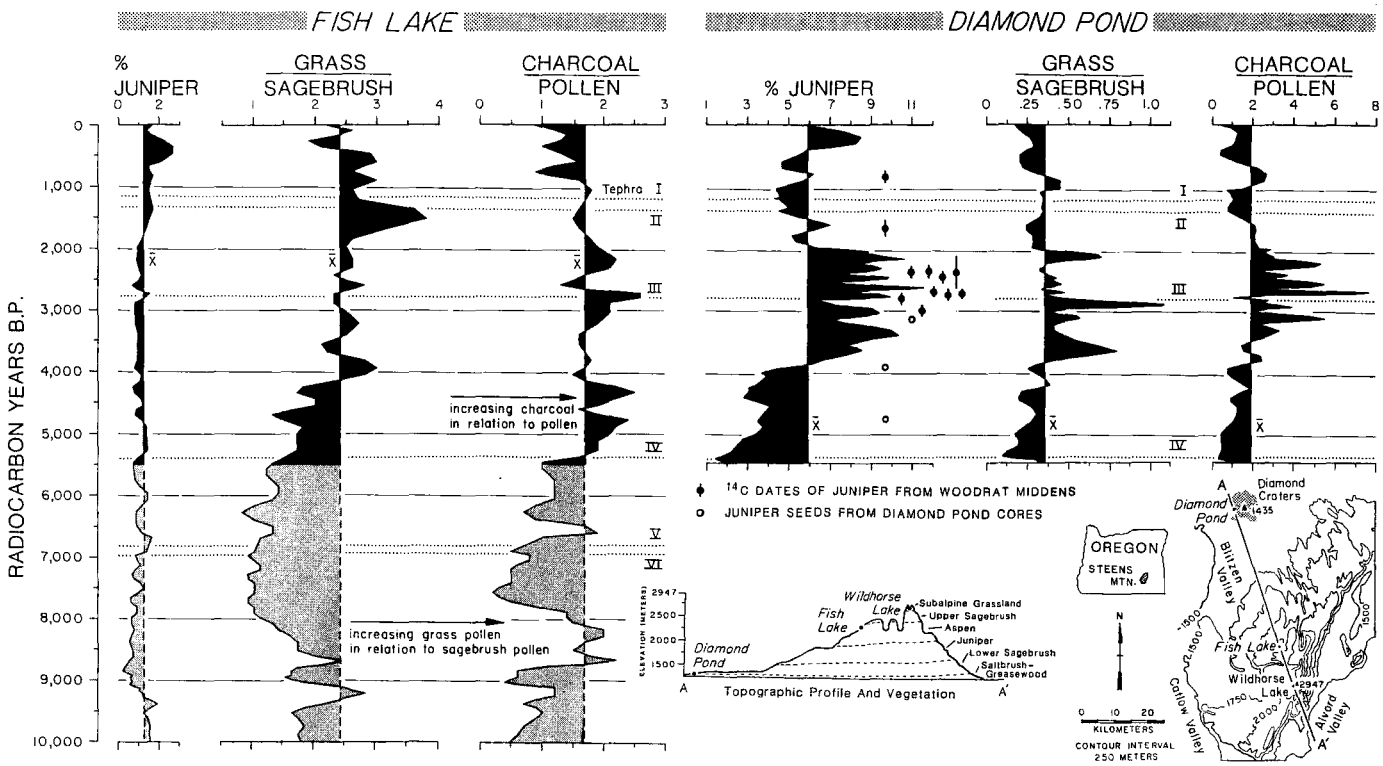


Figure 4.--Smoothed (A+2B+C/4) juniper pollen percentages and ratios from Diamond Pond and Fish Lake are plotted about the mean of the average values of each 500 year interval since 5500 B.P. Vegetation zones are generalized from Hansen (1956) and Mairs (1977).

Further evidence bears on interpretation of fossil juniper pollen percentages. Diamond Pond cores harbored single fossil juniper seeds in the same levels (about 4730 and 3900 B.P.) that produced average juniper values of only 3 and 6%, whereas 14 seeds came from a section of core averaging 9% juniper pollen (about 3250 to 3100 B.P., fig. 4). At that time mature western junipers, growing 100 m lower than currently expected on thin soils and southwest facing aspects, shed their fruits onto the slopes of Malheur Maar, and the pond collected considerably more juniper pollen than now (fig. 6).

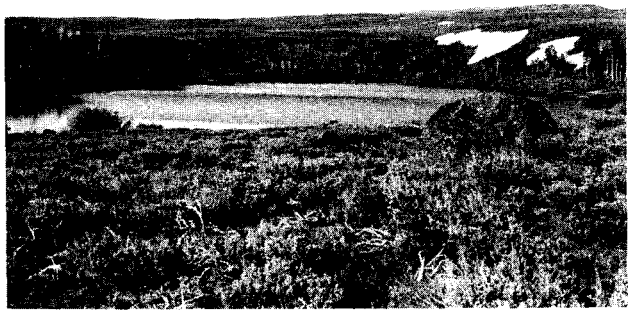


Figure 5.--Microfossils have been continuously deposited for nearly 13,000 years in the glacier scoured basin of Fish Lake (2250 m) that is surrounded by mountain big sagebrush and aspen (P. J. Mehringer, June 19, 1979).

Failure of Fish Lake pollen spectra to show interesting variation in juniper over the past 10,000 years suggests to us that juniper density has not changed markedly near the higher elevations of its present range. However, a long-distance, downslope source supplied some juniper pollen to Fish Lake through the early- and mid-Holocene and western juniper seems the most likely, but unproven contributor before about 5000 B.P. Apparent lack of significant Holocene variation before 1000 B.P. at the upper limit of western juniper contrasts with clear indications of considerable change at lower elevations. Before about 4400 B.P. small juniper pollen percentages characterize the records from both Fish Lake and Diamond Pond. We speculate, therefore, that mid-Holocene woodlands, if they existed, occupied considerably less area on the long western slope of Steens Mountain than they have at times since.

Although fluctuating juniper pollen percentages suggest periods of varying juniper abundance, these might indicate either expansion or increasing density of juniper, or both. However, juniper seeds from the cores confirm presence of trees at Diamond Pond on the sagebrush-shadscale ecotone; also, for junipers to grow nearby and downwind of Diamond Pond they must have invaded the west and southwest periphery of Diamond Craters between Diamond Pond and the Malheur Marshes. This area now supports greasewood (*Sarcobatus vermiculatus*), saltbushes (*Atriplex confertifolia*, *A. spinosa*), and sagebrush including bud sage (*Artemisia spinescens*).

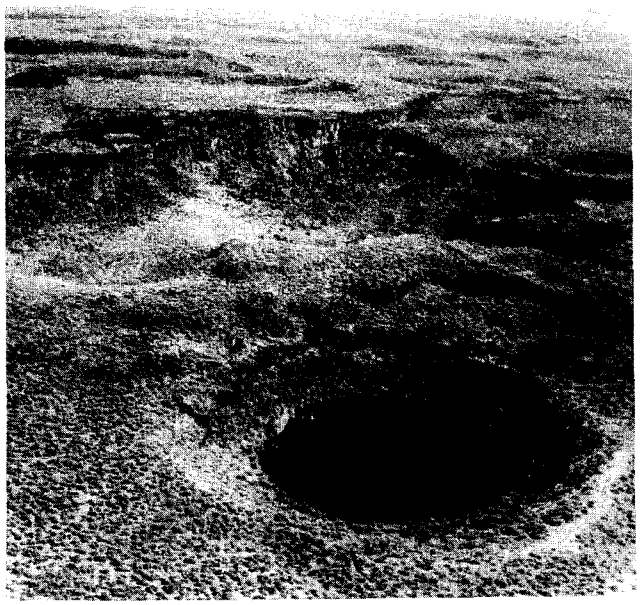


Figure 6.--Diamond Pond lies astride the sagebrush-shadscale ecotone east of Malheur Marshes and north of Steens Mountain. One of the many explosion craters in this volcanic terrain (Malheur Maar) holds a 50-meter diameter pond that has accumulated pollen, algae, seeds and molluscs for at least 6000 years. This part of Diamond Craters supported woodland at times within the last 5500 radiocarbon years (W. Bright, September 1978).

Woodrat Middens

Because macrofossils in woodrat middens must have come from within the 30 to 50 m that woodrats are known to forage, these records indicate actual movement of juniper populations, not simply increased density. Both juniper pollen percentages and location of juniper containing middens confirm downslope migrations of woodlands about 30 to 100 m below their present distribution on Diamond Craters, and perhaps farther if we exclude trees less than 100 years old. Although macrofossils confirmed contemporaneity of large juniper pollen percentages with actual spread of juniper, rates and magnitudes of these changes could not have been deduced from the middens alone.

Excepting western juniper that is 100 m to 1 km distant, all 12 middens contain species that now grow near enough to the midden sites to be collected by foraging woodrats; in fact, present site to site differences are reflected in the midden assemblages. The 2700 B.P. middens from Surprise Cave, a lava tube beneath Surprise Flow are good examples. Indian ricegrass (*Oryzopsis hymenoides*) remains are scarce in the Surprise Cave middens, whereas *Penstemon deustus* fossils are common (table 3). This penstemon is now abundant on Surprise Flow where even a few millimeters of wind-born dust have accumulated. By contrast, the sand-loving Indian ricegrass is rare on such substrates. Only abundant juniper remains suggest former woodlands on a terrain that appears young and perhaps in the early stages of primary plant succession (Peterson and Groh 1964).

According to woodrat midden assemblages from Surprise Cave and nearby Spattercone Cave, plants that are now sparsely distributed probably grew in greater abundance when junipers dotted the lava flows. Woodlands have come and gone from the rugged, nearly barren volcanic rocks without leaving a trace--except in the woodrats' ancient hoards. Juniper pollen from Diamond Pond (fig. 4) shows that this event about 2700 B.P. was not restricted to particular flows; nor was it exceptional.

Sagebrush, Grass and Charcoal

Through continued study of macrofossils and pollen the Holocene comings and goings of western juniper will surely be known. So, we proceed to related problems for which our new historical perspectives may suggest solutions. These include understanding the roles of climate and "natural" fire regimes in the spread, maintenance and decline of woodland and steppe.

Humans have been resource managers on this continent for at least 12,000 years. They diverted water, accidentally and intentionally spread propagules, and otherwise modified local habitats to their liking. Because fire was the most important tool for manipulating the environment (Barrett and Arno 1982; Gruell 1985), prehistoric fire regimes must have varied with population densities and lifeways. Still, regional patterns of fire history may emerge from studies of charcoal accumulation in lake sediments (Mehringer 1985, table 3; Tolonen 1983).

Smoothed grass pollen/sagebrush pollen, and charcoal/pollen ratios (fig. 4) illustrate some relationships of pollen types and charcoal to each other and to juniper pollen at Fish Lake and Diamond Pond. The more interesting of these include:

1. Grass/sagebrush ratios from the Fish Lake cores, showing relative dominance of sagebrush pollen centered on 8000-6000 B.P., decline from 5400 to 4000 years ago when grass pollen increases abruptly (in relation to sagebrush pollen).
2. Increased importance of grass at Fish Lake is mirrored in the chronologically similar rise of juniper pollen percentages and grass pollen (with respect to sagebrush pollen) at Diamond Pond.
3. During this same period, about 5400 to 4000 B.P., charcoal abundance (in relation to pollen) lies above the 5400 B.P. average for the first time since about 8000 B.P. at Fish Lake, but remains below the 5400 year mean at Diamond Pond.
4. The largest juniper, grass and charcoal values characterize the Diamond Pond record between 4000 and 2000 B.P. Since 2000 B.P. they have returned to values more characteristic of 5500 to 4000 B.P.

Table 3.--Weights of macrofossils (grams) and radiocarbon ages from woodrat middens from Diamond Craters

	Spattercone Cave			Surprise Cave
	SP-1	SP-2	SP-3	SC-4
	2350±80	no date	2670±70	2680±90
TREES AND SHRUBS				
Juniperus occidentalis				
twigs	12.817	4.392	8.206	6.909
seeds & berries	3.035(98W/6F)	.412(19W/2F)	1.423(55W/5F)	3.187(105W/8F)
bark	.126		.121	.052
galls	.012	.014	.170	.017
Artemisia (sec. Tridentatae)				
twigs	.259	.017	.018	.210
bark	.378	.208	.637	.552
leaves	.263	.012	.044	.016
Chrysothamnus nauseosus				
bracts	.032	.002	.001	.066
pappi and seeds	.001	.001	.001	.001
Tetradymia glabrata (twigs)		.006		
Atriplex confertifolia (fruit)				
Atriplex spinosa (seeds)				
FORBS				
Amsinckia tessellata (nutlets)			.003(1W)	
Castilleja cf. *chromosa* (seeds)	.005(13W)			
Cicuta douglasii (seeds)				
Collinsia parviflora (seeds)				
Cryptantha cf. *torreyana* (flowers & leaves)	.002		.001	.002
Eatonella nivea (seeds)	.001(2W)			
Galium aparine var. *echinospermum* (seeds)	.004(2W)			.002(1W)
Leptodactylon pungens (bracts)			.002	.033
Lupinus sp. (seed)				
Penstemon deustus (capsules)	.055	.009	.009	
Phacelia linearis (seeds)				
Phacelia lutea var. *lutea* (seeds)			.001(2W)	
Plagiobothrys kingii var. *harknessii* (nutlets)	.023(11W)			
Plectritis macrocera (fruits)	.001(2W)	.001(1W)	.001(2W)	
Polemoniaceae (capsules)	.003	.002	.001	.001
GRASSES				
Elymus cinereus (spikelets)				
Oryzopsis hymenoides (caryopses)	.027(22W)		.079(11W)	.001(2W)
Sitanion hystrix (spikelets)				.002(2W)
Stipa comata (spikelets)	.003(4W)	.007(1W)		
Stipa cf. *occidentalis* (spikelets)				
Stipa thurberiana (spikelets)	.002(3W)	.004(1W)		
Vulpia octoflora var. *hirtella* (spikelet)				.001(1W)
MOSSES				
Grimmia spp.	.088	.026	.054	.141

W = whole seeds, fruits or nutlets; F = seed fragments.

5. On the contrary, at Fish Lake grass pollen (in relation to sagebrush pollen) is generally greater from about 2000 to 500 B.P. than at any other time over the last 10,000 years.

In summary, between 5500 and 2000 B.P. charcoal fragments appear to increase with decreasing sagebrush or increasing grass pollen at both sites. At Diamond Pond juniper pollen follows this same trend; it is most plentiful between 4000 and 2000 B.P. when charcoal is also most abundant and grass is relatively more important than sagebrush. Since 2000 B.P., however, such relationships are less apparent; perhaps climatic regimes or patterns of aboriginal resource management peculiar to this period, or accumulated effects of Holocene "development" of biotic and edaphic conditions make the two sites less comparable in their responses to changing climate. Also, sampling intervals over the last 2000 years are quite long by comparison with the preceding 3500 years, especially at Diamond Pond where, on the average, decade-long samples were analyzed every 25 years between 4000 and 2000 B.P. (Wigand 1985).

Table 3.--(continued from facing page)

Surprise Cave		Rat Amber Ridge			Graben Dome		
SC-2	SC-1	RA-2	RA-3	RA-1	GD-2	GD-3	GD-1
2700±80	2800±110	2340±90	2455±90	3000±75	835±55	1625±150	2390±260
.977	4.976	2.102	1.831	5.831	7.189	2.229	.877
.805(10W)	2.228(78W/45F)	.962(33W)	3.777(126W/4F)	1.377(50W/3F)	2.450(94W/3F)	.666(21W/6F)	.297(9W/1F)
	.049	.146		.850	.030		.051
		.019	.033	.021		.030	.001
	.264	.183	1.577	.075	.105	.009	.008
	.001	.002	.089	.003	.020	.023	
	.013	.003	.010	.005	.021	.008	
			.001		.009	.001	
						.015	
			.002(1W)				
			.006(7W)				
			.059(21W/4F)				
					.001(1W)		
			.002(1W)				
	.001(1W)	.001(1W)	.018(17W)	.001(1W)			
	.001			.002	.003	.001	
		.001(1W)	.001(1W)	.001(3W)			
			.047(17W/1F)	.002(1W)		.003(1W)	
	.026						
	.003(1W)						
.027	.006						
		.001(4W)	.001(2W)				
	.001(1W)		.001(1W)				
	.001				.001	.004	
			.010(4W)				
	.001(1W)	.095(43W)	.140(80W)	.028(17W)	.047(29W)	.101(35W)	.005(3W)
	.004(2W)		.019(13W)			.001(1W)	
			.003(1W)		.002(1W)	.004(2W)	.001(1W)
			.003(1W)		.004(2W)		
			.008(2W)				
.001	.072		.150	.001	.014		

Although these studies shed light on general relationships, the details remain in shadow. Even the 196 pollen and charcoal analyses summarized in figure 5 were insufficient to evaluate notions about the causes and effects of fire, and related importance of shrubs, grasses or western juniper. They do, however, give clear indications of long-term trends and suggest responses to varying climate. At Diamond Pond large or increasing juniper, grass and charcoal values came from the same levels that produced the most seeds or pollen of deep water aquatic plants such as pond weed (*Potamogeton pectinatus*), water-milfoil (*Myriophyllum spicatum*) or coontail (*Ceratophyllum demersum*) with respect to shallow water and pond-fringe species such as cat-tail (*Typha latifolia*), bulrush (*Scirpus acutus*) or dock (*Rumex maritimus*). Thus, western juniper spread with increasing effective moisture as reflected in the rising regional water table. Its borders and density diminished, along with grass in relation to sagebrush, and sagebrush in relation to saltbushes, when precipitation declined and the water table fell (Wigand 1985, fig. 27).

DISCUSSION AND CONCLUSIONS

Knowledge of pristine vegetation, successional trends, and driving processes in ecosystems are essential for the understandings necessary to implement appropriate management practices. However, information on rangeland vegetation before the appearance of Europeans and the roles of environmental factors, such as climate and fire, in these systems are usually based on studies of short duration. Until recently, for example, we did not know if change wrought by livestock or fire suppression over the last 150 years was any more dramatic than "natural" occurring variation over the past few hundreds or thousands of years. Late-Holocene fossil records from lake sediments and woodrat middens offer answers to this and other questions about the rate and magnitude of prehistoric variation in northern Great Basin steppe and woodland.

Radiocarbon dated pollen records, supported by macrofossils, disclose juniper's rapid responses to climatic changes, as tempered by dispersal potential, competition and chance. When viewed in the perspective of the last 4000 years, the spectacular and persistent expansion of western juniper over the last hundred years--despite chaining, bulldozing, cutting, poisoning and burning--is not an unusual event necessarily requiring explanations unique to the historic period. In fact, the rate and degree of change in the comings and goings of western juniper over the late-Holocene are equal to or greater than those seen over the past hundred years.

To better understand prehistoric variation we are exploring methods for calibrating fossil assemblages against historic fire, climate and discharge data, and tree-ring series. We have begun with close interval sampling of sediments spanning the last 1000 years at Fish Lake, Diamond Pond and other sites in eastern Oregon and by continued study of ancient woodrat middens. Through these studies we intend, for instance, to relate charcoal content of lake cores to historic fires and to prehistoric fire frequencies as indicated by independently dated fire scar studies (Madany and others 1982).

Thus far our investigations suggest most clearly that western juniper is riding the tides of changing climate and that:

1. Woodrat middens from Lava Beds National Monument reveal presence of junipers over their full present elevational range at other times during the past 5300 years.
2. At Diamond Craters woodrat middens from 100 m to 1 km from the nearest living junipers--for the most part evidencing historic expansion--are dominated by western juniper remains. Radiocarbon dates of these middens range from 3100 to 835 B.P.; the dates, either in clusters or singly, correspond to increasing juniper pollen percentages from the independently dated Diamond Pond cores.
3. The largest charcoal/pollen and grass/sagebrush ratios, and juniper pollen percentages from the Diamond Pond cores coincide with deep water episodes within Malheur Maar.
4. If juniper pollen percentages reasonably reflect abundance of western juniper at lower elevations then, on the average, the period from about 4000 to 2000 B.P. witnessed fluctuating expanses of juniper woodlands exceeding those of today. Also, historic spread of juniper may be no more significant than potentially similar events about 1600 and 850 B.P., and another that began about 400 years ago only to wane 200 years later.
5. Juniper pollen percentages from Fish Lake do not indicate corresponding upward spread of western juniper since 10,000 B.P. In fact, the largest juniper percentages, perhaps indicating significant populations near Fish Lake on Steens Mountain, occur in deposits dating to only 500 B.P.

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PALYNOLOGICAL EVIDENCE FOR HISTORIC JUNIPER INVASION IN CENTRAL ARIZONA: A LATE-QUATERNARY PERSPECTIVE

Owen K. Davis

ABSTRACT: During the late-Pleistocene, pinyon-juniper pollen was abundant in Neotoma middens from the Tinajas Altas Mountains (365 - 580 m) in the Lower Colorado River Valley. At ca. 9000 yr B.P. (radiocarbon years before present) juniper pollen percentages in these middens drop to 0; but at the same time juniper pollen percentages increase in three sites above 1300 m elevation on the Colorado Plateau. Juniper percentages are greatest in these high-elevation sites during the late Holocene. At Pecks Lake in central Arizona, juniper pollen percentages increase from ca 10% at 2630 yr B.P. to ca. 30% at 200 yr B.P. A sudden increase to over 40% ca. 100 years ago is preceded by the first occurrence of exotic weeds and indicators of the presence of livestock. Thus, the Pecks Lake pollen diagram clearly shows historic juniper invasion, but the expansion is part of a trend that started over 2600 years earlier.

INTRODUCTION

Pollen analysis of sediments from lakes, caves, and packrat middens in the Southwest can provide information for prehistoric expansion and contraction of pinyon-juniper woodland. Unlike macrofossil analysis, pollen analysis cannot indicate which species of pine or juniper were present. But because pollen of these plants is produced in abundance and spread through the air for many kilometers, pollen analysis can indicate the relative abundance of the genera of plants in the regional vegetation. When used together, pollen and macrofossil analysis can provide a detailed picture of the response of pinyon-juniper woodland to environmental change.

The cold climate of the last glacial age had a profound influence on the distribution of pinyon-juniper woodland in the Southwest. At the height of the cold period about 18,000 years ago this vegetation type was restricted to low elevations south of the Utah - Arizona border (Van Devender and Spaulding 1979). As the climate warmed, it was displaced northward and toward higher elevation. This migration can be seen in the pollen diagrams from four sites in Arizona and southern Utah (figs. 1 and 2).

The Tinajas Altas Mountains are in the Colorado River valley of southwestern Arizona. The pollen and macrofossil analysis of 17 packrat middens from this range provide a detailed history of the desert vegetation of this hyper-arid region over the last 18,000 years (Davis, Anderson, and Van Devender, in prep.). From 18,000 - 12,000 years ago, both pinyon pine and California juniper were present even though the middens were collected

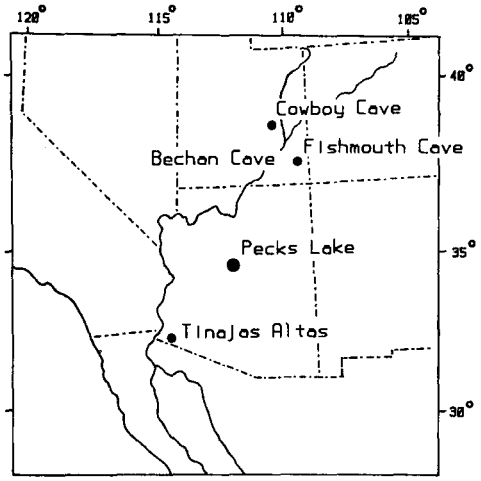


Figure 1.--Map of southwestern United States showing location of pollen-analytic sites. Exact location of Bechan Cave is not plotted, as requested by National Park Service.

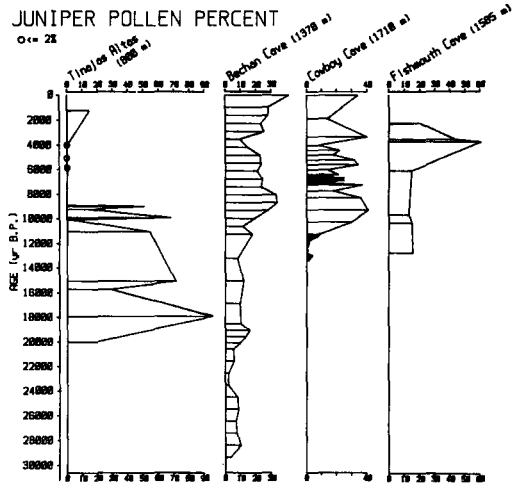


Figure 2.--Percentage diagrams for juniper pollen versus radiocarbon age for four sites in the southwestern United States.

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Owen K. Davis is Assistant Professor of Geosciences, University of Arizona, Tucson, AZ.

below 1000 m elevation. Juniper pollen abruptly disappears 9000 years ago (fig. 2), at which time juniper woodland vanished from low-elevation sites in the area.

At the same time pinyon-juniper woodland was shrinking at low elevation, it was expanding at high elevation. At Bechan Cave (elev. 1370 m) juniper pollen is present in small amounts (<15%) before 12,000 years ago, but juniper macrofossils present at that time are from common juniper (Juniperus communis) rather than one of the woodland species (Davis and others 1984). Juniper pollen percentages increase to 34% by 8700 years ago, and then decline to 21% during the height of post-glacial warmth 6000 years ago. Greatest abundance (41%) is reached in the most recent sample. Presumably, the high percentages of juniper in the last 11,000 years represent the establishment of juniper woodland at the site, but macrofossils are not present in sediment of this age so the exact species responsible are not known.

The Holocene expansion of juniper woodland can also be seen in pollen diagrams from Cowboy Cave (elev. 1770 m) and Fishmouth Cave (elev. 1585 m) in southern Utah (fig. 1). At Cowboy Cave (Spaulding and Petersen 1980; Lindsay 1980) juniper pollen increase from 2% 12,000 years ago to > 40% 9000 years ago (fig. 2). By combining macrofossil and pollen analysis of packrat middens from Fishmouth Cave (fig. 1), the increase of juniper pollen percentages from 3000 to 4000 years ago (fig. 2) can be attributed to Utah juniper (Betancourt 1984). Pinyon pine (Pinus edulis) is also most abundant at this time, so the increase from 15% to 60% in juniper pollen marks the local expansion of pinyon-juniper woodland at that site.

On a time scale of millennia, the distribution of pinyon-juniper woodland has been constantly changing. At the end of the last glaciation, there was a general shift northward and toward higher elevation. At 1585 m (Fishmouth Cave), maximum extent of pinyon juniper woodland was from 3000 - 4000 years ago; but at Bechan Cave, near the current lower limit of juniper, there is a very recent increase of juniper pollen percentages. This may reflect historic expansion of pinyon-juniper woodland at its low-elevation boundary. However, only one sample from Bechan Cave shows the recent increase (fig. 2). In order to thoroughly investigate the historic juniper expansion, a site with several pollen samples of historic age is needed.

POLLEN ANALYSIS OF PECKS LAKE

Pecks Lake (fig. 1) is an ideal site for examination of the historic juniper expansion because it is situated below the main distribution of pinyon-juniper woodland in a type of vegetation (semi-desert grassland) in which the historic increase has taken place. Upland vegetation near the lake is dominated by a variety of grasses with an overstory of crucifixion thorn (Canotia holocantha) and creosote bush (Larrea divaricata). Mesquite (Prosopis velutina) and catclaw (Acacia greggi) form dense groves east of the lake, and a riparian woodland covers its southern margin. Several species of sedge (Carex), bulrush (Scirpus), and rush (Juncus) are common in shallow water and water milfoil (Myriophyllum verticillatum) is very abundant where the water is over 50 cm deep.

Pecks Lake is also a good site for examination of the historic juniper increase because its rapid sedimentation rate permits the examination of many pollen samples during the historic period. Over three meters of sediment have accumulated in less than 3000 years (2630 ± 140 at 329-337 cm). Eleven pollen samples were analyzed in the sediments above the first appearance of exotic weeds at 100 cm, and a date of <140 years Before Present was obtained for plant macrofossils from 65-70 cm depth.

The presence of major archeological ruins near Pecks Lake permits a comparison of historic and prehistoric human disturbance on the regional vegetation, including juniper woodland. Tuzigoot National Monument, the site of a pueblo-style archeological ruin, is about 1 km south of the lake. Four hundred eleven burials and 86 rooms were discovered when the site was excavated (Caywood and Spicer 1935). Tree-ring analysis dates the construction of Tuzigoot pueblo to A.D. 1137 through A.D. 1386, but earlier occupation of the area is evident (Hartman 1976).

METHODS

Two cores, 10 cm diameter, were taken in the deepest part of Pecks Lake on May 8, 1982. After routine pollen extraction (Davis and Turner 1985), a minimum of 500 pollen grains of upland plants were counted per sample above 230 cm. A minimum of 300 grains (and 500 tracers) were counted below this depth because the number of grains per slide was extremely low. The percentage of each pollen type is based on a pollen sum (divisor) that is the total of upland (non aquatic) plants.

Three pollen types require special mention because they are from exotic species and can be used to date sediments to the historic period. Filaree (Erodium cicutarium) is thought to have been introduced in the early 1700's (Thornber 1906; Parish 1890). Its striate pollen is easily distinguished from the reticulate pollen of the native species, Erodium texanum. Russian thistle (Salsola) pollen can be distinguished from other Chenopodiaceae by its lesser number of pores. This widespread weed was present in Arizona by 1895 (Karpiscak 1980). The pores of marijuana (Cannabis) pollen make it distinctive, marijuana was grown in southern Arizona by 1908 (Brown 1908).

THE POLLEN DIAGRAM

Over 90 different pollen and spore types were identified from Pecks Lake sediment. The diagram (fig. 3) is divided into an upper zone with juniper percentages generally over 25% and a lower zone with chenopod (Chenopodiaceae - Amaranthus) percentages generally over 20%. Concentration is higher in the juniper zone (ave. 71415 grains cm^{-3}) than in the chenopod zone (ave. 19815 grains cm^{-3}). The zone boundary is marked by the lowest (first) occurrence of filaree pollen at 100 cm. Marijuana and Russian thistle pollen first appear at 85 cm.

THE JUNIPER INVASION IN CENTRAL ARIZONA

The dramatic increase in juniper percentages in the juniper zone (fig. 3) provides a clear demonstration of the historic expansion of juniper in the area. Although the causes for this expansion remain the topic of considerable debate, the temporal relationship between human disturbance and the juniper invasion is clear -- the major increase in juniper percentages occurs after the first occurrence of the pollen of exotic plants and after the earliest indications of increased grazing pressure. The maximum abundance of sunflower (other Compositae) pollen at the base of the juniper zone probably coincides with maximum disturbance of the vegetation near Pecks Lake in ca. A.D. 1880 (Johnsen and Elson 1979). The sunflower type is produced by many native and introduced weed species (Parker 1972).

The increased percentages of Sporormiella spores below the historic increase in juniper percentages indicate that the grazing pressure had increased before juniper woodland expanded. The Sporormiella fungus inhabits the dung of herbivores (Munk 1957). Percentages of this spore are much greater in sediments deposited after the introduction of European grazing animals to southeastern Washington (Davis and others 1977), and in the northern Great Basin (Davis 1981).

The pollen diagram (fig. 3) also shows a historic increase in desert shrubs (mesquite, catclaw, and creosote bush). This may result from the continued erosion of soils after the juniper expansion. Creosote bush has spread onto southwestern rangeland in the last 100 years (Gardner 1951; Humphrey and Mehrhoff 1958), and its establishment is enhanced on open and unstable soil (Valentine and Gerard 1968). The beginning of this expansion can be dated by its coincidence with increased lake level above 50 cm, which reflects artificial flooding of the lake basin shortly before 1913 (Herb Young personal communication). After the flooding, water millifoil pollen increases to 380%, Pediastrum, a planktonic alga, increases to > 50%, and the pollen of several trees now growing along the southern shore of the lake increased. The brief pine pollen peak at 85 cm (fig. 3) is difficult to explain, but it could have been produced by a cultivated plant that is no longer present.

Although the occupation of Tuzigoot pueblo produced a recognizable impact on the local vegetation, juniper did not expand during that period of human disturbance as it did in historic times. Radiocarbon dates of A.D. 1255 - 1950 (AA580) and A.D. 1040 - 1515 (AA581) for 210-220 cm overlap the tree-ring dates of A.D. 1137-1386 for the construction Tuzigoot pueblo (Hartman 1976). Evidence for disturbance at that time includes increased pollen percentages of several native weeds (buckwheat, spiderling, Arizona poppy, tidestromia, and globe mallow) as well as high percentages of chenopod pollen. These genera include several species that are important weeds

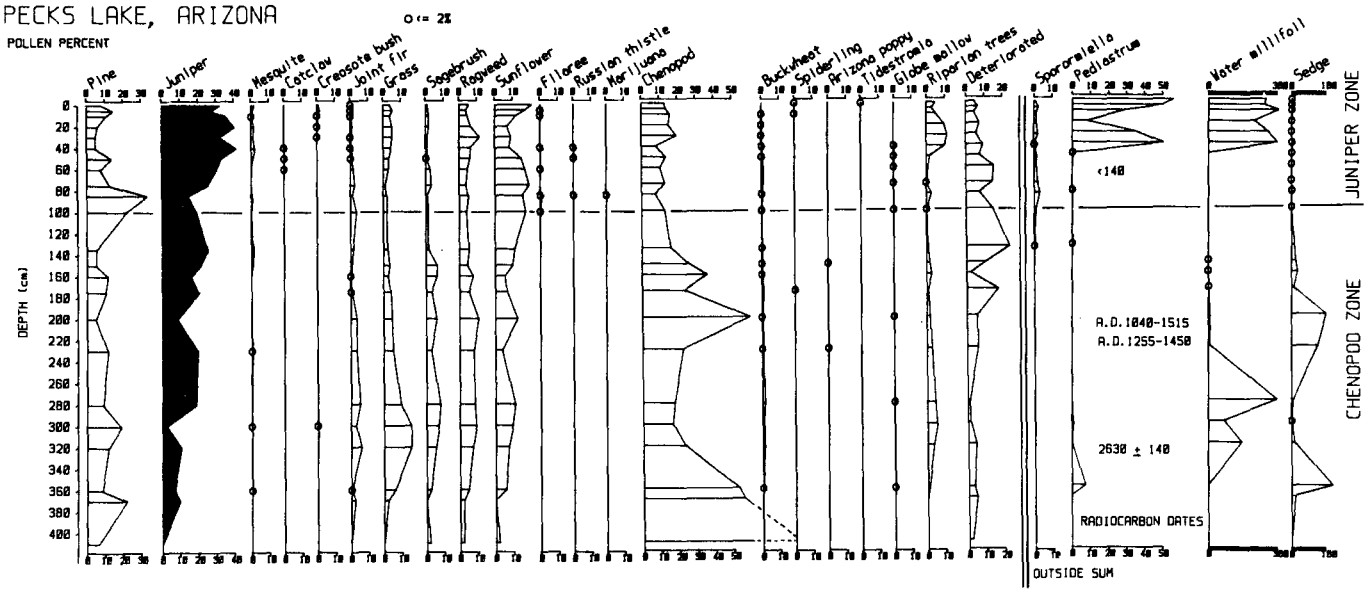


Figure 3.--Percentage pollen diagram for Pecks Lake, Yavapai County, Arizona. Radiocarbon dates are shown toward the left margin. Percentages are based on the sum of upland pollen types. Note scale change for water milfoil and sedge.

today (Parker 1972), and pollen of these taxa has been recovered in high percentages from sites where prehistoric agriculture was practiced (Fish 1984; Bohrer 1978). High percentages of chenopod pollen, which reaches 60% at 200 cm, are characteristic of Southwestern archeological sites (Fish 1984; Schoenwetter 1962; Hevly 1981).

High chenopod values (85 %) in sand at 410 cm probably result from sorting of pollen during stream transport (Fall 1981) rather than from environmental change. Lesser values at 360 and 370 cm may result from slight mixing, by less than 10 cm, associated with the development of peat on the abandoned channel.

HUMAN DISTURBANCE AND CLIMATIC CHANGE

Much of the vegetation change seen in the pollen diagram (fig. 3) has been attributed to human disturbance. During the historic interval juniper percentages suddenly increase. But during the the prehistoric period, juniper percentages reflect only the long-term increase that begins at the bottom of the core. This slow increase is accompanied by steady decreases in joint fir, grass, sagebursh, and ragweed(fig. 3).

In the modern vegetation, joint fir, grass, sagebrush, and ragweed pollen is most abundant in low-elevation desert grassland whereas juniper is more abundant at higher elevation (Hevly 1968). The simplest interpretation of the long-term trends is a gradual lowering of vegetation zones during the last few millennia, which probably resulted from climatic cooling. Similar increases in juniper percentages in recently-deposited sediments are reported for Montezuma Well (Hevly 1974) and at Bechan Cave (fig. 2).

While temperature cooled during the late Holocene, precipitation also may have changed. The most direct indication of precipitation change may be lake depth, which has decreased over this period of time, implying increased aridity. The lake was apparently deep soon after the lake formed, because percentages of water millifoil and riparian trees are high. Above and below this interval Cyperaceae percentages are very high (180% of terrestrial pollen). This sequence of aquatic types may have resulted from a single rise in lake level: (1) at first water depth was relatively shallow and sedges predominated; (2) later water depth increased to near present depths and water millifoil became abundant; (3) finally, lake level dropped and sedges once again occupied the site.

Although this sequence may be explained by non-climatic causes, the increased lake level may have resulted from greater precipitation about 2000 years ago. The low percentages of sedge and other aquatic plants at the first occurrence of exotic pollen types imply low lake level (and relatively low precipitation) in early historic time. This is confirmed by historic photographs of Pecks Lake (Davis and Turner 1985).

Both climatic change and human disturbance appear to have influenced the distribution of pinyon - juniper woodland in the Southwest during the late Quaternary. The gradual downward migration of juniper woodland in response to late Holocene cooling may be a widespread phenomenon in the western United States that was accelerated by historic vegetation disturbance. Hastings and Turner (1965) concluded that climate and cattle both effected the historic increase of juniper in the Southwest. The Pecks Lake study supports that conclusion and provides a longer chronology: the expansion of juniper began at least 2600 years before the introduction of grazing.

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EPISODIC, HISTORIC PINYON USE AND DEFORESTATION IN THE CORTEZ MINING DISTRICT, EUREKA COUNTY, NEVADA

Eugene M. Hattori and Marna A. Thompson

ABSTRACT: Pinyon stumps and logs at Cortez, Nevada, were crossdated with living trees to determine cutting dates. The chronology reveals distinctive intervals of local pinyon use related to historic mining activity. Living tree ages indicate survival of old-age trees close to mines and mills, and possible expansion of woodlands at lower elevations.

INTRODUCTION

Central Nevada, pinyon-juniper (Pinus monophylla-Juniperus osteosperma) woodlands played a crucial role in the economic development of the area between 1862 and 1890. The causes and effects of wood cutting to provide fuel and timber for mines, mills and communities are documented on a regional level (Sargent 1879; Thomas 1971; Young and Budy 1979:117, 119). There has been little work, however, to study woodland use in central Nevada woodland by means other than documentary research and limited match photography. The data for some of these studies, however, are inadequate to address specific questions on the history and actual intensity of wood cutting in the region.

This project is an outgrowth of a Bureau of Land Management and University of Nevada historic archaeology project in the Cortez Mining District (Hardesty and Hattori 1983). During archaeological surveys of the Mt. Tenabo woodlands, numerous pinyon stumps on the hillside and pinyon structural timber in abandoned buildings and mines were located. In 1983, a preliminary study of the pinyon-juniper woodland in the Cortez Mining District was conducted to locate and age date tree stumps and historic structures (Hattori and others 1984). The results of this study chronicle the vicissitudes of the district's mining history and changes in woodland between about 1864 and 1923.

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Eugene M. Hattori is Senior Scientist, Advanced Technology Division, Bechtel, San Francisco, CA; Marna A. Thompson was Research Associate, Laboratory of Tree-Ring Research, University of Arizona, Tucson, AZ.

SETTING

The Cortez Mining District (40° 10' N. Lat., 116° 35' W. Long.) is located at the northwestern end of the northeast to southwest trending Cortez Mountains in north central Nevada, 50 km south of of the Humboldt River at Beowawe. The principal mines and latest historic settlement of Cortez lie below an impressive horizontal exposure of Eureka quartzite called the Nevada Giant Ledge. Mt. Tenabo, the highest peak in the range, rises above the Nevada Giant Ledge to an altitude of 2793 m (Guilluly and Masursky 1965).

The pinyon-juniper woodland dominates the west facing upper bajada slopes and west and south facing mountain slopes of the district between about 1760 m at Shoshone Wells, 2 km northwest of Cortez, to 2667 m on Mt. Tenabo (fig. 1B). Small, localized stands of limber pine (P. flexilus) occur at higher elevations on Mt. Tenabo from about 2370 m in canyon bottoms with north facing exposures. Mountain mahogany (Cercocarpus ledifolius) forms stands at the upper edge of the pinyon-juniper zone from about 2286 m. Substrate for the area is principally derived from dolomite, quartzite, and limestone (Roberts and others 1967).

CORTEZ HISTORY

The Cortez Mining District was founded in the fall of 1863 and the Tenabo Co. Mill constructed the following year at the original site of Cortez about 11 km northeast of the present site of the community (Bancroft 1889). The early mining operations in the district were unprofitable because the oxidized ore resisted the Washoe pan milling processes developed for Comstock Lode ores in western Nevada Territory (Oberbillig 1967). Then, in 1867 or 1868, the Tenabo Mill was converted to the "Reese River Process" which required roasting the ore with salts for up to seven hours to reduce the ore to a more easily refined state (Bancroft 1889; Reese River Reville 9/14/1869; Whitehill 1875; Oberbillig 1967; Young and Budy 1979). The fuel for this long and intense roasting process was charcoal, preferably from the pinyon pine (Molinelli & Co. 1879; Bliss 1889).

In 1886, a new mill was built on the west slope of Mt. Tenabo closer to Wenban's principal mines, the Garrison and Arctic (Bancroft 1889). Nineteenth century mineral production peaked in

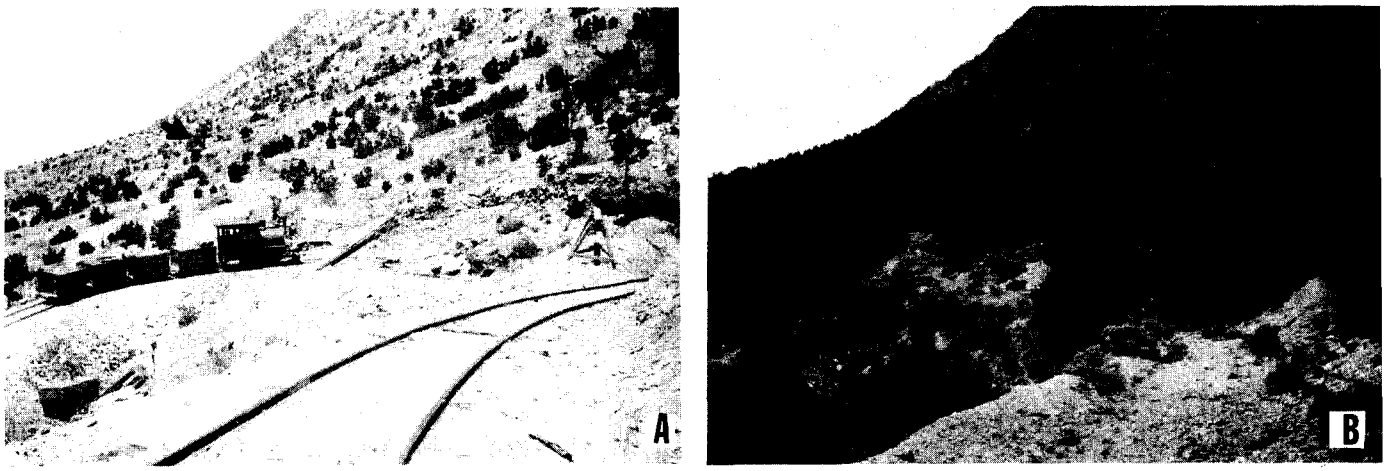


Figure 1.—Matched photographs of the railroad grade on Mt. Tenabo between the Garrison Mine and Wenban mill (elev. 1980 m). A, Photograph taken about 1900 showing reemerging pinyon-juniper woodland. The hillside and upper bajada slope were probably intensively logged between 1886 and 1892. Arrow denotes mature tree. B, Photo taken in 1983 of the dense, modern pinyon-juniper woodland. Four living trees cored on the upper bajada near this locality yielded innermost dates of between 1891 and 1911. (Photograph A. Nevada Historical Society; B. Authors)

1891 with over $380,000 worth of silver, gold, and lead produced from 8534 tons of ore (Couch and Carpenter 1943). With two intervening minor resurgences in activity, the district did not surpass these production figures until 1928 when the yield from gold, silver, copper, and lead exceeded $493,700 (Guilluly and Masursky 1965).

METHODS

Seven localities along the western edge of the Cortez Mountains between 1814 m and 2423 m elevation yielded 29 historically cut pinyon wood samples and 78 tree-ring cores from living pinyon. Additionally, 25 pinyon trees in the Keystone Mining District were cored for a control chronology.

Sampling sites were selected where well-preserved pinyon stumps were located in close proximity to mature living trees. When structures containing pinyon logs or isolated cut pinyon logs were encountered, the logs were cored, sectioned, or collected whole. The skeleton plot technique was used to crossdate the cores from the Keystone site, producing a chronology to be used as a dating control for trees and stump samples at the seven study sites (Douglass 1941; Stokes and Smiley 1968; Swetnam and others 1985). The accuracy of the Keystone chronology was verified by crossdating with existing pinyon tree-ring chronologies from eastern Nevada (Drew 1974).

Absolute dates from the outermost rings on each stump sample were determined by crossdating the stump ring width pattern with the Keystone control chronology. If bark or well-defined beetle galleries were present on the outermost surface of the stump, the date of the outermost ring was interpreted as the cutting date. In other instances, however, the outer surface was weathered and only a minimal cutting date could be determined. For example, six specimens with minimum cutting ages between 1883 and 1885 were assigned to the interval between 1886-1892 because of obvious weathering of the trunk.

FINDINGS

The Keystone control chronology ranges between (A.D.) 1557 and 1983. One living pinyon from the Keystone site exhibits over 750 annual rings, but is undatable because of missing rings. Two living trees from Mt. Tenabo sites at Cortez were about 300 years old. A sample transect across the bajada west of Mt. Tenabo between Cortez (elev. 1875 m) and Shoshone Wells (elev. 1760 m) yielded living trees with relatively recent maximum ages from the 1840s and 1850s. Only one uprooted, badly weathered stump was recorded for this transect. It had an innermost date of at least 1763 and was cut sometime after 1850.

The greatest concentrations of historic stumps were on the hillsides, with fewer stumps on the upper bajada slope and fewer still within the modern lower limits of the bajada woodlands. Although no systematic measuring techniques were used, the modern forest appears to be more dense and comprised of trees with smaller trunk diameters than the historic forest represented by the stumps. Widely spaced, old pinyon exist on upper slopes of Mt. Tenabo.

Twenty-nine stumps and logs were dated. The condition of the cut wood specimens ranged from a well-preserved timber retaining all of its bark to badly weathered and abraded specimens lacking bark and beetle galleries. Most specimens retained bark at the stump base and weathered beetle galleries near the top of the stump.

Two dates were rejected because they were from badly weathered specimens. Two other samples

Table 1.--Distribution of Cortez tree-ring dates

Mining Period	No. Yrs.	No. Dates	Tree-Ring Range	Avg. Mining Production
1930-1938	9	1	1932	$4,697
1908-1929	22	0	0	$114,161
1897-1907	11	2	1897-1898	$92,288
1893-1896	4	0	0	$1,900
1886-1892	7	13	1883-1891	$306,999
1863-1885	23	9	1864-1883	$55,488

yielded approximate cutting ages of 1850+ and 1853+, too young for the accepted history of the area. One of these specimens was a roof beam from a structure which dates archaeologically to about 1890. The presence of these older dated specimens in the collection is unexplained.

Twenty-five cutting dates range between 1863 and 1932. The cut wood specimens were assigned to specific historic intervals based upon their tree-ring age and outer surface condition. In some specimens this consisted of adding a maximum of 4 years to the tree-ring age determination when interpreting the date. The chronological distribution of the specimens is presented in table 1.

Historic photographs were examined and the photograph localities were relocated for match photographs. Changes in vegetation were noted in comparing the photographic pairs. A group of historic photographs, tentatively dating to the turn of the century, shows various areas in and around the town of Cortez. At this time, the bajada woodland was principally comprised of young trees characterized by short stature, conical growth form, and lower branches obscuring the trunk. In one photograph, however, a mature tree with a diffuse crown is visible in the distance (fig. 1A). This is one of the few photographs showing, not the inhabited areas, but a view nearly 1.6 km from the major habitation centers. One of the problems in the use of match photography for studying vegetation change is that the views are often of cities or mills (Thomas 1971; Young and Budy 1979). In these areas it is expected that woodland use would be most pronounced and atypical of the surrounding region.

CORTEZ WOODLAND HISTORY

From historic records, tree-ring dates, and historic photographs we are able to provide a tentative reconstruction of local pinyon-juniper utilization for the Cortez Mining District, Nevada. The effects of 19th century mining upon the pinyon-juniper woodlands in the district were dramatic and principally associated with one 7-year period of intensive mine and mill activity.

Beginning in 1863, initial demands were moderate and probably consisted of local thinning of the woodland for timber suitable for construction and cordwood. The early Tenabo Mill was 11 km from the study area and used the Washoe pan milling process in the first few years of production. With the implementation of the Reese River milling process, however, the wood requirements to supply the mill with charcoal undoubtedly led to extensive cutting in the area around the mill.

A combination of factors then led to the decimation of the woodland from the mid-1880s. An increase in mine production prompted the principal mine owner, Simeon Wenban, to construct a new mill closer to his mines in 1886. The local woodlands were intensively logged to produce charcoal and cordwood for this mill and the mines. The settlement of Cortez was also relocated to the study area and expanded, increasing the demands for cordwood. By the early 1890s the woodland was greatly reduced.

Woodland recovery began during a mining depression in the early to mid 1890s. When the next mining boom began in the late 1890s, the mining companies probably turned to other regions for wood, and they also began importing coal and coke to supplement charcoal supplies (fig. 1A). The local woodlands, however, probably continued to supply the town with cordwood. This era of mining prosperity continued, but a technological change was introduced in 1908 that eliminated the demand for charcoal and allowed the woodland to develop. The Wenban mill at Cortez was refitted in 1908 with equipment to recover precious metals using the cyanide process. In 1923 a new cyanide plant was built by the Consolidated Cortez Silver Mines Co. 0.4 km south of the site of the Wenban mill. The new facility was powered by electricity supplied by diesel-fueled generators. Mining activity consisted of reworking low-grade ore bodies, mine dumps and mill tailings.

Subsequent mining booms in the Cortez Mining District have used the cyanide process with limited impact to the pinyon-juniper woodland. Recent mining practice utilizing open pit mining, however, is expected to impact the region within the next 15 to 20 years.

SUMMARY AND CONCLUSIONS

The pinyon-juniper woodland at Cortez has been subject to human impact over the past 122 years. These impacts have varied from thinning to clearcutting, and then to greatly reduced cutting. The decimation of the woodland at Cortez probably occurred within a relatively short interval some 20 years after the initial settlement of the area.

Despite the heavy logging in the mid- to late 1880s, numerous mature trees survived the interval of intensive cutting. Reasons for this may include difficult access to the trees, undesirable growth forms, and/or protection.

From the distribution of pinyon stumps, and the ages of the mature trees dated, a post-1840 downward expansion of the woodland to the bajada

may be indicated. Possible explanations include settlement and overgrazing of sagebrush-grasslands, differential fire history, and/or climatic change. Woodland expansion has also been suggested for other areas in the Great Basin (Blackburn and Tueller.1970; Rogers 1982). Alternate explanations for the observation that the older living trees and greater concentration of stumps occured at higher elevation include poor preservation of stumps at lower elevations, lower vigor of pinyon at its lower limits, removal of stumps in the lower bajada, and/or sampling error.

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PALEOECOLOGY OF PINYON-JUNIPER WOODLANDS: SUMMARY

Julio L. Betancourt

ABSTRACT: Modern distributions of pinyon and juniper species (and their associations) should be considered ephemeral over the past two million years. Today Pinus edulis and P. monophylla occupy a regional platform with a base level above 1500 m, roughly their lower limit. A late Wisconsin upper limit of ca. 1500 m kept these pinyons south of the platform, where they expanded into desert lowlands. P. edulis immigrated to the Colorado Plateau by 10,000-8000 yr B.P. It failed to reach its uppermost sites until 6000-4000 yr B.P., possibly due to an expanded ponderosa pine zone. P. monophylla delayed its migration across the Great Basin until after 6500 yr B.P., awaiting mid-Holocene climates or dispersal by man. Traditionally attributed to overgrazing and fire suppression, historic invasions could also mark the current progress of continued migration, climatic fluctuation, or recovery from historic and prehistoric woodcutting.

INTRODUCTION

The Quaternary record for the pinyon-juniper (p-j) type in western North America is unique among woodland associations worldwide, primarily due to the contributions of palynology, packrat midden analysis, and tree-ring studies. Pigmy conifers are wind pollinated species that are well represented in pollen rain and thus, in the pollen spectra of fossiliferous deposits. Taxonomic diversity, however, is understated by palynology. Distinctions within the Cupressaceae are seldom made, although, if well preserved, haploxylon pine pollen less than 70 μ long can be assigned to the pinyons (for example, Jacobs 1985). Because of long distance transport and the complex nature of depositional environments, the relative contributions of local and regional woodlands to a given pollen spectrum are often indeterminate.

The taxonomic and geographic resolution of western paleoecology was greatly refined with Wells and Jorgensen's (1964) discovery of fossil packrat middens near Las Vegas and the work that followed, which now represents over 1100 radiocarbon dates and close to 100 published papers (Webb and Betancourt, in preparation). The leaves and seeds of pigmy conifers are often the most abundant plant remains in middens (fig. 1), commonly provide the few grams needed for radiocarbon dating, and currently serve as cellulose targets for paleotemperature/stable isotope studies (for example, Leavitt and Long 1983). In this region of environmental extremes, middens can pinpoint past plant associations within a hectare plot. Middens are not without shortcomings, however. They do not persevere in areas of high rainfall (and consequently, high elevations) and preserve better in some substrates (limestone) than others (sandstone and granite). A serious bias results from the restriction of middens to rocky environments, regardless of rock type. In the scarp woodlands of the Great Plains, middens would have no doubt missed the sea of grass for the few trees. Midden floras are also subject to the food preferences of different species of packrats. Middens of Neotoma stephensi, one of only two North American mammals that are conifer leaf specialists, probably overrepresent the importance of juniper in the local community (Vaughan 1982). Midden sequences are adequate to discern changes from one century to the next, but are inadequate for oscillations of higher frequency.

Tree-ring series from pinyons and junipers cannot only yield age distributions of modern stands and architectural histories, but can also chronicle high-frequency climatic variations over the past 2000 years. Dendroclimatology and migrational dynamics are seldom considered in tandem, with the classic exception of Pinus longaeva at upper treeline in the White Mountains (La Marche 1973). Perhaps this is one way to resolve the relative influences of man and climate at lower treeline where pigmy conifers have recently invaded grasslands.

This summary of the paleoecology of p-j woodlands does not attempt to be comprehensive (the reader is referred to Van Devender and Spaulding 1979; Spaulding and others 1983; Spaulding 1984; and Mehringer, in press), but rather to reflect on key issues, discuss topics not covered in the other symposium papers, and point the way for further progress. I will contrast the Pleistocene and Holocene and emphasize that the glacial pattern, different as it may seem from "the norm of the present," predominated over the last two million years. We have yet to find a vegetation zone, with the possible exception of steppe dominated by Artemisia tridentata, that overlapped in the Wisconsin and the present. There is not a

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Julio L. Betancourt is a paleoecologist with the U.S. Geological Survey, Research Project Office, Tucson, AZ.

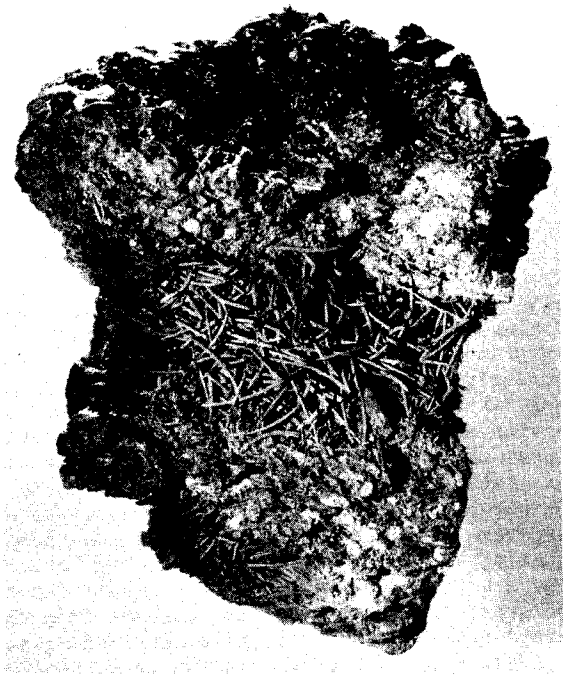


Figure 1.-- Packrat midden dated at 13,400 ± 250 yr B.P. (A-1357) from the Kofa Mountains, southwest Arizona. The monophyllous needles are from the same pinyon that now occupies refugial sites in submogollon chaparral, but was widespread in Sonoran Desert lowlands during the Pleistocene (courtesy of T.R. Van Devender).

single site where the vegetation was the same then as now in spite of the broad vertical amplitude of modern associations such as p-j woodlands. I will devote some time to the impressive northward and upward expansions of pinyons that took place in the Holocene and will discuss how topography, competition, climate, and prehistoric man might have affected rates of migration and presettlement distributions. A paleoecological perspective seems essential for understanding the scale, if not the causes, of historic encroachment by p-j into other vegetation types. Here, I will argue that there is little basis to assume that migrational equilibrium now exists and that present range shifts necessarily reflect the actions of man or random climatic variations about some long-term mean. I will end with a plea for a more synthetic approach to the study of p-j woodlands that considers historical factors.

WOODLANDS OF THE LAST GLACIAL

The most salient aspect of p-j woodlands in the late Wisconsin was their restriction to regions south of 35-37°N where they expanded to desert elevations. Low elevation woodlands, preempted by the modern deserts, date back to the late Miocene (Axelrod 1979), though woodland taxa, including pinyons, occur as early as the late Eocene in the Florissant and Green River floras of Colorado and Utah (MacGinitie 1953, 1969). Localities near Prescott and Safford, Arizona, yielded pollen floras suggestive of oak-conifer woodlands in the early Pliocene and early Pleistocene, respectively (Gray 1960, 1961).

The marine stratigraphic record suggests that Pleistocene history (the last 2 million years) consists of up to 16 prolonged (100,000 yrs) glaciations punctuated by brief (10,000 yrs) interglacials (Imbrie and Imbrie 1979). During the last cycle, p-j woodlands replaced subalpine conifer communities in the Great Basin and Colorado Plateau, and were in turn replaced by desertscrub and grassland in the Chihuahuan, Sonoran, and Mojave regions. Our few pre-Wisconsin records suggest that this turnover is probably representative of earlier cycles, though there is little assurance that biotic change on land kept exact pace with the reiterations of the oxygen isotope curve from deep sea cores.

Clearly, the number of glacial-interglacial repetitions in the last 2 million years bears directly on patterns of species diversity, community development, and genetic variability for those species with unstable distributions. Geographic isolation during the longer glacials probably resulted in great genetic differentiation among refugial populations, with occasional episodes of secondary contact during the brief interglacials. This also works in reverse, though gradualists might view geographic isolation during interglacials as too ephemeral for extensive genetic differentiation. The importance of the Pleistocene in the evolution of pinyon and juniper taxa should not be underrated, while their modern distributions and associations should be recognized as only transient states in the Quaternary.

Gross differences between Wisconsin and Holocene woodlands can be conveniently described in terms of elevation. The average lower limit of pinyons today, recognizing latitudinal variations due to seasonal precipitation and base level, is about 1500 m. Upper limits are extremely variable (as is competition as a limiting factor), ranging from 2200 to 2900 m. Juniperus osteosperma can occur both below and above the pinyons. This juniper extends farther north than the pinyons or its equivalent to the east, J. monosperma. The seeds of J. osteosperma germinate in the spring, as opposed to mid or late summer for the other taxa, which allows it to become well established by the end of the growing season and prior to autumn frost (Meagher 1943).

In the late Wisconsin, pinyons expanded down to 460 m and junipers down to 240 m in the Sonoran Desert region, while their lower limits apparently coincided along the Big Bend of the Rio Grande (Van Devender, this volume). In the Mojave Desert, cold steppe or chaparral elements were recovered from middens without pigmy conifers between 425 m (Wells and Woodcock 1985) and 910 m (Spaulding 1985).

Wisconsin upper limits are less well known. In th northern Mojave Desert, Pleistocene middens contai ing only J. osteosperma outnumber p-j assemblages between 1500 and 2000 m, where Pinus flexilis was also dominant (Spaulding 1984). There, the northernmost pinyon ranged no further than 37°N, while J. osteosperma extended another 2 degrees into the Great Basin (Thompson 1984). Very few middens hav been collected from above 1100 m in the Sonoran Desert region, a prerequisite for defining the

upper limits of the Wisconsin woodland. Oaks, pinyons, junipers, and Arizona cypress were common in the Santa Catalina Mountains at 1430 m on a ridge overlooking Tucson (Thompson and Van Devender 1982). Presumably, the upper limit of the woodland in the Sonoran Desert approximated that in the Chihuahuan Desert. Full glacial middens from south-facing limestone slopes on opposite sides of southern New Mexico's Tularosa Basin suggests that pinyon's upper limit was locally between 1550 and 1705 m (fig. 2). Pinyon and xerophytic junipers are missing from Wisconsin middens down to 1390 m, or essentially base level, in the Four Corners area (36-38°N, 108-112°W; fig. 3). Instead of pigmy conifers, these middens record Pinus flexilis, Pseudotsuga menziesii, Juniperus scopulorum, and Picea pungens on Mesozoic sandstones flanking Lake Powell. P. flexilis and J. scopulorum might have formed woodlands such as exist today in the foothills of the central Rockies, perhaps the ecological equivalent of modern p-j woodlands on the Colorado Plateau. The nearest J. osteosperma reappeared on Paleozoic limestones of the eastern Grand Canyon, where it was a common associate of Pseudotsuga menziesii, Pinus flexilis, and Abies concolor from 1400 to 1800 m (Cole 1982). Out of a total of 70 Wisconsin middens from the eastern and western Grand Canyon between 425 and 2050 m, only two (at 635 and 1300 m) contained pinyon. The latter were previously considered to be Holocene contaminants until two-needle pinyon from one of these middens was directly dated to the full glacial. The pinyon anomaly in the western Grand Canyon could be explained by a northern disjunct restricted to a small area or poor sampling of middens in topographic situations favorable to pinyons.

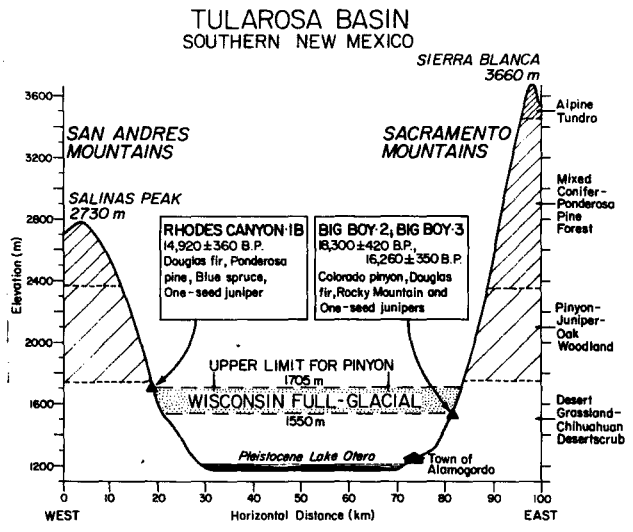


Figure 2.-- Vertical profile of the Tularosa Basin and surrounding mountain ranges. Full glacial middens from south-facing, limestone slopes suggest an upper limit for P. edulis between 1705 and 1550 m elevation.

Figure 4 shows that modern pinyon distributions largely coincide with a regional platform with a base level above 1500 m, their present lower limit. Conversely, an upper limit of 1500 m would have confined pinyons to areas below and south of the platform, where indeed pinyon macrofossils have been recovered at desert elevations. This same platform today determines the northern limits of thermophilous species, particularly Larrea. This dominant shrub of the warm deserts has a distribution similar to that of P. monophylla and P. edulis in the late Wisconsin.

While there is general agreement about the gross patterns of p-j history, pinyon taxonomy and its relevance to glacial climates is hotly debated. The controversy stems from the taxonomic status variously attributed to Arizona populations of single leaf pinyon and their distributions in interior chaparral of central Arizona (Wells, this volume). Whether they are regarded as P. edulis var. fallax (Little 1968) or synonymized with P. monophylla (Lanner 1974), there is no dispute that the pinyon in these populations is the same one that occupied Sonoran Desert lowlands during the Wisconsin. Taxonomists living in the last glacial might have considered "P. fallax" as a separate species. The controversy attains paleoclimatic significance because of this taxon's present "monsoonal" distribution and possible evolutionary ties with P. edulis or P. monophylla, each presently associated with summer rains or summer drought, respectively. Wells (1979, this volume) takes the former view and argues for increased summer rains to support Wisconsin populations of P. edulis var. fallax at their lowland positions. Lanner and Van Devender (1974) assigned Arizona fossil needles to P. monophylla and drew on this and other data to imply a southerly displacement of the westerlies with consequent winter rains and summer drought. I suspect that there is much overlap in how much or how little summer rain either model would require, though quantitative estimates are not given.

Both models calling for increased summer or winter rains recognize the uniqueness of central Arizona climate and vegetation due to the orographic influence of the Mogollon Rim. Most instructive are Mitchell's (1969) maps of precipitation in the West, normalized to 1500 m elevation. In winter, moist air sweeping around the southern end of the Sierra Nevada impinges and precipitates on the southwest-facing Mogollon Rim, producing higher rainfall in central Arizona than in other parts of the state. This is reflected in the high frequency of annual flood peaks in winter for streams originating on the Rim, such as the Salt and Verde Rivers. A similar effect might result from fall tropical storms pulled from the Pacific inland by a low pressure trough over the Southwest. In summer, however, the Rim is simply a barrier to the northeastward movement of moisture, with little enhancement of precipitation in central Arizona. Contrary to Wells' model, the interior chaparral of central Arizona coincides with abnormally high rainfall in winter, not summer. Coastal chaparral, which shares many taxa with sub-mogollon associations, now thrives under a mediterranean climate. Perhaps this coastal chaparral expanded inland during the glacial periods and sat out the interglacials in sub-mogollon areas where winter rainfall was plentiful. Further

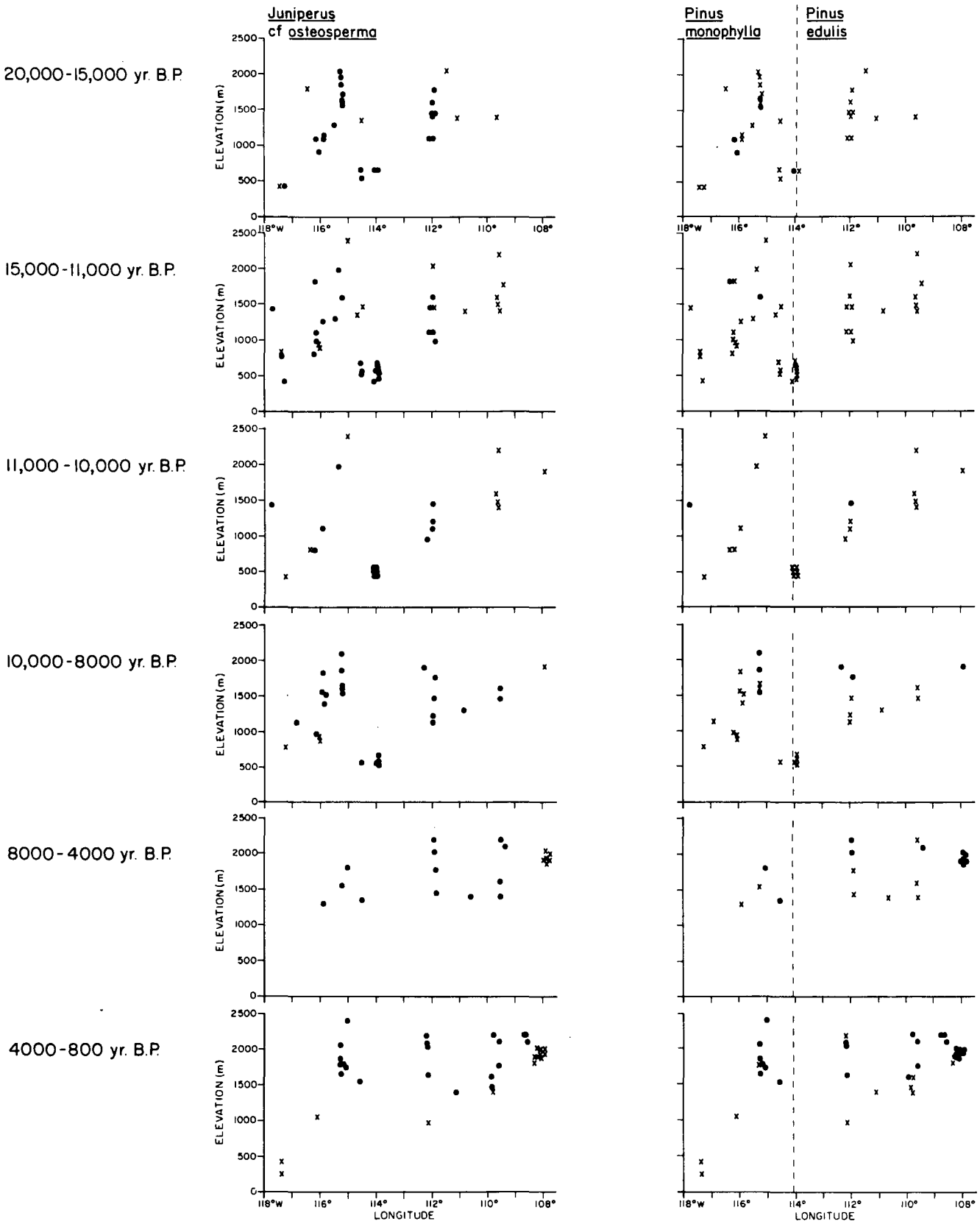


Figure 3.--Vertical and longitudinal distribution of middens in different age categories between 36-38°N, showing presence (closed circles) or absence (x's) of J. cf. osteosperma, P. monophylla, and P. edulis. Note eastward and upward migration of J. cf. osteosperma and the advance of P. edulis from the south.

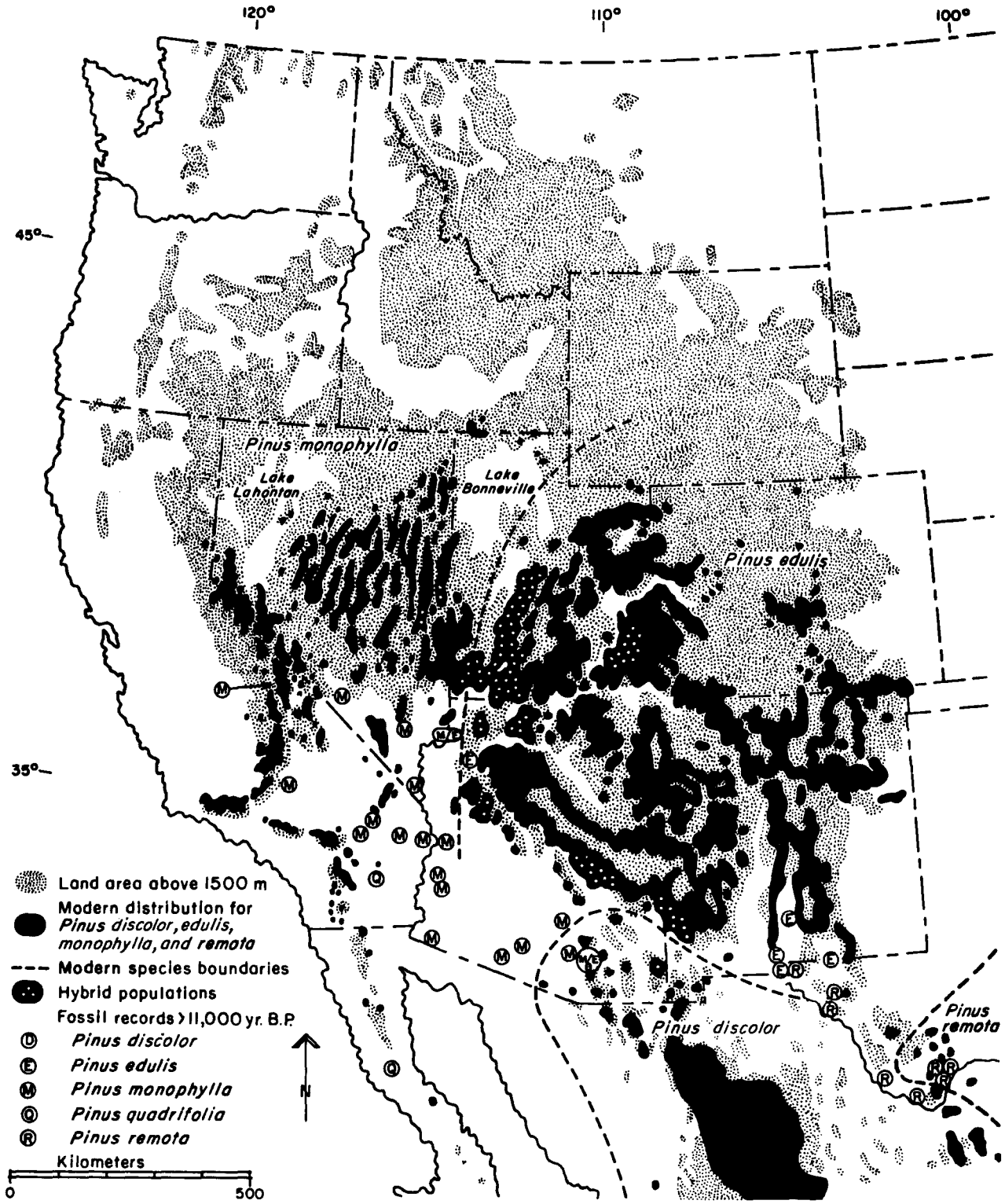


Figure 4.--Map of western North America with areas >1500m stippled, modern pinyon distributions in black (hybrid areas dotted), and fossil occurrences (letters in small circles). Southwest Arizona fossils are referred to P. monophylla by Lanner and Van Devender (1974) or P. edulis var. fallax by Wells (1979).

research should focus on identifying the relative importance of p-j woodland and interior chaparral in the Sonoran Desert region during the last glacial.

In terms of taxonomy, one has to be impressed with the morphological similarity of "P. fallax" to P. edulis and relative dissimilarity to P. monophylla in starchiness of seed and number of stomatal bands in the leaves (Wells, this volume, in reference to D.K. Bailey's work in progress). Figure 5 is a rough and tentative model that contrasts maximal and refugial distributions of four pinyon taxa, with "P. fallax" considered as a separate species, for the last glacial-interglacial cycle. This model implies refugial status for P. edulis and maximal ranges for "P. fallax" and P. remota during the glacial period, with their status reversed in the Holocene. P. monophylla was absent from the Great Basin, with protracted isolation from P. edulis in the glacial period. Fleeting opportunities for hybridization and introgression occurred in the Holocene when P. monophylla and P. edulis expanded into broad areas of sympatry. The evolutionary order of these pinyons remains unclear. Monophylly need not have arisen independently in "P. fallax" and P. monophylla to explain the relation of these taxa, as was suggested by Lanner and Van Devender (1974). The hypothesis that "P. fallax" could be ancestral to P. monophylla, or perhaps a relict hybrid, awaits chemosystematic and chromosomal analyses of both modern populations and fossil material. Extraction of DNA from 44,000 yr old plant tissue in packrat middens (Rogers and Bendich 1985) suggests that molecular preservation is excellent, though the volatile terpenoids are probably short lived.

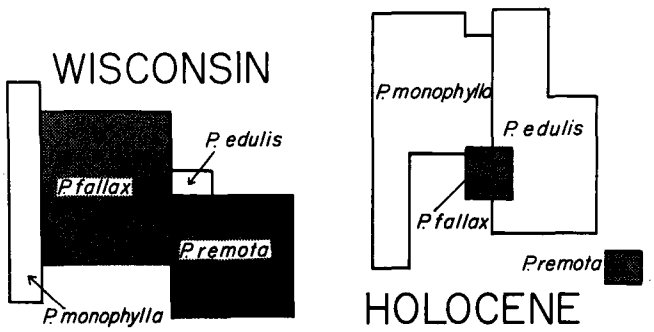


Figure 5.-- Schematic representation of maximal vs. refugial ranges of four pinyon taxa during the last glacial-interglacial cycle; scale and geography are generalized. "P. fallax" is here considered a separate taxon, possibly ancestral to P. monophylla or a relict hybrid.

WOODLANDS OF THE HOLOCENE

With the onset of Holocene warming, p-j woodlands rose onto the regional platform above 1500 m and migrated north as subalpine conifers retreated upslope. Altitudinal displacements occurred more rapidly than latitudinal ones, so that the changes were time-transgressive and perhaps contributed to "vegetational inertia" (Cole 1985). P. edulis vacated its lowland refugium in the northern Chihuahuan Desert by 11,000 yr B.P. (Van Devender, this volume). On the Colorado Plateau, Pinus flexilis, Picea pungens, Pseudotsuga menziesii, and Juniperus scopulorum held their ground at relatively low elevations (1585 and 1910 m) for 1000 yrs more (Betancourt and Van Devender 1981; Betancourt 1984).

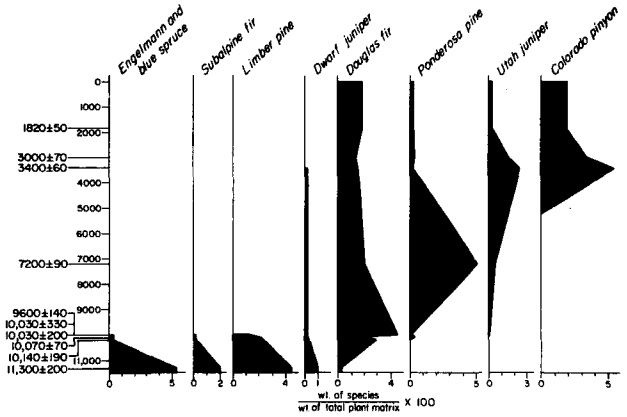


Figure 6.-- Macrofossil diagram for nine conifers in middens from Allen Canyon Cave (2200 m) on the south slopes of the Abajo Mountains, southeast Utah.

Pinyon's northward advance was accompanied by the development of a Pinus ponderosa transition that now widely separates p-j woodland from mixed conifer and subalpine forests. Both P. edulis and P. ponderosa colonized the Plateau ca. 10,000 yr B.P., at about the same time that Juniperus osteosperma expanded eastward from the Grand Canyon (fig. 3). The early dominance of P. ponderosa at relatively low elevations on the Plateau might have prevented P. edulis from advancing to its uppermost elevations until the last 6000-4000 yrs (Cole 1982; Betancourt 1984). Figure 6 shows the macrofossil abundance for nine conifers through time in middens from Allen Canyon Cave, southeastern Utah. Today, the site is in the ecotone between p-j woodland and P. ponderosa forest on the south slope of the Abajo Mountains. The rather recent arrival of P. edulis coincides with a significant reduction in P. ponderosa. Here it could be argued that climate has tipped the competitive balance first in favor of P. ponderosa and later of P. edulis. This hypothesis is testable at the northern limits of P. edulis, where an early or middle Holocene expansion of P. ponderosa would have truncated the pinyon's "altitudinal wedge" (Neilson, this volume: fig. 1) and forestalled its northern advance until the late Holocene.

Though the northward migration of P. monophylla was equally spectacular, its arrival at sites throughout the Great Basin was delayed until after 6600 yr B.P. (Thompson 1984). Thompson and Hattori (1983) have speculated that the advance of P. monophylla awaited the development of winter inversions, summer

rainfall, and elevated summer temperatures in the middle Holocene (post 8000 yr B.P.). At least part of the delay may be due to its insular distribution in the Great Basin, unlike the more continuous range of P. edulis in the southern Rockies and Colorado Plateau (fig. 4). Much has been made of the role of corvids as dispersal agents and the possible effect of these birds on Holocene pinyon migrations (Lanner 1983; Wells 1983). Mehringer (in press) has recently suggested a possible link between the expansion of Archaic peoples and that of their staple, P. monophylla, across the Great Basin. At Gatecliff Shelter in the Toquima Range, charred seeds of pinyon precede its presence in packrat middens by only a few hundred years (Thompson and Hattori 1983).

Early speculation about man's role in dispersing pinyon actually involved a small P. edulis grove on a limestone ridge in northeastern Colorado, some 250 km north of the nearest pinyon. Beidleman's popular account of the Owl Canyon disjunct bears repeating:

> For two miles the grove stretches, an open forest at the southern end, interspersed with competing ponderosa pine, juniper, and mountain mahogany... What mystery shrouds the origin of this isolated grove! Is it a relict of some temperate forest which was forced southward by the arduous climates of the last Ice Age... might it be an exploratory northern venture of an expanding southwestern woodland? Or is it a mere distribution, a chance planting by some animal, perhaps man, on a site where soil and sunlight and moisture fortuitously combined...? (Beidleman 1953: 7).

Through tree-ring analysis, Wright (1952) demonstrated that the age of the pinyons radiated out from a few 400 yr old trees in a protected ravine at the northern end of the site, an unlikely distribution were the stand of considerable antiquity. Most authors now agree that the oldest trees may represent the first pinyons ever to colonize the site through long distance dispersal (Weber 1965; Lanner 1975). They also recognize the unlikelihood of a corvid flying uninterrupted for 250 km with a crop full of seeds. Perhaps a nut or two was spilled from the trail mix of some Cheyenne or Arapaho, who stopped for the night near the wooded scarps along the grassy foothills of the Front Range.

A series of packrat middens a few hundred meters east of the oldest trees at Owl Canyon demonstrates the youth of the stand (fig. 7; Betancourt, Van Devender, and Anderson, in preparation). Middens without pinyon but with abundant Juniperus scopulorum are common along the pinyon-dominated scarp of the Owl Canyon monocline. The oldest tree along the scarp is probably less than 200 yrs old (Wright 1952), in fair agreement with the radiocarbon age of the first pinyon macrofossils. P. edulis replaces P. ponderosa and J. scopulorum in the midden sequence, recalling Beidleman's reference to competition. Today junipers are most common at the periphery of the grove. Sixty kilometers north in the arid Laramie Basin, Wells (1970) has documented the demise of J. scopulorum, as evidenced in packrat middens and dead stumps, within the last 200 years. Tree rings in the dead stumps average a full magnitude wider than living trees at one of Wells' sites (Elliott-Fisk 1983). Perhaps the competitive balance at Owl Canyon has been affected by climatic change, selecting against the more mesophytic juniper and possibly P. ponderosa.

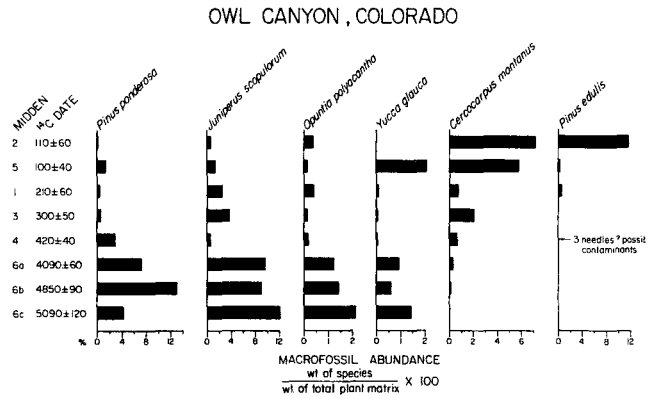


Figure 7.-- Macrofossil diagram for Owl Canyon (1890 m), Larimer Co., Colorado showing recent arrival of P. edulis with consequent reduction in P. ponderosa and J. scopulorum.

According to Hawksworth (1979), corvids are actively dispersing pinyon within a 30 km radius of Owl Canyon, resulting in several localities with isolated trees. Questions that remain unanswered at Owl Canyon are the likely limits and limiting factors to this local expansion and the possible effects of pinyon-specific parasites (for example, Pinyonia edulicola, Junetiella), should they discover this small and distant target. Perhaps the success of the Owl Canyon pinyons is because they do not suffer the additional stress of biotic factors present to the south. Or perhaps it is the high specific heat of limestone, which rarely outcrops at critical elevations on the foothills of the Front Range, that buffers temperature extremes at this northerly site. Lindroth (1953) relied on this factor to explain the coincidence of limestone outcrops and disjuncts of Carabid beetles north of their normal range in Europe.

Like weed invasions (Mack 1985), recent p-j colonizations offer excellent opportunities to study population biology. One case study in Nevada caused Harper (1972: 608) to comment that "there is no more beautiful set of population growth curves in the whole of plant biology." Because we are probably dealing with the founder effect, the pinyon grove at Owl Canyon presents the unusual opportunity to estimate intrinsic rates of population growth, which are currently only modeled by theoretical equations. Not only can population growth be measured, but the pathways and rates of expansion, as well as the effects of competition, can also be observed directly. Hence, one might anticipate growth suppression of

P. ponderosa and J. scopulorum to be manifested in tree rings, were competition with P. edulis a factor. Lamentably, the ecological importance of Owl Canyon has been undermined by over 40 years of limestone quarrying, despite early attempts to save the pinyon grove. Even so, the age structure of the survivors, seedling recruitment, and species interactions remain relatively undisturbed in areas not quarried and should be the focus of further study.

PRESETTLEMENT CONDITIONS AND POSTSETTLEMENT INVASIONS

The debate about the relative influences of livestock, fire suppression, and climate in recent p-j invasions parallels the controversy over what caused historic arroyo-cutting. In many parts of the West, ranchers saw vegetation and streams change drastically and in tandem. They made the connection between cows and gullies and voiced it in the newspapers of the day. Kirk Bryan (1928), the geologist who actually knew many of these ranchers, conceded that overstocking pulled the trigger. In buried paleochannels, however, he saw evidence that arroyos were a natural part of the landscape and would have developed anyway. Likewise, Mehringer and Wigand (this volume) show that the recent invasion of J. occidentalis in the northwestern Great Basin is no more dramatic than its comings and goings at the same sites over the past few millennia. Davis (this volume) suggests that historic juniper invasion in central Arizona is simply an accelerated version of something that has been going on for 2000 yrs. How stable then was the so-called pristine, presettlement vegetation and how unique are the most recent invasions? Can we really blame overgrazing and fire suppression for the fact that "one-half of the area of the Great Basin now occupied by pinyon and juniper is of rather recent, historical derivation" (West 1984: 131)? Could p-j invasions reflect the woodland's resilience from historic (Lanner 1977) and prehistoric (Betancourt and Van Devender 1981) fuelcutting, or perhaps even severe drought? The westwide drought of 1899-1904 killed many trees, principally P. edulis, in New Mexico and Colorado (Phillips 1909). How has recovery affected the age structure of these stands, presumably near the woodland-grassland boundary?

Unfortunately, the studies at Lava Beds, Diamond Craters (Mehringer and Wigand, this volume), and Pecks Lake (Davis, this volume) are only rare, if not pioneering, attempts to give greater time depth to records of historic invasion. Few Holocene paleobotanical data have been collected from the woodland-grassland boundaries in the Chihuahuan, Sonoran, and Mojave deserts, or from the areas of reported invasions throughout the Great Basin and Colorado Plateau. In general, though, the now dominant species of pinyon and juniper apparently arrived at their northern and uppermost stations only within the last few thousand years, and may "still be riding the tides of a changing climate" (Mehringer and Wigand, this volume). Today, J. osteosperma reaches as far northeast as the Big Horn Basin in Wyoming, where it occupies rocky sites between 1370 and 1910 m (Wight and Fisser 1968; Waugh and Fisser, this volume). What will limit J. osteosperma from eventually migrating south along the Front Range to join northern outposts of P. edulis and J. monosperma at Owl Canyon and Colorado Springs?

The notion that woodland recovery from settlement or presettlement woodcutting accounts for the apparent invasions is seldom given much importance (West 1984). Hattori and Thompson (this volume) conclude that woodland expansion actually predated mining impacts and thus, woodland recovery, near Cortez in central Nevada. Oak-conifer woodlands near Tombstone, Arizona, have recovered quickly from historic mining, due to the lesser damage caused by pollarding and subsequent protection by the Forest Service (Bahre and Hutchinson 1985). Though intense, the demands of the charcoal industry, whether in Cortez or Tombstone, were short lived compared to prehistoric fuelcutting in the Southwest. Muir's (1894) account of California Indians killing white men caught felling pinyons should not be generalized. Fuel harvesting by native peoples seriously decimated marginal p-j woodlands on the Colorado Plateau, particularly in the last 1000 yrs. One need look no further than the Hopi Mesas (Hack 1942) or Chaco Canyon (Betancourt and Van Devender 1981) for the lasting effects. There the daily fuel needs of large pueblos over several centuries have left a landscape barren of trees. Marginal p-j stands throughout the Colorado Plateau probably suffered a similar fate, though at wetter sites such as Mesa Verde, recovery was swift (Martin and Byers 1965).

DISCUSSION

During the last glacial-interglacial cycle, some pinyon and juniper species shifted from refugial to maximal distributions, while others did the reverse. In either case, extinctions were avoided by the presence of refugial sites at low elevations and southerly latitudes. Though the present interglacial is almost over, species that expanded are still on the move. Given enough time, J. osteosperma might eventually grow with P. edulis on the east side of the Rockies, each advancing from the north and south, respectively. Historic invasions at some localities may only mark the present progress of such migrations. Northern disjuncts (J. scopulorum in British Columbia: Adams 1983) and hybrids where one of the parents is missing (P. edulis x monophylla: Lanner and Hutchinson 1972; Q. gambelii x turbinella: Cottam and others 1959; Neilson and Wullstein 1983) have been attributed to northern advances during mid-Holocene warming and retreat with late Holocene cooling. Harper and others (1985) suggest that the oak hybrids in northern Utah may be the result of long-range pollination, certainly during the Holocene, but not necessarily in the Altithermal. Currently, there is little paleoecological basis for either model, though packrat middens offer a way to determine the age and history of these disjuncts.

Paleoclimatology by way of the fossil plant record relies heavily on uniformitarianism and assumptions about the equilibrial state of modern vegetation with present climate. The present alignment of

range limits with air mass boundaries (Mitchell 1969; Neilson, this volume) could be fortuitous. Part of the problem is the dearth of knowledge about the physiological tolerance of plants relative to their modern distributions. Such knowledge is now acquired incidental to queries about historical biogeography or past climates. This can be remedied by recruiting plant physiologists and ecologists to study key plants and particular issues raised by the fossil record. One example is Neilson's (this volume) suggestion that irregular mast years in pinyon may be linked to short-term cycles in the relative position of the jet streams, perhaps bearing directly on former pinyon distributions. The infrequency of seed years may be controlled by the need to accumulate food reserves over several growing seasons, as indicated by inverse correlations of precipitation and tree-ring widths for flowering and fruiting years (Fritts 1976). Synchroneity of bumper crops across a wide area may have evolved as a way to satiate predators and ensure that a large part of the seed crop is carried away and stored where trees are scarce (for example, Janzen 1971). Climate may indeed explain different recurrence intervals for mast years in the various species of pinyon. What, for example, is the recurrence interval for P. edulis var. fallax and peripheral populations of P. edulis and P. monophylla? Finally, it is clear that the relationship between both modern and historical branches of ecology must be symbiotic, if we are to understand migrational dynamics and community development of p-j woodlands.

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Fire in Pinyon-Juniper Woodlands

Chaired by:

Henry A. Wright, Professor, College of Agricultural Sciences, Texas Tech University, Lubbock

USE OF PRESCRIBED BURNING IN JUNIPER AND PINYON-JUNIPER WOODLANDS

Stephen C. Bunting

ABSTRACT: Postfire succession in juniper and pinyon-juniper is primarily dependent upon the potential of the site, the preburn plant community and the characteristics of the fire. The successful use of prescribed burning is dependent upon the appropriate selection of treatment sites. As juniper and pinyon become more dominant on a site, the shrub and herbaceous layers decline in productivity. This reduces the fine fuels on the site making it more difficult to burn. There are also fewer herbaceous perennial plants remaining on the sites with greater tree dominance and the response of this component is less than that of sites burned at an earlier stage of juniper invasion. Treatment sites should be selected that are in stages of succession that can be efficiently burned in an economical and environmentally sound manner.

INTRODUCTION

Pinyon-juniper and juniper (Pinus spp., Juniperus spp.) communities are major grazing types throughout the western and central portions of the United States. They occur on a wide variety of soil types (West and others 1978) and environmental conditions. In the southern Great Plains, eastern redcedar (Juniperus virginiana) and Ashe juniper (J. ashei) occur in areas receiving over 750 mm of precipitation annually. Pinyon-juniper communities in the Great Basin may occur in areas receiving as low as 250 mm.

There are two aspects that nearly all pinyon-juniper and juniper communities have in common. They are increasing in tree density and/or invading into adjacent grassland or shrubland types. It has been estimated that at least one-half of the present juniper acreage has become established since the settlement of the areas by Euro-Americans (Tausch and others 1981; West 1981). As the juniper stand develops, the herbaceous productivity of the site declines. Jameson and Reed (1965) found that as the juniper coverage increased from 0 to 60 and 80 percent, herbage production declined from 660 to 110 and 55 kg/ha, respectively. This loss of productivity seriously reduces the area's carrying capacity for wild and domestic animals.

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Stephen Bunting is associate professor in the College of Forestry, Wildlife and Range Sciences, University of Idaho, Moscow.

Natural control of increase in pinyon and juniper during pristine periods was by fire during short periods of time (Burkhardt and Tisdale 1976) and climate factors during longer periods (Wells 1966; Mehringer and Wigand 1984). Research has shown that under present conditions plant competition alone will not prevent the establishment of juniper seedlings (Smith and others 1975; Burkhardt and Tisdale 1976). Furthermore, complete protection from grazing will not reverse the trend. Potter and Krenetsky (1967) found that after 25 years of livestock exclusion from a pinyon-juniper stand, the herbaceous production was not different from that of a grazed community.

Control of pinyon and juniper can result in increases of herbaceous production of up to 650 percent (Clary and Jameson 1981). Mechanical treatments have been successful (Aro 1971; Winegar and Elmore 1978) as well as the use of prescribed fire (Wink and Wright 1973; Martin 1978).

PRESCRIBED FIRE EFFECTIVENESS

Prescribed fire has been successfully used following mechanical control of pinyon and juniper (Aro 1971; Wink and Wright 1973) and sites may produce up to a 10-fold increase in herbaceous production after such treatment (Aro 1971).

Prescribed fire has also been used to treat green standing trees but control of the pinyon and juniper under such conditions may be more difficult. Martin (1978) found that often more than 50 percent of western juniper (J. occidentalis) individuals greater than 6-m tall survived fire under prescribed burning conditions. General observations indicated that less than 30 percent of the trees survived wildfires. Dwyer and Piper (1967) found that fire killed nearly all pinyon and juniper less than 1.2-m tall but only 24 percent of the pinyon and 13 percent of the juniper greater than 1.2 m.

As a stand of juniper becomes dominant on a site, it becomes more difficult to burn. The juniper compete with the understory which declines in cover and productivity with time (Arnold and others 1964; Barney and Frischknecht 1974). An overstory of pinyon increases the likelihood of a stand burning and pure stands of juniper are almost impossible to burn (Blackburn and Bruner 1975; Martin 1978). The reduction of herbaceous material also reduces the fire intensity which in turn reduces the scorch. Consequently, areas with low amounts of fine fuels may burn but not scorch

the junipers sufficiently to kill the plant. In order to compensate for this, the fire prescription must be widened to increase fire intensity. The behavior of higher intensity fires is more difficult to predict and has a greater impact on the survival of understory plants. Fires of these intensities may severely reduce understory grasses from the burned site (table 1).

FUEL CONSIDERATIONS

The relationship of fuels, tree canopy cover and fire intensity is not completely understood. Wink and Wright (1973) found that sites with greater than 2245 kg/ha of fine fuels would develop a fire intensity sufficient to easily kill Ashe juniper greater than 3.7 m tall. Many juniper and pinyon-juniper sites of the Columbia and Great Basins are not productive enough to provide this amount of fine fuel, particularly if they have an overstory of trees. The amount of herbaceous production varies greatly depending upon the site, but Wright and Bailey (1982) estimated the average production to be approximately 675 kg/ha for sites with moderate amounts of pinyon and juniper in the Great Basin. Yields on productive sites may be as great as 1575 kg/ha. Hall (1973) described four community types of western juniper in the Blue Mountains of Oregon. The production on all of these types was estimated to be less than 450 kg/ha.

The lower limit of fine fuels required for a successful prescribed fire in these types has not been documented and depends upon a number of factors such as: (1) density and size of pinyon or juniper trees present, (2) slope of the site, (3) fuel continuity, and (4) amount of sagebrush or other shrubs in the community. Beardall and Sylvester (1976) have indicated that sagebrush/grasslands are difficult to prescribe burn in the spring when the fine fuels are less than 675 kg/ha. Britton and Ralphs (1979) stated that they did not believe that prescribed burning on sagebrush/grasslands could be consistently conducted if the sagebrush cover was less than 20 percent. Fire behavior in open stands of juniper

Table 1.--Vegetal composition (percent canopy cover) of burned plots prior to and 1 and 2 years following fall prescribed burning of western juniper in the Owyhee Mountains of southwestern Idaho

	Site 1			Site 2			Site 3		
	1979	1980	1981	1979	1980	1981	1979	1980	1981
Shrubs:									
Artemisia tridentata ssp.vaseyana	10	Tr	1	32	Tr	1	32	Tr	Tr
Grasses:									
Agropyron spicatum	4	3	3	1	Tr	Tr	1	Tr	Tr
Festuca idahoensis	2	1	1						
Sitanion hystrix	4	1	2	7	1	1	4	Tr	Tr
Stipa occidentalis	1	3	4	5	6	2	1	Tr	8
Stipa thurberiana	4	1	1	2	Tr	Tr	1	Tr	Tr
Other grasses	8	4	9	1	1	2	1	Tr	Tr
Forbs:									
Balsamorhiza sagitata	Tr	Tr	Tr	2	3	4	1	4	4
Lupinus spp.	1	3	3				3	7	17
Annual forbs	Tr	4	8	Tr	4	17	Tr	8	23
Other forbs	2	10	30	5	7	22	2	4	11
Total shrub cover	21	Tr	1	32	Tr	1	32	Tr	1
Total grass cover	22	11	18	16	7	8	7	1	9
Total forb cover	4	15	42	11	23	66	5	23	54
Total plant cover excluding juniper	47	26	61	59	30	75	44	24	64

or stands in the early stages of invasion is often similar to that of sagebrush/grasslands. These minimum values may also have application in the juniper and pinyon-juniper types.

The increase in dominance of the site by pinyon or juniper not only reduces the productivity (Jameson and Reid 1965) but also the density of herbaceous plants. Consequently, areas with dense tree overstories may not have adequate amounts of perennial grasses to respond quickly if they are burned (Bedell and Bunch 1978). The fire intensity and severity is also necessarily greater to burn areas with lower amounts of fine fuels. We have noted greater amounts of mortality on Idaho fescue (Festuca idahoensis), bluebunch wheatgrass (Agropyron spicatum), western needlegrass (Stipa occidentalis), and Thurber needlegrass (S. thurberiana) when burning under these conditions in western juniper. Under the most extreme conditions the sparse understory may be virtually eliminated by the fire and only slowly becomes re-established on these sites. These sites are then susceptible to establishment by annuals such as cheatgrass (Bromus tectorum), autumn willoweed (Epilobium paniculatum), and cryptantha (Cryptantha spp.).

RESPONSES TO FIRE INTERVAL

Prescribed fire can be used successfully as a management tool in juniper and pinyon-juniper vegetation. However, care must be taken when selecting the treatment areas. Areas with older and/or denser stands of trees will be more difficult to burn and will require more time to become vegetated by desirable perennial plants. The earlier in the invasion process that fire occurs, the more easily pinyon and juniper plants are controlled. This will require burning an area more frequently, however. Burning on a very short interval may also remove other shrubs such as mountain big sagebrush and antelope bitterbrush (Purshia tridentata) from the site, which may not always be desirable (table 2). Bitterbrush in juniper communities is poorly adapted to fire (Bunting and others 1985) and may require 20 years or more to recover completely from the fire. Big sagebrush does not resprout and this species will also be removed from the community if the fire-free interval is short. Green rabbitbrush (Chrysothamnus viscidiflorus) resprouts and establishes from seed readily following fire and may dominate sites if fires occur frequently. More frequent fires will help maintain the productivity of many of the herbaceous species, particularly forbs. An interval should be chosen which will allow the area to meet the management objectives and continue to maintain the potential of the site.

Table 2.--Scenario of plant response to varying fire intervals relative to current conditions in western juniper communities in the Owyhee Mountains of southwestern Idaho

	Average fire recurrence (yrs)			
	<10	25	50	100
Shrubs:				
Artemisia tridentata ssp. vaseyana	-	0	0	-
Chrysothamnus viscidiflorus	+	+	0	-
Juniperus occidentalis	-	-	0	+
Purshia tridentata	-	-	0 to +	-
Grasses:				
Agropyron spicatum	0	+	+	-
Festuca idahoensis	0 to -	+	+	-
Sitanion hystrix	+	+	0	-
Stipa occidentalis	+	+	0	-
Stipa thurberiana	-	0	0	-
Forbs:				
Agoseris spp.	+	0	-	-
Balsamorhiza sagittata	+	+	0	-
Crepis spp.	+	0	-	-
Lupinus spp.	+	+	0	-

[1] This region receives greater than 350 mm annual precipitation and is over 1500 m in elevation.

[2] Symbols indicate that in the long term this species will: - = decrease, 0 = not change, or + = increase in abundance under this fire interval as compared to the current status.

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HISTORY AND RESULTS OF PRESCRIBED BURNING OF PINYON-JUNIPER WOODLAND ON THE HUALAPAI INDIAN RESERVATION IN ARIZONA

Del W. Despain

ABSTRACT: Nearly 22,000 acres of pinyon-juniper woodland were burned and seeded from 1953 to 1963 on the Hualapai Indian Reservation in northwestern Arizona. Burning was conducted during very hot, dry conditions. Seeded grass species currently dominate these areas and reestablishment of pinyon or juniper trees is largely absent.

INTRODUCTION

The Hualapai Indian Reservation, located in northwestern Arizona, covers approximately 992,500 acres(Schroeder [1962?]). Natural woodlands dominated by pinyon pine (Pinus edulis) and Utah juniper (Juniperus osteosperma) cover from 460,000 acres (BIA 1964) to 540,000 acres (Schroeder [1962?]) or about half the reservation.

An extensive prescribed burning program of pinyon-juniper woodland was carried out on the Hualapai Reservation during the late 1950's and early 1960's. Nearly 22,000 acres of woodland were successfully burned and seeded during this period. Currently, seeded grass species still dominate the burned areas with little invasion by tree or shrub species. Forage yield is still significantly higher on burned and seeded areas than on unburned areas.

HISTORICAL BACKGROUND

Large scale vegetation conversion on the Hualapai Reservation began with William L. Schroeder, a range conservationist for the Bureau of Indian Affairs (BIA). Mr. Schroeder credited his interest in vegetation conversion to experience on the Fort Apache Indian Reservation in eastern Arizona in company with a Montanan by the name of William R. Centerwall. Schroeder believed Mr. Centerwall to be the "first person in the Indian Service to recognize the seriousness of the juniper problem". The "problem" was encroachment of grasslands by pinyon and juniper. Loss of forage as well as sheet and gully erosion were attributed to this change in plant community structure (Schroeder [1956?]a).

In 1940 Mr. Centerwall issued a report concerning the need for "eradication" of pinyon and juniper on the Fort Apache Reservation (Centerwall 1940). This report resulted in a CCC project where two small areas were cleared of alligator juniper (Juniperus Deppeana); one by cabling, the other by hand cutting. World War II put a temporary end to conversion projects.

After the war, juniper control projects were reinitiated. Several controlled burns were attempted, but "never proved successful, mainly due to lack of ground cover to carry the fire" (Schroeder [1956?]a). Individual tree burning with torches was tried and even burning with what was called "goop", the substance of incendiary bombs used in the war. Most of the acreage treated on the Fort Apache Reservation during this period was treated by hand cutting smaller trees, piling them around the base of larger trees and then burning these piles when they dried. It was felt that the soil sterilization that resulted under these piles was offset by "the value to the range in getting rid of seed trees" and the fact that "little or no grass" occurred beneath the trees anyway. About 80,000 acres were reportedly treated in this manner on the Fort Apache Reservation between 1948 and 1954 (Schroeder [1956?]a, Arnold and Schroeder 1955). It was with this background that Schroeder went to the Hualapai Reservation in 1955.

In late June of 1953, prior to the arrival of Schroeder, BIA personnel on the Hualapai were attempting to burn sagebrush in Prospect Valley on the east side of the Reservation. The fire escaped into adjacent pinyon and juniper woodland where it burned out of control for 10 days (Schroeder [1962?]). Most reports and articles written about this fire estimate the total acreage burned at about 16,000 acres. However, recent digitizing of the boundaries of the burn indicates that the correct figure is closer to 10,000 acres.

Junior Tapija, a BIA employee involved with the initial sagebrush burning says the tribal council was especially upset and that for a time their jobs were in jeopardy (Tapija 1985). Attitudes of the time can also be discerned from a later report which says in reference to the 1953 burn; "Although we call this fire a controlled fire, it actually was a wild fire and finally went out of its own accord" (BIA [1957]). This, incidently, was not until it reached the rim of a finger of the Grand Canyon. There is very little information available concerning this fire. "Due to the fact that this fire got to such a large size and with the thought that there might be quite a little criticism concerning it, there were few reports and little data made on the fire" (Schroeder [1962?]).

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Del W. Despain is Range Associate, Division of Rangeland Resources, School of Renewable Natural Resources, University of Arizona, Tucson, AZ.

The year following the fire, 14,000 of the estimated 16,000 acres were aerially broadcast seeded with a mixture of grasses. By 1955, the potential benefits of the fire and seeding to the livestock industry, which was and still is an economic mainstay on the reservation, were recognized to the point that burning plans were initiated. By 1956, a full scale burning program was underway which continued through 1966. Only a small amount of burning was successfully accomplished after 1963. A small amount of burning was completed in 1964 and burning conditions were poor in 1965 (Schroeder 1966). BIA personnel were ready to burn in 1966 (Gray 1966), but apparently little burning was successfully accomplished. It was at about this time that Mr. Schroeder became ill and retired. Prescribed burning largely ceased on the reservation until recently.

The reason given for such a large burning program on the Hualapai at a time when mechanical means of tree removal were popular was that funds were too limited to use mechanical means on a widespread basis (Schroeder 1956b).

FIRE PRESCRIPTIONS

Fire prescriptions used on the Hualapai can be summarized as selecting the hottest and driest conditions possible during the year. Specific recommendations were outlined as follows (Schroeder 1966):

- The best burning period is in late June after the dry May-June period but just before the summer thunderstorm season. Most burning during the 10 year period (1953-1963) on the Hualapai was done between June 20th and July 10th. Late spring precipitation usually prevented successful burns.

- Fires should be ignited between noon and 3:00 pm.

-Air temperature must be in the high 80's or higher.

- Wind velocity should be from 15-20 mph and steady.

- Relative humidities should be less than 8%.

Experience from this period indicated that it was difficult to burn stands with tree densities of less than 200 trees/acre (Schroeder [1962?]). Most burns were ignited from 20-50 ft. wide windrows created by pushing a band of trees up against adjacent trees. More complete burns were obtained when parallel windrows were constructed at 1/2 mile intervals perpendicular to wind direction. An interesting opinion expressed was that the presence of some pinyon was necessary because "the volatile oils in the pine make for a hotter fire" (Schroeder 1966, [1962?], [1956?]a, BIA [1962?]). Any relationship between the presence of pinyon and tree densities was not indicated. Mr. Schroeder summarized conditions when he said; "due to the extreme conditions necessary ... burning is possible only a very few days each year" (Schroeder 1966).

An example of burning scenarios is available from 1957 notes (Schroeder, 1957b). Burning that year was done from a windrow that extended over about 5 1/2 miles of terrain. The resulting successfully burned band was somewhat narrow, however.

June 19
1:30 pm - temperature 75 degrees
- wind velocity 15 mph
- 300 yards ignited - did poorly
3:00 pm - 200 yards ignited - did poorly

June 20
1:00 pm - temperature 87 degrees
- wind velocity 13 mph
- humidity 10%
- 1 1/2 miles set - fair to good results

June 25 & 26
- Fair burning

June 27
- temperature 100 degrees
- wind velocity 8 mph
- humidity 10%
- good burning

Approximate total acreages of pinyon-juniper woodland burned during the 10-year period from 1953 to 1963 are listed in table 1. Acreages were

Table 1.--Original and current estimates of acreages of pinyon-juniper woodland burned from 1953 through 1963 on the Hualapai Indian Reservation

	TOTAL AREA BURNED (acres)	
YEAR	ORIGINAL[1] ESTIMATES	CURRENT[2] ESTIMATES
1953	16,000	10,008
1954		
1955	700	824
1956	6,000	3,182
1957	2,000	722
1958	300	---
1959	1,000	664
1960		
1961	3,110	2,143
1962	1,820	1,052
1963	2,220	2,112
Year unknown		153

1 (BIA 1964)

2 Current estimates do not include unburned islands or sagebrush bottoms within burned areas.

determined by computer digitizing of burned boundaries transferred from aerial photographs to topographic maps. Estimates are generally less than those given in BIA reports. A portion of the differences in the estimates may be explained by the exclusion of unburned islands of trees and open sagebrush bottoms from the most recent estimates. Burning conditions were reported to be poor in 1955 and 1958 because of late-spring precipitation. Efforts in 1960 were concentrated on chainings (BIA 1964).

SEEDINGS

All major burns were broadcast seeded mostly with introduced grass species (table 2). Some areas were seeded by hand with "Cyclone" or "Banjo" spreaders in July, soon after burning, to take advantage of summer storms. Others were aerially seeded, usually in the fall. (Schroeder 1966; BIA 1964). At the end of the 10 years of experience, crested wheatgrass (Agropyron cristatum) and western wheatgrass (Agropyron smithii) were considered the best species for seeding. At one time, considerable optimism was expressed for Lehmann lovegrass (Eragrostis lehmanniana) following very good initial establishment. It was soon realized, however, that the climate was not suitable for continued survival of that species. (Schroeder [1962?], 1966).

COSTS

Preparations prior to burning on the Hualapai Reservation were minimal compared with common practices today. Few fire lines were constructed and fires were often started from sagebrush dominated drainages with little mechanical preparation. The greatest expense was incurred on those burns where windrows were constructed from which to ignite the fires. Total per-acre costs varied depending on the method of burning used and the size of the areas successfully burned.

Seed costs accounted for the largest single expense of the burning projects. In 1956, seed alone reportedly cost $3.12/acre as applied to 6,000 acres at a rate of 8 lbs./acre. The total per acre cost of burning and seeding that year varies among reports, but was as high as $5.12/acre. The cost would recalculate to $9.60/acre if the estimate of about 3200 acres burned in 1956 were used (see table 1). This was the most expensive project reported in spite of the fact that few windrows were constructed that year with most fires ignited from sagebrush bottoms. Cost figures steadily declined over the next few years to a low of $3.80/acre in 1963 despite the increased use of windrowing. The reason for the steady decline in costs is not apparent from records available. (BIA 1964, Schroeder [1962?], Schroeder 1957a).

PAST AND CURRENT PERCEPTIONS

After 10 years of burning and seeding experience, perceptions of success and attitudes at the time can be inferred from a 1964 "brush control" report (BIA 1964). "Brush" was still considered one of the major "problems" on the Hualapai Reservation. The report indicated plans to convert a total of 300,000 acres of woodland over the following years in addition to the 35,150 acres estimated to have already been burned and chained. One third of this

Table 2.--Species and approximate rates used in major seedings on the Hualapai Indian Reservation from 1954 to 1963 (BIA 1964)

SPECIES	RATE BY YEAR (lbs/acre)						
	1954[1]	1956	1957	1959	1960	1962	1963
Crested wheatgrass	1.00	3.50	2.50	6.00	5.00	3.00	5.00
Western wheatgrass	3.00	2.00					
Yellow sweet clover	1.00	2.00	1.00	0.75	0.25		
Weeping lovegrass	0.50	0.25	0.33	0.75			
Sand dropseed		0.25	0.33	1.00	0.25		
Intermed. wheatgrass		0.50[2]			1.00	1.00	1.00
Perennial ryegrass			1.50				
Lahontan alfalfa			0.33				
Lehmann lovegrass					0.25		0.25
Smooth brome					1.00	1.00	1.00
Russian wildrye						1.00	

[1]1953 burn was seeded in 1954

[2]Applied only on a portion of the area burned in 1956

additional acreage or 100,000 acres was to be burned with the remaining 200,000 acres to be chained or hand cut. Only 125,000 (27%) of the original estimated 460,000 acres of woodland were to be left unconverted, mostly because they were considered "to be on slopes too steep to control or on acres not thought worth treating". It was also recognized that some areas should be left "for the protection of the wildlife". A goal was also set to burn half of the estimated 200,000 acres of blackbrush on the reservation (BIA 1964).

Except for some mechanical clearing, little of this planned conversion was actually completed. Burning programs largely ceased after the departure of Schroeder although there have been wildfires. A small area of pinyon and juniper was burned in 1982 and recently some blackbrush dominated areas have been burned.

Current attitudes of tribal livestock operators and BIA personnel are still favorable concerning the burned areas. Livestock operators talk as much about the benefits of tree removal for simplifying livestock management and handling as about any increase in forage realized. Elk were introduced on the area in 1963 and have done reasonably well. McCulloch (1969) concluded that the burned areas have been beneficial for deer except perhaps the very large burns.

Management emphasis for pinyon and juniper woodlands has now changed on the Hualapai just as it has elsewhere. Future burning activities and other woodland conversion projects are being considered only as one part of a comprehensive plan centered more around management of the woodland as a resource rather than as a liability.

VEGETATION CONDITIONS

Few records are available regarding vegetation changes that have occurred as a result of prescribed burning on the Hualapai Reservation. In 1954, 21 permanent, 100 ft. "line transects" were established to monitor vegetation trends on the 1953 burn (Schroeder [1956?]b [1962?]). Basal intercept of perennial grass species was recorded along these transects. Changes in grass cover were followed on these transects through at least 1959 (table 3). Photographs from the same period indicate that forbs were very abundant during the early stages of plant establishment on the burned areas.

An additional 24 transects were established in cooperation with Joseph F. Arnold of the U.S. Forest Service Rocky Mountain Forest and Range Experiment Station. Twelve transects were located on burned sites and 12 on unburned sites (Schroeder [1956?]b, BIA 1955). Seven transects were established on the area burned in 1956 (Schroeder [1956?]b). Donald A. Jameson, also of the Rocky Mountain Experiment Station, estimated forage yield on several burned areas in 1959 (BIA 1959b). Arnold, Jameson and Reid briefly summarized early vegetation conditions on the Hualapai burns (1964). McCulloch (1969) compared vegetation conditions on burned and unburned areas on the Hualapai from 1966 to 1968 and found a much higher frequency of shrubs on unburned areas than on burned areas.

In 1983, vegetation and ground cover conditions were sampled on areas burned between 1953 and 1963 on the Hualapai Reservation. Adjacent unburned conditions were also sampled for comparison. A total of 10 paired macroplots were sampled for direct comparison of burned and unburned conditions on the same sites. Additional non-paired sites were also sampled to quantify specific sites within the area. (Despain 1983, 1985). Differences between burned and unburned stands are generally still obvious. However, sampling was conducted to quantify those differences for use in a general evaluation of the longterm effects of the burning on forage resources and soil cover characteristics. A summary of preliminary results of this study is presented here.

In general, the percentage of exposed bare ground and rock is slightly higher on burned areas than under adjacent unburned stands, while plant basal cover is usually higher on the burned areas. However, these differences are usually less than 10%. Litter cover (except large branches) is usually lower on burned than on adjacent unburned areas, but was never found to differ more than 20%.

Current vegetation is dominated by crested wheatgrass and western wheatgrass on the burned and seeded areas whereas mutton grass (Poa fendleriana) and either squirreltail (Sitanion hystrix), junegrass (Koeleria pyramidata) or blue grama (Bouteloua gracilis) dominate the understory of the unburned areas. In addition to crested and western wheatgrasses, other seeded species found to have persisted in varying amounts on the seedings are intermediate wheatgrass (Agropyron intermedium), yellow sweet clover (Melilotus officinalis), sand dropseed (Sporobolus

Table 3.--Percent basal cover of perennial grasses on the 1953 burn as measured on 21, 100 foot line transects (BIA [1959?]a)

SPECIES	YEAR				
	1955	1956	1957	1958	1959
Crested wheatgrass	.22	.48	1.05	1.49	2.62
Blue grama	.29	.34	.33	.35	.41
Sand dropseed	.11	.17	.22	.23	.26
Mutton grass	.14	.17	.13	.09	.14
Western wheatgrass	.00	.01	.02	.05	.13
June grass	.01	.02	.02	.02	.02
Squirreltail	.00	.00	.00	.01	.07

cryptandrus), smooth brome (Bromus inermis) and russian wildrye (Elymus junceus). Weeping lovegrass (Eragrostis curvula) can still be found, although it is quite rare.

On the 10 paired plots, forage yield was generally low in 1983 on both burned and unburned areas ranging from 221 to 439 kg/ha on the burned and seeded areas and from 42 to 155 kg/ha under adjacent unburned stands. Differences in yield between individual paired plots ranged from 2 to 6.7 times greater on burned and seeded areas than on unburned sites. Higher and lower yielding areas were found on both unburned and burned areas on some of the additional non-paired sites, but the 10 paired plots are most representative of typical conditions encountered. Yield was found to range from about 400 lbs/ac to nearly 900 lbs/ac on burned areas in 1985.

Compiling estimates of forage yield from various reports and papers indicates that overall yield has not changed much over the years. Depending on the year and location, most early estimates range from 200 to 617 lbs/acre on burned areas and from 25 to 137 lbs/acre on adjacent unburned areas (BIA 1964, BIA [1962?], Schroeder [1962?], MuCulloch 1969, BIA 1963). In 1965, spring moisture was apparently high (Schroeder 1966) and yield was estimated at 916 to 2177 lbs/acre on burned and seeded areas and at 166 to 280 lbs/acre under adjacent unburned stands (BIA 1965, Gray 1966).

Invasion of the burned areas by pinyon or juniper is generally not occurring, especially where seeded grasses are dominant and well established. A few small areas exist where the trees are returning, however these areas are usually dominated by sagebrush and often appear to have either been excluded from original seeding efforts or to be where those efforts failed. Occurrence of shrubs such as turbinella oak (Quercus turbinella), gambel oak (Quercus gambelii) and New Mexico locust (Robinia neomexicana) is spotty and seems restricted to areas of original occurrence, although these shrubs have resprouted to large sizes. Manzanita (Arctostaphylos pringlei) commonly dominates the few locations where sandstone finds its way to the surface amidst the normal limestone parent material.

A few of the original monitoring transects established by Schroeder in 1954 have been relocated. Figure 1 compares one location as photographed in 1955 and 1985.

RECENT PRESCRIBED BURNING

The BIA, with assistance from tribal foresters, burned and seeded a small area of pinyon-juniper woodland in 1982. They were able to successfully burn about half of a planned 540 acres. Several permanent macroplots were established prior to burning and plant cover and frequency as well as ground cover were recorded. Both burned and unburned plots are being monitored to follow vegetation changes following burning.



Figure 1.--Photographed in 1955 A and in 1985 B, this location was burned in 1953 and seeded in 1954. The large shrubs in the background of photo B are gambel oaks.

Prior to burning, tree densities ranged from 94 to 505 trees/acre on the plots and all were dominated by Utah juniper. Understory vegetation was dominated by either small amounts of grasses, including mostly blue grama, squirreltail, and mutton grass, or by sagebrush (Artemisia tridentata) or snakeweed (Gutierrezia sarothrae). There were also scattered cliffrose (Cowania mexicana) or turbinella oak.

In 1984, seeded species were largely absent and the burned plots were dominated by forbs including mostly globemallow (Sphaeralcea coccinia), verbena (Verbena spp.), four-o-clock (Mirabilis multiflora), and ground cherry (Physalis fendleri). The most important perennial grass was sideoats grama (Bouteloua curtipendula) which was important only on sites where it was common before burning.

Prior to burning, ground cover was generally more than 40% litter and about 30% bareground and 20% gravel. After burning, bare ground varied from 40% to more than 70% whereas litter had generally dropped to less than 20%. Cover of gravel remained about the same.

SUMMARY

Nearly 22,000 acres of woodland dominated by pinyon and juniper were burned and seeded from 1953 to 1963 on the Hualapai Indian Reservation in northwestern Arizona. Prescribed burning was done in late June or early July during hot dry conditions prior to the summer thunderstorm season. Most fires were ignited from extensive windrows of dozed and piled trees while relying on the terrain to keep the fires in check. Burned areas were seeded with a variety of mostly introduced grass species. The main purpose of the burning program was to provide more forage for livestock which is an important economic activity on the Hualapai Reservation.

Today, burned areas are still dominated by seeded grass species with very little invasion by pinyon and juniper. Total forage yield is still much higher on the burned and seeded areas than on adjacent unburned areas. Vegetation changes on recent burns are currently being monitored.

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PLANT RESPONSE TO FIRE IN THE PINYON-JUNIPER ZONE

Richard L. Everett

ABSTRACT: The understory base in pinyon-juniper woodlands has been depleted by past abuse and suppression by the tree overstory. Wise use of fire provides a means of reestablishing understory species in the successional cycle. Postfire survival of understory plants depends upon physical placement of the plant in the community as well as the physiological characteristics of the species. Understory species demonstrate an array of methods for establishing themselves in postfire successional communities. Succession follows the "initial floristics" successional model where most species are present at the time of disturbance. Plant succession has a strong spatial component. Predicting postfire response is difficult because of several chance factors, but qualitative prediction is possible when we consider aspect, elevation, and the known response of individual species in the preburn community.

INTRODUCTION

Wildfire has been a major force in maintaining an understory base in pinyon-juniper woodlands through the periodic reduction (every 10 to 90 years) of tree encroachment (Wright and others 1979; Young and Evans 1981). Loss of understory to carry fire because of grazing, fire prevention activities, and increased tree density has made many stands relatively fire safe.

Prescribed burns have been used in recent years to reestablish understory in woodlands (Barney and Frischknecht 1974). Response to fire for many of the important understory species has been worked out (Wright and others 1979; Wright 1985) and successional models have been developed to explain postfire succession (Erdman 1970; Everett and Ward 1984). Uncertainty of plant response remains high because of unknown soil seed reserves, species immigration potential, and postburn weather. But attention to aspect, elevation, and preburn community has improved our prediction capabilities (Koniak 1985).

We are becoming increasingly aware of the potential problems with wildfire and prescribed burns. Opportunities to establish desirable species are often lost when burned sites are not seeded promptly and undesirable species such as cheatgrass (Bromus tectorum) dominate sites (Evans and Young 1978). We are faced with an increasing problem of stand closure and dwindling understory base. But the solution is not indiscriminate burning that wastes the tree resource and enhances the establishment of undesirable understory species.

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Richard L. Everett is Project Leader, Intermountain Research Station, Forest Service, U.S. Department of Agriculture, Reno, NV.

VEGETATION BASE FOR POSTFIRE SUCCESSION

Postfire plant succession in Great Basin pinyon-juniper woodlands often starts from a depleted understory base. Current stands developed in association with an understory that had been significantly disturbed by intensive tree harvesting, indiscriminate burning, and overgrazing in the late 1800's (Young and Budy 1979). The situation was made worse by prolonged tree dominance. Nonuse of wood products in preference to cheap fossil fuels and fire prevention activities over the last century have allowed tree exclusion of understory to proceed unchecked. Tree competition has reduced understory productivity, cover, and plant density (Tausch and others 1981; West and others 1979). In one study, understory ground cover in mature singleleaf pinyon (Pinus monophylla)-Utah juniper (Juniperus osteosperma) stands averaged only 3 percent (Everett and Koniak 1981). Western juniper (Juniperus occidentalis) stands have similarly purged their understory of most forbs, grasses, and shrubs (Young and Evans 1981).

Because woodlands are declining in understory cover, seed production, and soil seed reserves, the potential for a favorable response to fire is diminishing. Tausch and others (1981) reported significant loss in understory cover once tree species start to dominate the site (fig. 1).

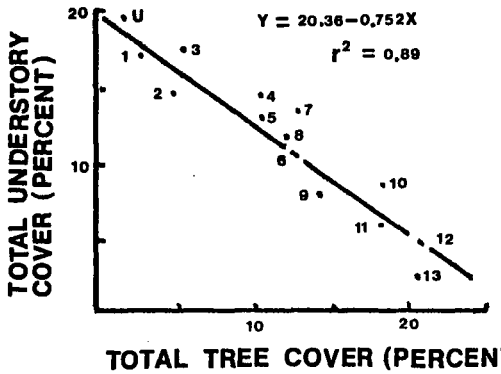


Figure 1.--Decline in understory cover as tree cover increases (Tausch and others 1981).

Seed production of understory species was an order of magnitude lower in closed stands than in adjacent cleared areas (Everett and Sharrow 1983). Soil seed reserves declined exponentially from recently burned to mature stands (Koniak and Everett 1982) (fig. 2). Although fire is a natural phenomenon, plant response may now be a product of a disturbed ecosystem. Current postfire succession may have its roots in disclimax communities.

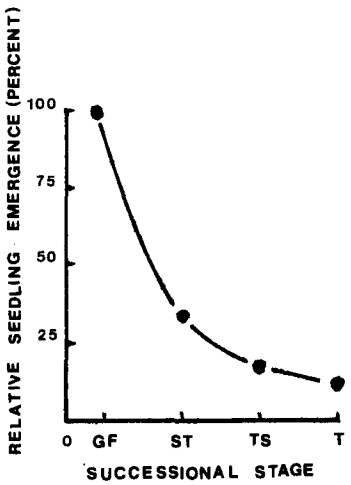


Figure 2.--Decline in number of seedlings emerging from soil seed reserves in grass-forb (GF), shrub-tree (ST), tree-shrub (TS), and closed tree (T) communities (Koniak and Everett 1982).

POSTFIRE SUCCESSIONAL THEORY

Postfire succession often has the appearance of a species replacement series where one species or group of species replaces another in sequence ("relay floristics," Egler 1954). Gross similarities in succession among burn areas have led to the creation of a standard successional model (Erdman 1970) (fig. 3A). Succession in reality is more likely a visual shift in aspect dominance of species present on the site almost immediately after disturbance ("initial floristics," Egler 1954). Tausch and others (1981), Everett and Ward (1984), and Koniak (1985) suggest succession in pinyon-juniper woodlands follows the initial floristic model.

Succession is a species-by-species replacement process (Drury and Nisbet 1973) where there may be no "unifying successional scheme" (Noble 1981). Succession may simply be a collection of individual species-specific trends (Pickett 1976) that collectively provide the character of the sere. Successsion then becomes a continuum of possibilities based on the individual species present and conditions at the time of the burn. Everett and Ward (1984) reported postfire succession on prescribed burns started from multiple entrance points in the successional model (fig. 3B). Among several similiarly aged burns, an array of succession stages occurred simultaneously.

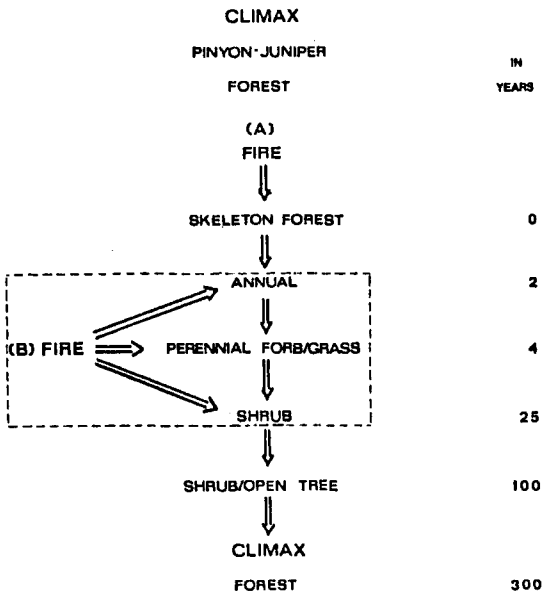


Figure 3.--The standard successional model (A) from Erdman (1970) showing multiple entrance points (B) from Everett and Ward (1984).

SPECIES CHANGES FOLLOWING FIRE

Everett and Ward (1984) determined that the number of annual and perennial plant species increased following prescribed burning. Koniak (1985) found forb species numbers increased most following wildfires. There was an initial period of rapid species turnover following fire. Rate of change stabilized to less than 20 percent within a 5-year period. Nabi (1978) reported diminishing numbers of species as succession progresses.

SPATIAL VEGETATION PATTERNS IN BURNS

The wide ecological amplitude of pinyon and juniper allows trees to compete favorably in diverse understory communites. Continued exclusion of understory species by trees causes previous understory communities to become indistinct. Once fire removes tree competition, understory communities reappear on their respective landform types.

On a prescribed burn site in eastern Nevada we found numerous species were common to both drainage bottoms and side hills following fire. But Great Basin wildrye (Elymus cinereus), poverty sumpweed (Iva axillaris), current (Ribes sp.), and rose (Rosa sp.) were more common in drainage bottoms. Sidehill slopes were occupied by skullcap (Scutellaria nana), Indian ricegrass (Oryzopsis hymenoides), and globemallow (Sphaeralcea sp.) (unpublished data). In western Nevada, cheatgrass dominated southeast facing side slopes 2 years after fire. At present, the drainage bottom remains bare, but coyote tobacco (Nicotiana attenuata) has established and should occupy the site next season (unpublished data).

Plant distribution varies by microtopography within landforms. Root-sprouting shrubs such as stickyleaf low rabbitbrush (Chrysothamnus viscidiflorus) reoccupy their previous coppice dune locations. Ward (1977) found 94 to 98 percent of rodent-cached desert bitterbrush (Purshia glandulosa) occurred on burned shrub coppices, and 21 to 41 percent of those coppices were from previous bitterbrush plants. On other sites, plant distribution among microsites was opposite that in preburn communities. Skullcap dominated the formerly bare interspace areas between the raised ash beds of now-absent sagebrush plants (personal observation). A similar pattern with interspace areas occupied by cheatgrass has been reported by Young and Evans (1978).

Initially, seed reserves are evenly dispersed among soil microsites but they shift from one microsite to another during succession. Soil seed reserves shifted to the shrub coppice in mid-succession and finally were adjacent the crown drip zone in closed stands studied by Koniak and Everett (1982) (fig. 4).

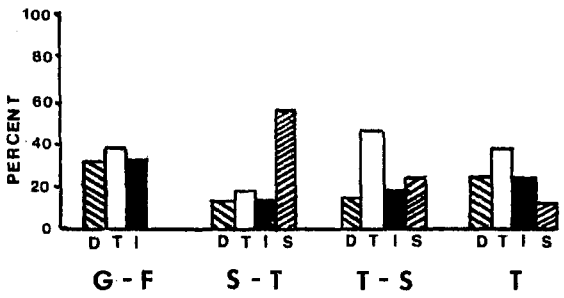


Figure 4.--Shift in percentage of soil seed reserves among soil microsites: duff (D), transition (T), interspace (I), and shrub coppice (S) during successional stages: grass-forb (G-F), shrub-tree (S-T), tree-shrub (T-S), and closed tree (T) communities (Koniak and Everett 1982).

INDIVIDUAL SPECIES RESPONSE TO FIRE

Wright (1985) suggested a guide to grass response to fire: Burning impact on bunchgrasses declines from spring to fall to summer. Small plants are less impacted than large plants by fire. Rhizomatous and early successional grasses tolerate fire better than late successional species. Narrow-leaved species such as Idaho fescue (Festuca idahoensis) and needlegrass (Stipa sp.) are more impacted by fire than broader leaved wheatgrasses (Agropyron sp.) or cheatgrass.

Perennial forbs balsamroot (Balsamorhiza sp.) and lupine (Lupinus sp.) that die back to the soil surface are less impacted than bunchgrasses (Bunting 1985). Rapid increases in plant density of globemallow and skullcap followed prescribed burning (Everett and Ward 1984). Density of other perennial forbs generally remains at preburn levels (Wright 1985).

Several of our important shrub species (sagebrush and bitterbrush) have no, or reduced, resprouting capability. Antelope bitterbrush (Purshia tridentata) has a resprouting capability of 6 percent in western juniper (Bunting 1984) and 2 percent of desert bitterbrush resprouted in singleleaf pinyon stands (Ward 1977). Root- or stem-sprouting shrubs are less impacted by fire. Ward (1977) found 57 percent of stickyleaf low rabbitbrush plants survived prescribed fire. Martin (1978) found a 30 percent survival rate for western juniper in wildfires, 100 percent survival in backfires, and 37 to 73 percent survival in headfires. Ward (1977) found no survival among singleleaf pinyon and Utah juniper following headfires in eastern Nevada. For a complete description of individual species response to fire see Wright and others (1979) and Wright (1985).

Zschaechner (1985) suggested that variation in plant survival among root-sprouting shrubs, perennial forbs, and grasses could be related to differences in litter buildup under individual plants and plant placement relative to other sources of fuel. This concept suggests species survival is directly related to the physical placement of individual plants in the community structure. Species that grow in association with higher fuel loads (greater litter or adjacent trees) have reduced opportunity to survive fire.

SPECIES ESTABLISHMENT IN POSTFIRE COMMUNITIES

Root- or shoot-sprouting shrubs, forbs, and grasses such as green ephedra (Ephedra viridis), snowberry (Symphoricarpos sp.), Great Basin wildrye, and lupine can rapidly assume aspect dominance of some sites following fire. These species rapidly produce aboveground biomass from surviving meristematic tissue. Species increase in density by several methods that include separation of the parent plant (horsebrush [Tetradymia sp.]), underground stems (desert peach [Prunus andersonii]), and seedling establishment from copious seed production (rabbitbrush) (Young and Evans 1978).

In adjacent microsites, annual and biennial forbs often follow a two-step establishment process. Immediately following fire a few flixweed tansymustard (Descurainia sophia), lambsquarters goosefoot (Chenopodium album), coyote tobacco, prickly poppy (Argemone polyanthemos), tumblemustard (Sisymbrium altissimum), or globemallow plants may germinate from the soil seed reserves. These germinants can become large, seed-producing plants the following growing season. Seed from these parent plants can create localized dense stands of the species the following year.

Young and Miller (1982) reported a similiar two-step establishment pattern for bottlebrush squirreltail (Sitanion hystrix) following fire in

western juniper. Young and Evans (1978) reported this pattern for cheatgrass and root-sprouting rabbitbrush. Cheatgrass plant densities increased from 10 to 10,000 plants/m^2 in 3 years. Barney and Frischknecht (1974) reported sagebrush populations on Utah juniper burns were composed of two age classes because of the two-step establishment process. All two-step establishment species have the capability of producing seed the first or second growing season after establishment.

Apparently, perennial grasses such as squirreltail (Young and Miller 1985), Indian ricegrass (Everett and Ward 1984), western needlegrass (Stipa occidentalis) (Bunting 1984), and bluebunch wheatgrass (Agropyron spicatum) (Stager 1977) can increase in density immediately following fire. The dramatic increase in seed production of grasses that followed tree harvesting found by Everett and Sharrow (1983) may apply to fire communities as well. Reproductive shoots of squirreltail increased by 60 percent following fire in western juniper stands (Young and Miller 1985).

Other shrubs and the major tree species do not follow the two-step establishment process. Their seed may not be in the soil seed reserves, and seed production may be delayed for several years or decades after establishment. Bitterbrush appears dependent upon rodent caching of seed for species reestablishment (Ward 1977; Koniak 1985). Seed caches may be abundant (1,600-4,300 caches/ha) or nonexistent on adjacent burn sites (Ward 1977).

Singleleaf pinyon requires a nurse plant to establish because of the solarization of seedlings (Phillips 1909). Ward (1977) found that singleleaf pinyon seedlings emerging from under burned tree canopies died by the second year. Erdman (1970) reported numerous pinyon (Pinus edulis) seedlings following burns when shade was present. Utah juniper established on burn sites from 1 to 5 years following fire (Barney and Frischknecht 1974).

SPECIES DURATION IN POSTFIRE SUCCESSION

Plant form dominance follows the standard successional model, but individual species of all plant forms may be found throughout the sere. Annual forbs such as coyote tobacco, tansymustard, groundsmoke (Gayophytum sp.), and lambsquarters goosefoot often invade burn sites and provide cover to barren sites (Erdman 1970; Barney and Frischknecht 1974; Everett and Ward 1984). These "band-aid" species have short cycles of maximum cover in early fire succession (fig. 5). Other forbs--blue-eyed Mary (Collinsia parviflora), annual stickseed (Lappula redowskii), and spiny skeletonweed (Lygodesmia spinosa)--are found in association with the mature woodland (Erdman 1970; Koniak 1985).

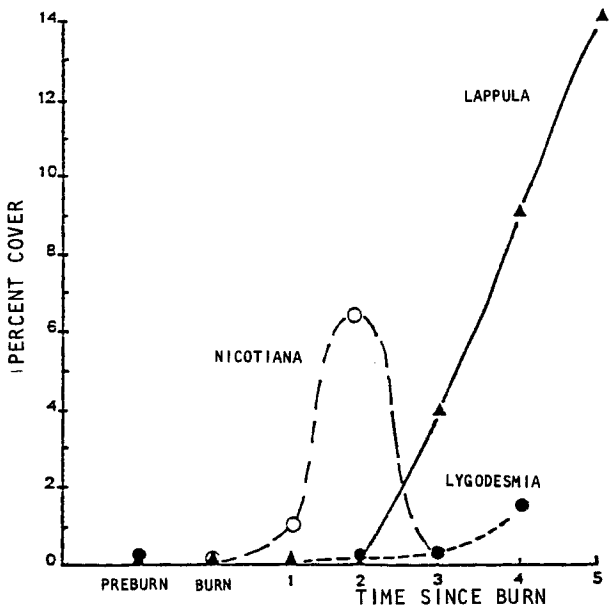


Figure 5.--Differences in cover for annual forbs coyote tobacco (Nicotiana attenuata) and stickseed (Lappula redowskii) and the perennial forb spiny skeletonweed (Lygodesmia spinosa) following prescribed fire.

Often postfire grass cover is a function of preburn conditions rather than length of time since disturbance. Koniak (1985) found no increase in grass cover following fire over a period of several decades. Barney and Frischknecht (1974) found perennial grasses started to decline under increasing Utah juniper competition after 50 years.

Root- and stem-sprouting shrubs such as green rabbitbrush and horsebrush may be major components of the community for 20 to 60 years (Barney and Frischknecht 1974; Wright 1985). Sagebrush and bitterbrush eventually dominate root-sprouting species if fire cycles are greater than 10 to 15 years (Young and Evans 1978). Bitterbrush cover appears to decline 50 to 100 years after establishment (Koniak 1985).

Once trees are established they continually increase their dominance of the site. Trees seriously start competing with understory when they are approximately double the size of the shrub nurse plant (Tausch 1985) and can exclude understory from the site within a 100-year span (Koniak and Everett 1982).

PREDICTING POSTFIRE PLANT RESPONSE

Plant response is often unpredictable because of unknown soil seed reserves, plant immigration, and postfire climatic conditions. Soil seed reserves may contain species that will dominate the site, yet are rare in the unburned community (for example, globemallow, Everett and Ward 1984; Ceanothus, Bunting 1984). Immigration of antelope bitterbrush or sagebrush onto burn sites

often forms the base for midsuccessional communities. But establishment depends upon the vagaries of seed production and immigration (for example, rodent caching).

Aspect and elevation have been used by Koniak (1985) to estimate the general character of postburn vegetation. In a study of 21 burns she found highest plant cover of perennials (shrubs, grasses, and forbs) on north and east aspects. A high cover of annuals occurred on south and west aspects. Indian ricegrass, mutton bluegrass (Poa fendleariana), Thurber needlegrass (Stipa thurberiana), and Anderson peachbrush were associated with east slopes, Rubber rabbitbrush (Chrysothamnus nauseosus) and cheatgrass were more prevalent on west than north or east slopes. Sandberg bluegrass (Poa sandbergii) and bottlebrush squirreltail had no differences in occurrence among aspects (Koniak 1985).
The rapid return of 60 to 90 percent of preburn species within 5 years following prescribed burns allows us to make qualitative predictions of postburn community composition (Everett and Ward 1984; Bunting 1984). Past experience suggests there are certain species that will be found on pinyon-juniper burns in the Great Basin. Sagebrush, rubber rabbitbrush, low rabbitbrush, antelope bitterbrush, desert gooseberry (Ribes sp.), cheatgrass, Sandberg bluegrass, bottlebrush squirreltail, lupine, hawksbeard (Crepis sp.), and prickly poppy have 75 to 100 percent constancy among 21 burn sites sampled by Koniak (1985).

MANAGEMENT IMPLICATIONS

Opportunities for forage resource renewal are declining as we allow tree suppression of understory to continue. Indiscriminate use of fire in closed stands that have few desirable understory species can worsen the situation while destroying a valuable wood resource. On many wildfire sites in the Great Basin, the flammable annual cheatgrass invades and dominates the understory.

Depending upon postfire plant communities to follow the standard successional model is unwise. The perennial grass stage of the standard successional model was often absent in postburn plant communities. As postfire plant response follows the "initial floristics" theory, desirable species that are not present on the site at the time of disturbance are not likely to enter the community at a later date.

Knowing that natural response will be greatest at high elevations on north and east aspects provides a guide for selecting sites for prescribed burns and assessing the need for seeding both wildfire and prescribed burn areas. Presence of the undesirable species rabbitbrush and cheatgrass suggests seeding is required. Spatial differences in plant response on burn sites suggest there may be selected sites where natural response will be lacking and opportunities for seeding desirable species exist.

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WILDFIRE PATTERNS AND VEGETATION RESPONSE IN EAST-CENTRAL NEVADA

Mark J. Barber and Wallace R. Josephson

ABSTRACT: Historical mining activity, settlement, heavy grazing, and increased fire suppression activities have led to an increase in the number of large (100+ acres) fires over 2.4 million acres of pinyon-juniper woodlands. A method of evaluating existing burns is used to make application in predicting vegetation responses as part of prescribed burning, escaped fire analysis, or rehabilitation of wildfire burns.

WILDFIRE PATTERNS

Ely District, Bureau of Land Management, is presently covered by over 2.4 million acres of pinyon-juniper. During the late 1800's and early 1900's the district had three factors which are believed to have altered these stands and wildfire patterns in pinyon-juniper.

1. Mining activity and the increase of settlements which utilized pinyon-juniper stands for heating, cooking, mining timbers, charcoal production, building construction, and fencing.
2. Heavy grazing of grasses and shrubs by sheep and cattle reduced the competition which pinyon-juniper had prior to grazing.
3. As the settlement populations increased, suppression of wildfires became more frequent thereby changing the natural competition between pinyon-juniper and grass-shrubs.

The extent of use of pinyon-juniper stands during the mid to late 1800's is very difficult to estimate. Most records kept identified populations and their locations, gold and silver production, and cattle-sheep numbers. However, using estimates from Virginia City-Comstock Mines (Crouch and Carpenter 1943; Hose and others 1976) during the same period, a rough estimate may be calculated for pinyon-juniper use in east-central Nevada. Pinyon-juniper use for mining operations and residential use from 1865-1890 by this method is estimated at 160,000 acres. This is approximately 7 percent of the current acreage. However, we feel that the actual percentage of old woodland stands removed may have been as high as 20-40 percent or about 480,000-960,000 acres.

Paper presented at the Pinyon-Juniper Conference, Reno, NV, January 13-16, 1986.

Mark J. Barber is District Wildlife Management Biologist and Wallace R. Josephson is Fire Management Officer, Bureau of Land Management, Ely District, Ely, NV.

During the early 1900's pinyon-juniper use for mining operations decreased; however, high grazing levels were maintained to sufficiently reduce grass and shrubs into the mid-1900's (West and others 1979). This allowed the pinyon-juniper stands to reclaim areas which were removed during the mining activity and increase in area along the benchlands previously dominated by grass-shrub types. This reinvasion of pinyon-juniper occurred over the past 80-100 years; these stands have been very healthy and have increased in area. We believe these pinyon-juniper stands have increased beyond the original boundaries on the benchlands due to heavy grazing pressure and increased suppression activities.

Because of the even-aged, healthy nature of the pinyon-juniper stands (less than 100 years old), the ability for wildfire to carry to a large size (100 acres or more) is believed to be reduced as compared with older aged, decadent stands.

Approximately one half of the Ely District stand is currently within the 50-100-year age class (BLM 1979). We would expect the number of larger (100+-acre) fires to increase due to the fact that stands throughout the district have disease (root rot) and insect infestations (needle borer).

In fact, the current trend shows an increase in large fires. In the past 26 years the district has had 38 fires in pinyon-juniper over 100 acres. It is interesting to note, however, that 15 of the 38 fires have occurred in the last 5 years (39 percent). The increase in these large fires has occurred without major changes of suppression forces in the district.

Some items which may account for this increase, besides the reduced vigor of the trees, are the invasion of cheatgrass into the Ely District due to the high precipitation in the past 3 years and the increased density of pinyon-juniper stands.

These fires have occurred in three general areas throughout the district, the southeast corner, mid-section, and northwest corner. Approximately 55 percent of the fires over 100 acres were caused by lightning and the other 45 percent were caused by man or unknown causes.

The historic use of the woodland products for mining, heavy grazing pressure, expansion of exotic grass species, and the spread of insects and disease all are believed to have contributed to an increase in the size of wildfires in the

pinyon-juniper type. These factors are expected to continue to influence the size and patterns of fires in the future.

EVALUATION OF VEGETATION RESPONSE TO WILDFIRE

In 1983 the management of the Ely BLM District, partly in response to the increase in larger fires in pinyon-juniper areas, saw the need to develop a technique for evaluating vegetation responses to wildfires on public lands. District personnel in various disciplines were consulted in order to be sure necessary information was collected. We decided to develop a form that district personnel could complete during normal field operations. This form would record the needed information on existing wildfire burns encountered during field operations. Information was required in the following categories: location, nature of site, fire site information, current observations, animal uses, current utilization, and comments.

Once a basic format existed for collecting information, files were set up to handle completed forms. A district instruction memorandum was distributed to all employees explaining the use and need for the collection of information on existing burns.

Next came the use of the information gathered. Whenever possible it is important to match information collected with the original fire history or Individual Fire Report (DI-1201) prepared during suppression efforts. Location of this information can be made easier if a fire history of past burns is compiled which consists of: fire number, fire name, acreage, fuel type, month/year, and location. After the early history and present condition information is matched, and current use of the area collected, we can draw some conclusions. Given a number of variables including original vegetation, fire behavior, prefire and postfire moisture conditions, and site restrictions, we can get a feeling for what type of vegetation response we can expect after a given period. The more burns at different ages, site locations, and varying other conditions evaluated, the more accurate we can be in predicting future responses to burning.

In the early stages of information collection, it is valuable to try to concentrate our efforts on the vegetation types/areas where one or more of the following occur:

1. Highest frequency of wildfires can be expected.
2. Planning efforts indicate a need for vegetation conversions.
3. Prescribed burning is being planned or studied in this area for feasibility as a vegetative conversion method.
4. Fire suppression plans call for less than full suppression.

Existing planning documents, such as allotment management plans, habitat management plans, and horse herd management plans, should be reviewed to determine location(s) of planned vegetation conversions by site and vegetation type. As discussed earlier, a fire history of the area is valuable in predicting future wildfire sites and fuel types. With this additional information, including current areas being studied for feasibility for vegetation conversion and areas in fire management plan(s) under consideration for less than full suppression, we can concentrate our evaluation efforts. This leads us to the vegetation types and locations where information on response to burning will have the most managerial application.

Once we have gathered the proper information about the vegetation types of high interest then we are ready to make application of this technique. Areas of particular use include:

1. Analysis of prescribed burning as a possible method of vegetation conversion.
2. Analysis of need/feasibility of rehabilitation of wildfire burn.
3. During escaped fire analysis, to determine short-term/long-term effects of fire in the area.
4. During fire management planning, to determine from a vegetative basis, what benefits/detriments could result from allowing a particular area to burn under certain conditions.

As an example of using and applying this technique, from our preliminary findings there are definite advantages to allowing wildfires/prescribed burns in mature dense pinyon-juniper stands, under the right conditions. Due to the lack of understory, the large stands of dense pinyon-juniper in the Ely District receive almost no use by livestock, most wildlife, and wild horses. Investigations of burns between 15-20+ years of age show a favorable response of grass, forbs, and some shrubs with corresponding increased use by wildlife, wild horses, and livestock in some areas. Ideally we would be able to open up selected closed stands of pinyon-juniper with a combination of wildfires and prescribed burns to provide for future increased forage. Even some woodland uses can be enhanced as young, Christmas tree-sized trees come back. Also, in cooler burns standing snag trees are highly sought after for firewood.

Since over 2 million of the 8 million acres of public lands in the Ely District are in pinyon-juniper woodlands, we feel that developing a history of past burns and then evaluating vegetative responses can be a valuable tool in managing our pinyon-juniper forests to maximize uses while still protecting the basic resource.

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MANAGEMENT STRATEGIES IN PINYON-JUNIPER ON THE HUALAPAI INDIAN RESERVATION

Robert R. McNichols

ABSTRACT: The management of pinyon-juniper woodlands on the Hualapai Reservation has changed from no management, to an emphasis on removal or eradication, to the current strategy of multiple use and sustained yield. While there are still significant pressures from grazing interests for removal of pinyon-juniper the increased value of woodland products has caused the tribe to reevaluate their objectives.

RESERVATION SETTING

The Hualapai Indian Reservation lies west of Grand Canyon National Park and east of Kingman in northwestern Arizona. The north boundary of the reservation follows the Colorado River for 108 miles. The south boundary is just south of Highway 66 and north of new Interstate 40. The reservation contains 992,000 acres of which over 45 percent, or 460,000 acres, is pinyon (Pinus edulis) and Utah juniper (Juniperus osteosperma) woodland. This pinyon-juniper woodland is a significant natural resource to the Hualapai Tribe with the potential of meeting many of the tribe's goals and objectives.

In order to gain a better understanding of today's management of the pinyon-juniper woodland we need to look at the historical use and the changes that have taken place on the reservation. For the Hualapai Tribe there have been three major changes in their management of pinyon-juniper woodlands.

Pre-Reservation Days (Prior to 1883)

There was no management of the woodland during this period. Up until the middle of the 19th century the tribe did not make any attempt to manage or manipulate the pinyon-juniper woodlands. They often located their homes in the pinyon-juniper type and their subsistence was through hunting and gathering of native plants and animals. They would travel to where the game was plentiful and plant foods in good supply. If food became scarce in one location they could freely move to a better place. When the weather turned cold in the winter they moved to winter encampments where the fundamental criterion was a large supply of readily available firewood, for the fire kept them warm during the cold winter weeks. The pinyon-juniper woodland was their home for much of the year because it provided easy access to the lower plateaus and canyons as well as the more productive high country.

The woodlands were used to construct the makeshift shelters which they used for windbreaks and sunshades. It also provided cover for the game they hunted and a large portion of their food.

The pinyon nuts were eaten raw or roasted, made into a paste, soup, or formed into cakes. The pinyon pine needles were used to make a very pleasant tea. The inner bark was used for gluing arrows and cradleboards, and it was chewed as gum. The pitch is very flammable and was used to start fires (Watahomigie and others 1982).

The berries of the juniper tree have been referred to as the starvation food because they were always plentiful to prevent starvation when other foods were in short supply. The juniper leaves were burned and the ashes applied to sores to draw infection and facilitate the healing process.

During this early period it was not necessary to manage or manipulate the pinyon-juniper resource. If one area did not provide what was needed the Indians could freely move to a more productive location.

Early Reservation Period (1883-1980)

Woodland management was primarily that of eradication or removal. As the West became more populated and the conflicts increased between the Indians and the white man there were more and more restrictions placed on where the Indians could go. Although land was still plentiful in the late 1800's, water was not. The areas with dependable water were the first to be sought out and settled by the non-Indians, leaving less and less land for the Indians to use for themselves.

With the establishment of the Hualapai Reservation in 1883, by executive order of President Chester A. Arthur, free movement became a thing of the past. For the first time

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Robert R. McNichols is Natural Resources Officer, Truxton Canon Agency, Bureau of Indian Affairs, U. S. Department of Interior, Peach Springs, AZ.

the Indians had a restricted, finite area in which they must live. It became necessary to live with the limited resources within the boundaries of their reservation. Management of the available resources on the reservation was to become a necessity. The first Indian-owned cattle were introduced onto the reservation in 1913. In 1933, with the establishment of the Civilian Conservation Corps, extensive water developments were begun. Dirt tanks and catchments were constructed around the reservation to extend the usable grazing areas available for the cattle. By 1936, there were over 7,000 head of cattle and 800 horses on the reservation which exceeded the 6,800-animal carrying capacity that was set at that time.

By 1940, cattle industry matters occupied the tribal council: refusing to sell water to a cattle outfit just outside the reservation, hearing a complaint about Hualapai boys practicing roping on dogs, listening to the BIA conservationist argue that Hualapai stockmen overgrazed their range, etc. (Dobyns and Euler 1976).

By 1945, over 200 miles of fence, 13 corrals, 10 spring developments, 59 livestock water reservoirs, 5 wells, and 98 miles of truck trails had been constructed (Watahomigie and others 1983).

A dilemma the Tribe faced in 1946 highlighted the fact that the reservation's range cattle industry had reached its environmental limit. While 35 to 40 Hualapai veterans wanted to enter the cattle business, drought had forced a reduction to about 4,000 head grazing on tribal land (from the previous 7,800 head). The definite limits of the range capacity were experienced firsthand (Dobyns and Euler 1976).

In the early 1950's, the direct competition between the pinyon-juniper woodland and the range grasses could no longer be tolerated. The pinyon-juniper which had been so valuable to the tribe in the past had now become a liability. An eradication program was developed to enhance forage and beef production. The pinyon-juniper was recognized as an invader, a weed tree, encroaching onto formerly productive open grass lands. Not only did it reduce the quantity and quality of forage, but also increased erosion, increased the cost of livestock handling, and decreased water yields. The suppression of palatable understory browse species by overstory evergreens reduced the forage supply for game, as well as livestock. Dense stands of over-mature, evenaged trees often dominated a site so that the soil surface was largely barren of understory grasses and forbs.

Management of the pinyon-juniper type as a wood producing area was not economically attractive during this period because of the high cost of harvesting the wood supply, the slow tree growth, the high cost of transportation, and the lack of markets for pinyon and juniper products. To cattle growers grass was both the key to prosperity and a means of maintaining a stable livestock industry.

During this removal or eradication period several methods of reducing the pinyon-juniper stands on the Hualapai Reservation were used to provide for range improvement:

Chaining.--A 300-foot ship's anchor chain was dragged between two bulldozers. The chain was looped behind two dozers so that trees were uprooted in a swath about 100-feet wide. Between 1962 and 1965 over 4,800 acres of pinyon-juniper were chained on the Hualapai Reservation. The 1969 Range Improvement Plan called for clearing another 200,000 acres of pinyon-juniper country by chaining.

Burning.--Broadcast burning has been used to remove pinyon-juniper on approximately 22,000 acres on the reservation. Del Despain spoke in detail about the burning program earlier in this session. Prescribed burns were simple then. You just had to pick out the hottest, driest, windiest day of the year and set it off. The results were immediate, obvious, and observable. In 1969, the Range Improvement Plan called for burning an additional 100,000 acres of pinyon-juniper.

Bulldozing.--Bulldozers were used to push the pinyon-juniper trees into windrows and piles to enable burning. The extent of piling with dozers was less than 1,000 acres.

Clearing with hand axes.--Hand cutting was done by ax brigades under the Agriculture Conservation Program. This provided jobs for Indian people while improving the rangelands. Between 1958 and 1961, nearly 3,000 acres were cleared of pinyon-juniper using crews with axes.

All of these removal efforts were expensive. The purpose of the removal was almost always to improve forage and beef production although other benefits such as decrease in erosion, increase in game animals, and an increase in water yield were also achieved.

Current Management Approach (1980-present)

Major changes in the economy have recently caused us to reevaluate our woodland management strategy. First, the price of beef has declined while production costs have continued to increase. This makes the forage produced on the reservation less valuable and the range management practices and improvements less cost-effective. It is no longer feasible to spend $20 to $30 per acre for pinyon-juniper removal even though the forage production may be increased by three to ten times as a result of such efforts. The increased beef production on a treated area is not sufficient to recover such a large investment. Second, the value of pinyon-juniper products, particularly fuelwood, has dramatically increased over recent years.

In the November 1975 issues of our local newspaper, the Mohave Daily Miner, Kingman, Arizona, fuelwood was advertised for $40 per cord. The same type of wood was advertised in the same paper 10 years later, November 1985, for $85 to $100 per cord, a substantial increase.

MISSION STATEMENT

To develop any meaningful management strategy the land manager must obtain a clear understanding of the agency's mission, or as the "new age thinkers" are calling it, their vision. Whether it is called a mission statement, a list of core responsibilities, or a vision for the future, we must identify our constituents and clarify our responsibilities to them. On the Hualapai Reservation we have identified our mission to be that of "caring for the land resources to best serve the Hualapai people." A mission statement is valuable in setting an attitude under which we operate. It is particularly important when several disciplines are involved in the management of a single resource. In the pinyon-juniper woodlands we have a forester, a wildlife manager, and a range conservationist each with his own ideas of how the woodlands should be treated. The mission statement "caring for the land resources to best serve the Hualapai people" requires a broad perspective.

GOALS

We have identified three major goals for natural resources on the reservation, whether for commercial ponderosa pine forest, pinyon-juniper woodland, wildlife, range and livestock management, tourism and recreation, etc. These goals are:

a. To generate economic return to the tribal government from the development and utilization of the natural resources on the reservation.

b. To provide employment and personal development to tribal members and to increase personal income and standards of living.

c. To protect, conserve, utilize and enhance the natural resources on the reservation to assure perpetual availability to tribal members for traditional and cultural uses and to maintain environmental quality.

These goals will sometimes conflict with each other. To attempt to maximize any one of the goals may detract from the other two. However, with the goals in mind we can better balance management alternatives to most nearly meet the desires of our constituents--in this case, the Hualapai Tribe.

OBJECTIVES

To meet tribal goals at an acceptable level we have determined it necessary to manage the pinyon-juniper type on a multiple-use, and a somewhat loosely defined, sustained-yield basis. We recognize that all land resources are subject to change over time in value, usefulness, and demand. The output of some resources will rise while others will fall. The output mix will change as will the marketability of a resource. This has certainly been true of pinyon-juniper. Our desire is to maintain a sustained output of benefits from the composite of all the natural resources on the reservation. It is not necessary that we maintain an even flow of any one resource as the marketability and other conditions will change over time.

Until the last decade pinyon-juniper was a liability as it detracted from the more valuable grazing resource on the reservation. While pinyon-juniper still conflicts with grazing the increased value of fuelwood and other forest products helps to justify tolerating it.

In the past, it was not economically possible to remove or eradicate the pinyon-juniper as rapidly as the cattle owners and range conservationist would have liked. Had the high cost of removal not been so prohibitive in the late 1960's and early 1970's an additional 300,000 acres of pinyon-juniper would probably have been removed as called for in the 1969 Range Improvement Plan. Had this removal actually taken place the potential for marketing wood products today would have been much less.

Management objectives specific to the pinyon-juniper woodland are:

a. To maintain desirable growing stock levels for improved and accelerated growth rates in residual pinyon-juniper stands.

b. To breakup large, contiguous stands of pinyon-juniper to improve diversity in species, density, and cover.

c. To provide management blocks for specialized woodland products such as pinyon nuts, cured fuelwood, traditional and cultural uses, research and demonstration, etc.

A high percentage of the pinyon-juniper type consists of mature and overmature, evenaged, stagnated stands. Growth in these stands is extremely slow or nonexistent. In order to increase the rate of growth it is necessary to thin out the stands significantly enough to allow reproduction and release of the residual stand.

Thinning of the stands will provide saleable products such as fuelwood and fence posts. The harvesting of the wood products will help meet tribal goals by providing income to the tribal government through the collection of stumpage fees, and by providing self-employment to tribal members who harvest the products for resale.

Currently stumpage rates for pinyon-juniper fuelwood are $3 to $5 per cord. The thinning of the pinyon-juniper will also help to increase forage production and reduce erosion. This should benefit wildlife as well as livestock production.

Of the 460,000 acres of pinyon-juniper on the reservation, around 60,000 acres will be clearcut to improve diversity. These clearcuts will range in size from 10 to 250 acres each. The openings will be targeted for the deeper soils and more productive sites where response by grasses and forbs will be greatest. The openings will usually be irregularly shaped to blend in with the contours of the land. Uncut strips will be maintained in the drainages and along the ridges to provide cover for wildlife travel routes. The "edge-effect" around the openings should also benefit wildlife.

The esthetic qualities should improve by providing more variety to the observer. Again, the wood products removed will provide stumpage fees to the tribe, employment to woodcutters, improved grazing to livestock and wildlife, and reduced erosion.

Management blocks within the pinyon-juniper type will be established for special uses. Some areas which are scheduled for clearcutting will be first treated with herbicide. These blocks will provide a ready source of dead, "cured" wood for those who wait until late in the season to do their cutting. It is also much easier to cut wood when the foliage has dropped. One 200-acre block has already been treated in this manner to provide wood to tribal members for their personal use, not for resale. The block was set up close to town with easy access. The demand was so great that it was decided to do similar blocks for the commercial cutters. In these blocks the stumpage fees will be increased enough to recover the treatment costs.

Management blocks will be set up to increase pinyon nut production. Currently there are nearly 500 tribal members who collect around 2,500 pounds of pinyon nuts per year. The sale of the nuts generates approximately $12,500 per year to tribal members. In these pinyon nut blocks the juniper will be removed to reduce competition for water. Management practices such as fertilization will be tried in order to increase nut production. We will be looking to various researchers to advise us on possible methods to increase the size and quantity of pinyon nuts.

Some areas will be withdrawn from any cutting to protect steep slopes and fragile soils. Cutting will be restricted along the main transportation corridors on the reservation to maintain esthetic qualities.

Tribal members are now cutting over 2,000 Christmas trees per year. They pay 25 cents per tree stumpage to the tribe and the trees are sold for $4 to $5 each wholesale. This is a significant income for several tree cutters. Although it is unlikely that any management blocks will be maintained for the production of Christmas trees, cutting prescriptions will attempt to protect the smaller pinyon trees for this purpose. Cutting of Christmas trees will be restricted to given stands and rotated each year so that any particular stand is entered no more than once every six years. Once our inventory analysis is completed we will set maximum allowable cutting for Christmas trees in each stand.

Currently there is thinning of the commercial ponderosa pine stands on the reservation for timber stand improvement. The thinning is being done by forestry employees and also by tribal members under contract with the tribe. When the thinning backlog is eliminated in the ponderosa pine those individuals now doing the thinning should be able to later harvest pinyon-juniper fuelwood for resale. The woodland type should assure the continuity of employment so long as markets are available for fuelwood.

Although the data analysis is not completed for the pinyon-juniper inventory we estimate around two million cords of wood in the pinyon-juniper type. Of this, about 260,000 cords would need to be removed to achieve the desired growing stock levels and diversity in the stands. Once this backlog is removed we estimate an annual allowable cut on a sustained basis of around 3,300 cords per year. These figures are tentative and will surely be adjusted when inventory results are available. However, we know the resource is of significant economic and social value to the tribe.

While the range managers were successful in removing over 30,800 acres of pinyon-juniper prior to 1980, the economics of that time prevented greater range improvements. It's ironic that more pinyon-juniper removal may be accomplished under sustained-yield management than was when the emphasis was on removal.

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Economics

Chaired by:

Lawrence D. Garrett, Dean, School of Forestry, Northern Arizona University, Flagstaff

SPECIALTY WOOD PRODUCTS FROM PINYON-JUNIPER

Patrick M. Murphy

ABSTRACT: Feasibility studies utilizing pinyon-juniper woodlands for providing specialty wood products show mixed promises. Current costs of chipping and hauling proved too high for feasible production of oriented-structure board. A cement board plant proved feasible at one location in eastern Nevada. However, the present slump in the housing market and the high interest rates on money will have a negative effect on this project.

INTRODUCTION

The singleleaf pinyon (Pinus monophylla) and Utah juniper (Juniperus osteosperma) of the Intermountain Basin have been used on a local basis for fuels, but have seen only limited use as wood fiber. The growth habit of these trees is so poor that it is almost impossible to cut any dimension lumber out of them. However, the predicted shortages of wood fiber and increasing costs from normal sources require that this low-grade resource be investigated.

The Division of Forestry under the leadership of our previous State Forester, George Zappettini, conducted some studies and a pilot project on the harvest and use of pinyon-juniper. The major pilot project was a whole-tree chipping project that showed about break-even in the chip market. A proposal, supported by the Nevada Department of Economic Development, was made to find out if a viable industry based on pinyon-juniper could be established in Nevada.

The proposal was to investigate the pinyon-juniper resource and supportive resources in White Pine County, NV, an economically depressed area within the State.

Following are summaries of the activities carried out by subcontractors and the Division of Forestry with a goal of answering the question, "Can an industry be established based on the pinyon-juniper resource?"

PARTICLEBOARD

In June 1974, small pinyon and Utah juniper log samples were sent to the U.S. Forest Service's Forest Products Laboratory in Madison, WI, to determine the potential of using pinyon-juniper for making particleboard. The laboratory made four types of boards with the material and produced the following results:

> It appears that the urea-bonded panels would meet the strength requirements of commercial standards (CS 236-66) at the 1-B-1 level and the phenol-bonded panels at the 2-B-2 level. On the other hand, dimensional stability in terms of linear expansion is generally greater than levels recommended in the standard. This is especially true with the pinyon panels. Because of somewhat low bending properties and much higher linear expansion of the phenol-bonded panels as compared to other western softwoods with which we have worked, we would not recommend a Utah juniper or pinyon exterior-type panel. If, however, a somewhat longer flake (approximately 1-1½ inches) were used as a basic raw material for a urea-bonded panel, it should be possible to produce an interior panel meeting both the strength and stability requirements at the standard.

In December 1975, pinyon and juniper logs with branches and needles intact were sent to Bison-Werke Research Center in Springe, West Germany, for further testing in making particleboard. Their results were:

> The panels of 100 percent pinyon with bark, had good enough physical properties at the 40 lb/ft^3 density level to meet both class 1-B-1 and 1-B-2 property requirements for medium-density particleboards. The presence of bark does reduce modulus of rupture and internal bond strength at both density levels. On the other hand, the fact that the required physical property levels for commercial standards were met with bark, certainly suggests that whole tree chipping of the trees in the forest with limbs, bark, and wood all being utilized may be practical.

PAPER

In July 1974, pinyon and juniper logs were sent to Ben Ward and Company, Sacramento, CA, to be evaluated for use in paper products. This

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Patrick M. Murphy is Assistant State Forester, Nevada Division of Forestry, Carson City, NV.

company, which purchases wood chips for various Japanese and local companies, tested the samples and found that the material could be used for making good-quality Kraft paper. The sample was not large enough to further evaluate the quality of paper that could be produced. At this time, the price of chips was approximately $60.00 per bone dry unit and the potential use of western Nevada pinyon-juniper appeared feasible. However, the market faltered shortly thereafter and the price of wood chips dropped drastically, making this consideration not economically feasible.

NAVAL STORES PRODUCTS

In April 1976, samples of pinyon and juniper wood, branches, and needles were sent to Dr. Fred Shafizadeh, a world-reknowned wood chemist at the University of Montana, Missoula, for chemical analysis. Results from the chemical analysis were very positive in that he found up to four times more resin in branches and needles of pinyon and juniper than that contained in Douglas-fir.

Since small limbs and foliage of these species can make up to 60 percent of the tree, the possibilities of using branches left after logging or chipping operations for naval stores products should be explored.

CEMENT BOARD

In 1978, the Nevada Division of Forestry under the auspices of the Four Corners Commission received a grant for a survey of material, manpower, and services which would determine the feasibility for a West German company (Bison-Werke) to build a wood-cement board mill in eastern Nevada.

Cement board is composed of 60 percent by weight cement, 20 percent by weight wood fiber, and 20 percent by weight fluids (mostly water). The cement board is reported to be fireproof, unaffected by water, and can be worked with the same tools used on particleboard. Because this product is extremely heavy in comparison with other building products, the following end-use applications were suggested for wood-cement products:

1. Building elements from the Bison Folding System.
2. Exterior siding--smooth, embossed or colored in 4x8, 9 or 10 foot dimensions or ripped to wide board widths, to be applied directly to framing.
3. Air conditioning and ventilation or utility ducts.
4. Fence materials and sound barrier walls along heavily traveled roads.
5. Concrete forms.
6. All-weather foundations for buildings with basements.
7. Patio blocks or porch decks, colored or natural.
8. Box beams, soffits, fascias, and exterior trim.
9. Elevator shaft linings and fire doors.

After a lengthy study, a potential wood-cement board plant site was located in Lincoln County, NV. The study included a positive financial feasibility analysis for the development of a plant to produce approximately 37.2 million ft^2 of 3/8-inch board per year. The proposed plant would only produce 2.8 percent of the potential market, with projected volume to operate 141 years.

The present slump in the housing market and the high interest rates on money have had a negative effect on this project. Therefore, no plant development can be foreseen for the immediate future.

ECONOMICS OF MANAGING PINYON-JUNIPER LANDS FOR WOODLAND PRODUCTS

Fred J. Wagstaff

ABSTRACT: Pinyon-juniper forests provide a broad array of economic products ranging from edible nuts and various wood products to recreational benefits and wildlife habitat. Utilization of the renewable woodland products provides basic employment, income, and other benefits. Value of the standing crop on some of the more productive pinyon-juniper sites is several hundred dollars per acre based on just the value of domestic fuelwood. Although rotations may be long, the lack of viable alternative uses of the land and the strong demand for the woodland products means management and use of these forests makes economic sense.

INTRODUCTION

Pinyon-juniper (P-J) forests cover a large area of the Southwestern United States. The exact acreage, for the States of Colorado, New Mexico, Arizona, Nevada, and Utah, varies by the species included in the estimate and source of reference. A recent Forest Service analysis (USDA 1982) shows 41 million acres in the five States. About 6 million acres are in adjoining States. In this paper no attempt will be made to separate the species, although most of the information relates to southwestern Utah and southeastern Nevada where singleleaf pinyon (Pinus monophylla) and Utah juniper (Juniperus osteosperma) are the major species.

The P-J woodlands have been used for centuries as rangelands and sources of building materials, fuelwood, and food. Indians and early Spanish settlers used pinyon and juniper along with adobe to construct their houses, fences, corrals, and churches. Many examples remain today to show the creative use of these materials (Horgan 1984). Early Anglo settlers of the West used these woodlands to provide various products such as fenceposts, firewood, and charcoal for smelters and railroads; the settlers also learned from the natives about eating pine nuts.

The concern about how to convert some of these woodlands to more productive rangeland has been a long-standing issue for landowners, managers, and ranchers. Millions of dollars have been spent in cabling, bulldozing, burning, and otherwise controlling pinyon-juniper. There has been and still is an inverse correlation between effectiveness in killing trees and efficiency or expense of treatment. Individual tree treatments such as bulldozing or cutting are highly effective but very expensive; chaining is relatively cheap by comparison but much less effective in most instances. Large acreages treated from the late 1950's through the 1970's are now being dominated by regrowth or release of seedling trees that were present before treatment. Federal agency budgets for treatment have declined, and much more economic analysis and justification is needed since the efficiency of treatment has been questioned. It appears evident that treatment of many areas cannot be justified economically on the basis of livestock forage improvement (Clary and others 1974).

Present evidence indicates that in any probable future situation millions of acres of pinyon-juniper will be available to be managed for various purposes. This paper will briefly explore some of the economic implications of managing these woodlands as forests as an alternative to their conversion to grasslands, although some areas could become modified in the forest management process to provide transitory range.

The primary focus will be on fuelwood harvesting activities since few data on other products are available. The characteristics of the southwestern Utah-southeastern Nevada fuelwood industry are examined and some general economic information is provided.

STUDY OBJECTIVES

The objectives of this study were:

1. From primary data, determine a typical budget for commercial fuelwood harvesting in the study area.

2. For the area managed by the Las Vegas District of the Bureau of Land Management (BLM), determine whether fuelwood harvest could be used to accomplish multiple-use objectives.

3. From market data, isolate characteristics of the various market levels (harvest, transport, wholesale, retail) for a typical commercial operation in the Salt Lake City, UT, area.

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Fred J. Wagstaff is Range Economist, Intermountain Research Station, Forest Service, U.S. Department of Agriculture, Provo, UT.

4. Discuss management implications of study results.

METHODOLOGY

Information concerning volumes and physical characteristics of P-J was extracted from literature (Howell 1940; Chojnacky 1985; Jensen 1972; Miller 1971; Meeuwig 1979; Meeuwig and Cooper 1981; Clendenen 1979). Reported per-acre volumes vary considerably which indicates the need for local data to accurately estimate the volume available.

Economic information was gathered from a variety of sources including personal interviews, observations, published data, advertised prices, public records, and unpublished materials. Conversations were held with commercial wood harvesters and individuals selling wood at the retail level. There was no attempt to define the total populations of either harvesters or retailers.

Contacts with National Forest and BLM offices in the study area were made to determine the amount of P-J harvested in southwestern Utah and southeastern Nevada by commercial operators. The informal interviews with commercial wood harvesters and businesses selling P-J wood at retail revealed typical operating costs and prices of fuelwood at various stages of processing and marketing. Retail selling prices of wood were determined from advertised prices and interviews.

RESULTS

Much P-J fuelwood harvesting occurs in areas that were chained or where road construction has pushed over trees. The accelerated harvesting since the 1970's has depleted much of this supply. In the areas nearest the Wasatch Front of Utah and other population centers fuelwood from these sources is becoming scarce. People are faced with longer driving distances or cutting green trees that require aging before use. All commercial operators contacted were harvesting both live and dead trees. In the Caliente area of Nevada and Iron County in Utah most commercial operators largely depended on live-tree harvesting, particularly of pinyon since it is the locally preferred fuelwood.

The major interest in harvesting live P-J for fuelwood is in older stands with larger trees because wood can be harvested more efficiently. Juniper trees with many branches close to ground level are difficult to cut and trim, and a relatively large amount of effort per tree is needed. Studies in Arizona showed that the time needed to fell juniper trees varied tremendously and depended mostly upon the skill of the sawyer and the growth form of the trees (Miller and Johnson 1970; Miller 1971).

An overall estimate of the standing volume of P-J is not very meaningful because much would be unavailable economically because of distance to market or physical difficulties in harvesting some areas. Currently, P-J forests distant from the large populations centers are being used very little. For example, the Caliente area of Nevada has an estimated potential harvest of 12,000 cords per year; currently only 800 cords are harvested.

Volumes determined by the BLM by direct measurements of wood harvested on commercial sale areas in 1984-85 in southeastern Nevada averaged about 10 cords per acre. These volumes are similar to those measured by others (Howell 1940; Barger and Ffolliott 1972). As pointed out in a study of methods for determining volumes, local estimates are needed because of wide variability in the species across their range (Chojnacky 1985).

Most commercial interest in Utah is in harvesting pinyon, which sells for $10 to $15 more per ton than juniper on the Salt Lake City market. In southeastern Nevada, harvesting juniper for the Las Vegas market is the largest fuelwood harvest activity. Most of this is for special orders from people who prefer juniper wood. About 800 cords per year are harvested in the Caliente area for the Las Vegas market.

According to commercial harvesting permits, issued by the Forest Service and BLM, commercial harvesting in Utah is concentrated in Beaver, Iron, Wayne, and Duchesne Counties. This distribution is the same as that found by LeBaron in his 1967-68 studies (LeBaron 1968). Wood from southwestern Utah moves into both the Las Vegas and Salt Lake City markets; the other areas of Utah are tied to the Salt Lake and local markets.

The very limited scope of this study precluded gathering data needed to make specific statements about the general market for P-J fuelwood. The survey of Federal agencies did reveal that the bulk of permits are for private fuelwood harvesting. This suggests that results similar to those of a study in Colorado where only 4 percent of total fuelwood harvest was by commercial operators could be expected (McLain and Booth 1985).

One large retail firm dominated the Salt Lake City market in terms of volume, although several businesses were engaged in retailing P-J wood. An accurate appraisal of individuals selling wood was impractical due to the structure of the market. Considerable wood is sold by local church groups, civic organizations, and individuals by word-of-mouth advertising. The extent of such sales and market share is not known, but it is evidence of an open and competitive market with free entry.

Another aspect of the structure of the market is the lack of vertical integration among larger operations. Large retailers of wood do not generally harvest their own trees, but contract for harvest or purchase wood from harvesters. Small operations often do involve harvest-to-retail integration. Typically, harvesting was done on a piece-rate basis rather than hourly

wage rates, and most wood was traded on the basis of weight at the various stages of processing and marketing.

Harvesters typically transport the wood to marshalling points where processing and aging occurs. If the wood is sold at this point it is typically at a per-ton price. A typical wholesaler buys wood from harvesters, splits and piles it, holds it for aging (4-5 months), reloads it, and arranges for transportation to the retail yard. The loss of weight during drying is part of the expense of the wholesale operation. Transportation costs are quite variable, with larger loads being moved more efficiently.

Retailing operations consist of unloading the wood, storing it, reloading small retail lots, and sometimes delivery. Delivered prices of wood vary depending upon distance and whether the wood is stacked at the consumer's residence. Retail prices of wood vary but have increased at a relatively lower rate over the past 5 years as evidenced by advertised prices. Advertised prices in the daily newspapers show P-J wood at about $90 per ton in 1980 and $95-100 per ton in 1985. Various daily newspapers (Salt Lake Tribune, Deseret News, in 1980 and 1985) were the data source.

From the data, a typical harvest-to-consumer summary was developed. The following information is representative of commercial operations in the study area:

Item	Cost, price or profit per ton
Stumpage	$ 5
Cut and trim and load	25
Haul to yard	5
Handling and splitting load on semi	15
Haul to market	20
Wholesale sales price to retailer	80
Retail selling price	100
Retail gross profit	20
Retail cost for handling, storage, selling, and overhead	10
Net profit	$ 10

A few operators who make all or a major part of their living from harvesting pinyon-juniper fuelwood were identified from the sales records of the BLM and Forest Service and informal contacts with those in the business. Only two such operators have been in business for more than 5 years. Numerous harvesters cut a few cords each year and many more supplement their incomes periodically with fuelwood harvesting. Entry into the business is easy but the work is hard, the investments are substantial relative to returns, and profits are not large or guaranteed. As pointed out by Johnson and LeBaron (1967), harvesting fuelwood does not provide high rates of return for labor.

Christmas trees are an important product of pinyon forests. Some good Christmas tree harvest sites are in areas that were chained, burned, or otherwise treated 20 to 30 years ago. Harvesting that leaves selected trees could provide for Christmas tree harvest and successive wood crops. Both commercial and personal-use harvest of Christmas trees are common, with an estimated 500,000 pinyon trees harvested annually. The economics of management of areas for tree production needs further study.

Pine nuts are important, with 1 to 2 million pounds harvested each year by commercial operators. In some years the harvest has exceeded 8 million pounds. The crop is uncertain and will be heavy in very localized areas so that average production per acre is meaningful only across a large area (Fisher and Montano 1977; Montano and others 1980).

DISCUSSION

Fuelwood harvesting for personal use is often viewed as a combination activity in which acquiring the wood can be a primary or secondary purpose of a trip. Recreation of various kinds is often associated with wood harvesting trips by individuals. The harvesting skill and motivation of individuals varies greatly, so meaningful time and expense estimates are difficult to generate. The total value of the wood harvesting trip to an individual would be the value of the wood and the recreation. If viewed as a secondary purpose for a trip, private cutting of fuelwood makes more sense economically than if viewed only as a project to obtain fuel.

Regardless of the expense of harvesting by the consumer, this wood has the same market value as commercial fuelwood. If the market price for fuelwood is $100 per ton and the consumer spends only $70 per ton in getting the wood, he or she has a $30 per ton savings. To any such savings would be added any recreational values associated with or induced by the wood harvesting. This leads to a conclusion that consumer harvesting may generate more per-unit value than commercial harvesting.

If a consumer surplus exists due to associated recreation benefits, acceptance of low labor costs, low equipment costs, and other factors, it could be a basis for policy decisions. Also, the distribution of net benefits associated with fuelwood harvesting would be quite different between commercial and individual harvesters. Because commercial operations are such a small part of the entire fuelwood harvest, any profit is concentrated and associated recreational values would not be generated.

Commercial harvesting is more straightforward to analyze because each activity or phase has a cost or value that can be readily determined. A typical woods operation consists of felling, trimming and bucking to length, hauling to a loading point, and loading on a large truck for transport to a storage yard. At the storage yard the wood is unloaded, split, and piled for aging. After aging the wood is loaded and hauled to the retail yard where it is unloaded,

stored, and later loaded on customer's trucks or delivery trucks.

The commercial operators have developed a marketing system that efficiently processes fuelwood. Because of few operations in a given area, administration is fairly easy. Consumer harvesting, if properly managed, can be used to remove wood that commercial operators would not be interested in due to small sizes, low volume per unit area, or rough terrain. However, individuals are not oriented to harvesting green wood a year in advance of use or in the early summer of the year of use. Most consumers want dry wood and like to cut in the fall. The existence of an apparent net consumer benefit (selling price-harvest costs and associated recreation benefits) indicates that policies which permit charging higher stumpage fees or require special harvesting techniques could be successfully implemented without reducing demand by private harvesters.

The practice of clearing areas by chaining and burning trees in place should be scrutinized. If harvested by commercial operators the stumpage value is at least $5 per cord, which for many stands would equal $50 per acre. On-site burning of the wood is costly not only for the actual burning, but because of the fuelwood stumpage value foregone. In fact, harvest for fuelwood may be an alternative to chaining or other tree removal practices.

Because neither pinyon or juniper deteriorates rapidly when chained, the fuelwood harvest can take place for a number of years after treatment. Chained areas represent a stockpile of harvestable fuelwood, are assets of considerable value, and contain the kind of wood most individuals are looking for. If the downed trees are not destroyed the only loss from a fuelwood standpoint, in conversion of a stand for grazing, is the reduction in future growth.

Pine nuts are an important product, but managing stands specifically for production seems impractical (Jensen 1972; LeBaron 1968; Montano and others 1980; Little 1941). There is some concern about harvest of older pinyon trees since they produce the most nuts. There is also concern about the depletion of nutrients and other impacts of harvesting (Samuels and Betancourt 1982).

CONCLUSIONS

Commercial P-J wood harvest would yield about $50 per acre in stumpage value for mature stands with a fair level of stocking in the Great Basin. These funds could be used for brush disposal and other on-site conservation measures if agency regulations and policy would allow it. Regardless of the cash flow sequence, this amount is a direct economic benefit to the land's owners. Other costs and benefits would be included in an economic analysis of management and would include watershed, range, wildlife, and woodland values (Wagstaff 1983). The commercial market system appears to be well developed, competitive, and efficient.

Firewood harvesting by individuals for personal use or small lot sales will probably continue to dominate the P-J fuelwood situation. Many people feel the satisfaction of getting and using their own wood is valuable. Individuals who harvest their own wood appear to gain considerable recreation value. Woodlands will probably continue to experience strong and growing demands, although cheaper alternative fuels exist.

The supply appears adequate when considering the availability of substitute wood, location of markets, and harvesting costs. Central Great Basin forests have a sustained harvest level many times greater than present cutting. Unless commercial use of these resources for other purposes takes large amounts of wood, the supply seems adequate. Fuelwood harvesting can be used to accomplish multiple-use goals such as better watershed conditions, improved range forage production, more and better wildlife habitat, and more productive woodlands.

Where maximum benefits and a broad distribution of the benefits are desired, individual use of the products appears to be the best policy. This will require more management effort, but it seems inevitable that greater demand for woodland products will force land managers to pay more attention to more intensive management of this resource.

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FUELWOOD OPPORTUNITIES FROM ARIZONA PINYON-JUNIPER STANDS

Bruce E. Fox

ABSTRACT: Increasing human population levels and more expensive fossil fuels have stimulated interest in fuelwood production from pinyon-juniper sites. Past research indicates that although more expensive than traditional mechanical conversion treatments herbicide treatments of pinyon-juniper stands to provide fuelwood also increase forage and water production. Given the current cost disadvantage, and ignoring increased water yields, fuelwood prices must increase to a minimum of four times current rates to result in net cost equality between treatments. A review of treatments, costs, and management implications of various treatments to provide fuelwood from pinyon-juniper stands is presented in this paper.

INTRODUCTION

The pinyon-juniper forest type in the southwestern United States covers over 40 million acres of land. Although of limited present value for traditional commercial forest products use, this type produces important recreational, wildlife, watershed and grazing values. Historically, the pinyon-juniper type provided Native American and the early Hispanic and Anglo settlers with charcoal and fuelwood. Increasing populations in the Southwest along with rising fossil fuel costs have again made the pinyon-juniper type an important source of residential fuel through the harvesting of firewood. The multiresource characteristics of the pinyon-juniper forest place the harvesting of firewood in a larger management context that must recognize the full range of resources generated by the pinyon-juniper type, including their economic costs of production and economic values. Given the multiresource interdependencies of the pinyon-juniper forest, this paper has the following objectives:

1. To present the results of a vegetation manipulation experiment designed to increase water yields while simultaneously providing fuelwood from the pinyon-juniper forest; and
2. Update treatment cost data and fuelwood values to current levels.

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Bruce E. Fox is Assistant professor of Forest Economics, Northern Arizona University, Flagstaff, AZ.

TREATMENT AREA

The treatment area (known as Watershed 3) consists of a small (146 hectares) watershed located on the Coconino National Forest approximately 56 km south of Flagstaff, Arizona. It is a subdrainage of the Beaver Creek watershed. Elevations range from 1525 meters to 1676 meters with fairly gentle terrain (less than 15% slope), and generally a southwest aspect. Soils are of the Springerville Series, a very stony clay from basalt parent material. A two-storied stand existed before treatment dominated by a Utah juniper (Juniperus osteosperma [Torr.] Little) overstory and an understory of various annual grasses and perennial greasses, shrubs and forbs. Total ground cover averaged 66% with tree crown cover averaging 26% (Larson 1970). The control watershed, 51 hectares in size and located in the same vicinity, constitutes another subdrainage to the larger Beaver Creek drainage.

TREATMENT

Objectives

The original study had four objectives:

1. To test the movement of herbicides, especially picloram, through soil;
2. To reduce transpiration losses on pinyon-juniper sites by killing trees;
3. To decrease evaporation losses by leaving standing dead trees to reduce windspeed and insolation; and
4. To avoid problems of overland waterflow being trapped in soil pits created by uprooting trees (Clary 1974).

Control

The control watershed received no management treatments.

Chemical

In May 1967 Watershed 3 received an aerial application of an ester of 2,4-D and 2,4,5-T at a rate of 9 kilograms acid equivalent per hectare. Unfavorable weather conditions and erratic application caused poor overstory kill. As a result, a second herbicide treatment was applied in August 1968. This second treatment

consisted of an aerial application of picloram at the rate of approximately 3 kilograms acid equivalent per hectare and 2,4-D at the rate of 6.5 kilograms acid equivalent per hectare. These active ingredients were mixed in water for a total application rate of 112 liters per hectare. Of the entire watershed, approximately 98 hectares received a helicopter-applied aerial spray with an additional 30 hectares receiving hand application of the same herbicides. The remaining 18 hectares were mechanically cleared of vegetation to provide fuel breaks and buffer strips around the watershed. Given an original study objective of testing the movement of picloram through soil into the streamflow runoff, the application rate of herbicides was higher than necessary to achieve the desired level of vegetation kill.

Harvesting

The treatment area was set up for fuelwood sale by the U.S. Forest Service. Approximately 3,830 cubic meters of live and dead wood were available for harvest, for an average of approximately 29 cubic meters per sprayed hectare. Of this total, only approximately 1,660 cubic meters (43%) were removed. Removals occurred between November 1975 and September 1976. Slash in the cleared fuelbreaks was burned during the fall of 1977.

RESULTS

Table 1 displays the effect of the chemical treatments on the overstory vegetation by comparing live pre- and post-treatment overstory stems per hectare and gross volume by diameter class. The treatment was especially effective on the pinyon pine (Pinus monophylla Torr. and Frem.) in the watershed. Before treatment, pine comprised 3% of the stems greater than 2.54 mm in diameter. After treatment, no pine stems greater than seedling size were alive (Larson 1970).

The herbicide treatment had mixed effects on understory vegetation. Shrub species such as cliffrose (Cowania mexicana Dougl.) were heavily damaged while shrub live oak (Quercus turbinella Greene) was only lightly damaged. Perennial and annual grasses as well as most forb species experienced little or no herbicide damage. Actual grass and forb production rates increased dramatically due to the elimination of the overstory vegetation (Johnsen 1970).

As mentioned previously, of the 1660 cubic meters of live and dead fuelwood available for harvest from the watershed only approximately 43% was removed.

Two original study objectives were to measure the movement of picloram in stream runoff and then determine changes in water yields due to the killing of the pinyon-juniper overstory. Measurements taken one and two years after application showed only small concentrations of picloram, less than 20 parts per billion, in the runoff waterflow (Johnsen 1970). The herbicide treatment also resulted in increased water yields as compared to control areas (Clary 1974).

Table 1.--Number of live overstory stems per hectare and cubic volume by diameter class

Diameter Class (mm)	Before Treatment						After Treatment					
	Stems/HA			Volume (M^3/HA)			Stems/HA			Volume(M^3/HA)		
	Juniper	Pine	Total	Juniper	Pine	Total	Juniper	Pine	Total	Juniper	Pine	Total
Seedlings	396.0	113.7	509.7	----	----	----	78.4	15.7	94.1	----	----	----
2-100	38.8	7.1	45.9	0.01	0.02	0.03	----	----	----	----	----	----
101-201	78.4	----	78.4	3.42	----	3.42	21.6	----	21.6	0.94	----	0.94
202-303	56.6	----	56.6	8.70	----	8.70	2.7	----	2.7	0.41	----	0.41
304-405	26.6	0.5	27.1	8.05	0.11	8.16	5.0	----	5.0	1.52	----	1.52
406-507	8.9	----	8.9	4.24	----	4.24	1.7	----	1.7	0.79	----	0.79
508-609	4.5	----	4.5	2.75	----	2.75	0.9	----	0.9	0.58	----	0.58
610-711	1.5	----	1.5	1.11	----	1.11	0.1	----	0.1	0.09	----	0.09
712-813	0.2	----	0.2	0.17	----	0.17	----	----	----	----	----	----
814 +	0.2	----	0.2	0.21	----	0.21	----	----	----	----	----	----
Total*	215.7	7.6	223.3	28.66	0.13	28.79	32.0	0.0	32.0	4.33	0.0	4.33
Percent*	97	3	100	99	1	100	100	0	100	100	0	100

*Excluding seedlings
(Larson 1970)

COSTS

Treatment Costs

The 1968 herbicide treatment, averaged for both ground and aerial applications, totalled approximately $91.18 per hectare, including the cost of the chemicals, direct application and ground support (Clary 1974). Two factors contributed to this high cost: 1) the high level of chemicals used; and 2) the small size of the spray area. Chemical rates could have been reduced by approximately one half and still have resulted in effective overstory kill. Minimum efficient tract size for aerial spraying is approximately 259 hectares. Therefore, on an operational basis, the cost for this treatment would have averaged approximately $60.00 to $70.00 per hectare.

Sale preparation and administration costs for the treatment area fuelwood sales were not determined. Sale preparation and administration costs for a similar area harvested in 1980 totalled $47.73 per hectare including archeological survey, marking and administration (USDA 1982).

In comparison to the herbicide treatment, the standard practice for pinyon-juniper removal in 1968 was the mechanical pushing and piling of stems using crawler tractors. Costs for this treatment ranged from $41.27 per hectare to $58.56 per hectare, on a 1972 basis (Clary 1974). These costs include pushing and piling, slash burning and subsequent seeding of the area. Such a treatment would result in forage and range conditions roughly comparable to those in the herbicide-treated area except that no standing dead shade would exist.

Current Costs

Current costs for equivalent herbicide stand treatments and fuelwood sales administration have increased substantially since the Watershed 3 treatment (table 2). Estimated 1985 herbicide treatment costs based on the aerial application of 2,4,D and picloram at active ingredient rates of 4.4 liters per hectare and 1.14 liters per hectare, respectively, mixed with triclopyr at 5.6 liters per hectare in a total application of 168 liters per hectare, total $262.71 per hectare. In terms of acid equivalents, application rates are as follows:

2,4,D	:	2.42 kilograms/hectare
Picloram	:	0.60 kilograms/hectare
Triclopyr	:	3.36 kilograms/hectare

(Personal Communication, Dow Chemical Company)

Site conversion costs have also increased substantially. A conversion treatment including individual tree raking ($58.81 per hectare), slash pile burning ($11.21 per hectare) and subsequent seeding total approximately $90.02 per hectare (USDA 1985).

Both treatments provide the opportunity to harvest fuelwood from treated areas. The conversion treatment does present a number of obstacles to full utilization, however. First, the large slash piles created by machine clearing pose great difficulty and danger to fuelwood cutters due to the jumbled arrangement of stems and limbiness of the down material. Second, the large amount of dirt accumulated on stem material reduces the utilization due to a reluctance on the part of cutters to dull chainsaw equipment by cutting through such dirty stems. Third, due to the pushing up of root mats and associated cutting problems, "long-butting" of stems may occur. On the other hand, the conversion treatment does concentrate fuelwood material with the potential for easier general access.

The net effect of the conversion treatment on fuelwood availability is difficult to determine. But any loss in available fuelwood on conversion treatment acres will increase the financial attractiveness of the herbicide treatments by increasing the relative fuelwood stumpage returns from herbicide treated acres. For example, if the conversion treatment eliminated all available fuelwood from a site, the net cost of this treatment would equal its gross cost (table 2). But, the herbicide treatments become more attractive financially since fuelwood could be harvested and those returns used to offset the treatment cost. Based on an average of 45 cubic meters per hectare of fuelwood, current fuelwood stumpage values of $0.88 per cubic meter, and current treatment costs (table 2), the net cost of the herbicide treatment, including the value of harvested fuelwood, totals $223.11 per hectare. Obviously, the conversion treatment is still more attractive financially, but an increase in fuelwood stumpage value to $3.84 per cubic meter would achieve cost equality between treatments.

Table 2.--Treatment cost comparisons for pinyon-juniper management (dollars per hectare)

Treatment	Watershed 3	Current (1985)
Fuelwood[1]	91.18	262.71
Conversion[2]	58.56	90.02

[1]Includes herbicide application, timber sale preparation and administration.

[2]Includes individual tree raking, slash piling and burning, and subsequent seeding operations (estimated) for areas similar to treatment area.

Table 3 displays the combinations of conversion treatment, fuelwood availability and corresponding fuelwood stumpage values required to achieve net cost equality between herbicide and conversion treatments. The "break-even" prices for fuelwood increase as wood availability on converted sites

increases, with the lowest price four times current stumpage prices, corresponding to zero fuelwood availability.

Table 3.--Break-even fuelwood stumpage values and availability

Percent Fuelwood Availability on Converted Sites[1]	Break-even Fuelwood Storage Price for Herbicide Treatments[1,2]
100	N/A
75	15.35
50	7.68
25	5.12
0	3.84

[1]Based on an average 45 M^3/HA total fuelwood availability

[2]Value of fuelwood stumpage required to equalize net costs of conversion and herbicide treatments (dollars per cubic meter).

MANAGEMENT IMPLICATIONS

As the figures on table 2 demonstrate, an herbicide/fuelwood treatment of pinyon-juniper sites has a large net cost disadvantage compared to a mechanical conversion treatment. However, relatively small absolute value increases in the price of fuelwood coupled with decreased wood availability on converted sites would change these net relationships. In addition to potential net revenue, the herbicide/fuelwood treatment has the following advantages over mechanical conversion:

1. Potential for increased water yields;
2. Elimination of smoke hazards from slash burning; and
3. Provision of standing dead shade for wildlife and grazing animal cover.

Disadvantages of an herbicide/fuelwood treatment are:

1. Potential social and legal barriers to herbicide application;
2. Negative aesthetics associated with herbicide killed overstory trees;
3. Additional workforce demands required in aerial herbicide application and administration of fuelwood sales; and
4. Potential long-term deleterious effects of herbicides on wildlife populations.

When making decisions with regards to the treatment of pinyon-juniper stands, resource managers should consider the potential gains of an herbicide/fuelwood treatment prescription in light of available workforce resources and the demands for fuelwood. Treatment decisions must be made on an individual area basis that recognized location, usable timber volumes, treatment cost and multiresource goals and constraints. Blanket, generalized prescriptions will only be correct for the elusive "average" stand and are no substitute for careful, site specific evaluation.

CONCLUSIONS

The study generated the following five conclusions:

1. Herbicide treatments are effective in the control of pinyon-juniper vegetation, especially pinyon pine;
2. Herbicide treatments have low levels of environment damage in terms of soil movement and the creation of soil pits;
3. Herbicide treatments for pinyon-juniper control can generate increased water yields by temporarily leaving standing dead trees to reduce windspeed and insolation;
4. Although currently more expensive than conversion treatments, increased fuelwood stumpage rates coupled with any reduced fuelwood availability on converted sites will increase the financial attractiveness of herbicide treatments; and
5. Rates of residual picloram found in water runoff were minimal.

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THE VALUE OF INCREMENTAL WATER FLOW FROM PINYON-JUNIPER LANDS

Thomas C. Brown

ABSTRACT: Benefit-cost analyses of pinyon-juniper treatments that significantly increase runoff should include the value of the incremental flows. The value depends on the use of those flows, which is affected by the stochastic nature of flows and institutional arrangements for water storage and routing. Under common institutional arrangements, much of the incremental flows from pinyon-juniper manipulation probably would not be consumptively used. This would diminish the at-the-watershed value of incremental flows.

INTRODUCTION

The monetary value of streamflow increases from pinyon-juniper removal depends on (1) the amount and timing of the increase, (2) the routing of the increase to users, and (3) the willingness of those users to pay for the increase. The first and last of these factors have been examined in numerous studies; but the second factor has not. This paper briefly reviews the first and third factors, and then focuses on the routing of the increase in flow to downstream users in a hypothetical case study of pinyon-juniper removal from a watershed. The results have implications for other vegetation types as well.

A thorough examination of water value should consider both quantity and quality, as well as the full range of uses, from instream uses such as recreation and power generation, to offstream uses such as irrigation and municipal and industrial uses. This paper focuses more narrowly on quantity (streamflow) changes in offstream uses.

Most studies of pinyon-juniper removal have shown little or no net streamflow response. Water yield before treatment generally is less than 25 mm. Any reduction in transpiration by removing pinyon-juniper may be offset by evaporation from soil pits (Skau 1961) and transpiration from herbaceous growth that replaces the trees. As early as 1960, Dortignac suggested that increases resulting from treatment would be small. Later, Gifford (1973) reached the same conclusion on a chained site in Utah. Clary and others (1974) reported similar results for mechanical treatments in northern Arizona. Hibbert (1979), in his summary of opportunities for increasing flow in the Colorado River Basin, concluded that, "The potential for increasing water yield in the pinyon-juniper type is negligible on most sites."

However, an herbicide treatment yielded a statistically significant flow increase as long as the dead trees were left standing. Clary and others (1974), Clary (1975), and Baker (1984) reported increases for such a treatment of about 10 mm per year. However, the acceptability of herbicide treatments is questionable (Cortner and Berry 1978) and the scenic beauty of standing dead trees is low.

Recent studies have estimated the monetary value of increments in water supply. Among consumptive uses, estimates are available for municipal, industrial, and agricultural uses (Young and Gray 1972; Young 1982; Young 1983). In most situations likely to be affected by pinyon-juniper removal, agriculture is the marginal user. Estimates of marginal values in agriculture are based on the marginal value product of irrigation water to individual crops or to whole multicrop farms. Analyses of crop production functions, for example, yielded marginal water values of about \$20 per 1,000 m^3 (\$25 per acre foot, 1980 dollars) for wheat and alfalfa in Arizona and New Mexico (Ayer and Hoyt 1981; Hoyt 1982). For cotton, these estimates rose to about \$49 per 1,000 m^3. Analyses of crop budgets yielded similar figures. For example, Willit and others (1975) obtained values of about \$16 for wheat and alfalfa and \$32 for upland cotton (1980 dollars). These estimates should be considered upper bounds to the extent that (1) government price support programs have inflated crop prices, (2) government subsidies have depressed the prices of nonwater inputs, and (3) costs would be incurred to convey the additional water to the irrigated land.

Water values such as these apply to incremental flows produced on upland watersheds if the incremental flows can be used when they reach users. Studies of the economic benefits of vegetation treatment have assumed that the increases reach points of consumptive use (Brown and others 1974; Krutilla and others 1983). However, ongoing studies in the Verde and Colorado River Basins suggest that a significant portion of such increases is likely to pass

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Thomas C. Brown is an Economist, Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Fort Collins, CO.

beyond users, only to infiltrate and evaporate in uninhabited regions or flow to the ocean.

METHOD

For the sake of simplicity and generality, a hypothetical river basin was designed to examine routing of incremental flows. In this basin, water flows were generated, stored, and routed to users according to a realistic stochastic regime. Several scenarios, differing in storage capacity, water demand, and flow response to vegetative treatment, were simulated. Each scenario was "run" with and without incremental flows that could have been created by vegetation treatment. The difference between the with and without cases indicated the routing of the increment.

The hypothetical basin contains a river that drains a large watershed and flows past a metropolitan area where water use is concentrated. Just above the use area, a reservoir is available to store water for future use. Storage for each time period is given by:

$$S_i = S_{i-1} + Q_i - R_i - L_i \qquad (1)$$

$$\text{st.} \quad S_i \leq Sc$$

$$R_i \leq D_i$$

where S_i = storage at end of period i,

S_{i-1} = storage at end of period i-1, beginning of period i,

Q_i = inflow in period i,

R_i = releases to users in period i,

L_i = spill loss in period i,

Sc = storage capacity,

D_i = quantity demanded by users in period i.

Demands of users (D_i) were assumed to be completely satisfied before water was spilled. Sophisticated reservoir operation models, such as stochastic dynamic programming (Stedinger and others 1984), were not used. Evaporation and seepage losses were assumed to be zero (accounting for evaporation and seepage would have complicated the analysis without seriously affecting the results). Also, return flows were ignored.

Pretreatment inflows were modeled on a monthly basis using a first-order Markov model (Fiering 1967). The first-order Markov model predicted monthly flow based on the mean historical flow for that month, as adjusted by (1) the previous month's flow, incorporating the historical relationship between the current month's and previous month's flow, and (2) a random term including the variance in the current month's historical flow and the correlation of the current to the previous month's flow. The full model is:

$$X_i = \bar{Q}_i + r_{i/i-1}(S_i / S_{i-1})(X_{i-1} - \bar{Q}_{i-1}) + tS_i(1-r^2_{i/i-1})^{1/2} \qquad (2)$$

where i indicates the time period (month),

X = predicted flow volume,

$\bar{Q}$ = mean flow volume for period of record

r = Pearson correlation of flow volumes for historical record,

S = standard deviation of flow volumes for historical record,

t = random normal variate.

Ninety-three years (1889-1981) of monthly streamflow data from the Verde River (Arizona) above Horseshoe Reservoir were applied to the Markov model to simulate the pretreatment situation. Thus, the pretreatment flows, termed "normal" flows here, have the stochastic property of the Verde River. The Verde River watershed covers about 4 million acres, ranges in elevation from about 2,200 meters to under 600 meters, and contains large areas of chaparral, ponderosa pine, pinyon-juniper, and desert shrub.

The first-order Markov model is appropriate for use where flow in a given month is normally distributed about its mean and where flows of proximate months are sufficiently correlated. A log transformation of the data was necessary to satisfy the normality requirement. Proximate month correlations ranged from 0.05 for July to June, to 0.47 for May to April. Correlations for the heavy flow months (December to May) with the previous month all were above 0.26. The model was tested by comparing historical data with results from 1,000 years of simulated data. Mean monthly historical flows differed from mean monthly simulated flows by no more than 12 percent. Mean monthly flows for the 1,000-year period are listed in the first column of table 1. The probability density function for the 1,000 simulated annual flows is depicted in figure 1.

Table 1.--Monthly distribution of streamflow and water demand

	Simulated normal flow	Demand (Mr_1)	Flow increase[1]	Flow increase[2]
	million m^3	- - - - percent - - - -		
October	21.1	6	0	0
November	25.5	3	0	3
December	46.4	3	5	22
January	57.5	3	15	6
February	94.6	5	20	12
March	137.0	9	25	15
April	72.0	10	30	17
May	17.9	11	5	0
June	9.1	13	0	0
July	14.4	15	0	0
August	30.1	12	0	13
September	24.4	10	0	12
TOTAL	550.1	100	100	100

[1] Assumed for most scenarios.

[2] Source: Clary and others 1974, figure 7.

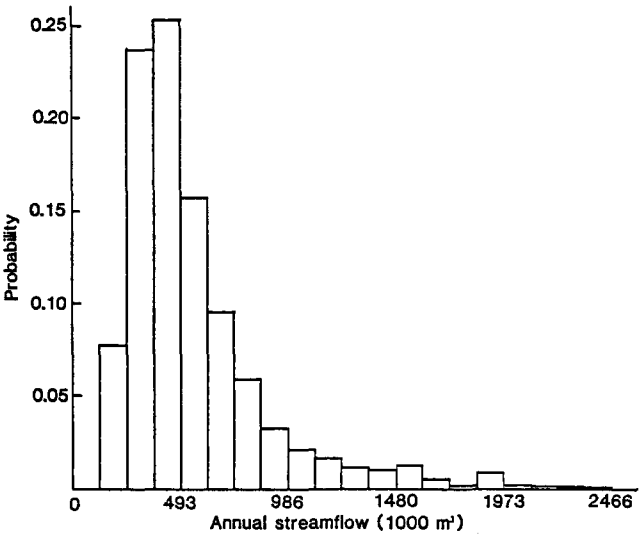


Figure 1.--Distribution of simulated annual normal streamflow.

Estimates of streamflow increases were added to normal flows (X_i) for the "with increase" case. Although a precise derivation of the relationship between normal flow and flow increase cannot be attained, the data suggest that the annual increase from pinyon-juniper removal is strongly, positively correlated with annual pre-increase flow (Clary and others 1974; Baker 1984). This information, along with estimates of the monthly distribution of flow increase, was used to estimate monthly streamflow increase. The monthly streamflow increase was approximated as follows:

$$I_i=(0.0000031\ X-0.379)\bar{X}\ Pq\ Mq_i \qquad (3)$$

where

I_i = predicted streamflow volume increase for month i,

X = annual normal flow volume, or for a given year, $\sum_{i=1}^{12} X_i$

$\bar{X}$ = mean annual normal flow volume (550 million m^3 in this study),

Pq = ratio of mean annual streamflow increase to $\bar{X}$,

Mq_i = proportion of annual streamflow increase coming in month i.

The Pq term in equation 3 allows mean annual increase to be expressed as a function of mean annual normal flow. The product of $\bar{X}$ and Pq gives the average annual volume increase. The terms in parentheses, .0000031X - 0.379, give the log of the return period of annual Verde River flow, which was separately estimated by linear regression (R^2 = .98).

Assuming simulated annual flow has identical stochastic properties to historical annual Verde River flow, this relationship can be used to express the increase as a function of normal flow.

The effect of this contrivance is seen by example. If the Markov model predicted an annual streamflow equal to mean annual predicted normal flow (550,114,047 m^3), the predicted annual streamflow increase would be approximately $\bar{X}Pq$, because mean annual flow has a return period of about 2.72 years, the natural log of which is 1.0. For a very dry year, such as one with annual streamflow of 154,704,510 m^3 (return period of 1.01 years), the streamflow increase would be $0.01\bar{X}Pq$. For a wet year, such as one of 1,985,130,000 m^3 (return period of 100 years), the streamflow increase would be $4.62\bar{X}Pq$.

Predicted annual flow increases were apportioned by month, based largely on Baker's (1984) observation for an herbicide-treated pinyon-juniper watershed in Arizona that most of the water yield increase comes during the normal spring streamflow period. The increase was assumed to come between December and May, concentrated in the spring months. The third column of table 1 gives the assumed values for Mq_i of equation 3.

Demand for water was expressed as a function of mean annual normal flow and then was distributed through the year on a monthly basis as follows:

$$D_i = \bar{X}\ Pr\ Mr_i \qquad (4)$$

where D_i = water volume demanded in month i,

$\bar{X}$ = mean annual normal flow volume,

Pr = proportion of $\bar{X}$ demanded each year,

Mr_i = proportion of Pr demanded in each month i.

Monthly distribution of annual demand (Mr_i) was assumed to be roughly as it currently is in the Phoenix metropolitan area (second column of table 1).

Each scenario was simulated for fifty 20-year periods (1,000 years total). Storage at the beginning of each 20-year simulation was assumed to be equal to one-half of an average year's normal flow (0.5 $\bar{X}$), except for scenarios with storage capacities (Sc, in equation 1) of less than $\bar{X}$, when initial storage was assumed to be one-half of storage capacity.

RESULTS

To facilitate presentation, storage capacities, water demands, and flow increases were specified in terms of their relationship to mean annual normal flow ($\bar{X}$). For example, a storage capacity capable of holding 2 years' average flow would hold $2\bar{X}$.

The degree to which streamflow increases are consumptively used in the demand area was examined for a range in storage capacities, demanded levels, and flow increase levels. The consumptive use percentage is presented for each scenario for the normal (pretreatment) flow and for the flow increase, to allow comparison of the use rate of the increase with that of the normal situation. For normal flows, consumptive use (R in equation 1) is presented as a percentage of mean annual inflow ($\bar{X}$), across all 1,000 years simulated. For flow increases, the difference in consumptive use between the with and without conditions is presented as a percentage of the increase in flow, again across all 1,000 years simulated.

Storage Capacity

The greater the storage capacity is, the greater is the capability to deliver water for consumptive use, all else equal. Given the stochastic nature of the Verde River and an annual demand ($\bar{X}Pr$, equation 4) of $1.05\bar{X}$, consumptive use of normal flow varies from 48 percent of $\bar{X}$ with no storage capacity to 95 percent of $\bar{X}$ with storage capacity of $3\bar{X}$ (fig. 2). Presumably, consumptive use of normal flow would approach 100 percent if storage capacity were sufficient to capture even the largest flows (and evaporation and seepage were zero).

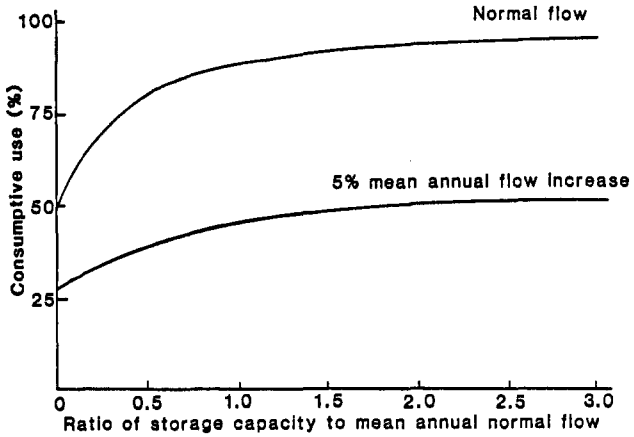


Figure 2.--Relationship of consumptive use to storage capacity, assuming annual demand equals mean annual posttreatment flow.

The use of incremental flows is quite different from the use of normal flows. Figure 2 graphs the percentage of a 5-percent mean annual streamflow increase (Pq = 0.05 in equation 3) that is consumptively used at a range of storage capacities, again assuming annual demand of $1.05\bar{X}$. The portion of the increase that is consumptively used varies from 28 percent, with no storage capacity, to about 50 percent at high storage capacities. Thus, even where storage capacity is sufficient to deliver nearly all normal flow to consumptive uses, only 50 percent of a 5-percent average annual streamflow increase is consumptively used at a demand level equal to average annual posttreatment flow.

Demand Level

The greater the demand level is, the greater is the likelihood that flow will be consumptively used, all else equal. Given a storage capacity of $1.05\bar{X}$ (equal to mean annual posttreatment flow), consumptive use of normal flow varies from 0 with no demand to 98 percent with annual demand of $3\bar{X}$ (fig. 3). The proportion of normal flow that is consumptively used increases dramatically, as demand increases, up to about the point where demand equals mean annual inflow. Consumptive use changes little as demand increases further. Note that a demand of $3\bar{X}$ represents a highly over-appropriated river (rights to much more water than is available in most years).

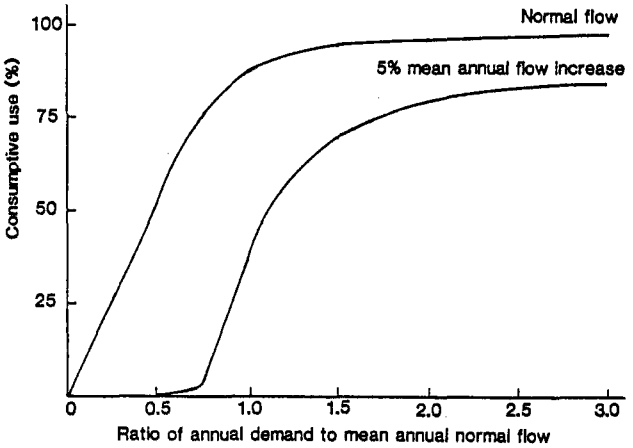


Figure 3.--Relationship of consumptive use to annual demand, assuming storage capacity equals mean annual posttreatment flow.

Flow increases contribute little to consumptive use when demand is less than $0.5\bar{X}$ (fig. 3). At high demand levels, flow increases contribute significantly to consumptive use. Close to 85 percent of a 5-percent flow increase is consumptively used if demand is $3\bar{X}$. However, only 42 percent of the increase is used when demand equals mean annual posttreatment flow.

Flow Increase Level

Given constant storage capacities and demand levels, increases in streamflow increase consumptive use. However, the proportion of a streamflow increase that is used consumptively drops as the increase becomes larger. At a storage capacity and an annual demand level equal to $\bar{X}$, the portion of any increase that is consumptively used drops from close to 50 percent for a very small increase to about 20

percent for a 50-percent increase (fig. 4). Similarly, if demand is $1.5\bar{X}$ and storage capacity is $\bar{X}$, the portion of any increase that is consumptively used drops from 72 percent for a very small increase to 53 percent for a 50-percent increase. Larger storage capacities would shift the curves of figure 4 upward without seriously changing their relative position.

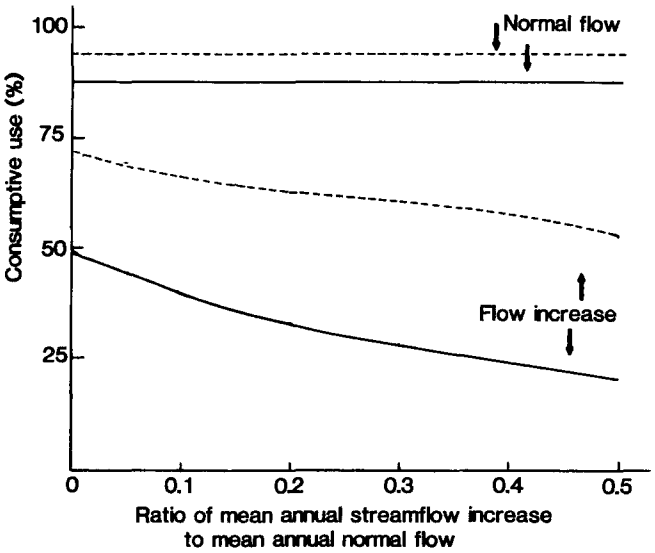


Figure 4.--Relationship of consumptive use to mean annual streamflow increase, assuming storage capacity equals mean annual normal flow (solid lines represent annual demand equal to mean annual normal flow; dashed lines represent annual demand equal to 1.5 times mean annual normal flow).

Timing of Flow Increase

Opportunities for consumptively using flow increments are quite sensitive to the timing of the increment, especially at lower storage capacities. In the foregoing, flow increases were assumed to occur almost exclusively during the spring runoff, with 75 percent coming during February through April (table 1). Alternatively, the increases were assumed to be distributed monthly as normal pinyon-juniper flows were at Beaver Creek Watershed (see the right-hand column of table 1), where 37 percent of the flow occurred during the last 4 months of the calendar year (Clary and others 1974). This change in monthly distribution of incremental flows increased the portion of incremental flow that was consumptively used. Across a range of storage capacities (fig. 2), the percentage of the flow increment consumptively used increased from 13 percentage points at a storage capacity of $0.25\bar{X}$, to 1 percentage point at a storage capacity of $3\bar{X}$. Across the range of annual demand levels, from $0.25\bar{X}$ to $3\bar{X}$ (fig. 3), the percentage of the increment consumptively used increased from 0.5 to 5 percentage points, respectively. Across the range of annual flow increase levels, from $0.01\bar{X}$ to $0.5\bar{X}$ (fig. 4), the percentage of the increment consumptively used increased by about 2 percentage points.

SUMMARY AND CONCLUSIONS

The routing of flow increases to users must be considered when estimating their value. This paper shows that, under common storage capacities and demand levels, nearly 50 percent of the flow increment may not be consumptively used, even though nearly all of the pretreatment flow is used. The loss of a substantial portion of the increase lowers its at-the-watershed value. The unused flow may have nonconsumptive uses, such as producing hydroelectric power, but may also contribute to flooding.

Conditions that tend to increase the portion of incremental flow that is consumptively used include large storage capacities, heavy demand levels, and closely matched distributions of monthly demand and monthly flow. Although storage capacity can be managed, decisions about storage capacity are not likely to be heavily influenced by opportunities for capturing small incremental flows. Demand levels and monthly distributions of both demand and flow are largely fixed in any specific situation. In arid regions and where irrigation is a significant water use, demand is usually heaviest during the summer, when flow is lowest.

The portion of an increment to flow that is consumptively used could be affected by factors not considered here. Three factors suggest decreases in consumptive use of incremental flow. First, evaporation and seepage decrease consumptive use to the extent that incremental flows increase water surface areas or wetted soil surfaces. Second, reservoir operating rules may conflict with maximizing consumptive use. For example, flood control policies or hydroelectric power production objectives may require release of water at times when it cannot be consumptively used. Third, demand may vary with flow. If precipitation changes affect the watershed and area of consumptive use in a similar fashion, demand may drop when supply is greatest, lowering opportunities to consumptively use flow increments. The following two factors suggest increases in consumptive use of incremental flows. First, flow not consumptively used may infiltrate in areas where it can subsequently, via pumping, be made available for use. Second, a more sophisticated reservoir operating rule than that used here might enhance opportunities for consumptive water use.

A stochastic regime of less variability about mean flow than that of the Verde River would result in greater levels of consumptive use at a given storage capacity, because there would be fewer flows that exceeded available storage capacity. Given the importance of considering the stochastic regime for the Verde River case, the relationships examined here probably should be examined for other stochastic regimes of interest.

These hypothetical results indicate that the value of increments to streamflow from pinyon-juniper removal may be lower than previous estimates. Even where treatments produce as much as 10 mm per acre per year on site, more than one-half of this increase may be lost to consumptive use. At a reasonable 1980 marginal water value of $24 per 1000 m^3, and assuming one-half of a 10 mm increase is consumptively used, the average annual value of consumptive use of streamflow increases from pinyon-juniper removal is $0.20 per hectare ($0.50 per acre).

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SIMULATION MODEL TO TEST ECONOMIC CONSEQUENCES OF MANAGEMENT DECISIONS FOR A STEER OPERATION ON PINYON-JUNIPER WOODLANDS

Phil R. Ogden

ABSTRACT: A simulation model for forage crop, beef production and economic returns for grazing steers on pinyon-juniper woodlands is presented. The model is modified from one developed for steers grazing in the summer on a ponderosa pine site in northern Arizona. The model provides a means for identifying data needs necessary to make reliable management decisions and provides estimates of net economic return to livestock production for scenarios resulting from management decisions and biotic and abiotic parameters.

INTRODUCTION

Upon delving into the economics of increased livestock production resulting from manipulation of pinyon-juniper woodlands, one quickly realizes that results depend on the interactions of site potential, weather, grazing and livestock management, market prices, and many variables associated with P-J treatments. Simulation models provide a tool by which the many factors influencing results can be displayed and many scenarios may quickly be evaluated. I have, therefore, chosen to present a simulation model which yields as the final output the net annual return to livestock resulting from P-J treatment. The parameter inputs are for one year time steps and final output is dollars per hectare. The present values of annual returns over a specified planning period provide the benefits to livestock production which may be utilized in benefit-cost or present net worth analyses.

The model is modified from one developed for steers grazing on a ponderosa pine area, the U.S. Forest Service Wild Bill Range near Flagstaff, Arizona (Ogden 1982). The pinyon-juniper model contains 15 steps to calculate 15 state variables as shown in the flow diagram (fig. 1). The solid arrows represent flow of material from one state variable to another. The dashed line arrows indicate information from state variables and parameters required at each step or regulation of flow. The organization of this paper is to show the 15 steps for calculation of each state variable from A through O. Parameters required to make the calculations are discussed and specific numerical values selected as an example for a one-year simulation.

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Phil R. Ogden is Professor of Range Management and Extension Range Specialist, Division of Range Resources, University of Arizona, Tucson, AZ.

A. MEAN INCREASE IN HERBAGE PRODUCTION

Herbage production is used here in a general sense and should include shrub as well as herbaceous production. When data are available, it may be desirable to separate A into A_1-grass, A_2-forb, and A_3-shrub production. For step 1, $A \equiv m$ where the input parameter m is the herbage production after pinyon-juniper treatment minus herbage production before treatment. Parameter m may be a function of tree canopy cover before treatment (t_1) and tree canopy after treatment (t_2).

As an example for northern Arizona, Arnold and others (1964) show herbaceous production as about 100 kg/ha with 60% P-J tree canopy and 670 kg/ha without trees. The input for m, if all trees are cleared, is 670-100 = 570 kg/ha. Since A = m, A = 570 kg/ha.

B. MEAN HERBAGE PRODUCTION CONSIDERED FORAGE FOR STEERS

Step 2 requires the input parameter f which is the percentage of A which is palatable forage for steers, B = fA. For our northern Arizona example, we may consider f = .70 and B = .70(570) = 399 kg/hr.

C. STEER FORAGE USED BY OTHER HERBIVORES

At step 3 the input parameter h is introduced to consider forage which is used by herbivores other than steers and would include forage eaten by large wildlife species, rodents, rabbits, and insects. For our northern Arizona example, we shall consider h = .10. Since C = hB, C = .10 (399) = 40 kg/ha. This amount then goes out of the system which the current model considers.

D. FORAGE RESERVED FOR NONCONSUMPTIVE USES

Not all of the forage produced is available for use by herbivores if range condition is to be maintained and multiple use objectives are to be met. The parameter n is the percentage of the forage which is allocated to nonconsumptive uses such as to maintain plant vigor, soil protection, wildlife cover, and aesthetics and D = nB. The value of n will be greatly influenced by the value

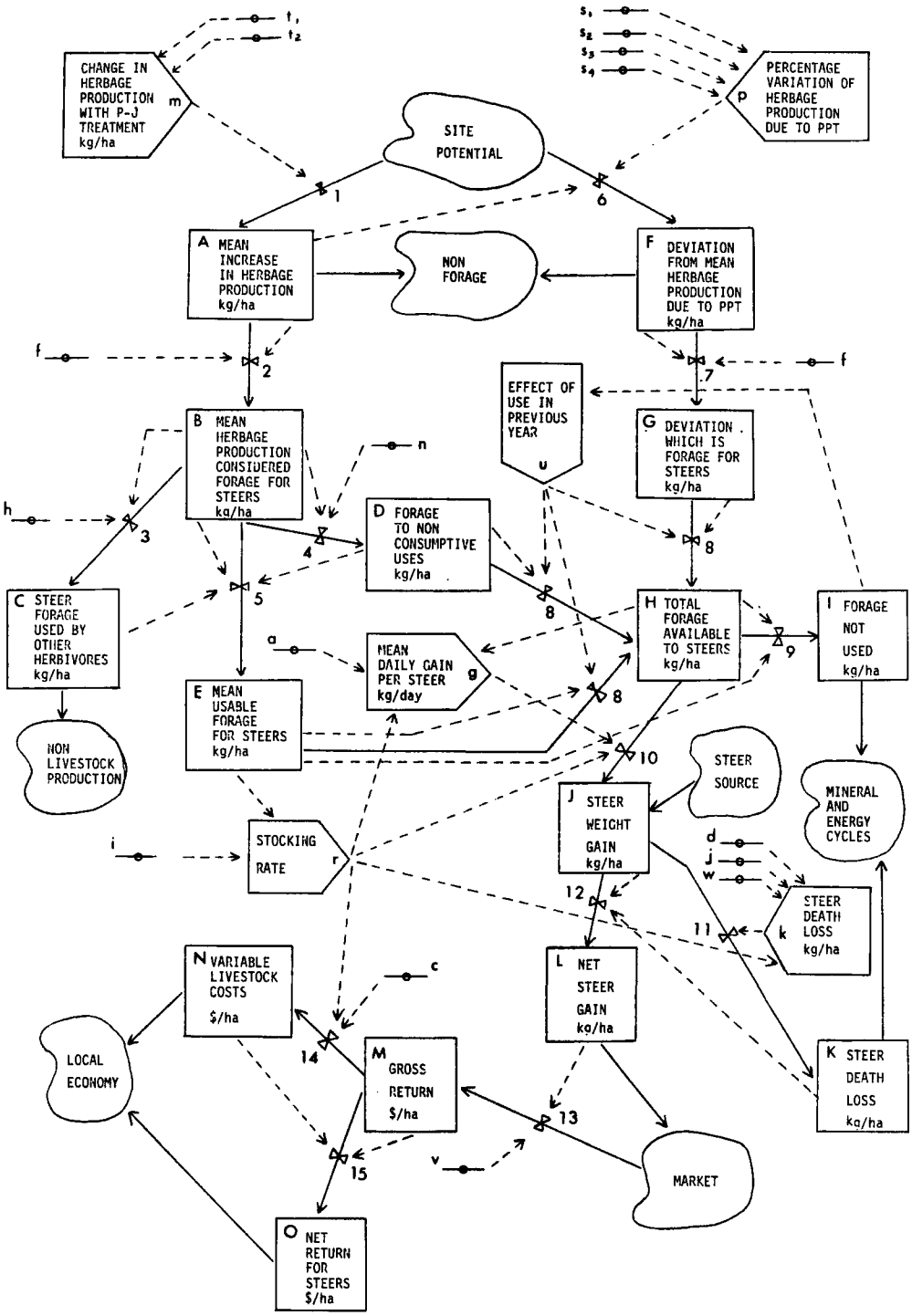


Figure 1. Flow diagram for simulation model, one-year time step

for f, season of use, use distribution and grazing systems used in the management of the treated area.

For our example, let us consider the treated area is fenced into two pastures with one pasture used early season and the other late season each year. The early and late use is rotated between the two pastures and use is uniform over the pastures. We may consider that n = .50 and D = .50(399) = 200 kg/ha.

E. MEAN USEABLE FORAGE FOR STEERS

The mean annual forage which is available for consumption by the steers and which provides the basis for determining the stocking rate is calculated in step 5 as E = B-C-D. For our example, E = 399-40-200 = 159 kg/ha.

F. DEVIATION FROM MEAN ANNUAL HERBAGE PRODUCTION DUE TO PRECIPITATION

Analyses are usually based on mean conditions which ignore the annual extremes which result from seasonal and/or annual variations in precipitation. When functional relationships between seasonal and/or annual precipitation and annual herbage production are available, inclusion of a random or selected precipitation factor in the model provides for more realistic values than when only mean values are used.

For the model developed from the Wild Bill Range data for ponderosa pine (Ogden 1981, 1982), parameter p was expressed as percentage deviation of mean peak grass and forb crops as a function of seasonal precipitation, s_1, s_2, s_3 and s_4 for fall, winter, spring, and summer precipitation, respectively. The seasonal parameters also were expressed as percentage deviations from mean seasonal precipitation. The s parameters were, therefore, inputs to the model and p was calculated and F = pA. Herbage production-precipitation relationships for P-J areas such as shown by Clary (1971) in Arizona and Pieper and others (1971) in New Mexico could be used to estimate p. Let us assume for our example that herbage production is 10% below average due to precipitation, so p = -.10 and F = (-.10)570 = -57.

G. DEVIATION FROM MEAN HERBAGE PRODUCTION CONSIDERED FORAGE FOR STEERS

The adjustment at step 7 uses the parameter f used at step 2 (percentage of herbage production which is forage for steers) to convert to portion of F which is forage, G = fF. For our example, G = (.70)(-57) = -40.

H. TOTAL FORAGE AVAILABLE TO STEERS

The actual forage that is available for livestock to select from in any given year is the sum of forage allocated to livestock and nonconsumptive uses, plus or minus the deviation due to precipitation, all adjusted for the intensity of grazing in the previous year (parameter u). The parameter u is the percentage of forage production attained as influenced by the intensity of grazing in the previous year. Heavy, continuous grazing is known to reduce plant vigor and subsequent herbage production. Controlling time and amount of use should maintain vigorous range forage.

Specific data often are not available for parameter u but many P-J treatment projects have failed to provide sustained yield because they were not well managed following treatment. This factor should not be ignored in economic evaluations. Data from the Wild Bill Range (Ogden 1981) supports a conclusion that there was no effect on following year forage production if use of forage crop was less than 30% summer long each year. Use in excess of 30% reduced the following year forage production by a percentage equal to the percentage use in excess of 30%.

For our example we shall assume that the 200 kg/ha reserved for nonconsumptive use and the deferred rotation grazing will maintain plant vigor for u = 1.0 except for drought years where use will be heavy and u will be less than 1.0. Total forage available to steers is calculated in step 8 as H = u (D + E + G). If we assume no reduction in plant vigor due to grazing in previous year, u = 1.0 and H = 1.0 (200 + 159 -40) = 319 kg/ha.

I. FORAGE NOT USED

This state variable represents the forage which is not consumed by steers and other herbivores and moves out of the system being modeled. The calculation at step 9 to show this amount for our northern Arizona example is I = H-E = 319 - 159 = 160 kg/ha.

J. STEER WEIGHT GAIN

Livestock weight gain per animal and per unit area are a function of stocking pressure (Mott 1960; Bement 1969) and the potential of the grazing animals to make daily gain if feed is not limiting. Data from summer grazing of steers on Arizona fescue-mountain muhly forage under ponderosa pine on the U.S. Forest Service Wild Bill Range near Flagstaff, Arizona (Ogden 1981) showed that 200- to 300-kg steers had a potential to gain .68 to .95 kg per steer day when grazed under very light stocking pressure. The daily gain decreased by .07 kg/steer day for each increase in stocking pressure of 1 steer per 45 kg/ha of forage. The kg gain per steer day, g, is, therefore, calculated as $g = a - \frac{.07r}{H/45}$ where r is stocking rate as steer days/ha and H is defined as above. r is calculated as r = E/i where i is forage intake or forage requirement per steer day. Cardova and others (1978) have shown that values for intake for range livestock are usually between one to 2.8% of their body weight per day. Selecting an average value of 2% for an average 250 kg steer results in an estimated daily intake of 5 kg. This is near the

4.5 kg average daily forage disappearance per steer day for Wild Bill Rangedata (Ogden 1981). For our example, then r = 159/5 = 32 steer days/ha and, if steers have a potential to gain (a) .90 kg/day,

$g = .90 - \frac{(.07)(32)}{319/45} = .90 - .32 = .58$ kg/steer day

Therefore, J = rg = (32 steer days/ha)(.58 kg/steer day) = 18.6 kg/ha.

K. STEER DEATH LOSS

Steer death loss may be expressed as a percentage stocking rate lost to death. This death loss expressed as kg/ha (parameter k) may be calculated as $k = \frac{jrW}{d}$ where j is the percentage death loss, r is stocking rate as calculated above, W is average weight of steers at death and d is length of the grazing season in days. If we take values of j = .03, W = 250 kg, r = 32 steer days/ha and d = 120 days in grazing season for our example, $k = \frac{(.03)(32)(250)}{120} = 2.0$ kg/ha and K = k = 2.0 kg/ha.

L. NET STEER GAIN

The net steer gain as kg/ha is calculated as L = J-K. For our example, this is L = 18.6 - 2.0 = 16.6 kg/ha.

M. GROSS RETURN

At step 13, the steers are sold at market value (parameter v) and the gross return calculated as $/ha. For our example with v = $1.30/kg and M = vL, M = 1.30(16.6) = $21.58/ha.

N. VARIABLE LIVESTOCK COSTS

The variable costs per steer (c) associated with increased animals as a result of the P-J treatment are the costs which would be included here. The fixed costs associated with the ranch operation which would exist with or without the extra steers gained as a result of the P-J treatment would not be included here. N expressed as $/ha = $\frac{cr}{d}$ where d is days in grazing period as used in calculation of variable K and r is stocking rate as defined under variable J and $c = c_1 + c_2 + c_3 + c_4 \text{ --- } c_n$ where the input parameters

c_1 = Interest charge for use of money for purchasing steers

c_2 = Grazing fees

c_3 = Transportation costs

c_4 = Veterinary costs

c_5 = Market costs

c_6 = Extra labor

c_7 = Other costs such as price difference for steers when purchased and when sold.

For our example:

c_1 = $10; c_2 = $5.50; c_3 = $10.00; c_4 = $3.00; c_5 = $5.00; c_6 = $10.00; c_7 = $20.00, so c = $63.50 per steer and $N = \frac{(63.50)(32)}{120}$ $16.93/ha

O. NET RETURN FOR STEERS

The net annual return for steers per hectare is calculated as O = M - N which for our example is O = $21.58 - $16.93 = $4.65/ha. This amount is the net return for the first year of grazing on the treated area. The value of this amount plus subsequent annual net returns for the life of the project discounted to the beginning of year 1 for the project would be the present value of the benefits to livestock production used in benefit/cost, present net worth or internal rate of return analyses.

SUMMARY

This simulation model can be programmed for computer analyses and input parameters for specific projects tested with various hypotheses relative to changes in these parameters over the life of the project. The sum of the present values of the annual net returns to livestock production over the life of a project provides an estimate of the project benefits attributable to livestock production. Other economic benefits attributable to the P-J treatment would be added to the return to livestock production to arrive at the benefits to compare with costs for specific P-J treatments.

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EVALUATING MULTIRESOURCE BENEFITS OF TREATMENTS IN PINYON-JUNIPER WOODLANDS

Lawrence D. Garrett

ABSTRACT: Changes in forest policy and law have placed greater emphasis on multiresource management, and techniques, to ensure its efficiency and effectiveness. Although the lack of multiresource data has impeded progress in multiresource modeling, conceptual and prototype models are being developed. The model "ECOSIM" developed in the Southwest has capability for evaluating multiresource benefits from pinyon-juniper woodlands. For multiresource models to find expanded use in land management planning, continued development must be based on sound scientific principles and reflect the needs of management. Managers and analysts using the models must do so within constraints specified in their development.

INTRODUCTION

Forestry professionals must continue to develop better methods for managing the productivity and use of the nation's forest resources. Emphasis is needed in research, development, and application. One area requiring additional research effort is modeling multiresource response to alternative management strategies (Hartgraves 1981). Better response functions are needed to describe an individual resource reaction to different management treatments. But, more important, better systems approaches are needed at the forest level to project the interrelated response of several resources to a given management alternative.

These approaches are most critical in forest or woodland types where single resource outputs cannot produce viable economic return. The economics of single resource outputs from pinyon-juniper type is marginal, suggesting emphasis on multiresource management for multiproduct yields from these areas.

The multiresource concept is not new. Foresters have been and are continuing to manage for multiple benefits. However, more stringent constraints are imposed on planning today due to changing law, special interests, and policy. The forester must be able to provide a clearer picture of expected outcomes from a management alternative prior to implementation.

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Lawrence D. Garrett is Dean, School of Forestry, Northern Arizona University, Flagstaff, AZ.

A brief overview of management direction reveals how critical the need is for multiresource evaluation and projection techniques. It relates the need for greater emphasis on analysis and interpretation of multiresource data for deriving multiresource models and/or systems for use in land management planning.

In 1960, the Multiple Use-Sustained Yield Act identified the multiple uses served by the national forests (USDA 1978). However, the problem of determining procedures for allocating resources, such as timber and recreation, among competing interests was not resolved.

Succeeding acts made the responsibility more explicit. The Renewable Resources Planning Act (RPA) of 1974 assigned responsibility to the Chief of the Forest Service to periodically assess the supply and demand for forest and range resources (USDA 1976). In 1976, an amendment to the RPA, titled the National Forest Management Act (NFMA), outlined systematic methodology for planning the allocation, use, and future productivity of the national forest system's multiple resources (USDA 1979). The amendment addresses the need to develop standards and methodologies for improving multiresource management planning and monitoring of the national forest system.

Whereas forests have traditionally been managed by a number of functional resource plans, the new process requires each forest to prepare a single, integrated plan developed by an interdisciplinary team of forest specialists. The process is described as a nationally controlled and directed program which attempts to:

1. Determine for each forest the operational and biological feasibility of achieving specified target output levels under given budgetary, operational, and production capacity constraints.
2. Determine the allocation of production targets at regional and forest levels which minimize the total cost of production (economic, social, and environmental costs are considered) (Hartgraves 1981).

To accomplish this intense planning process requires data sets on all resources being managed at the forest level. Inventories for commercial timber species are available and have proven useful in evaluating this resource in the planning process. Yet, inventories on economically marginal woodlands such as pinyon-juniper have not been effectively evaluated for use in intensive management. There are no

national continuous inventory methods applied for developing data bases on the many other resources currently managed.

Data bases on pinyon-juniper type developed by research in several areas of the United States are available. Existing research data bases, used in concert with continuous forest inventory and other forest inventory data, do afford a starting point for development and testing of multiresource projection systems. Such systems will be plagued by data weaknesses. However, they should be superior to many currently used approaches which place limited emphasis on good data and analytic techniques.

Adapting Multiresource Modeling to Forest Planning

The process of developing multiresource projection techniques is attainable, but at various levels of efficiency and effectiveness. As noted, many of the difficulties relate to data availability. Many national forests have little multiresource data, and must rely on estimates that cannot be supported by any level of statistical analysis. Other forests with ongoing data inventory and/or cooperative research programs may have sufficient multiresource data to develop statistical models for several resources.

No forest has sufficient multiresource data from inventory to develop absolute values for population parameters needed. Yet, if scientifically valid procedures are applied to even partial data bases, more efficient and effective methods can be developed for understanding and projecting multiresource outputs.

Currently, we have only begun to investigate multiresource models for projecting resource outputs under differing management alternatives. Efforts by Boyce (1977) were successful in developing DYNAST-MB, a multiresource projection model for evaluating multiple benefits for eastern hardwood forests. This system is now being evaluated for use in management.

Research efforts in the Southwest have been effective in developing the prototype multiresource model "ECOSIM" for projecting multiresource outputs from ponderosa pine forests and pinyon-juniper woodland type (Rogers and others 1981). The research was designed to evaluate tradeoffs in multiresources that result from implementation of differing forest management alternatives. Research outputs have been expressed in management guidelines and analytic models.

Development of the "ECOSIM" prototype multiresource model was dependent upon a data base obtained from twenty years of research. Data for development of pinyon-juniper multiresource algorithms were taken from six research watersheds studied to determine impacts of management treatments on fuelwood, range, wildlife, and water.

Results of the long-term research effort in the Southwest revealed aspects of multiresource modeling that could be helpful to researchers undertaking similar efforts. These aspects involve defining appropriate analytic technique and model structure in model development, as well as defining appropriate procedures for model use after development.

Developing Multiresource Models

Efforts should begin with evaluations of existing data that can be utilized in such an effort. Where insufficient and/or unreliable data exist, assessments should be made of minimal cost approaches to development of data bases that could be effective in developing individual resource models and/or calibration of models transported from other areas.

Even before data bases are in place, conceptual multiresource models can be structured to address specific problems. Many systems analysis techniques exist for development of models and/or systems. Linear programming, goal programming, integer programming, nonlinear programming, dynamic programming, simulation, queueing theory, decision theory, and network theory can be used, depending upon the problem addressed and data available.

Simulation is used by modelers because of the ability to accomplish objectives without extensive data bases. Bare (1971) gave several reasons for use of simulation. These include: (1) the versatility of the technique, enabling it to be used for a variety of purposes, (2) models and systems can be constructed to tailor fit the situation, (3) models and systems can be built around existing data base without requiring major data gathering efforts, (4) models can be developed with short lead times to provide timely inputs, and (5) solutions with minimal data are often satisfactory when one understands that the actual implementation of the prescribed plan is likely to be modified somewhat on the ground.

Any model developed for forest planning should respond to the manager's needs to meet legal and policy requirements or more generally implement effective management practice. The following outline illustrates general areas of capability which would be useful in multiresource models developed for forest planning.

A main program to control the simulation and call other components in proper sequence. It should provide capability for simulating several management alternatives during a single program execution.

An input and initialization component which reads user instructions and a description of the current forest stand. An interactive question-answer dialogue is most effective, and enables

the user to select different woodland species, choose among optional models for some species, and define variables which describe flora, fauna, and the physical character of the environment being evaluated.

Resource projection components to simulate resource outputs on an annual time step. Simulations could include:

1. Forest or woodland growth and yields
2. Herbage yields and carrying capacity
3. Forest or woodland floor, snag, log, and debris accumulation and decomposition
4. Water yields
5. Soil loss
6. Wildlife habitat
7. Land form characteristics
8. Climate
9. etc.

Activity simulators to provide the manager with methods of simulating the implementation of various forest prescriptions under differing management alternatives. Areas of simulation capability could include various methods of tree cutting, regeneration, salvage cutting, range improvement, prescribed burning, site preparation, fuelwood removal, water impoundment, road construction, recreation development, etc.

Output and summary component simulators to provide summaries of the effects of treatments on resources. Standard output could include information required in forest planning. Optional outputs could include detailed summaries of individual resource and activity impacts.

Implications to Management

The benefits which multiresource research and modeling can offer to forest multiresource planning are many. Most important is the ability to evaluate complex tradeoffs that occur in a woodland area when management actions are taken. Since discerning publics are scrutinizing all potential impacts of planned change, it is necessary to identify both the individual and the interactive impact of a management action.

With the important need and opportunity to improve our capability, are we gaining ground? And if not, why not, and what can be done?

Efforts are being made, and some are extensive. The Forest Service has adopted "FORPLAN," a linear program resource allocation model, for use on all national forests (Gilbert and others 1983). Using inputs from analysts or multiresource projection models, "FORPLAN" can provide the manager with guidelines as to the best management alternative to pursue.

Analytic capability is also being improved through adoption of new hardware and software. Compatible systems are currently being manufactured for assignment to each national forest.

Also, federal and university research is developing individual resource projection models for use in planning and management. As noted, extending these efforts to multiresource modeling is occurring, but at a slower pace. The availability of effective multiresource data impedes progress, but probably just as important are the actions of researchers and managers.

Researchers have too often taken the "ivory tower" approach to modeling. The models and/or results are often not an appropriate solution to the manager's problem. Managers then become skeptical of the real contribution modeling can make to management science.

Grayson (1973, 1975) indicated that managers may be reluctant to support and/or use these types of efforts because: (1) excessive time is taken by analysts to respond to managerial requests, (2) data needed for many models are inaccessible even after models have been constructed, (3) many managers are still uncomfortable and not familiar with systems and/or models and are resistant to use them, and (4) many analyst groups produce systems and models which barely resemble the real world.

Yet, it is a foregone conclusion, managers must use analytical models and systems to keep pace, and research must assist in their development. To do the job effectively requires a unique level of understanding and cooperation from each. It also requires that the mystique of computers and modeling be resolved and cast in the same light as calculators and arithmetic. They are simply that in another stage of development.

Managers and researchers alike must be aware of the difficulties associated with model development. Further, identified weaknesses and strengths must be the guidelines for their use. In this regard, both the researcher and manager have responsibility for their correct use.

DIFFICULTIES IN MODEL DEVELOPMENT

It must be understood by the manager and researcher that multiresource models are abstractions of the real biological world. Developing an analytic model to accurately describe one wildland process such as biomass production in pinyon-juniper type is difficult. The task is much more complex when many resource models are linked, as in multiresource modeling.

When a model must be further constrained to conform to a manager's requirements of brevity and simplicity, difficulties increase. That is, the model must capture the real world in the smallest number of variables possible, and with a minimal amount of complexity in the variable interactions. Normally, biological processes are not simplistic, and actions to simplify or constrain the model often increase error.

The researcher is always limited by his available data in structuring a model that is biologically reasonable and also affords prediction efficiency.

Most established guidelines constrain the number of variables contained in the model to a smaller subset, which will provide the predictive efficiency appropriate to its intended use. The inclusion of all variables known to affect the natural process is normally illogical due to restricted data availability, marginal increases in predictive efficiency, and increased cost with increased data requirements and model complexity.

Once the researcher has developed a model, two factors limit his ability to make the model useful to the manager.

1. The accuracy with which the developed model defines the biological processes being evaluated.
2. The accuracy with which data selected for model development represents the total variation in the environment under evaluation.

If the manager wishes to transport a model to an area different from where it was developed, the researcher is faced with additional problems. The model's usefulness then depends upon the extent to which parameters, which accurately describe natural processes in the new area, differ from areas where the model was developed. That is, are the same parameters appropriate and adequate? And, would the relationships among model parameters and structure be the same in the new area? It also depends upon the extent to which data differ, both in diversity and variability.

USING MODELS CORRECTLY

Models, developed with acceptable procedures, are sometimes misused. Correct use is critical, and it relates not only to how and where the model is applied, but also to how the manager and/or analyst uses the outputs. Models can give unreliable estimates, due to oversimplification of assumptions and relationships, rarely encountered situations which have not or cannot be properly modeled, or extreme conditions which have not been considered. Modelers are obligated to specify these constraints, and users must understand their significance. If managers deliberately use models or systems in questionable applications or blindly use outputs that are questionable, the true utility of models has been destroyed..

There is clearly an obligation to the researcher to clarify the capabilities and limitations of his modeling efforts. It is his responsibility to determine the quality of his predictions and present any constraints on the models which are appropriate.

It is not the responsibility of science or scientists to define a model as good or bad. It is the scientist's charge to define appropriate use, capability, and limitations. There is no absolute test as to the validity of most biological and economic models, but only subjective judgments based on the proposed use of the model, the acceptable level of errors, the availability of alternative models, and other user-related practical considerations.

Given the information on a model's capabilities and limitations, the manager must decide on its use. Once he has decided to use the system, he has a responsibility to use it within the limits of its design and evaluation.

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WHOLE TREE HARVESTING OF THE PINYON-JUNIPER TYPE: ECONOMIC AND INSTITUTIONAL CONSIDERATIONS

Donald E. Henderson and Mike L. Baughman

ABSTRACT: As public land management agencies are faced with tighter fiscal constraints, capabilities to effectively implement desired land management practices may be lessened. Such conditions require innovative partnerships between the public and private sectors. Such partnerships should seek to accomplish agency objectives while providing adequate economic incentives to the private sector. Under proper conditions, public land management agency objectives concerning the management of the pinyon-juniper type could be accomplished by the private sector.

This discussion focuses on the various economic and institutional considerations which may be prerequisite to effective public/private sector relationships. Within this discussion, a model management framework is outlined, necessary institutional relationships defined, and economic benefits assessed.

INTRODUCTION

Pinyon-juniper (P-J) woodlands have long been considered an increasing impairment to attaining multiple-use objectives on public rangelands. The problem evolves from the types' ability to invade rangelands, where adapted and under fire protection, replacing useable forage and habitat with dense overstory. As P-J density increases, understory vegetation such as shrubs, forbs, and grasses decrease, diminishing multiple-use amenities. Under such situations, the preferred management alternative has been the reduction or eradication of P-J with reintroduction of more desirable plant species.

Past P-J management has been relatively inefficient and ineffective, except on a small scale around urban areas, in reaching the desired objectives. The reasons are two-fold. The first reason is based on the destructive nature of current P-J control methods. Although burning, chaining, and chemical control techniques generally accomplish the desired effects, they fail to utilize P-J biomass and fiber as a potential resource. As a result, the public sector is incurring the total costs of P-J treatment while capitalizing on only a few of the potential benefits.

Secondly, in a political climate of increasing budgetary constraints and inflationary costs, the capacity of resource management agencies to effectively implement desired P-J management has been reduced. As a result, the majority of P-J woodland is currently under custodial management which implies the preservation of the status quo.

In the past, P-J biomass and fiber have had little economic value. Because of recent innovations in harvesting equipment and wood product technology, a demand has developed for inexpensive wood chips for energy generation, the production of chemical extracts, and construction materials. With its good fiber quality and high energy and resin contents, P-J biomass has the characteristics to meet many of these demands.

This demand may also provide a possible solution to the current P-J dilemma--the introduction of private industry into P-J management. This solution would require a partnership between public and private sectors whereby P-J is commercially harvested for private use while public land management objectives are simultaneously met. Based on the concepts of value in exchange, the costs incurred in P-J removal could be partially internalized by private industry with savings to the public sector.

For purposes of this discussion, value in exchange is defined as the equal trade of goods and services between parties which results in the economic and institutional objectives of each party being met. The public sector benefits from the harvest of P-J woodlands through the enhancement of multiple-use values. Likewise, a marketable raw material with a reliable, long-term supply is of use to private industry if the economic incentives are greater than the costs and risk. If the trade of goods and services between public and private sectors can be equalized there is little question that value in exchange concepts have a place in P-J management.

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Donald E. Henderson and Mike L. Baughman are Resource Planner and Principal Planner, Resource Concepts, Inc., 340 North Minnesota Street, Carson City, NV 89701.

The following offers a conceptual framework through which value in exchange concepts could be applied to large-scale P-J management and proposes economic and institutional changes necessary to promote equal trade between public and private sectors.

A CONCEPTUAL MANAGEMENT FRAMEWORK

The objectives of the value in exchange approach would be to optimize multiple-use values and returns from P-J woodlands through commercial harvest while reducing public costs. To successfully accomplish this objective, the concept must: (1) operate within the goals, budgetary constraints, and regulations of the public agency; (2) be economically feasible to the private operator; and (3) utilize ecologically sound practices in vegetation treatments and subsequent management.

A suggested management framework to meet these objectives while still operating under the above criteria would involve the following.

* Identification of P-J woodland areas in need of treatment by the public agency through normal planning and environmental assessment procedures.

* Solicitation of private sector proposals for P-J harvest by the public agency.

* Negotiation between the public agency and the private operator whereby a cooperative management agreement is reached to the benefit of both.

* Joint development of a harvesting/management plan, by the public agency and private operator, that incorporates public input, ecologically sound practices, and ensures that harvesting results meet management objectives.

* P-J harvest by the private operator in strict adherence to the specifications of the harvesting/management plan and under the supervision of the public agency.

* Implementation of site improvement practices, such as seeding, fencing, etc., by either the public agency or private operator as agreed upon in the harvesting plan.

* Monitoring of the treated area by the public agency to ensure proper management over the long term.

Under the appropriate conditions, the benefits of such a joint venture would be shared by both public and private sectors. To the public this management approach offers implementation of preferred and more intensive P-J management at lower public costs. The development of P-J biomass and fiber as a marketable resource could stimulate local rural economies through increased income, employment, and tax revenue. The private industry sector would have an abundant and renewable raw material available for sale to both domestic and foreign users.

ECONOMIC CONSIDERATIONS [1]

Actual costs for commercial whole tree harvesting of the P-J type are not well understood because of limited examples. Documented information from small-scale research and extrapolation from similar harvesting operations suggest the following costs: $33 per metric ton (M.T.) (Kilborn 1976), $30 per M.T. (Resource Management Services and Sverdrup Tech. 1980) and $30-$41 per M.T. (CDF 1981). Based upon these estimates, it is reasonable to assume that costs for P-J harvesting could run within the range of $33 to $39 per M.T. (table 1). This estimate includes on-site chipping of P-J and transportation of the chips within a radius of 64 to 80 kilometers. Costs not addressed are those associated with the transport of the P-J chips to market. Because of the isolated nature of P-J woodlands to major commercial areas, these costs are expected to be quite high and could raise the overall end product cost considerably.

An obvious opportunity for a private operator to recover P-J harvesting costs is through the sale of chips. Current market prices for wood chips at the Port of Sacramento, California, range from $36 to $41 per M.T. for high-quality chips and $20 to $23 per M.T. for low-quality (Lynch 1985). With P-J harvesting costs approaching and perhaps exceeding expected market prices, commercial P-J harvesting is not viewed as an economically viable alternative to private industry under present conditions.

To interest private industry in commercial harvest of P-J, either the costs must be reduced or market prices increased to the extent that economic incentives are greater than the risks. Possible solutions to improve the economics of commercial harvest would include: (1) technological advances in P-J harvesting systems and equipment aimed at lowering harvesting costs, (2) advances in P-J product development and marketability that foster increased prices through free-market forces, and (3) application of value in exchange principles to reduce private operator costs. Although application of

[1] For purposes of simplification, the costs and prices estimated in this paper address only those associated with P-J removal. Costs for site improvements, such as seeding, fencing, etc., are excluded because it is assumed that these costs are approximately equal between both public and private sectors.

all three solutions would improve the overall economics of commercial P-J harvesting, the latter offers the most immediately obtainable benefits.

Table 1.--Estimated commercial harvesting costs for P-J woodland and expected market price for wood chips

Operation and Product	$/M.T.	$/Hectare[1]
Whole Tree Harvesting	33-39	449-530
Chip Market Price[2]		
High-quality chips	36-41	490-558
Low-quality chips	20-23	272-313

[1]Conversion of monetary estimates from dollars per metric ton to dollars per hectare was based upon the following assumptions:

1. Average volume within a P-J woodland in the Ely District approximates 12 cords per hectare (Rhea 1985).
2. Average weight per juniper cord approximates 1,134 kilograms (Barger and Ffolliott 1972).

[2]Lynch, T. Personal communication. Sacramento, CA: Cal Wood Fiber, 1985, September.

As presented in table 2, current public agency costs in P-J removal approach $16, $28, and $36 per hectare for burning, chaining, and chemical treatments respectively (Rhea 1985). These costs are presently borne entirely by the public sector with little tangible economic return on the investment.

Table 2.--Estimated public costs in alternative treatments for P-J removal[1]

Treatment	$/Hectare
Burning	16
Chaining	28
Chemical	36

[1]Rhea, H. (forester). Personal communication. Ely NV, Ely District, Bureau of Land Management. 1985, September.

In contrast, use of these public funds to offset high commercial harvesting costs through cost-sharing would appear to be in the public's best interest as long as the subsidy costs were lower than current management costs. As an example, assume a public land management agency would be willing to pay a commercial harvester up to $14 per hectare for P-J removal. This price would be $2.00 per hectare less than the least expensive P-J control technique (burning) currently in use. With a commercial harvester incurring a harvesting cost of $490 per hectare and receiving a market price of $480 per hectare through P-J chip sales, the private operator could realize a net return of $4.00 per hectare for his efforts. Such an arrangement would meet public objectives through increased benefits at reduced costs, while possibly providing the economic incentives necessary to make commercial harvesting a viable activity.

Efforts such as these are already being experimented with on the Lassen National Forest, where the U.S. Forest Service is looking into cost-effective arrangements to promote private industry involvement in slash removal and thinning efforts (Oxford 1985).

INSTITUTIONAL CONSIDERATIONS

Economic considerations are not the only constraints presently limiting private sector involvement. The lack of public policy and regulations allowing for value in exchange concepts to be applied to P-J management and current efforts within government to maximize cost-effectiveness through fair market sales of resources have also discouraged efforts in this area.

To promote commercial harvest in P-J management, a formal commitment by the public sector to foster and encourage private utilization of P-J is necessary. This commitment would best be accomplished through the development of policies and regulations allowing for maximum agency flexibility in innovative and long-term cooperative agreements with private industry. Without such agency authority it is doubtful that commercial harvest will ever be a viable tool in P-J management.

CONCLUSIONS AND RECOMMENDATIONS

Under current economic and institutional conditions, commercial harvesting of the P-J type does not appear feasible. Given that commercial harvesting can be an effective tool in P-J management, the following recommendations are offered as a means to promote and encourage private sector involvement.

* Top priority should be given to the development of agency policies and regulations which promote commercial harvest of

P-J through the concepts of value in exchange. The policies should be directed toward equalizing the trade of goods and services between public and private sectors by offering P-J utilization at the lowest costs possible and allowing for long-term agreements.

* Research is needed in the development of improved and innovative harvesting systems and equipment specifically adapted to the terrain and operating conditions found in P-J woodlands. Such advances would reduce the high costs associated with commercial harvest of P-J and would greatly improve its competitiveness with other wood resources.

* Further research is needed in the area of P-J product development to improve its marketability. Success in this area would increase demand for P-J raw materials and possibly increase its market value.

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Inventory and Classification

Chaired by:

James S. Hagihara, Natural Resource Specialist, Bureau of Land Management, Denver Service Center

INVENTORY AND CLASSIFICATION FOR P-J--CHAIRMAN'S SUMMARY

James S. Hagihara

ABSTRACT: Current and future multi-resource management of pinyon-juniper woodlands requires the collection of inventory data that will provide the necessary information for classification and making management interpretations. Several different inventory methods and classification systems are currently being used by federal agencies and universities. As a result, it is difficult to develop consistent management interpretations and nomenclature for the pinyon-juniper vegetation associations. The presentations in the inventory and classification session should provide an opportunity to resolve some of these problems.

Vegetation classification is a complex process and has posed a very serious problem to ecologists, range scientists, and natural resource managers since the advent of the climax vegetation concept by Clements in 1916. Since then, a variety of vegetation classification schemes and inventory or measurement techniques have been developed. Unfortunately, neither an agreeable or uniform vegetation classification system nor an inventory procedure has been developed and implemented by Federal and State natural resource management agencies. In addition, the continuing remote sensing and computer assisted techniques research and developmental efforts associated with vegetation classification and inventory have compounded the problem.

The climax concept (Clements) as applied to the classification of natural vegetation requires knowledge, understanding, and interpretation of many ecological factors that influence growth and behavior of plants within any given geographic area or region. Some factors have a greater influence on plant growth than others; however, each factor interacts with all the other factors to provide information that expresses the character of the land's elements. These elements can then be combined to represent a homogeneous ecological site or unit.

Session chairman summary of papers presented at the Pinyon-Juniper Conference, Reno, Nevada, January 13-16, 1986.

James S. Hagihara is a Natural Resource Specialist, USDI Bureau of Land Management, Denver Service Center, Building 50, Denver Federal Center, Denver, Colorado.

The papers presented by this panel discuss the utilization of vegetation classification and inventory procedures currently being used by the Bureau of Land Management (BLM), Forest Service (FS), Soil Conservation Service (SCS), and universities. These papers emphasized the fact that neither a common or uniform vegetation classification system nor a vegetation inventory procedure currently exists between and within agencies.

Uniformity in vegetation inventories and sampling techniques would provide consistency in classifying and naming pinyon-juniper plant associations as well as assisting in making reliable management interpretations and exchanging information. Three authors addressed the need for combining soils, vegetation (current and potential), and other ecological factors into an ecological site.

The discussions by the authors in this panel reemphasize the need for a national ecological land classification system.

In 1978 five Federal agencies signed the "Interagency Agreement Related to Classification and Inventories of Natural Resources." The five agencies were USDI BLM, Fish and Wildlife Service (FWS), Geological Survey (GS), USDA FS, and SCS. The principal objectives of the interagency agreement are (1) to provide guidelines and to assure administrative action to minimize duplication of resource management efforts, (2) to enhance and encourage compatible data collection and data sharing, (3) to promote resource appraisal efficiency and management program compatibility, and (4) to expedite technology transfer. One of the major issues of the agreement is the development of a national ecological land classification system. The land classification system is required to (1) assure uniform accounting and data collection of natural resources, (2) facilitate information exchange among renewable natural resource management agencies, (3) assist in developing resource assessments and management of programs, and (4) provide a framework for organizing information about the land.

An interagency Resource Evaluation Team (RET) was established in 1978 at Fort Collins and initiated development of a national land classification system for renewable resource assessments. This classification was designed to assist in describing the natural vegetation of the forest and rangeland base of the United States.

This effort resulted in the development and publication of two reports by Driscoll and others entitled "A Component Land Classification for the United States: Status Report," Technical Note #360, USDI BLM, May 1983; and "An Ecological Land Classification Framework for the United States," USDA Forest Service miscellaneous publication 1439, July 1984. BLM, FS, and SCS concurred in the adoption of the potential natural vegetation classification element of the system and initiated independent evaluations and field tests in 1983 and 1984.

Although the evaluations and field tests resulted in positive responses, considerable effort is still required by BLM, FS, and SCS to fully implement the proposed classification system.

Hopefully, sessions such as this will continue to emphasize the need for a uniform potential and current natural vegetation classification system as well as achieve a better understanding of the complexities for classifying and inventorying the natural resources. Lest we forget, the primary objective for classification and inventory is to provide information that will assist the land manager in making reliable resource management plans and decisions.

CLASSIFICATION OF THE PINYON-JUNIPER VEGETATION TYPE

M. Hironaka

ABSTRACT: For land managers, the purpose of classifying pinyon-juniper land is to identify areas that would respond similarly to management practices. For identification of areas of similar potential in other major vegetation types, climax vegetation has been used as the basis of classification. With pinyon-juniper vegetation, due to the simple species mix of overstory and lack of understory in mature stands this strategy is unsatisfactory.

Primary succession is visible in many areas in the pinyon-juniper zone. The obvious invasion of juniper into adjacent sagebrush and grassland vegetation and their subsequent displacement in a period of less than a century and a half add to the frustration of developing a baseline classification scheme. Observable changes in soil properties associated with these vegetation changes are also present.

Use of plants alone to classify the pinyon-juniper vegetation type results in large, highly variable classification units because of the simple species mix in mature stands. It will be necessary to use soils to complement vegetation information to develop a useful classification of pinyon-juniper land.

INTRODUCTION

Classifying pinyon-juniper land is essential for management because it is necessary to know what resources are presently available and what resources might be made available in the future. It is important that we have an inventory of the vegetation that is present as well as what other kinds of vegetation the land is capable of supporting. The subtle changes in vegetation brought about by succession as well as retrogressive changes due to grazing and abrupt catastrophic changes brought about by fire and other allogenic influences make it doubly important that the current as well as future vegetation be considered. Each piece of land needs to be classified as to its potential as well as what vegetation is currently present. Of the two classifications, the one coping with potential vegetation is the more difficult of the two because clues and evidence of its potential may be obscured, missing, or misinterpreted. Classification of current vegetation is based on properties of vegetation that can be seen, measured, and touched. It can be revisited for another look and supported by a second opinion. This makes classification of current vegetation much simpler and greatly removes the uncertainty of misclassification.

Classification of the land's potential capability to support different vegetation than what is current is much more difficult and great reliance is placed on deduction. Chances of misclassification are likely due to misinterpretation because the same piece of land is capable of supporting many kinds of vegetation, depending on disturbance history. Further complications arise where juniper invasion of grasslands and shrublands is a recent event (Blackburn and Tueller 1970; West 1984). Nevertheless, both kinds of classifications are necessary--what is present and what other kinds of vegetation the land is capable and likely to support.

CONCERN IS MANAGEMENT

Speakers of this session will view classification of the pinyon-juniper vegetation from several aspects. Of primary concern is the classification of this major vegetation type for more effective management. What is sought in a good classification scheme is consistency, observability, and simplicity. The nearer one can come to such an ideal system the more successful and acceptable the classification. A system too complex, no matter how accurate, is doomed if no one would use it. A classification scheme is useless unless used.

We are basically looking for a classification system that will provide information on current vegetation as well as information as to what other kinds of vegetation can replace the one that is present. To accomplish that, it becomes important that we know what secondary successional community types (Dombois-Mueller and Ellenberg 1974; Shimwell 1978) are involved. We need two classifications for each piece of land, one dealing with the current vegetation and the other providing an indication of what other kinds of vegetation can also exist on the same site. The vegetation at the endpoint of secondary succession, defined as the climax vegetation for the purpose of identifying a unique potential

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M. Hironaka is Professor, College of Forestry, Wildlife and Range Sciences, University of Idaho, Moscow, ID 83843.

vegetation for each site, seems to be the logical way to go (Huschle and Hironaka 1980; Hironaka and others 1983). The terminal community type is the only unique vegetation associated with each habitat type (Daubenmire 1968) or range site (Dyksterhuis 1949), making the climax community type the logical one to be selected as the reference community type because lesser seral community types may occur in other habitat types. Typically, areas supporting or capable of supporting the same climax community type indicate areas of similar effective environment (Daubenmire 1968). Community types occurring on land that share the same climax community type can all potentially supplant one another. Which community type replaces another is dependent upon the manner, frequency, and intensity with which the land is disturbed and to chance events that affect ecesis of plants.

THREE CLASSIFICATION SCHEMES

Today, one hears much about habitat type classification, range site or ecological site classification (Anderson 1983), and community type classification. Each of these schemes of classification provides different kinds of information and details about vegetation. Habitat type classification is a land classification that is based on climax vegetation. Range site classification is also based on climax vegetation, but this classification differentiates levels of productivity as well. Community type classification is based on the current vegetation, regardless of ecological status.

Both habitat type and range site classifications, which are based on climax vegetation, have been used to classify coniferous forest, sagebrush steppe, grassland, and mountain brushland vegetation (Daubenmire 1952; Mueggler and Stewart 1980; Hironaka and others 1983). The use of climax vegetation has been successful in these major vegetation types because the combinations of species in the over- and understory have consistently segregated areas of similar, spatially recurring, effective environments. Examples of vegetation that have been relatively undisturbed for several hundreds of years have been used as the unique reference vegetation, the climax example of the vegetation for the land being classified.

In pinyon-juniper vegetation, it is suspected that the vegetation of the climax state of many communities might be quite simply one that consists of a juniper overstory with a simple understory, while other climax communities support a good complement of perennial herbs in the understory (West 1984). The uncertainty of where the latter conditions prevail makes the reliance on vegetation alone to differentiate effective environments by indicator or characteristic species of vegetation extremely tenuous. It appears that use of vegetation alone is too imprecise to indicate areas of similar effective environments to expect similarity in management response.

Because of difficulty in finding or identifying climax pinyon-juniper vegetation, a less direct method to identify areas of similar effective environment is needed. Areas of land that have soils of the same or similar soil genetic history have the same effective environment (Jenny 1958) and support or supported the same climax vegetation (Major 1951). By definition, the soil series is a soil classification unit that consists of individual pedons with a high degree of similarity of all properties, indicating a uniform effective environment (Hole and others 1973) . Thus, the stable state vegetation of a soil series is the climax vegetation. Due to the ability of plants to compensate, and the plant community being an aggregation of species that are growing together, the same plant community may recur on more than one soil series. Soil units higher in the hierarchy, for example the Soil Family, are too encompassing and often include more than one range site or one habitat type. Soil classification units at the Soil Family level are meaningful when the habitat type is already known but cannot be used to develop a habitat type classification (Hironaka and others 1983).

PINYON-JUNIPER CLASSIFICATION CHALLENGES

It becomes apparent that the classification of pinyon-juniper land is extremely challenging. There are many unknowns. Many grassland and shrubland areas are being invaded by juniper today. Other areas have been invaded in the recent historic past and some have supported juniper for many centuries (Burkhardt and Tisdale 1976; West 1984). How to classify these lands in some orderly and meaningful manner is not going to be easy. One of the purposes for classifying these lands is to determine their capability or potential to provide forage for domestic livestock. Other uses of these lands are due to their ability to provide a particular kind and type of habitat for specific wildlife species (Terrel and Spillet 1975). The ability to produce wood fiber for firewood, charcoal, and/or paper may be the kind of information sought (Johnson 1975). The usefulness of these kinds of information depends on the intended use of the present vegetation as well as the vegetation changes that will go on in the future (Clary 1975).

How can all this information be gathered and stored so it would be made available for management? Is it necessary to reinventory and reclassify for each of these uses or can a basic inventory and classification be used to satisfy the information needs for different land uses? The challenge is great but I firmly believe it can be done when the basic soil-vegetation relation is understood for these pinyon-juniper lands. Without a soil inventory to supplement the vegetation inventory the resulting classification would not be an integration of the soil and vegetation inventory but that of two separate inventories with little correlation between them. The two inventories must be conducted together with close collaboration between soil scientists and vegetation scientists (Shiflet 1973). The soil-vegetation

relationships are going to be more difficult to interpret in pinyon-juniper vegetation because of the simplicity of the vegetation with dominant species that are of wide-ranging nature. Productivity of these lands is going to be extremely difficult to estimate because of the variability in plant life and growth forms involved, which include annuals, perennial grasses and forbs, short and tall shrubs, and long-lived pinyon and juniper trees.

The following papers point to the ways with which pinyon-juniper lands are classified and what information is contained with each classified unit. For the monitoring of change in tree canopy cover and the encroachment of juniper onto new lands, remote sensing techniques will probably be used to good advantage, permitting monitoring of canopy cover and correlating the associated change in the understory with a minimum of ground truthing. In many ways, the monitoring of change will be much easier in this vegetation type than others, but the determination of site productivity will probably be much more difficult to evaluate.

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P-J--A COMMERCIAL RESOURCE?

Dwane D. Van Hooser and Osborne E. Casey

ABSTRACT: Pinyon and juniper are species of questionable character. During the frontier and mother lode era they were used extensively as fuel to convert ore to precious metals. From the turn of the century until recently pinyon-juniper woodlands were abused extensively, primarily by anchor chains and D8 "Cats." Now, use for fuel, Christmas trees, and pine nuts makes them once again a valuable, if not commercial, species. This paper discusses each of these areas. Also, the current and historic distribution of the species is presented, and some contemporary examples are given to establish that pinyon and juniper are a commercial resource.

INTRODUCTION

P-J--a commercial resource? The answer to the question certainly depends on perspective. The cattleman, the wildlife biologist, and the forester could be simultaneously viewing the same tract of pinyon-juniper (P-J) and simultaneously answer "absolutely" and "absolutely not."

This paper will attempt to answer the question from a forester's perspective and will be based on fact, not conjecture. The building blocks used to structure this factual foundation will include the current availability of P-J in terms of acres occupied and volumes present, how P-J has been used historically, and what, if any, revenues are being generated from these acres at present. In this discussion, the term P-J will be used to denote those acres on which the stocking is pinyon (Pinus edulis and Pinus monophylla) and juniper (Juniperus scopulorum, Juniperus occidentalis, Juniperus monosperma, and Juniperus osteosperma) either singly or in combination.

DEMOGRAPHICS

P-J is the dominant forest type in the Western United States. Although data for the area occupied vary somewhat, and volume estimates are not available for all States, P-J covers vast acreages in the West and often features sizable wood volumes per acre.

Area

According to the latest timber analysis (USDA 1982), the P-J type is found in nearly all of the 11 Western States. In total, the type is predominant on more than 47 million forested acres. Nearly 90 percent of these acres are in the Rocky Mountain States, with most--41 million acres--in the Four-Corners States plus Nevada (fig. 1).

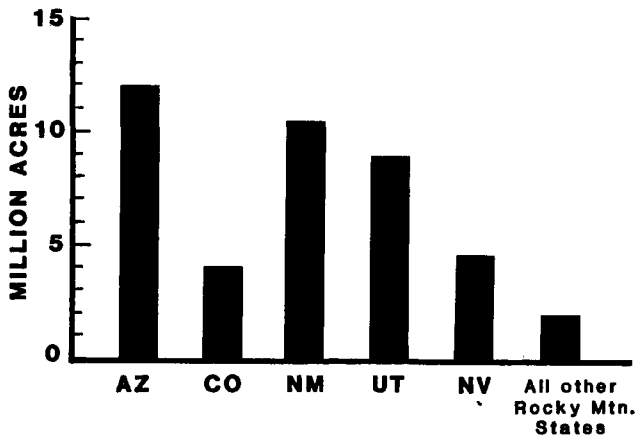


Figure 1.--Distribution of the pinyon-juniper forest type in the Rocky Mountain States, 1977 (USDA 1982).

These estimates are at best conservative. In the 1960's in Nevada, for example, the Forest Service estimated that there were 4.7 million acres of P-J. A more recent estimate, based on a remote sensing study conducted at the University of Nevada, Reno, determined that the P-J resource covered some 11 million acres (Tueller and others 1979). The latest Forest Service estimate, however, indicates the area covered by P-J in Nevada is 6.8 million acres. This is based on a field inventory using a systematic grid of intensities ranging from 5 000 m to triple 5 000 m covering the entire State (with the exception of the Atomic Energy Commission test site, which was excluded for obvious reasons!). This trend toward higher acreage estimates has also been found in other States.

By comparison, the 41 million acres of P-J in the southern Rockies represents well over half of the total forest land base. P-J alone exceeds the

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Dwane D. Van Hooser is Project Leader, Forest Survey, Intermountain Research Station, Forest Service, U.S. Department of Agriculture, Ogden, UT; Osborne E. Casey is Fishery Biologist, Nevada State Office, Bureau of Land Management, U.S. Department of the Interior, Reno, NV.

total timberland area by nearly 16 million acres, which makes it the most extensive forest type. Ponderosa pine, which occupies nearly 9 million acres, is the nearest rival in terms of area.

It is difficult to quantify how much of this area is available for harvest, but P-J is not a high-altitude species, and it does grow primarily on lands administered by public agencies. If we assumed that only half of the P-J acres were open to commercial exploitation we would still be talking about more than 20 million acres.

Volume

At present, complete estimates of the volume for P-J in all the States in the southern Rocky Mountains are not available. Preliminary data, however, have been compiled for State and private ownerships in Colorado, and basic plot summaries have been developed for Nevada.

In Colorado there are 2.1 million acres of P-J on State and privately owned lands. These acres support 971 million cubic feet of volume. On a per-acre basis this represents about 464 cubic feet or 5.5 cords. If we were to extrapolate this volume to the entire acreage of P-J we would have some 20 billion cubic feet.

In Nevada, some of our field locations support as much as 30 cords per acre, but this is the exception rather than the rule. The methodology for determining volume and a discussion of our research on site quality determination is given in the paper by Chojnacky, in this proceedings.

If areal extent and adequate volume determined that species were "commercial," the answer to our question would be yes!

SLIGHTLY HISTORICAL

When judging the usefulness of particular species it is usually helpful to "look back" and see how the species were treated by those that came before us. Lanner (1981) has done just that in his text dealing with the cultural and natural history of pinyon. Much of his discussion can be extrapolated to the general P-J type.

Early Times

From a historical perspective it is impossible to pinpoint the exact year that man first encountered the P-J woodlands, but there is evidence that the species were being used by early dwellers in Nevada and Utah some 3,000-6,000 years ago. In some cases this use appeared to be casual--convenient firewood during a brief trip away from the main village, and as a "snack" of pinyon nuts while pausing during a long journey. Other evidence indicates that the pinyon also played a central role in the culture of the many Indians of the Southwest. One legend, which relates the events surrounding the birth of the great leader, Montezuma, states that he was born after his mother was told to prepare two special rooms--one of which was for the pinyon nut harvest.

Trees from the P-J lands of early times were utilized extensively for fuelwood, and the Navajo used the main stems of the trees for hogan poles and roof beams, and as material for tools and other "domestic" implements. The branches were used to construct corrals for trapping and containing wildlife. The pitch was used to make glue for jewelry, for dressing wounds, and for relieving coughs and other symptoms of colds and flu.

While these uses were important, the pinyon's greatest contribution to the native Americans was as a primary source of food. For many tribes, winter without an adequate cache of pinyon nuts was a disaster. Thus when late summer approached, the entire population of a village would literally stop all other activities and head for the hills to harvest and roast the pinyon crop.

The pinyon also played an important role in the lives of the early southwestern Indians figuring "in the ritual practice, healing and ceremonialism literally from the cradle to the grave" (Lanner 1981). It is probably safe to conclude that these early Americans utilized the entire tree including the stem, buds, and shade.

Exploration Days

As we move down history road we find that pinyon served a pivotal role in the early exploration, if not settlement, of the West by Europeans. In the early 16th century, a group of Spaniards wandered through the Southwest after being shipwrecked on the Gulf of Mexico. The availability of pinyon nuts is credited with the very survival of this group. Their safe return to Mexico resulted in the initiation of a series of historically important expeditions into what is now the southwestern United States. The explorer Coronado led parties northward from Mexico deep into the pinyon country. These explorations resulted in the colonization of New Mexico and the discovery of the Grand Canyon.

Nearly Now

Perhaps the most colorful era in the use of the P-J resource occurred in the mid-1800's when silver was discovered in western Nevada. At that time the mountains around Virginia City were covered with pinyon and juniper, but, with a population of 20,000 and daily fuelwood requirements of more than 560 cords, it did not take long to deplete these forests. By the late 1860's wood was being hauled to the district from remote areas in the Sierra Nevadas.

Another example of how P-J was used during the boom days occurred in Eureka in east-central Nevada. By 1873 there were 13 smelting furnaces

in Eureka with a daily capacity of nearly 600 tons of ore. To smelt a ton of ore required about 30 bushels of charcoal, which, to produce, took 1 cord of wood. Thus, with each acre of P-J averaging about 10 cords, some 60 acres were "cleared" per day to feed the Eureka furnaces. After 1 year of operation the hills were bare for 10 miles; after about 5 years the charcoal makers had to go 50 miles or more to get wood. When we consider that Eureka was only one of many smelting centers in the State it is no wonder there is little old P-J in Nevada.

Now

After the mining boom was over, though, the pinyon-juniper ecosystem began being viewed as a nuisance and was given very little, if any, attention except to eradicate it through chaining or other such measures to convert the land to some "better uses." This attitude was exemplified in the pre-Resources Planning Act treatment of this ecosystem by the Forest Service's Forest Survey. We were required to estimate the aerial extent of the types as we went about measuring a State's timber resources, but we were not required to develop traditional resource statistics such as volume, growth, and removals estimates. Nor were those States in which P-J was predominant given the same treatment as those in which "commercial" timberland prevailed. For example, the first surveys of Arizona and Nevada--done in the 1960's--were really no more than cursory efforts on non-National Forest System lands. The forest survey of Arizona used a total of 20 locations on these lands and the Nevada survey was about the same. Arizona had a substantial commercial component on National Forest System lands, and as a result we were able to put together a respectable analysis of the timberland situation there (Spencer 1966). This was not true for Nevada, though, and the tally sheets were discreetly tucked away, to never again see the light of day.

Now, things have begun to change and we are seeing P-J in a new light. For example, we are currently involved in field inventories of P-J and other woodland species in all of our States. And during the last few years, we have engaged in cooperative inventories with the Bureau of Land Management, various Indian tribes, and the National Forests.

We have seen so far that P-J is certainly plentiful and potentially available for commercial use today, and it has been used historically in a "commercial" way.

CURRENT USE

The question now is: "Is P-J being used commercially <u>today</u>, and if so, how?"

To get the answer, an informal survey was conducted among the public agencies charged with administering the P-J resource. The survey consisted of four questions:

1. How many years have you been selling permits for pinyon nut gathering, P-J firewood, and/or Christmas tree harvesting?

2. Approximately how much revenue has the sale of these permits generated?

3. What do you perceive to be the future for revenue from your P-J woodlands?

4. How does the current level of revenue generation from these permits compare to revenues generated from grazing fees on those woodlands?

The organizations contacted were the State Divisions of Forestry and the State offices of the Bureau of Land Management in Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, and Wyoming, and the Northern, Rocky Mountain, Southwestern, and Intermountain Regions of the Forest Service.

Question 1 Responses

Some agency units with a P-J resource to manage, or at least oversee, have been selling permits since the 1940's. Those who have only recently begun to sell permits gave two reasons for not doing so earlier. The first was that historically firewood cutting and nut gathering had been on a free-use basis and apparently had not been abused. The second reason was there really was not much concern about what was going on on the P-J lands, except for their use by cattle.

For the most part, the interest in selling permits was directly related to the acreage administered. The Forest Service Northern and Rocky Mountain Regions, for example, have very little P-J. And since only incidental amounts of pinyon-juniper are used, the products sold and harvested from these acres are not separated from the commercial volume. The Southwestern Region, however, has a fairly extensive P-J resource, and managers have been selling permits and reporting on volumes sold since 1940.

An interesting and unusual reason for selling permits for P-J came from one of the Federal organizations. It seems they were operating under a free-use system, but wanted to do some inventory work. When they approached national headquarters to secure funding, they were asked how they could justify spending money on a resource they were giving away, and the request was turned down. The unit immediately began charging for fuelwood permits and lo and behold the next fiscal year funds were secured.

To summarize answers to question 1: Of the 20 agencies surveyed, 11 have been selling permits for P-J products for an average of 16 years. The responses ranged from 3 to 45 years.

Question 2 Responses

The responses to the revenue question were also quite variable. Recently the sale of products from P-J woodlands generated about $900,000 annually for all of those agencies that sell permits. Most of this revenue came from federally administered lands; however, the State agencies do generate several thousands of dollars annually from permit sales.

The average return to the agencies selling permits was about $75,000; it ranged from $13,500 to $450,000 per year. These revenues are not trivial and probably represent at least a break-even return. They are even more significant when we consider that there are probably no formal management plans for P-J woodlands in place in any of these agencies.

Question 3 Responses

The ability of the P-J woodlands to produce revenue in the future is projected to increase and is directly related to projected population growth. Most Western States, especially those in the Sun Belt, have recently experienced increasing populations, and this trend is expected to continue. This will create increasing pressure on all natural resources, and if the demand is to be met management will have to be intensified and formalized.

Of the 11 organizations that expected to generate future revenues, nine projected that they would increase slightly. The others expected the income from the P-J woodlands to remain stable over time. One rather unusual response to this question was that the highest value for pinyon-juniper is for wildlife habitat, and as a result management for wood products and grazing was being deemphasized.

Question 4 Responses

The final question dealt with the comparison of revenues from P-J woodlands with those generated by grazing. Taken in total, most organizations polled felt that grazing revenues were far greater than those generated from P-J products, and generally favored grazing by 3:1. Of course, much of this revenue is coming from acres that do not support a P-J resource. Thus, when those areas are eliminated and only the acres of pinyon-juniper are considered the differences fade and in some cases actually favor nuts, fuel, and Christmas trees.

In Nevada, for example, it takes from 10 to 100 acres of P-J to produce 1 animal unit month (AUM) of grazing, depending on age and condition of the stand. The value of an AUM in 1985 was $1.37. Thus, the grazing income range is from 1.37 to 13.7 cents per acre per year. Recent nut harvests have been averaging about 70 to 250 pounds per acre and in one area, where a large chaining has reverted back to pinyon, about two Christmas trees per acre have been harvested over the past 8 years, and the area still looks undisturbed.

Using the best grazing allocations of 10 acres per AUM as the benchmark the following revenues could be generated on an annual basis:

Grazing:	
10 acres/AUM @ $1.37/AUM	= $1.37
Pine nuts:	
70 to 250 lb/acre x 10 acres x $0.20/lb	= $140-$500
Christmas trees:	
1 tree/acre x 10 acres x $2.50/tree	= $25

Discounting the nut harvest by three to account for the cyclical nature of pinyon nut crops reduces the revenue potential for this product to $47-$167/AUM. Thus on a 10-acre AUM, revenues from nongrazing sources would far exceed those that could be generated from grazing alone. The greatest revenue potential, however, certainly lies in some sort of multiple-use management strategy.

THE FINAL CRITERION

Certainly P-J could be viewed as a commercial resource from a forester's perspective. It is available, it has a historical basis of commercial use, and it is generating positive financial returns at the present time. There is one more test, though, that can be applied that will surely remove any doubt as to the worth of P-J products and that is, are they valuable enough to steal!

Every year during "nut gathering" season commercial pickers descend on Nevada like a horde. A few years ago a local manager became suspicious that one particular group was not being square with their payments. After some sleuthing, he determined that the pickers were stashing sacks of cones in several locations, but only paying for those that were in plain sight. After observing this activity for several days, the manager decided to attempt collecting the additional revenue. Using the agency standard of 4 pounds of nuts per gunnysack full of cones, the manager determined that the pickers probably owed the government for 6,000 to 8,000 pounds of nuts, but he did not really have proof. So he ran a bluff. He confronted the leader who immediately denied any wrongdoing stating that it must have been "those other guys." The manager rebutted, saying that he had been observing the pickers' activities for several days and was certain that the government had been shortchanged. He told the picker to either pay up or he would call in the law. The bluff worked, but instead of paying for 6,000 to 8,000 pounds of nuts the picker admitted shortchanging the government by 32,000 pounds or $6,400!

CONCLUSIONS

We have seen that the P-J woodlands can be considered a commercial resource, and they are so now, in spite of our lack of attention. If we look to these acres as economic opportunities for developing good-quality wildlife habitat and livestock forage as well as woodland products, the benefits will far exceed those realized to date. And, the answer to the question "P-J--a commercial resource?" will most certainly be "absolutely," no matter which resource specialist is responding.

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VOLUME AND GROWTH PREDICTION FOR PINYON-JUNIPER

David C. Chojnacky

ABSTRACT: Summarizes the author's recent work in volume and growth prediction for pinyon-juniper trees. Two volume models are compared, volume conversions to different utilization standards are explained, and prediction errors are examined. Three stand growth prediction measures are discussed: (1) current annual growth, (2) a mean annual volume growth (MAI) for uneven-aged stands, and (3) a potential MAI for fully stocked stands. An appendix lists tables of equations developed.

INTRODUCTION

Land managers attempting to administer large acreages of pinyon-juniper (P-J) woodlands need wood fiber data on P-J volume and growth. But they cannot get that information by taking simple measurements. More elaborate methods such as destructive volume sampling or comprehensive bole growth measurements taken over time are costly and impractical for widespread use.

One solution is to use mathematical models to predict obscure variables such as volume and growth from readily measurable variables such as tree diameter, height, and crown dimensions. I recently constructed such equations for P-J to predict individual tree volume and stand growth.

VOLUME

Two aspects of volume prediction considered in my past research were model form and utilization standards. The work also provided some insights into the problem of prediction errors.

Model Forms

Good correlation was found between a tree's cubic foot volume and the combination variable DRSQH, basal diameter near the root collar (DRC) squared times total height (fig. 1). This relationship was modeled two ways. First, a model using the cube root transformation was fit to visual segmentation volume data (Born and Chojnacky 1985) collected throughout the central Rocky Mountain States (Chojnacky 1985):

$$V = [\beta_0 + \beta_1 X^{1/3} + \beta_2 S]^3 \qquad (1)$$

where

- V = volume of all wood and bark having branch diameters larger than 1.5 inches (ft^3)
- X = DRC (inches) squared times total height (ft)
- S = 1 for a single-stem tree, 0 otherwise
- β_i = coefficients estimated by linear regression using a cube root transformation.

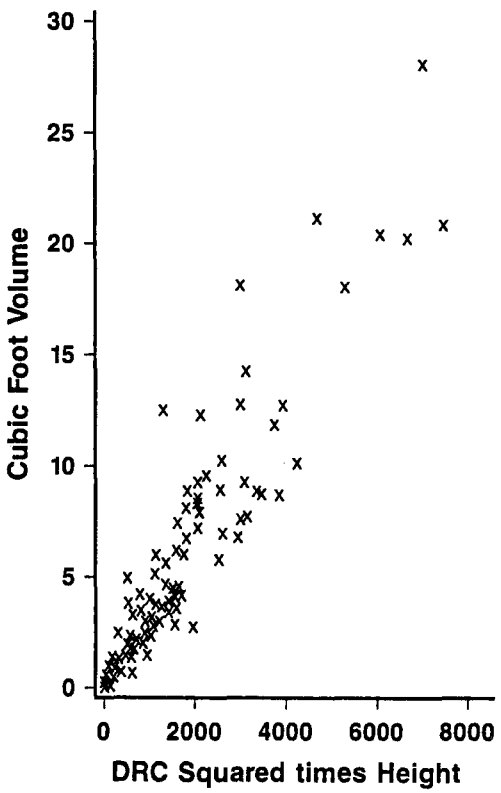


Figure 1.--Pinyon volume (estimated with visual segmentation technique) graphed against DRC squared times height (DRSQH).

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David C. Chojnacky is a Research Forester, Intermountain Research Station, Forest Service, U.S. Department of Agriculture, Ogden, UT.

A second, more complicated nonlinear model was developed from felled tree volume data collected in the Great Basin (Chojnacky in preparation, a)

$$V = \begin{cases} \beta_0 + \beta_1 X + \beta_2 X^2 & \text{for } X \leq 4{,}500 \\ \beta_3 + \beta_4 X^{\beta_5} & \text{for } X > 4{,}500 \end{cases} \quad (2)$$

where

V, X = same as in equation 1

B_i = coefficients estimated by nonlinear regression.

Comparison of the two models showed equation 2 was more flexible for modeling volume of small and large trees with one smooth, continuous function (fig. 2). The nonlinear model (eq. 2) allowed a change in slope between small and large trees, making it less likely to overestimate volumes for large trees, which can be a problem for transformation models.

Utilization Standards

For large-scale inventories, federal agencies have accepted a 1.5-inch outside bark minimum branch diameter (*mbd*) as a cut-off between usable and unusable fuelwood (Born 1985). However, a more flexible standard is often needed for local management. For instance, firewood cutters in some area might only want the larger branches and consider those under 3 inches *mbd* of no value (see fig. 3).

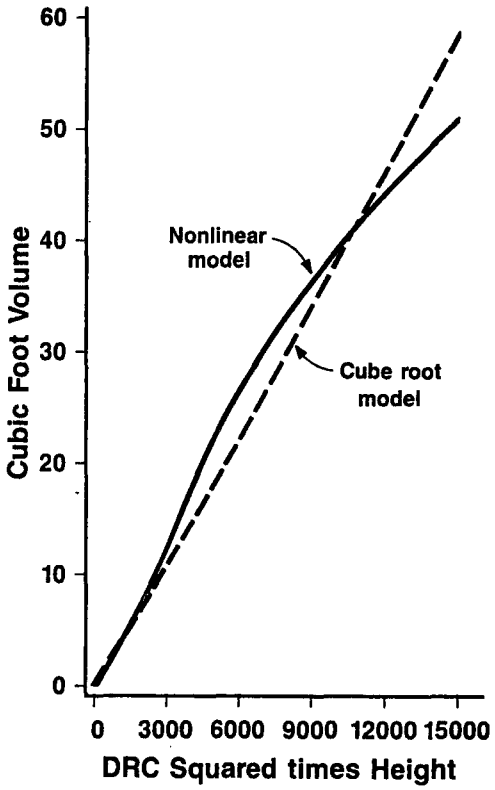


Figure 2.--Pinyon volume prediction from a cube root model compared to prediction from a nonlinear model.

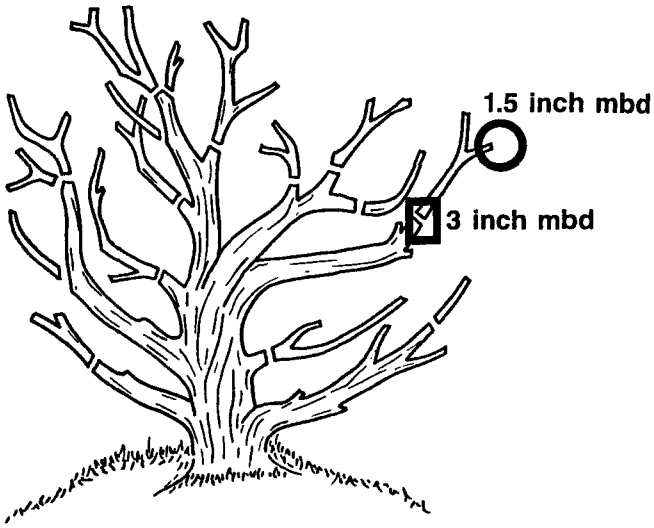


Figure 3.--Comparison between 1.5-inch and 3-inch minimum branch diameter (*mbd*).

I constructed equations and tables to estimate outside bark volume between 1.5 and 6 inches *mbd* and inside bark volume between 1 and 5 inches *mbd* (Chojnacky in preparation, a). This was done using a ratio technique (Burkhart 1977) to convert volume equation predictions from a 1.5-inch *mbd* to the other *mbd* standards. The volume ratio model had the form:

$$VR = 1 + \beta_1 (mbd - \alpha)^{\beta_2} / DRC^{\beta_3} \quad (3)$$

where

VR = volume ratio for either outside or inside bark

α = 1.5 for outside bark *mbd*'s, 0 otherwise

β_i = coefficients estimated by nonlinear regression.

Applying the volume ratio is a simple multiplication with a 1.5-inch *mbd* volume equation:

$$V_3 = V \cdot VR \quad (4)$$

where

V_3 = volume to a 3-inch *mbd*

V = volume prediction from an equation with a 1.5-inch *mbd* standard

VR = volume ratio from eq. 3 (in this example *mbd* = 3).

Prediction Errors

Considerable variation has been observed in the volume-to-DRSQH relationship for P-J (see fig. 1). Since this relationship was the underlying principle for modeling volume in P-J, three facets of volume-to-DRSQH variance were studied: (1) visual segmentation error, (2) confidence interval limits, and (3) sampling considerations.

Visual segmentation error was examined in detail, because most P-J volume equations were developed from data collected by this method instead of by

traditional felled tree methods. We found visual segmentation data very reliable for constructing volume equations (see fig. 4), but not so reliable for estimating volume of individual trees (Born and Chojnacky 1985).

Confidence intervals were calculated for single-stem pinyon for two volume prediction situations: (1) volume to a 1.5-inch *mbd* as in equation 2 and (2) volume to a 3-inch *mbd* as in equation 4. The second situation was of greater concern because Alonso (1968) warned about errors propagating for a quantity that is a product of two components, each having an associated error.

The jackknife resampling method (see appendix A) was used to construct confidence intervals, expressed as percentages of volume predictions for 2-inch diameter classes (table 1). Results showed the confidence intervals were smallest near the data distribution's midrange and the largest at the extremes.

Comparison of confidence intervals for two utilization standards indicated intervals ranged from ± 10 percent to ± 42 percent for volume to a 1.5-inch *mbd* and only slightly higher, from ± 13 to ± 42 percent, for volume to a 3-inch *mbd*. Therefore, excessive error propagation was not a problem for volume prediction for different utilization standards. However, the confidence intervals were large, especially for big trees.

When a model prediction has a large confidence interval, sampling designs used to estimate model coefficients are of special concern. For P-J volume prediction, this means the estimated volume model coefficients are simply best estimates from sample data, and not necessarily precise estimates for the population. In other words, two different volume model samples from a single area will likely result in two different sets of volume model coefficients. For example, a large sample of pinyon trees collected in the Great Basin resulted in a volume prediction much different from predictions from an equation developed from another smaller sample also from the Great Basin (see fig. 5).

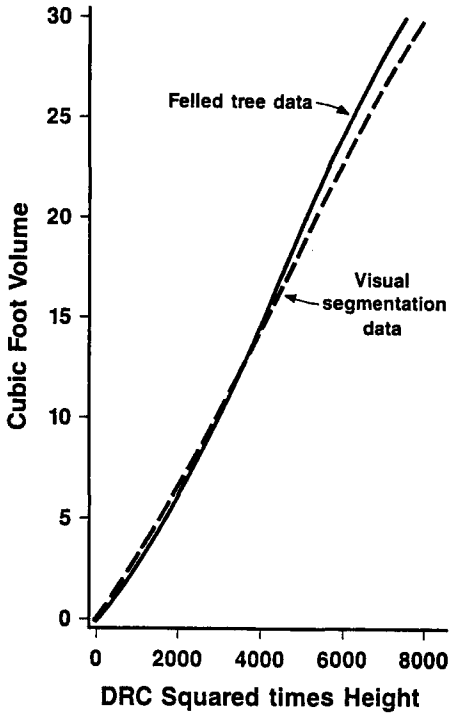


Figure 4.--Pinyon volume predictions constructed from visual segmentation data compared to predictions from felled tree data for the same trees.

Because good site and growth-form descriptor variables, necessary for precise regional P-J volume equations, have yet to be discovered, I recommend collection of visual segmentation data on a subsample of every inventory population in order to construct new volume equations. This will ensure an unbiased volume equation appropriate for the population.

Table 1.--Volume, predicted volume, and confidence intervals (C.I.) for single-stem pinyon

DRC diameter class	1.5-inch *mbd*			3-inch *mbd*		
	Mean volume	Mean predicted volume	95% jackknife C.I.	Mean volume	Mean predicted volume	95% jackknife C.I.
Inches	- - - Ft^3 - - -		Percent[1]	- - - Ft^3 - - -		Percent[1]
3-4.9	0.38	0.38	±17	0.35	0.37	±20
5-6.9	1.06	1.20	±16	0.94	0.93	±19
7-8.9	2.92	2.92	±13	2.20	2.23	±14
9-10.9	5.76	5.72	±10	4.31	4.44	±13
11-12.9	9.91	9.19	±20	7.70	7.22	±19
13-14.9	17.84	17.44	±23	13.56	13.82	±24
>15	29.37	31.01	±42	25.13	24.90	±42

[1]The confidence intervals are expressed as a percentage of mean predicted volume for each diameter class.

GROWTH

Three different measures of stand volume growth were studied in my recent P-J site quality and growth work for Nevada (Chojnacky in preparation, b). The growth measures were labeled and defined as:

1. CAI - sum of the current annual volume growth rate for all live trees ($\geq$ 3 inches DRC) in a P-J stand,

2. MAI - sum of the average annual volume growth rate for all live trees ($\geq$ 3 inches DRC) in a P-J stand, and

3. Potential MAI - MAI (as defined above) for those fully stocked stands where undergrowth shrub and grass cover was less than 10 percent of total plant and tree cover.

All growth measures were modeled as functions of easier-to-measure variables.

CAI was best modeled as a function of (1) total crown volume, (2) total basal area growth, and (3) percent of juniper crown cover. Crown volume was the most important variable, perhaps reflecting the photosynthetic potential for a P-J stand. A tree's crown volume was easily computed from a geometric formula (usually an ellipsoid or paraboloid) using crown diameter and crown height measurements.

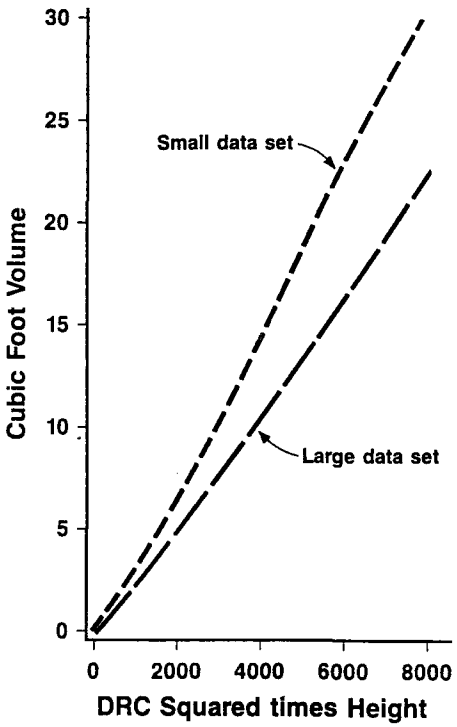


Figure 5.--Pinyon volume predictions derived from a large Great Basin data set compared to predictions derived from a different smaller Great Basin data set.

Basal area growth, the second most important variable, seemed to function as a measure of site quality in the CAI model. Several other variables were examined as potential site quality indicators in the CAI model. Next best was a combination variable of stand basal area divided by quadratic mean diameter. Two site indices, height-to-age and height-to-DRC curves, were considered, but added little to the CAI model. Percent of juniper crown cover, the third term in the CAI model, was simply a dummy variable distinguishing the amount of juniper compared to the amount of pinyon on a site.

For modeling MAI, crown volume was the most important prediction variable. The second best predictor variables involved basal area. Basal area divided by median stand age worked best, but basal area alone performed nearly as well. A dummy variable for the amount of juniper cover also was used.

The equation for CAI and MAI growth prediction was an exponential model form:

$$G = exp[\beta_0 + \beta_1 ln(X_1) + \beta_2 ln(X_2) + \beta_3 X_3] \quad (5)$$

where

G = CAI or MAI
X_1 = crown volume variable
X_2 = basal area growth or basal area combination variables
X_3 = juniper crown cover variable.

This equation is illustrated in figure 6 for CAI predicted from crown volume and basal area growth at two levels of juniper crown cover.

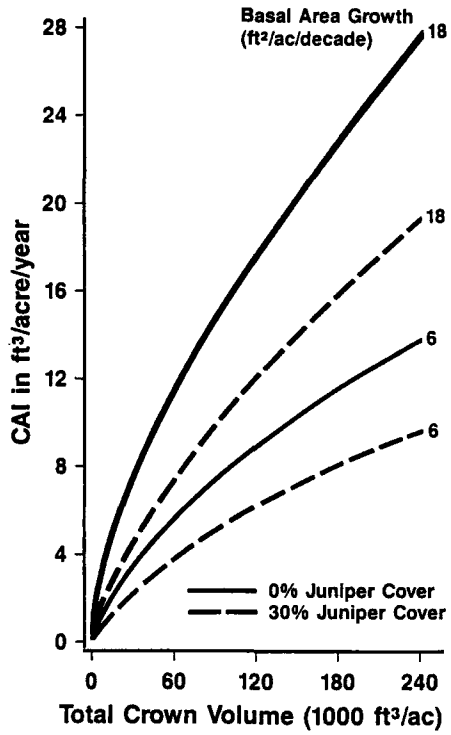


Figure 6.--Current annual volume growth (CAI) for P-J graphed as a function of crown volume and basal area growth, for two levels of juniper crown cover.

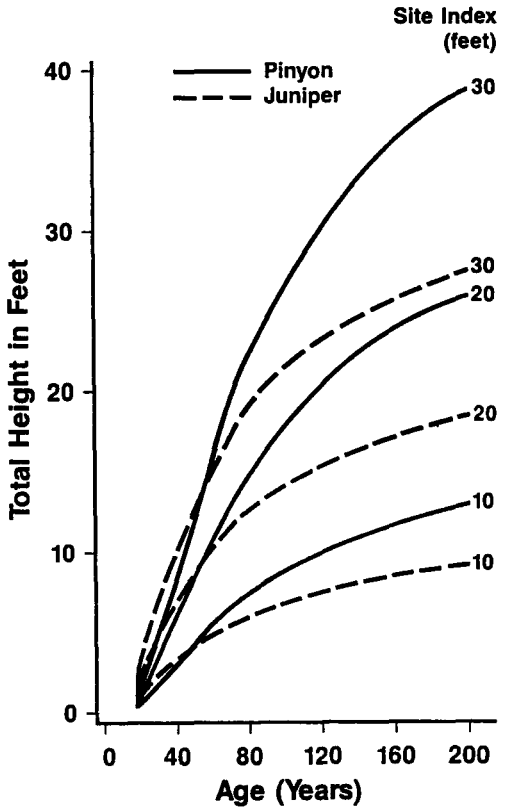


Figure 7.--P-J height-to-age site index curves (reference tree is a 120-year-old pinyon).

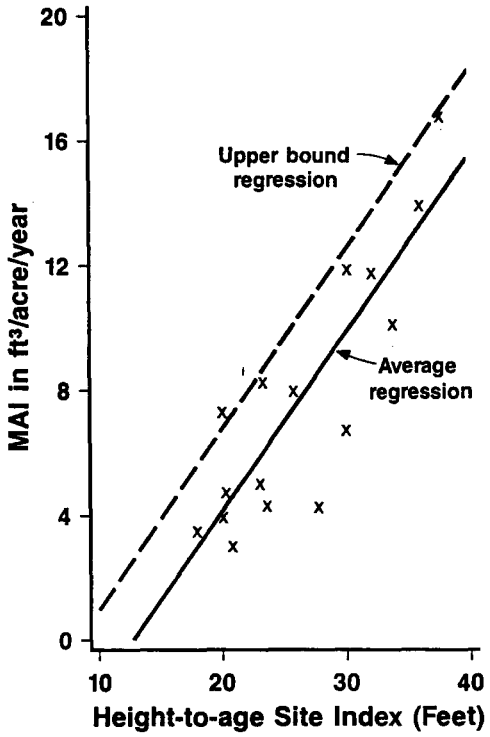


Figure 8.--Potential mean annual volume growth (MAI) regression predictions overlaid on data from fully stocked P-J stands.

A potential MAI growth model was sought as a function of some variable(s) independent of the stand's present density and age. A site index relating height and age (as in fig. 7) proved best among indices considered. Two simple linear models were constructed to predict potential MAI from height-to-age site index. One model was an average regression fit to the data, while the other was an upper bound regression fit to the data. These two models are illustrated in figure 8.

COEFFICIENTS AND FUTURE WORK

Estimated coefficients are reported in tables in appendix B for all volume growth and site index equations discussed in this paper. Each table is adapted from one of my publications where methods and data are discussed in detail.

Future plans include refining the models using data collected in Arizona and giving more emphasis to the combined effects from model prediction errors and sampling errors. This error analysis should lead to better guidelines for applying volume and growth equations to P-J.

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APPENDIX A

This appendix contains a brief description of the jackknife resampling method (Mosteller and Tukey 1977, p. 133) used to construct confidence intervals in table 1.

Volume data for 127 single-stem pinyon were randomly divided into six groups of 19 to 20 trees each. The groups were then combined into six data sets, where a different group was deleted from each data set. All nonlinear model coefficients (for eqs. 2 and 3) were estimated six times, once from each of the six data sets. Next, volumes to a 1.5-inch *mbd* and 3-inch *mbd* were predicted from each data set using each data set's unique coefficients. These volume predictions were averaged into 2-inch diameter classes to compute pseudo-values:

$$Y^*_j = (k)Y_{all} - (k-1)Y_{(j)},\ j=1,2,\ldots,k$$

where

Y^*_j = a pseudo-value
k^j = 6 (number of groups)
Y_{all} = volume prediction based on all groups
$Y_{(j)}$ = volume prediction based on k-1 with group j deleted.

A variance was easily calculated from the pseudo-values:

$$S^2 = \frac{\sum_{j=1}^{k} (Y^*_j - \overline{Y}^*)^2}{k-1}$$

where

$\overline{Y}^*$ = the arithmetic mean of Y^*_j.

Once variances were computed, 95 percent confidence limits were calculated using a t-statistic:

$$\overline{Y}^* \pm t_{\alpha/2:k-1}\, S/\sqrt{k}$$

where

$t_{\alpha/2:k-1}$ = 2.571 for α equals 0.05 and k equals 6.

APPENDIX B

This appendix contains tables of equations for all volume, growth, and site index models mentioned in the text. These tables were taken from my previous works.

Table 2.--Volume prediction equations for woodland tree species in the central Rocky Mountain States (reprinted from Chojnacky 1985)

State	Species	Area of application	Volume equation coefficients[1]		
			a	b	c
Colorado	Hardwoods[2]	entire State	-0.13822	0.121850	0
	Oneseed juniper	eastern Colorado	-.19321	.136101	0.038187
	Utah juniper	western Colorado	-.08728	.135420	-.019587
	Rocky Mountain juniper	entire State	.02434	.119106	0
	Pinyon	entire State	-.20296	.150283	.054178
	Gambel oak	entire State	-.13600	.145743	0
Idaho	Mountain-mahogany	southern Idaho	-.13363	.128222	.080208
	Hardwoods[2]	southern Idaho	-.13822	.121850	0
	Western juniper	southern Idaho	-.22048	.125468	.100092
	Utah juniper	southern Idaho	-.13386	.133726	.036329
	Rocky Mountain juniper	southern Idaho	.02434	.119106	0
	Singleleaf pinyon	southern Idaho[3]	-.14240	.148190	-.016712
Nevada	Mountain-mahogany	entire State	-.13363	.128222	.080208
	Western juniper	entire State	-.22048	.125468	.100092
	Utah juniper	Carson City, Battle Mountain, Elko, and Las Vegas[4]	-.13386	.133726	.036329
	Utah juniper	Ely[4]	-.03655	.135689	-.018476
	Utah juniper	Winnemucca and Susanville[4]	.04829	.114358	-.045779
	Singleleaf pinyon	entire State	-.14240	.148190	-.016712
South Dakota	Bur oak	Black Hills	.12853	.105885	0
Utah	Mountain-mahogany	eastern Utah	-.13363	.128222	.080208
	Utah juniper	eastern Utah	-.08728	.135420	-.019587
	Utah juniper	western Utah	-.13386	.133726	.036329
	Rocky Mountain juniper	eastern Utah	.02434	.119106	0
	Pinyon	eastern Utah	-.20296	.150283	.054178
	Singleleaf pinyon	western Utah	-.14240	.148190	-.016712
Wyoming	Mountain-mahogany	entire State	-.13363	.128222	.080208
	Hardwoods[2]	entire State	-.13822	.121850	0
	Utah juniper	entire State	-.08728	.135420	-.019587
	Rocky Mountain juniper	entire State	.02434	.119106	0
	Pinyon	entire State[3]	-.20296	.150283	.054178
	Bur oak	Black Hills	.12853	.105885	0

[1]The volume equation is: $V = [a + b(DRSQH)^{1/3} + c\ STEM]^3$, where: V = gross cubic foot volume of wood and bark to a 1.5-inch *mbd*
DRSQH = DRC (inches) squared times height (feet)
STEM = 1 for single-stem trees; 0 for multiple-stem trees.

[2]This equation is a rough approximation for the following trees: willow, boxelder, maple, hawthorn, ash, locust, and cherry.

[3]Only a few trees were represented in the sample for this State.

[4]These are Bureau of Land Management Districts in Nevada.

Table 3.--Volume ratio and volume prediction equations for Great Basin P-J (reprinted from Chojnacky in preparation, a)

Equation[1]	Equation No.	Species	Basal stems	Estimated coefficients β_0	β_1	β_2	β_3	β_4	β_5	Nonlinear regression statistics z_n	C.V.	R^2
$\hat{VR}_{ob} = 1 + \frac{\beta_1(mbd-1.5)^{\beta_2}}{DRC_{sh}^{\beta_3}}$	(11)	Juniper	Single		-0.44761	0.65698	0.38835			56	13%	0.76
			Multiple		-.82565	.59404	.45831			79	17%	.80
		Pinyon	Single		-.27612	.67360	.21114			130	11%	.76
			Multiple		-.66949	.62895	.44205			34	14%	.82
$\hat{VR}_{ib} = 1 + \frac{\beta_1(mbd)^{\beta_2}}{DRC_{sh}^{\beta_3}}$	(12)	Juniper	Single		-.46178	.55473	.27152			56	15%	.69
			Multiple		-.62671	.55423	.30675			80	19%	.69
		Pinyon	Single		-.37567	.59369	.25692			125	13%	.65
			Multiple		-.61912	.61412	.39859			34	16%	.73
$\hat{V}_{ob} = \begin{cases} \beta_0+\beta_1X+\beta_2X^2 \text{ for } X \leq 4{,}500 \\ \beta_3+\beta_4X^{\beta_5} \text{ for } X>4{,}500 \end{cases}$	(13)	Juniper	Single	-0.156	.002726	8.101×10^{-8}	-96.806	33.867	0.1406	55	29%	.96
			Multiple	-.064	.001768	2.671×10^{-7}	61.794	-1,259.330	-.3872	78	38%	.90
		Pinyon	Single/ multiple	-.057	.002572	3.508×10^{-7}	-49.445	2.8136	.3788	163	31%	.96

where

β_i = coefficients estimated by nonlinear regression

$CSST = \sum_{i=1}^{m}(Y_i-\bar{Y})^2$

$C.V. = \sqrt{MSE}/\bar{Y}$

DRC_{sh} = outside bark diameter at 6-inch stump height (inches)

height = total tree height (ft)

m = number of observations

mbd = minimum branch diameter (inches)

MSE = SSE/(m-p)

n = number of trees used in nonlinear regression

p = number of coefficients estimated

$R^2 = 1 - (SSE/CSST)$

$SSE = \sum_{i=1}^{m}(Y_i-\hat{Y}_i)^2$

V_{ob} = outside bark volume (ft^3) for all woody material larger than 1.5-inches *mbd* (*ob*)

VR_{ib} = inside bark volume ratio

VR_{ob} = outside bark volume ratio

$X = DRC_{sh}$ squared times height

Y_i = dependent variable for nonlinear regression

$\hat{Y}_i$ = prediction of dependent variable

[1]For eq. 11 *mbd* (*ob*) is limited between 1.5 and 6 inches and for eq. 12 *mbd* (*ib*) is limited between 1 and 5 inches.
[2]The actual number of observations used to develop equations 11 and 12 was 4 to 5 times n, because 4 to 5 different *mbd* volumes were available for each tree.

Table 4.--Site index and volume growth prediction equations for Nevada P-J (reprinted from Chojnacky in preparation, b)

Equation type	Equation description	Equation formula	Regression statistics R²	√MSE	C.V.	n	Equation number
Site index	Height-to-DRC_{sh}	$HT = 1.0555 \cdot SI_D \cdot exp\ -[3.6778 \cdot D_P + 2.5244 \cdot D_J - 0.3137 \cdot SP]$	0.83	1.99	13%	168	(7)
	Site prediction	$SI_D = 0.9474 \cdot HT \cdot exp[3.6778 \cdot D_P + 2.5244 \cdot D_J - 0.3137 \cdot SP]$	--algebraic manipulation of eq. 7--				(8)
	Height-to-age	$HT = 1.1963 \cdot SI_A \cdot exp\ -[76.4529 \cdot A_P + 52.1632 \cdot A_J - 0.4579 \cdot SP]$	0.76	2.34	15%	168	(9)
	Site prediction	$SI_A = 0.8359 \cdot HT \cdot exp[76.4529 \cdot A_P + 52.1632 \cdot A_J - 0.4579 \cdot SP]$	--algebraic manipulation of eq. 9--				(10)
Growth	Best practical model	$MAI = exp[-2.6298 + 0.6584 \cdot ln(CRNVOL) + 0.3406 \cdot ln(BA) - 0.6818 \cdot JCOV_{TR}]$	0.86	1.47	25%	44	(11)
	Best model	$CAI = exp[-1.2533 + 0.6482 \cdot ln(CRNVOL) + 0.0580 \cdot BAG - 1.1746 \cdot JCOV]$	0.90	1.79	20%	44	(12)
	Best practical model	$CAI = exp[-1.7821 + 0.7481 \cdot ln(CRNVOL) + 0.2697 \cdot ln(BA/D_Q) - 1.4238 \cdot JCOV]$	0.76	2.70	30%	44	(13)
	Potential MAI, least squares average	$MAI_P = -7.2099 + 0.5639 \cdot SI_A$	0.73	2.19	28%	16	(14)
	Potential MAI, upper 30% tolerance point	$MAI_{P7} = -4.9796 + 0.5808 \cdot SI_A$	--tolerance point regression--				(15)

where

age = total tree age (yrs)

A_J = 1/age for juniper, 0 for pinyon

A_P = 1/age for pinyon, 0 for juniper

BA = basal area at DRC_{sh} (ft^2/acre)

BAG = 10-year basal area growth (ft^2/acre/decade)

CAI = current annual volume growth (ft^3/acre/yr)

CRNVOL = crown volume per plot area divided by 1000 (ft^3/1000/acre)

Crown area = 0.7854·CRMX·CRMN (ft^2)

Crown volume = 0.5236·CRMX·CRMN·HT (ft^3)

CRHT = tree crown height (ft)

CRMN = tree crown diameter perpendicular to CRMX (ft)

CRMX = maximum tree crown diameter (ft)

DRC_{sh} = tree diameter at 6-inch stump height (inches)

D_J = $1/DRC_{sh}$ for juniper, 0 for pinyon

D_P = $1/DRC_{sh}$ for pinyon, 0 for juniper

D_Q = quadratic mean DRC_{sh} (inches)

exp = exponential function

HT = total tree height (ft)

JCOV = juniper crown area per plot (ft^2/ft^2)

$JCOV_{TR}$ = JCOV/TREECOV

ln = natural log function

MAI = mean annual volume growth (ft^3/acre/yr)

MAI_P = potential MAI for fully-stocked stands (ft^3/acre/yr)

MAI_{P7} = 70th percentile maximum of MAI_P (ft^3/acre/yr)

SI_A = age site index (ft) referenced to a 120-year-old pinyon

SI_D = DRC_{sh} site index (ft) referenced to 10-inch DRC_{sh}

SP = 1 for pinyon, 0 for juniper

TREECOV = P-J crown area per plot area (ft^2/ft^2)

CLASSIFICATION OF PINYON-JUNIPER (P-J) SITES ON NATIONAL FORESTS IN THE SOUTHWEST

W. H. Moir and J. O. Carleton

ABSTRACT: We define woodland plant associations, subseries, and ecological sites, all of which are invariants under changing management systems (unless soils are degraded or enriched).

To date there is no classification of P-J woodlands at the level of plant association or ecological site. Literature from Arizona and New Mexico contains numerous descriptions of P-J vegetation which are generalized over diverse sites and stages of succession and which are not clearly set apart from other kinds of vegetation such as chaparral or Madrean evergreen woodland. Our classification at a subseries level gives an overview of woodland diversity and biotic potentials. This subseries classification relates to patterns of regional climate and provides consistency for applying soil classification at a subgroup level of Soil Taxonomy. A few, known P-J associations are fitted into this subseries classification.

Based on literature review and field experience, we estimate about 70 plant associations and perhaps 280 ecological sites within the P-J woodland of Arizona and New Mexico.

INTRODUCTION

Woodlands of pinyon or juniper have long been recognized as a major vegetation of the Western U.S., and numerous descriptions exist (Aldon and Springfield 1973, Springfield 1976, Driscoll 1964, Everett 1985, Brown 1982). In this paper, we review the current status of classification of pinyon-juniper (P-J) woodlands at different levels of vegetation and ecosystem generality. Our major purpose is to see how adequately these levels of communication help serve research, management, and communication to the public.

WOODLANDS IN GENERAL: CONCEPTS AND CONFUSIONS

Everybody knows what P-J woodlands are, but no one seems to agree where they stop. The prestigious UNESCO defined woodlands as a vegetation whose trees are $\geq$ 5 m (16 feet) tall and whose crown coverage is $\geq$ 40 percent. Woodlands were then subdivided into those composed mainly of evergreen, broadleafed trees (UNESCO II.A.1) and those mainly of evergreen needle-leafed trees (II.A.2), as well as some other categories of woodlands which need not concern us here. But UNESCO also permitted trees whose crown cover ranged between 10-40 percent to be classified as grassland (e.g. V.C.1) or even as shrubland (e.g. a sagebrush understory with emergent conifers having 10-40 percent crown cover).

In the western United States, it was not easy for agencies or individuals to accept the UNESCO classifications into which woodlands were fitted. An effort to make a structural classification of woodlands more cohesive and useful expanded the UNESCO definition to vegetation whose trees are $\leq$ 5 m tall and whose crown coverage is 26-60 percent (Driscoll et al. 1984). Another widely used definition of woodlands is "Communities dominat by trees with a mean potential height usually under 15 meters (50 feet) in height, the canopy of which is usually open--sometimes very open (e.g. savannas)--or interrupted and singularly layered" (Brown 1982). Despite the confusion or arbitrariness of such definitions, we still "know" what a woodland is, at least for the most part. Or do we?

Layser and Schubert (1979) and others have taken a plant taxonomic approach to woodland definition. A pinyon series (for the Southwest) includes stands dominated by Pinus edulis, P. monophylla, or P. cembroides, or where these pines are codominant with junipers (Juniperus spp.). A juniper series includes stands of junipers, with other conifers absent, widely scattered, or confined to microsites. Following this lead to its ultimate, one can propose the following series:

Pinus edulis (Johnson 1984)
P. monophylla (Everett 1985)
Pinus discolor (Wentworth 1985)

Juniperus osteosperma (Johnson 1984)
J. monosperma (Johnson 1984)
J. scopulorum (Johnson 1984)
J. deppeana (Clary et al. 1974)
J. erythrocarpa (Fletcher 1985)

Each of these series reflects a portion of a geographic-moisture-temperature gradient as reflected in the tallest vegetation stratum.

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W. H. Moir and J. O. Carleton are respectively Ecologist and Assistant Director, Soils and Geology, USDA Forest Service, Southwestern Region, 517 Gold Avenue SW, Albuquerque, NM 87102.

Some novel definitions of P-J woodland and other vegetation have been developing in the field of remote sensing. Perhaps the woodlands are discriminated more "objectively" through the "eyes" of sensing devices. Perhaps they are classified and mapped more consistently using computers and verbal or graphic displays. There is certainly promise with this high technology approach. However, remote sensing and its attendant analytical methods is concerned with existing vegetation. Conversions from woodland to herbaceous or shrub dominance will be "sensed" and classified other than P-J woodland. As remote sensing becomes more coupled to ground verification and successional dynamics, these limitations will become, we hope, insignificant.

These generalized woodland concepts are useful as abstractions or conventions when we do not intend to get lost in detail. We still "know" what woodlands are and where examples can be found that fit these concepts.

But woodlands adjoin other vegetation not fitted to these general concepts. And other vegetation types can be modified to resemble woodlands. The woodland "stage" of these other types may persist for a long time or may be rather brief. In either case, it is not very convenient to change the classification (now the woodland, now something else) as vegetation changes.

Pinyon-juniper woodlands commonly adjoin and intergrade to such vegetation as chaparral (shrub dominated plant communities), grasslands, shrub-steppes (codominant mixtures of grasses and shrubs), evergreen oak woodlands (or encinal cf the Madrean evergreen woodland, 123.3, of Brown 1982), and ponderosa pine or other "forest" types. Where these intergrades occur, some people or agencies may call such vegetation woodland, while others refer to it as chaparral, grassland, or whatever. For example, maps of P-J woodland distribution in the Southwest do not show its occurrence south of the Mogollon Rim in Arizona. Yet thousands of acres of P-J woodlands there satisfy definitions of UNESCO, Driscoll et al. (1984), and Layser and Schubert (1979). Brown (1982), on the other hand, would consider woodlands dominated by Pinus discolor, Juniperus deppeana, and perhaps Juniperus erythrocarpa to be a derivative of the Madrean evergreen oak woodland.

For many of the above reasons, we do not know how many acres of P-J woodlands there are in the Southwest. We use general woodland definitions loosely. The language allows comfortable communication only when we fall into the serenity of vagueness. After all, we really "know" what the woodland is, so why nit-pick about vegetative details? But these broad woodland conventions may not serve the purpose of inventory, research into woodland function, or resource allocation at local or project levels. For these purposes, we must communicate more precisely.

P-J WOODLANDS AT THE SUBSERIES LEVEL

We have identified four distinctive woodland climates over Arizona and New Mexico (Carleton and Brown 1983). For convenience, these climates have been named Low Sun Cold (LSC), High Sun Cold (HSC), Low Sun Mild (LSM), and High Sun Mild (HSM). Also for convenience, these climatic regions can be identified by some major indicator plants:

Climate	Plant indicators
LSC	Artemisia tridentata, Coleogyne ramosissima
HSC	Quercus gambelii
LSM	Quercus turbinella, Arctostaphylos pungens
HSM	Quercus grisea, Q. arizonica

Within each climate P-J woodlands can be divided into elevational subzones or segments of a climatic gradient. Climatic modifiers are used to represent local climatic gradients from relatively warm, dry to relatively cold, wet environments. Within the P-J woodlands of Arizona and New Mexico these elevational subzones have the following general characteristics:

Climatic modifier	Woodland features
-1	Tree canopy cover 5-30% Height of tallest tree < 5 m. Fuelwood production (Typic Haplustalfs): 0-3 cords/acre. Dominant conifers: Juniperus spp. (Pinus absent or accidental)
0	Tree cover: 30-50% Height of tallest trees: 4-10 m Fuelwood production (Typic Haplustalfs): 3-8 cords/acre Dominant conifers: both Juniperus and Pinus
+1	Tree cover: 50-80% Height of tallest trees: 7-14 m Fuelwood production (Typic Haplustalfs): 8-15 cords/acre Dominant conifers: Pinus (P. ponderosa absent or < 5% cover).

The major vegetation subseries (U.S. Forest Service 1985, TES-1) in each climate and subzone are shown in table 1. Vegetation having the indicated dominant or codominant plants belongs to one of the twelve subseries of table 1. Each subseries is "major" in the sense that stands can be found over a wide variety of soils and topography in the Southwest. The subseries of table 1 do not exhaust all combinations of dominant plants in the P-J woodlands. For example, sandy soils in the woodland LSC, -1 climate feature Juniperus monosperma, Artemisia tridentata, and Muhlenbergia pungens - a combination that is very distinct from

the corresponding vegetation in table 1. We estimate that there are about three or four such vegetation departures, which are usually controlled by special soils, topography, or soil-topography combinations, in each of the climates and subzones of table 1. On this basis, there seem to be about 40-50 vegetation subseries in the P-J woodlands of Arizona and New Mexico. Vegetation of the P-J woodlands within all of these subseries would reflect all combinations of climates, local climatic gradients, soils, and topographic conditions.

Table 1.--Major pinyon-juniper woodland subseries in Arizona and New Mexico

CLIMATE	ELEVATIONAL SUBZONE[a]	DOMINANT OR CODOMINANT SPECIES[b]
LSC	0	Pinus edulis, Juniperus osteosperma, (Juniperus monosperma), Artemisia tridentata
	-1	as above except Pinus edulis absent or accidental
	+1	as zero (0) above but includes Quercus gambelii.
HSC	0	Pinus edulis, Juniperus monosperma, (J. deppeana), (J. osteosperma)
	-1	as above except Pinus edulis absent or accidental
	+1	as zero (0) above but includes Quercus gambelii, (Q. undulata).
LSM	0	Pinus monophylla, Juniperus osteosperma, (J. monosperma), Quercus turbinella, Arctostaphylos pungens
	-1	Juniperus osteosperma, (J. erythrocarpa), (J. monosperma), Quercus turbinella, Prosopis velutina
	+1	as zero (0) above but includes Quercus arizonica, Juniperus deppeana.
HSM	0	Pinus discolor, (Pinus edulis), Juniperus deppeana, Quercus grisea, (Q. arizonica)
	-1	(Juniperus deppeana), (J. erythrocarpa), Quercus emoryi
	+1	As zero (0) above but includes Quercus hypoleucoides.

a/ 0 = typical or modal open woodlands, -1 = low elevation juniper savannas, +1 = high elevation, generally closed-canopy woodlands

b/ Species in parentheses may or may not occur depending on geography. If evergreen oaks in tree layer exceed 10% of tree canopy cover, then woodland can be classified as Madrean evergreen.

This systematic classification of P-J woodlands in the Southwestern Region is more or less complete (USFS 1985, TES-1). There is allowance that new subseries wil be described as inventory and mapping proceeds on National Forests.

This subseries level of P-J woodland classification is most useful for inventory, mapping, and planning functions at the whole-Forest scale (ca. 1:24,000) where large acreages are involved. The relatively simple language of classification (at each subseries only a few dominant, easily identified plant species are diagnostic) allows rapid identification and mapping in the field. Communication of information at this scale is more precise than if more general woodland concepts (discussed above) were used.

For resource users at project levels, the subseries generalizations may be inadequate. For example, the Pinus edulis, Juniperus monosperma, (Juniperus deppeana), (Juniperus osteosperma) subseries (see table 1 at HSC, 0) may feature important wildlife browse plants and hiding cover on one slope and considerable fuelwood and potential grass for livestock on a nearby slope. Such important management implications on the local scale (e.g. about 1:5,000) are not communicated at the subseries level.

P-J WOODLANDS AT ASSOCIATION AND PLANT COMMUNITY LEVELS

The most precise and comprehensive communication of vegetation information about P-J woodlands usually occurs at levels of the plant association and plant community. Here we can differentiate variations in composition and structure of woodlands in the local landscape. The principal difference between association and community concepts is that the former is usually conceptualized from stands or samples late in successional development while the latter is sampled and described from stands regardless of successional stage (cf Moir and Ludwig 1985, Francis 1986).

Early literature often described woodland associations in a broad sense (NMEI 1981, Woodin and Lindsey 1954, Potter 1957, Donart et al. 1978). More recent classifications are usually performed using clustering techniques on vegetation or environmental data matrices or else by divisive techniques which partition vegetation ordinations (i.e. Pielou 1984). The result of these fully quantitative analyses are stand clusters or ordination partitions whose vegetational attributes both describe and define the woodland associations or communities. The validity of such classifications is usually tested by field application. The ease of field identification, the relationship of woodland groupings (whether associations or communities) to environmental features, and the utility of such groupings to management are all factors affecting acceptability and usage of local classifications (Hall 1980, RISC 1983, USFS 1983).

Woodland associations or plant communities are sometimes proposed by sampling from analog devices, such as remote sensing. However, as we view current technology, these analogue resolutions seem more appropriate to more generalized classifications discussed above.

When plant associations or communities have been developed in local areas, regional correlation is necessary to determine their extent (Johnson 1983). Such correlation can be quantitative (e.g. based on measures of similarity) or qualitative (e.g. based upon literature comparisons). In the Southwest, there are few studies of P-J associations or plant communities and none which are regional. The extensive sampling needed to produce the large data matrix for P-J woodlands over Arizona and New Mexico is not likely to be done in the near future. Our literature review of P-J woodland associations (table 2) is an approximation of woodland diversity on regional scale. The classification is also preliminary because the concept of plant association is difficult to apply in vegetation pervasively disturbed since European man's occupancy of the Southwest (Kennedy 1983, Everett 1985). Also, we make no assumption about the completeness of regional coverage from a literature survey comprised mostly of localized woodland descriptions. Our experience based upon forest habitat type studies in the Southwest (Moir and Ludwig 1983) together with intuition based upon the Terrestrial Ecosystem Survey (TES) in the Southwest, hints that about 70 P-J associations can be described in the Southwest (USFS 1985abc).

Table 2 is a catalog of some known or presumed P-J woodland associations. These associations (and some geographic or floristic phases) have been nested into climatic regions and elevational subzones. This allows a hierarchical aggregation to subseries and series levels of classification. The association names follow no nomenclatural procedures or rules other than simplicity and brevity. More important than the names are the descriptions in the references cited. Only few references provide releve tables or comparable information based upon modern clustering or ordination techniques (Francis 1986, Kennedy 1983, Medina 1985, Wentworth 1985). We know, therefore, that much remains to be learned and described about P-J woodland associations and plant communities of the Southwest.

Each association of table 2 can have distinctive successional stages, distinctive productivity classes, and perhaps some important environmental variation that warrants recognition of management phases (Hall 1980, RISC 1983). Stewart and Hann (1983) have called these variations in site characteristics within a plant association "site types," and several other names for these divisions of a plant association have also been proposed (e.g. RISC 1983, FSM 2060, 1983). There may be as many as 4-5 "site types" within each woodland association (Stewart and Hann 1983), and each "site type" may have 1-2 distinctive seral stages. Therefore, we can have up to about 500 different plant communities in the P-J woodlands of Arizona and New Mexico (70 p.a.s x 4 site types x 3 successional stages up to and including climax or potential natural community). Many seral communities in P-J woodlands appear the same, however, after prolonged and sustained periods of disturbance following the advent of European man into the Southwest (Stewart and Hann 1983, Everett 1985). Realistically, then, we speculate that considerably fewer than 500 plant communities occur in our P-J woodlands; just how many, we do not know.

P-J WOODLAND ECOSYSTEMS IN THE SOUTHWEST

So far we have been concerned about P-J woodland vegetation at different levels of vegetation taxonomy (e.g. series, subseries, association). The classification of woodlands as ecosystems (USFS 1983) is far more difficult. Two major approaches for ecosystem classification are: (1) Let vegetation indicate the ecosystem; (2) Use a component approach. We discuss each of these briefly.

Vegetation as Ecosystem

This viewpoint is widely subscribed to by plant ecologists. It assumes that vegetation (at whatever level of generality) reflects the causal and interactive factors of the environment (including biotic factors) that are also the forcing functions or governing processes of ecosystems. This viewpoint has the advantage that vegetation is more measurable than climate, soils, zootic influences, and the wide possibilities of interactions and combinations of causal factors.

When plant associations are mapped onto the landscape at the local scale, a habitat type map is produced. Habitat types draw attention to lands capable of supporting the same plant association. As discussed above, a plant association may be internally homogeneous in the kind and proportion of species, but may include a wide range of expression in functional ecosystem properties such as productivity or nutrient cycling. There may also be strong differences in management possibilities within the habitat type.

If we subdivide our P-J woodland habitat types into "site types" (sensu Stewart and Hann 1983) these seem equivalent to "ecological sites" as defined by the RISC Report (1983, p. 2). We estimate there are about 280 ecological sites within the P-J woodlands of the Southwest (70 p.a.s x 4 site types per p.a.).

Component Ecosystems

Component ecosystems (Driscoll et al. 1984) are defined by combinations of vegetation, soils, landforms, climates, or other component "attributes" of ecosystems. As stated in a recent revision of the Forest Service Manual (FSM 2061), ecosystem components may be described either (1) individually and then combined, or (2) by simultaneously evaluating a combination of components.

Table 2.--Pinyon-juniper woodland associations in Arizona and New Mexico inferred from literature. Associations are indicated by climatic regions and elevational subzones (+1,0,-1) after Carleton and Brown (1983)

I. All climates, all subzones	References
Scarp Woodland	Wells 1970, Martin et al (1981), Moir 1979, NMEI 1971 (juniper-oak breaks), Rogers 1950, USFS 1985ab, TES-3 (159,168,195,278)a/
II. Low Sun Cold (LSC)	
+1	
Pinus edulis/Quercus gambelii	TES-2 (208,315)a/, Donart et al 1978 (CW1a), Baker 1984, Johnson 1984, Erdman et al 1969 (C-3), TES-3 (140, 157,465,765)
Pinus edulis/Purshia tridentata	Johnson 1984, Erdman et al 1969 (M-1), TES-3 (769)
Pinus edulis/Cercocarpus montanus, Quercus gambelii phase	Johnson 1984, Erdman 1970, TES-2 (73,74,105), TES-3 (769), TES-4 (73)
0	
Pinus edulis/Festuca arizonica	Merkle 1952
Pinus edulis/Poa fendleriana	Johnson 1984, Peterson and Baker 1982, USFS 1985a
Pinus edulis/Artemisia tridentata	Johnson 1984, Schmutz et al 1967, Jameson et al 1962, USFS 1985a, TES-4 (145), TES-3 (119,145,194)
Pinus edulis/Cowania mexicana	Baker 1984, TES-1, USFS 1985a
Pinus edulis/Cercocarpus montanus	
Pinus edulis/Stipa neomexicana	Baker 1984, TES-3 (159,151,118,142, 149E)
Pinus edulis/Muhlenbergia pungens	TES-3 (153)
Pinus edulis/Chrysothamnus nauseosus	TES-2 (14), TES-4 (32), TES-3 (71)
-1	
Juniperus osteosperma/Artemisia tridentata, includes Juniperus monosperma phase	TES-4 (111), Donart et al 1978 (CW2c)
Juniperus osteosperma/Stipa neomexicana	TES-1, TES-3 (15,167,168)
Juniperus monosperma/Muhlenbergia pungens	TES-3 (143,144)
Juniperus monosperma/Chrysothamnus nauseosus	TES-3 (34)
Juniperus monosperma/Fallugia paradoxa	TES-3 (23)
III. High Sun Cold (HSC)	
+1	
Pinus edulis/Muhlenbergia dubia	Kennedy 1983, Donart et al 1978 (CW1a)
Pinus edulis/Quercus gambelii	Francis 1986, TES-1
Pinus edulis/Cercocarpus montanus, Quercus gambelii phase	Johnson 1984, USFS 1985b

con.

Table 2. Continued

III. High Sun Cold (HSC)	References
0	
Pinus edulis/Cercocarpus montanus, Quercus undulata phase	USFS 1985b, TES-7 (275)[a/]
Pinus edulis/Bouteloua gracilis,	
Juniperus deppeana phase	Kennedy 1983 (PIED-JUDE/BOGR)
Juniperus osteosperma phase	TES-9 (53,54)
Juniperus monosperma phase	Kennedy 1983 (PIED-JUMO/BOGR), Francis 1986
Pinus edulis/Cowania mexicana	USFS 1985a, TES-9 (51,52,55)
Pinus edulis/Muhlenbergia pauciflora	Kennedy 1983 (PIED-JUMO/MUPA)
Pinus edulis/Stipa columbiana	Kennedy 1983 (PIED-JUMO/STCO)
Pinus edulis/Fallugia paradoxa	TES-1
Pinus edulis/Chrysothamnus nauseosus	TES-1, TES-9 (58)
Pinus edulis/Andropogon hallii	USFS 1985b, cf TES-3 (153)
-1	
Juniperus monosperma/Bouteloua gracilis Juniperus osteosperma phase	Francis 1986, Dick-Peddie et al 1984, USFS 1985b, NMEI 1971 (Blue grama-cholla-juniper), Donart et al 1978 (GG4a), TES-8 (14), TES-9 (41,43,44).
Juniperus monosperma/Agave lechuguilla	Gehlbach 1967
Juniperus monosperma/Nolina microcarpa-Agave lechuguilla	Gehlbach 1967
Juniperus monosperma/Larrea divaricata	Van Devender et al 1984, Woodin and Lindsey 1954, TES-7 (274,278), NMEI 1971
Juniperus monosperma/Quercus undulata	NMEI 1971 (Assoc. 3,4), Pettit et al 1980, TES-7 (280)
Juniperus deppeana-J. monosperma/Cercocarpus montanus-Ceanothus greggii	Woodin and Lindsey 1954, USFS 1985b.
Juniperus monosperma/Andropogon hallii	USFS 1985b
Juniperus monosperma/Chrysothamnus nauseosus	TES-1
Juniperus monosperma/Fallugia paradoxa	TES-1
Juniperus monosperma/Falligia paradoxa/ Parmelia neoconspersa malpais	Lindsey 1951
IV. Low Sun Mild (LSM)	
+1	
Pinus monophylla/Quercus turbinella-Arctostaphylos pungens	TES-6 (4038,4768)
P. monophylla/Q. turbinella-Arctostaphylos pungens, Quercus emoryi phase	TES-6 (4366, 4839)
Juniperus deppeana/Panicum obtusum	TES-6 (4140)
0	
Pinus edulis/Arctostaphylos pungens	USFS 1984b, TES-6 (3705,3765,4820)
Pinus edulis/Quercus turbinella	USFS 1985c
Pinus monophylla/Quercus turbinella	TES-5 (4973)

con.

Table 2. Continued

IV. Low Sun Mild (LSM)	References
-1	
Juniperus erythrocarpa/Quercus turbinella	TES-6 (2055)[a/]
Juniperus erythrocarpa/Bouteloua eriopoda	USFS 1985c, Donart et al 1978 (CW2e)
Juniperus osteosperma/Hilaria mutica	USFS 1985c
V. High Sun Mild (HSM)	
+1	
Pinus edulis/Cercocarpus montanus, Juniperus deppeana phase	Medina 1985 (PIED-JUDE), USFS 1985c
Pinus discolor-Quercus arizonica/Nolina microcarpa	USFS 1985c
Pinus edulis/Quercus gambelii	TES-5 (4970)
0	
Pinus discolor/Muhlenbergia emersleyi	Moir 1982, 1979
Pinus edulis/Cercocarpus montanus, Juniperus monosperma phase	Medina 1985 (PIED-JUMO), Moir 1963
Pinus edulis-Quercus emoryi/Rhus trilobata	TES-5 (4850)
Pinus edulis-Juniperus deppeana/Bouteloua gracilis	TES-5 (4826,4835,4908), TES-10 (511,513)
Pinus edulis-Quercus emoryi/Arctostaphylos pungens (includes Pinus discolor phase)	TES-5 (4836)
Pinus discolor/Quercus toumeyi	Moir 1979
Pinus discolor/Cercocarpus breviflorus-Rhus coriophylla	Wentworth 1985
-1	
Juniperus deppeana-Quercus grisea/Rhus trilobata	Gehlbach 1967, TES-5 (3967)
Juniperus deppeana/Bouteloua gracilis	TES-5 (3828)
Juniperus deppeana/Panicum obtusum	TES-5 (3832,3914), cf TES-6 (4140)
Juniperus monosperma/Prosopis glandulosa includes J. erythrocarpa phase	Anderson et al 1985, TES-5 (3040,3829,3947), TES-10 (110)
Juniperus monosperma/Bouteloua gracilis, Quercus turbinella phase	TES-10 (120)
Juniperus deppeana/Muhlenbergia emersleyi	Ahlstrand 1979 (p. 37)

a/ Terrestrial ecosystem survey (TES) references are cited as U.S. Forest Service, various dates; numbers in parentheses are mapping units where the indicated association is likely to be found.

The component approach at ecosystem classification is most useful in landscapes or regions where vegetation has been extensively modified and simplified under human occupancy. In P-J woodlands, the loss of vegetation diversity after long periods of settlement and vegetation harvest may no longer permit a resolution of plant associations. One turns, then, to other ecosystem attributes, such as soils, to help classify ecosystems.

One component approach to classification of P-J woodland ecosystems is the Terrestrial Ecosystem Survey (TES) (USFS 1985, TES-1). Three ecosystem components used for classification are climate, vegetation, and soils. We have already discussed the four kinds of climate and the subseries categories of vegetation used in TES. Soil characteristics of P-J woodlands are extremely variable. The TES interprets the soil moisture regime in each of the four climates as ustic. The soil temperature regime is considered mesic, except in the LSM, -1 climate where prevalence of mesquite (Prosopis) and other plants of a Sonoran Basin flora indicate a thermic soil temperature regime.

The TES employs the Soil Conservation Service Soil Taxonomy (USDA 1975) in woodland ecosystem classification. There are five orders and ten great groups.

The major great groups are indicated by the asterisks:

Alfisols:	Haplustalfs*, Paleustalfs
Inceptisols:	Ustochrepts*
Entisols:	Ustorthents*, Ustifluvents, Ustipsamments
Mollisols:	Argiustolls, Calciustolls, Haplustolls
Vertisols:	Chromusterts

At the subgroup level of taxonomy, the TES indicates about 40 soils within P-J woodlands in Arizona and New Mexico. At the family level, there are probably several hundred distinctive soils. Such variation based upon soil taxonomic features at different levels of generality suggest one of the reasons why P-J woodlands have a wide range of wood and herbage production in the Southwest.

Our experience suggests that by combining soils at the subgroup level with climates and climatic modifiers (given above) and vegetation at the subseries taxonomic level, there are a limited and manageable number of P-J woodland ecosystems in Arizona and New Mexico.

If component classification of P-J woodlands becomes more specific by linking together lower ranks of vegetation or soils taxonomies, ecosystem complexity soon begins to overwhelm us. To illustrate, suppose there are 70 plant associations, 40 soil subgroups, and 150 soil families within our woodlands. Suppose that only one-tenth of possible vegetation-soils combinations actually exist. The number of classified P-J ecosystems would be about 280 and 1050 if soils were linked at respective subgroups and family levels. At present, neither our inventory nor management has capability of dealing with this level of resolution. If a third component (for example, landform) is attached to ecosystem classification, the number of ecosystem possibilities (and actualities) is multiplied still further. We become simply overwhelmed in the ecosystem variation of the P-J woodlands. The practice, therefore, of describing components individually and then combining them can lead to unmanageable and unnecessary complexity when lower (more specific) levels of component taxonomy are used.

Most component classifications, including TES, are developed by simultaneously evaluating a combination of components. Such procedures considerably reduce the combinations of possibilities. The procedures themselves may be subjective or intuitive. Thus different agencies and regions within agencies will likely develop different component classifications for their woodlands.

CONCLUSIONS

Classification of P-J woodlands on National Forest lands in Arizona and New Mexico has been completed at a subseries level of vegetation taxonomy. A woodland ecosystem classification couples this vegetation to a climatic classification and to soils at the subgroup level of Soil Taxonomy (USDA Forest Service, TES-1, 1985; U.S. Department Agriculture 1975). On National Forest lands a progressive survey is currently applying this ecosystem classification through inventory and mapping on a Forest-wide scale. The classification, based upon vegetation potential, is used in a variety of Forest planning activities and for storage and retrieval of certain inventory information.

Classification of P-J woodlands at plant association, plant community, or ecological site levels is incomplete. Only a handful of existing studies have a sufficient data basis for numerical classifications or ordinations. Therefore, there is yet little basis for regional correlations, nor is there a consistency for naming associations, plant communities, or woodland ecosystems at the local scale. We estimate, however, that there are about 70 plant associations and about 280 ecological sites in Southwestern P-J woodlands.

Different component classifications can be developed to reduce the number of ecosystem possibilities, depending upon the levels of generality at which component taxonomies are combined. Agencies responsible for inventory and management of P-J woodlands in the Southwest are not agreed on ecosystem classification. This may or may not be a problem, depending on the completeness of component (e.g. soil and vegetation) description and our ability to cross-walk at different classification levels.

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SOILS OF THE PINYON-JUNIPER WOODLANDS

S. G. Leonard, R. L. Miles, H. A. Summerfield

ABSTRACT: The Soil Resource Information System program on the Fort Collins Computer Center System 2000 was used to evaluate selected soil properties and mapping data for two pinyon and five juniper species in Utah, Nevada, and New Mexico. The soil data indicate two distinct concepts of interpretation between Utah-Nevada and New Mexico. New Mexico provides interpretations for all soils where pinyon or juniper species presently occur while Utah and Nevada provide interpretations only where these species are perceived to be part of the ecological potential or climax situation. Within suitable climatic regimes the range of other soil characteristics indicates a broad ecological amplitude that overlaps several other community types. This suggests associated species and community susceptibility to fire may be an overriding factor to edaphic characteristics in determining the distribution of pinyon-juniper communities.

INTRODUCTION

The Soil Resource Information System (SRIS) data base on the Fort Collins computer center system 2000 used for this analysis contains data from the national soil data base at Iowa State University as of July 1984 for eighteen Major Land Resource Areas (MLRAs). These MLRAs geographically cover Nevada, Utah, and New Mexico with some overlap into adjoining states. The area covered is also included in the geographic distribution of major pinyon and juniper species of the western United States.

SRIS provides an opportunity to relate a range of soil properties with common trees and forest understory vegetation as listed in the Soil Interpretations Record (SCS-SOI-5) and mapping information contained in Map Unit Records (SCS-SOI-6). Information from 110 soil survey areas was evaluated for this study.

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S. G. Leonard is BLM Range Scientist and R. L. Miles is SCS Soil Scientist, National Soil Range Team, Department of Range, Wildlife and Forestry, University of Nevada-Reno; H. A. Summerfield is Soil Scientist, Toiyabe National Forest, Forest Service, U.S. Department of Agriculture, Sparks, NV.

Pinyon species evaluated were pinyon, Pinus edulis and singleleaf pinyon, Pinus monophylla. Juniper species included Utah juniper, Juniperus osteosperma, alligator juniper, Juniperus deppeana, one-seed juniper, Juniperus monosperma, Rocky Mountain juniper, Juniperus scopulorum, and western juniper, Juniperus occidentalis.

METHODS

A range of values for each soil property by horizon is given in the SCS-SOI-5 for each taxon surveyed. When a taxon is included within a new map unit, the soil properties must be verified in the field as being within the allowable range. Therefore, for analytical purposes each occurrence of a taxon within a map unit can be considered a sample. All values were derived from map unit data. Soil descriptors were used according to Soil Taxonomy (Soil Survey Staff 1975).

Soil moisture, temperature, depth, and textural classes were determined from taxonomic classification at the soil family level (subgroup with family adjectives). Depth and textural classes were also segregated by state to evaluate differences in mapping concepts. Clay content, salinity, and pH values were obtained from the range of characteristics allowed by taxon (series or phase of series) and relative number of occurrences. Precipitation ranges were determined at the map unit level from associated range or woodland site information.

RESULTS

There were 942 occurrences of the seven species evaluated within 209 soil families. Relations associated with Rocky Mountain juniper (JUSC2), alligator juniper (JUDE2), and western juniper (JUOC) should be viewed with caution since there were only 15, 12, and 7 occurrences, respectively, in the data base. There were 366 occurrences of pinyon (PIED), 303 occurrences of Utah juniper (JUOS), 143 of singleleaf pinyon (PIMO), and 96 of one-seed juniper (JUMO).

Climate

Soil Temperature and Soil Moisture Regimes.--Table 1 illustrates the relative distribution of pinyon and juniper species within soil

Table 1.--Soil temperature and soil moisture regimes

	Udic	Ustic	2/ Ar/Ustic	Xeric	2/ Ar/Xeric	Udic	
1/ JUDE2	-	83	-	-	-	-	Mesic Temperature Regimes
1/ JUMO	15	46	31	-	-	7	
JUOC	-	-	-	86	-	-	
JUOS	12	7	24	9	21	-	
JUSC2	-	-	7	-	-	-	
1/ PIED	5	1	54	2	8	-	
PIMO	-	-	-	24	23	-	
JUOS	-	7	-	7	8	-	Frigid Temperature Regimes
JUSC2	-	86	7	-	-	-	
PIED	1	9	6	1	-	-	
PIMO	-	-	-	24	23	-	
JUOC	5	-	-	-	-	-	Cryic Temperature Regimes
JUOS	14	-	-	-	-	-	
PIMO	13	-	-	-	-	-	

Moisture Regimes

1/ Relative occurrence for these species does not total 100%. The remaining values did not identify the moisture and regimes.
2/ Aridic integrades of the ustic and xeric moisture regimes.

temperature and soil moisture regimes as determined from the soil classification. Soil moisture regimes are based on the principles of potential wetting depth and the period of time the soil is moist during the growing season. The ustic moisture regime is based on the concept that moisture is limited, but is present when conditions are suitable for plant growth or summer moisture. The xeric moisture regime is typified by moist, cold winters and warm, dry summers (Soil Survey Staff 1975). The aridic integrades to the ustic and xeric regimes infer the moisture occurs during the seasons mentioned, but the soils are drier than the central concept of either ustic or xeric regimes. The udic moisture regime implies that moisture is not limiting for plant growth. Aridic moisture regimes are dry during most of the growing season, and limited for plant growth.

The soil temperature regimes are based on the mean annual soil temperature measured at a depth of 50 cm. The temperature range(s) for each class is as follows: 1) thermic from 15° to 22°C; 2) mesic from 8° to 15°C; 3) frigid below 8°C, and with mean summer soil temperature less than 15°C; and 4) cryic, both mean annual and mean summer temperatures below 8°C (Soil Survey Staff 1975).

Generally, the pinyon-juniper zone can be characterized as occurring in the frigid and mesic temperature regimes and ustic and xeric moisture regimes or aridic intergrades of these regimes. No occurrences of any species were observed in the thermic temperature regime. Based on experience, the occurrences of these species in the mesic/aridic and cryic/udic regimes should be viewed with caution, because the species listed are generally not expected to extend into these zones.

Alligator juniper occurred exclusively in the mesic/ustic zone. Western juniper occurred primarily in the mesic/xeric zone and Rocky Mountain juniper occurred primarily in the frigid/ustic zone. One-seed juniper occurred exclusively in the mesic temperature regime and primarily in the ustic and aridic intergrade of ustic moisture regimes. Utah juniper had the widest distribution of the juniper species, but occurred primarily in the mesic temperature regime with a tendency to be in the aridic intergrades of both ustic and xeric moisture regimes.

Singleleaf pinyon was distributed primarily between the mesic and frigid temperature regimes preferring the xeric and aridic intergrade of xeric moisture regimes. Pinyon was widely distributed by temperature and moisture, but over 50 percent of the occurrences were in the mesic temperature regime and aridic intergrade of ustic moisture regime.

Precipitation.--Based on range sites (National Range Handbook, Soil Conservation Service 1976) or woodland data associated with the soils evaluated, pinyon and juniper species occurred within a precipitation range of 8-22 inches. With the exception of Rocky Mountain juniper, the most common range is 12-16 inches. Rocky Mountain juniper was generally in areas with more than 16 inches of precipitation.

Soil Depth and Texture

Other reports indicating that distribution of the pinyon-juniper association is not limited by soil depth or texture are substantiated by soil survey data. Depths ranged from shallow (< 20 inches) to very deep (>60 inches). Nearly every particle size family grouping was observed except silty and sandy skeletal. The dominant textural family groups in the particle size control section of the soil profile (generally 10-40 inches except for shallower soils) were coarse loamy and fine loamy. A considerable proportion of the soils are skeletal, that is, contain more than 35 percent rock fragments.

Table 2 shows some general depth and textural characteristics by species and state. The segregation of soil characteristics by state illustrates a basic difference in interpretation concepts. The soils in Nevada and Utah are predominantly shallow or skeletal or both reflecting a droughty condition, low understory production and thus lower susceptibility to natural fire. Pinyon and juniper species are not generally considered to be part of the ecological potential of

Table 2.--Soil depth and textural characteristics, percent relative occurrence textural family groups: fi = fine; fi-lo = fine loamy; co-lo = coarse loamy

SPP	State	Shallow (< 20")	Mod. Deep or Deeper (> 20")	Ave. Percent Clay Low-High	Dominant Tex. Fam. Groups
JUDE2	NM	33 sk1/	8 sk	18-27	fi-lo
			59		
JUMO	NM	25 sk	48	16-27	co-lo &
		27			fi-lo
JUOC	NV	100 sk		18-27	fi-lo
JUOS	NV	43 sk	32 sk	17-27	co-lo &
		15	10		fi-lo
	UT	51 sk	6 sk	16-26	co-lo &
		40	3		fi-lo
	NM	20 sk	80	21-34	fi-lo
JUSC2	UT		100	23-35	fi-lo
	NM	100		31-47	fi-lo & fi
PIED	NV		67 sk	18-25	fi-lo
			33		
	UT	21 sk	16 sk	13-21	co-lo &
		54	9		fi-lo
	NM	20 sk	6 sk	16-27	co-lo &
		25	49		fi-lo
PIMO	NV	47 sk	21 sk	20-30	fi-lo
		10	22		
	UT		100 sk	15-23	co-lo &
					fi-lo2/

1/ skeletal (> 35% rock fragments)
2/ all occurrences were carbonatic

Table 3.--Surface horizon characteristics, percent relative occurrence

Textures (USDA Abbr.)	LFS,LS LVFS	SL,FSL SCL,VFSL	L SIL	CL SICL	C	Rock Fragments by Percent Volume			
Approx. percent Clay (C) or Sand (S)	>85%S	10-26%C >50%S	10-26% C	27-35% C	>35%C	0	15-35	35-60	>60
JUDE2	-	-	100	-	-		-	100	-
JUMO	8	24	46	15	-	44	38	17	1
JUOC	-	86	14	-	-	-	-	100	-
JUOS	-	19	58	16	7	7	53	34	6
JUSC2	-	42	58	-		-	17	83	-
PIED	2	35	53	4	-	3	38	45	14
PIMO	3	26	65	6	-	37	36	21	6

sites occurring on deeper, higher producing soils with vegetation susceptible to periodic natural wildfire. New Mexico, on the other hand, has recorded these tree species wherever they have been observed growing, thus indicating the adaptability of these species.

Surface horizon characteristics (table 3) indicate textures predominantly from sandy loams to clay loams with few sands or clays. With the exceptions of one-seed juniper and singleleaf pinyon, the surface horizons are predominantly gravelly (15-35 percent rock fragments) or very stony (35-60 percent rock fragments).

Soil Reaction (pH) and Salinity

Alligator juniper occurred on soils slightly to moderately alkaline. Rocky Mountain juniper occurred on soils slightly acid to slightly alkaline. The remainder of the species occurred on soils from slightly acid

to moderately alkaline based on the average low pH and average high pH for each species. When considering ± one standard deviation from the mean, singleleaf pinyon extended into the moderately acid range and Utah juniper and pinyon extended into the strongly alkaline range. The average high salinity values plus one standard deviation never exceeded 4 mmhos/cm for any species considered. This indicates that the soils are predominantly nonsaline.

DISCUSSION

The soil data analyzed document and substantiate, for the most part, the variability of soils within pinyon-juniper woodlands as discussed by others (Wright and others 1979). Distribution of pinyon-juniper ecosystems is apparently not limited by soil texture, stoniness or depth. Although generally neutral to moderately alkaline, the soils range from moderately acid to strongly alkaline. The soils are nonsaline.

The soil data base also suggests that the pinyon-juniper zone may be limited on the lower end of its elevational range by precipitation and on the higher end by temperature as summarized by Wright and others (1979). The lowest precipitation of associated range sites is the 8-12 inch zone. The relative occurrence of these species is marginal in the cryic temperature regime.

The range of soil and associated climate characteristics of pinyon-juniper species spans many more specific characteristics of associated plant species in the sagebrush communities (Miles and Leonard 1984) and apparently the mountain shrub communities and some blackbrush communities. In this light, the synecological relationships within specific plant associations or ecological sites are probably of more value in understanding the distribution and management implications associated with pinyon and juniper species than the autecological relationships discussed here.

Except for alligator juniper, a sprouting species, the pinyon-juniper species discussed are killed by fire. Where there is a high probability of accidental ignition by lightning and the production and structure characteristics of associated plant communities enable wildfire to carry, pinyon-juniper establishment was probably limited historically. Where production or community structure inhibit natural wildfire, pinyon-juniper overstories might reasonably be expected within the soil and climate limits discussed here.

The synecology vs. autecology concept as it relates to fire susceptibility may also account, at least to some degree, for the apparent regional differences between Utah-Nevada and New Mexico in determining the "potential" for pinyon and juniper species.

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SCS INVENTORY AND CLASSIFICATION PROCEDURES

Gary K. Brackley

ABSTRACT: Under the National Cooperative Soil Survey Program, Second and Third Order soil surveys are currently being accomplished on about 3.5 million acres of public and privately owned rangelands each year in Nevada. Units of vegetation (range and woodland sites) are correlated to soil taxa identified in these soil surveys. Sites are differentiated by their ability to produce a characteristic natural (climax) plant community. Edaphic, climatic, topographic and other environmental factors such as the potential for periodic wildfire occurring in a pristine situation are evaluated to determine the ability of a site to produce a given climax plant community. A review of the concepts, rationalizations, and assumptions used in classifying and correlating units of vegetation to soil taxa inventoried in Nevada is presented.

INTRODUCTION

In Nevada, the Soil Conservation Service (SCS) and Bureau of Land Management (BLM) are jointly involved in basic resource inventories of public (BLM) and privately owned lands. SCS soil scientists and range conservationists, in coordination with BLM specialists, are completing Order 2 and 3 soil surveys at the rate of about 3.5 million acres each year. To date, approximately 33 million acres or about 47 percent of Nevada's public (BLM) and non-Federal lands have been inventoried through this effort.

RANGE SITES AND WOODLAND SUITABILITY GROUPS

Soil taxonomic units identified in these soil surveys are correlated to range sites or woodland suitability groups where appropriate. Range sites and woodland suitability groups are the interpretive units into which rangeland and grazeable woodland (forested range) are separated for study, evaluation and management.

Range sites are ecological subdivisions of rangelands that are differentiated in terms of the climax (original or natural potential) plant community they are capable of supporting (SCS 1976). Application of the range site concept and climax vegetation provides a framework in which to measure plant community changes over time (Pendleton 1984). Recognition of the natural potential plant community for a site allows for the rating of ecological condition and provides a basis for determining trend and changes in range condition (Shiflet 1973; SCS 1976; Pendleton 1984).

Woodland suitability groups can be assigned to units of vegetation where the climax plant community is dominated by a tree overstory. In Nevada, woodland suitability groups are used as the capability or interpretive units for woodland. In these groups are one or more soils that are capable of producing similar kinds of wood crops that are of approximately the same productivity and that have similar management requirements (SCS 1976). The kinds and amounts of understory plants in woodlands are influenced by the same environmental factors that determine the climax vegetation described in a range site. Woodland understory is additionally directed by the density and height of the tree overstory canopy (SCS 1976). Woodland understory composition and production are highly responsive to the amount and duration of shade provided by the overstory canopy. With variation in tree overstory canopy cover, significant changes in understory floristics and production occur, usually regardless of the degree of grazing use (SCS 1976). Ecological condition is thus not meaningful regarding grazing values for woodland (Pendleton 1984).

Woodland suitability group descriptions developed by the SCS in Nevada account for the kinds and amounts of understory plants expected under different overstory canopy cover classes. A forage value rating is

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Gary K. Brackley is State Range Conservationist, Soil Conservation Service, U. S. Department of Agriculture, Reno, Nevada.

assigned to woodland understory plant communities based on the amount of preferred and desirable plants in relation to their grazing value for specific kinds of livestock and wildlife. A forage value rating is a utilitarian rating and as such is not an ecological evaluation of the understory plant community as is the range condition rating for rangeland (SCS 1976).

This distinction in the assessment of plant communities as to whether they are recognized as rangeland or woodland may appear as no more than a procedural aspect of the SCS inventory method: where environmental conditions favor the dominance of trees and wood production, woodland sites are identified and woodland interpretations are provided; on rangelands (where tree production is not significant), range sites are applicable and ecological interpretations are appropriate. The expansion of juniper and pinyon from original woodland communities into adjacent rangeland communities, however, has presented problems to those of us who are attempting to classify present vegetation in relation to the natural potential vegetation and correlate the presumed climax vegetation to specific environmental factors.

INVENTORY AND CLASSIFICATION OF JUNIPER/PINYON COMMUNITIES

Juniper and/or pinyon pine communities presently occupy over 11.5 million acres in Nevada, or about 17% of the Nevada landscape (Tueller and others 1979). Juniper and/or pinyon communities occur throughout most of Nevada but achieve their best development in or about mountain ranges lying in a broad, generally west to east belt transecting the central portion of the state.

In areas where juniper-pinyon communities occur, correlation of the presence of either of these genera to soil properties, climate or topographic position has been quite variable. Average annual precipitation over areas of juniper and/or pinyon occurrence ranges from 8 to over 20 inches (West and others 1975). Juniper and/or pinyon are found at elevations from about 4,500 feet to near 9,000 feet in Nevada. Wright and others (1979) state that the general occurrence of juniper-pinyon communities is not limited by parent material, soil texture or soil pH. Studies of juniper dominated communities found soils of these sites to vary from deep alluvium to shallow, residual soils (Barney and Frischknecht 1974). West and others (1975) noted that the soils of juniper-pinyon communities vary greatly although they are basically related to climatic patterns. Tueller and others (1979) found juniper-pinyon communities restricted to north aspects in the south part of the Great Basin and equally restricted to south exposures in the northern portions of the Basin. This distribution is acknowledged as more a reflection of the ecological limits of the juniper-pinyon type (Everett 1985) than evidence of a general topographic relationship of the type.

Unlike plant communities in the grass-sagebrush type whose occurrence are considered to be largely controlled by a combination of edaphic, climatic and topographic factors (Hironaka 1979; Young and others 1984) the presence of pinyon and especially juniper is not easily related to these factors alone. In the absence of natural disturbances, juniper and pinyon will obtain wherever their moisture and temperature requirements are met. These conifers have been appropriately described as "climatic-climax dominants" (West and others 1975).

As climatic-climax dominants, the occurrence of these trees on a wide range of soils and landscapes is expected, and much of the uncertainty in the soil-vegetation correlation of juniper-pinyon communities is explained. This uncertainty in predicting the presence of juniper and pinyon based on soils and landscape features is contrary to the expected confidence in predicting plant community occurrence in other major vegetation types.

In assessing the climax vegetation best adapted to a site, such natural disturbances as drought, wildfires, and grazing of native fauna are recognized as inherent in the development and maintenance of the original plant community (SCS 1976). Plant communities that are protected from these natural influences for long periods do not always typify the climax plant communities (SCS 1976). The climax plant community, as interpreted by the SCS, is not a stagnated end point or impoverished terminal plant community that is achieved as a result of overprotection (Barrett 1984).

Many range ecologists have recognized that temporary instabilities are natural factors affecting long-term plant community maintenance. The controlling influences of wildfire, drought and competition with grasslands in the distribution of juniper and/or pinyon in pristine environments have been acknowledged (Johnsen 1962; Holling 1973; Barney and Frischknecht 1974; Burkhardt and Tisdale 1976; Tausch and Tueller 1977; West and others 1975; Wright and others 1979; Young and Evans 1981). Drought and competition operate primarily in slowing

the invasion of juniper and pinyon into adjacent grass-shrub communities (Wright and others 1979).

The SCS in Nevada recognizes wildfire as a natural disturbance occurring within the pristine environment that strongly influenced the composition and extent of many rangeland and woodland communities. Woodland and rangeland that supported continuous fuels are perceived as being periodically swept by fire. Settlement has reduced the incidence and size of wildfires through fire suppression and the disruption of fine fuel continuity by livestock grazing (Gruell 1983). With changes in the extent and frequency of natural fire, significant changes in the character of juniper and/or pinyon woodlands and associated rangelands have occurred. Rangelands adjacent to original habitats of juniper and/or pinyon have been invaded by both species, especially juniper. In many instances this expansion has resulted in closed stands of these conifers occurring on soil taxa that have elsewhere been correlated to grass-shrub climax plant communities. These extensive successional changes would have been unlikely in the pristine environment where fire suppressed woody vegetation (Wright and others 1973; Wright and others 1979; Gruell 1983).

When the role of fire is accepted as a controlling factor in the distibution of juniper-pinyon woodlands, these woodland types will be expected to occur in areas where soil and landscape features preclude frequently recurring wildfire. Within a fire-limited distribution of juniper-pinyon woodlands, soil-vegetation correlation is more certain.

For many areas of juniper-pinyon, the distinction between woodland and adjacent range sites is quite subtle. Often the break between rangeland and woodland is a subjective determination. Such a basis for separation of woodland sites and range sites is not necessarily improper, considering that the concepts of woodland site and range site are themselves subjective. Although there is need for judgment on the part of observers, reasonably valid ecologic criteria should be recognized in defining woodland communities and range sites.

Soil-vegetation correlations made in areas of juniper and/or pinyon have often been more an assessment of the management implications presented by these trees occupying a given landscape than an evaluation of natural environmental factors. It is important that inventory specialists do not allow their personal biases and individual management interpretations to override the inventory requirement of classifying units of vegetation in terms of the natural potential vegetation.

Guidelines for use by SCS personnel in Nevada have been established to assist in separating range sites that may support a low density of juniper and/or pinyon in the climax from juniper-pinyon woodlands. A 10 percent or greater tree canopy of "mature potential" juniper and/or pinyon trees is cited as being reflective of a woodland site. Using these criteria, a "mature potential" tree is defined as a presently existing tree that was established under pristine environmental conditions. In order for a tree to be considered as "mature potential" it must be at least 150 years of age. Where the canopy of "mature potential" trees is less than 10 percent and site characteristics would not appear to limit frequently recurring fire, a range site is usually recognized. Obviously these criteria have limitations in that they have application only where "mature potential" trees have not been harvested or otherwise removed from a site.

There are many examples of range sites that, over their area of occurrence, can be found in association with juniper and/or pinyon woodland. Where these sites occur adjacent to juniper-pinyon woodland, the pinyon and particularly juniper, readily invade these (elsewhere) non-wooded plant communites. Although natural fire is recognized as setting the woodland/range site ecotone it is not reasonable to suggest that fire claimed every juniper or pinyon tree that invaded into adjacent rangeland communities. It is reasonable to suggest, however, that on a large scale, natural fire maintained a mosaic of successional stages over the woodland-associated range sites. Within the fire-maintained mosaic, a few juniper and/or pinyon trees, usually clustered, may very well have been a part of some rangeland climax plant communities.

Range sites that commonly occur in association with juniper-pinyon woodlands can be expected to frequently support a very sparse canopy of trees that have escaped past wildfires. The presence of these trees is accounted for in the range site description as a range in percent composition of the total annual production. Range sites commonly associated with areas of extensive woodland are generally relatively productive and the few trees recognized as part of the climax plant community represent only a minor component of the total plant community annual production.

In differentiating between woodland and range sites in vegetation classification,

the potential for wood production on invaded range sites should not be ignored. Merely because a site is recognized as supporting a grass-shrub climax community in a pristine environment does not preclude the need to evaluate the site's ability to produce wood crops. Such evaluations are necessary where juniper-pinyon invasion into the site is common under present-day management. As part of the interpretations provided with descriptions of woodland associated range sites, the relative productivity of wood products should be presented in terms of site index, growth and other parameters for given stages of tree invasion into the site.

CONCLUSION

The climax concept employed by the SCS as a unit of land inventory has been aptly characterized as a notion that can "enrage the meekest of hearts and stir heated debate in the friendliest of groups" (Barrett 1984). Much debate can be avoided, or at least focused, when definitions of climax are provided and supporting rationalizations are presented.

The climax plant communities described by SCS range sites and woodland suitability groups reflect the influence of natural perturbations that occur within a pristine environment. Natural distrubances such as periodic wildfire are considered inherent in the development and maintenance of these climax communities.

In the absence of natural wildfire, juniper and pinyon have increased in original juniper-pinyon woodlands while juniper and pinyon have encroached into adjacent grass-shrub rangelands. These successional changes have developed to the point where the distinction between woodland communities and grass-shrub rangelands in many areas is obscured under a closed canopy of juniper and/or pinyon.

In Nevada, soil-site correlations made in separating rangelands, juniper-pinyon invaded rangelands and juniper-pinyon woodlands are evaluated within a fire-limited distribution of the juniper-pinyon type. In areas of woodland/rangeland transition, woodland sites are recognized where it is determined that a ten percent or greater canopy cover of juniper or pinyon is to be expected in the climax community. In these transitional areas, woodland suitability groups are assigned to sites where soil and landscape features preclude frequently recurring wildfire. Range sites are identified where it is reasoned that site productivity and landscape position are such that natural wildfire would have maintained a grass-shrub community in the pristine environment.

Dr. Heady (1984), limiting his remarks to the range site concept of the SCS inventory method, has made the following observations which have general applicability to SCS woodland classification:

1. It is impossible to prove "climax" except by one's own definition;

2. The purpose of range sites and condition is to provide an inventory for land management and not to prove succession and climax;

3. The land must be inventoried and managed and range site is an adequate concept for that purpose; and,

4. No better scheme has come along and until one does, range sites, condition and trend are the most workable concepts available.

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REMOTE SENSING APPLICATIONS FOR THE PINYON-JUNIPER WOODLAND

Paul T. Tueller

ABSTRACT: The pinyon-juniper woodland resource in the western United States can best be managed if suitable techniques are available for inventory and monitoring. Remote sensing procedures offer considerable potential for these applications. The pinyon-juniper woodland in the Great Basin was mapped from Landsat color composites. Low-elevation woodland boundaries were easily mapped on any imagery while winter scenes were required before upper ecotones could be mapped. Continuous areas of pinyon-juniper were mapped with tree densities as low as 41 trees/ha while isolated stands as small as 25 ha required at least 73 trees/ha. Large-scale imagery (1:1000 or larger) has proven successful for tree inventories, erosion evaluations, etc. Now there are many newer systems that await evaluation for use in the pinyon-juniper woodland. These include the Thematic Mapper, SPOT, AIS and radar systems. Computer assisted mapping techniques will become commonplace as we learn more about basic radiometric characteristics of the integrated pinyon-juniper pixels.

INTRODUCTION

Those who would successfully manage our renewable resources require management oriented information. The pinyon-juniper woodland is similar to many other vegetation resources in that it is subject to change. These changes are the result of management, of long-term vegetation succession, or are the result of catastrophic events that produce changes in a very short time. Managers often lack information about changes upon which they can, with reasonable confidence, base management decisions. In past, this information has been derived from either sporadic or intensive but costly field sampling procedures. In this age of intense information acquisition and transfer there is still a need for more accurate low-cost approaches to data acquisition, storage, and retrieval questions. Remote sensing based on computer technology offers a potentially strong data base from which to work.

By now it is well established that about 11 species of pinyon and nine species of juniper trees dominate woodlands covering some 325,000 km^2 (60 million acres) (West 1983) in semi arid regions of the western United States. These woodlands constitute a widely distributed resource with values for which use and management ought to be wisely accomplished. This forest resource generally is of low value when compared to many other forest types. Low value usually means that funding available for management is also low. Therefore it becomes logical to suggest that remote sensing technology should be evaluated as a possible approach to low-cost, effective data gathering to obtain the information potentially useful to woodland managers.

In this paper I have briefly described some of the management requirements in the pinyon-juniper woodland and have discussed one or more approaches for the application of remote sensing to these information requirements. In some cases I will refer to actual data that I have acquired and in other cases to procedures successfully used by others and described in the literature. Of necessity, one or more of the scenarios will be future oriented. Remote sensing technology is expanding very rapidly. The science of remote sensing is barely 25 years old and is now growing extremely rapidly. I would guess that our wildest yet reasonable suggestions for remote sensing applications over the next 40 or 50 years will, within 20 years, be woefully lacking.

PINYON-JUNIPER MANAGEMENT REQUIREMENTS

In this symposium many others will discuss the biology and ecology of the woodland. Others with considerable management experience will describe the best management. I propose that management information needs fall into a few general categories:

1. Mapping the distribution of the woodland.
2. Woodland productivity and biomass levels.
3. Vegetation cover, density, and species composition.
4. Watershed information including erosion evaluations, soil stability, litter accumulation, bare soil, and related factors.
5. Harvesting data required for logging, firewood harvest, fence posts, Christmas tree sales, pine nut management, etc.

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Paul T. Tueller is Professor of Range Ecology, Department of Range, Wildlife and Forestry, University of Nevada, Reno 98512.

6. Perturbations affecting any of the above, for example, fire, flooding, mass wasting, trampling destruction of seedlings, and insect or pathogen infestations.

7. Livestock and wildlife activity in the woodland, for example, heavy browsing with highlining, trail development sometimes leading to accelerated erosion, rodent activity, and species composition changes in disturbed areas.

These categories may not include all conceivable management information requirements but they do represent information types potentially addressable to remote sensing technology.

REMOTE SENSING TECHNIQUES APPLICABLE TO THE PINYON-JUNIPER WOODLAND

By remote sensing we are talking about the several procedures that collectively refer to the acquiring of information about objects or phenomena without being in direct physical contact. These procedures take many forms as we capitalize on the electromagnetic energy emitted or reflected by various landscape features, in this case within the pinyon-juniper woodland. The various levels of electromagnetic energy are sensed by various kinds of instruments depending on the wavelengths of the energy.

For example, aerial cameras and film emulsions allow us to capture energy in the visible and near infrared part of the spectrum. Scanning devices filtered in various ways provide information not only in the visible but in the near, mid and thermal infrared. Radar systems acquire data in the active microwave portion of the spectrum potentially useful for monitoring soil moisture and vegetation structure. Video cameras now being flown with spectral sensitivities in the visible and near infrared part of the spectrum and are being used to acquire near realtime remotely sensed data over field locations. Even longer wavelengths (radio waves) can be used to telemeter information for parameters of interest to a central data collection site on an hourly basis if necessary, although this degree of temporal sampling is somewhat difficult to envisage in the pinyon-juniper woodlands.

Each digital-based remote sensing system has an instantaneous field of view that determines the size of individual picture elements (pixels) that are separately evaluated during digital analysis of a scene. The brightness levels for each band pass (table 1) or individual spectral channels are each separately evaluated pixel by pixel. The individual spectral responses collectively constitute a spectral signature. Signatures of various kinds are compared and studied for their information content. For example, TM bands 5 and 7 are in the mid-infrared water absorption region of the spectrum and may serve to measure moisture content in the vegetation.

Before many of the other potential management applications can be realized, additional research much be accomplished in order to understand the spectral characteristics of the integrated pixels from the systems now being flown. Analysis and interpretation of individual spectra from a scene indicate that pixels from aircraft or spacecraft form a composite of vegetation, soil, and other elements in the scene that are difficult to measure (shadow, litter, etc.). Procedures have been developed to use individual ground-based spectra and simultaneous equations to predict the components in the integrated pixel.

Table 1.--Comparison of the Landsat Thematic Mapper and Multispectral Scanner

	Thematic Mapping (TM)		Multispectral Scanning (MSS)	
Spectral Resolution	Band number	Bandwidth (micro-meters)	Band number	Bandwidth (micro-meters)
	1	0.45 - 0.52	1	0.5 - 0.6
	2	0.53 - 0.61	2	0.6 - 0.7
	3	0.62 - 0.69	3	0.7 - 0.8
	4	0.78 - 0.91	4	0.8 - 1.1
	5	1.57 - 1.78		
	6	10.42 - 11.66		
	7	2.08 - 2.35		
Ground Instantaneous Field-of-View	30 meters (bands 1-5 & 7) 120 meters (band 6)		83 meters (bands 1-4)	

One approach to pixel analysis is the use of various vegetation indices or greenness measures. These fall into two general categories (Huete and others 1985), the ratio indices and the orthogonal indices. The former are what are generally referred to as the red-infrared ratios, the near-infrared to red ratio (NIR/red), normalized difference (NIR - red)/(NIR + red), and the transformed normalized difference (NIR - red)/(NIR + red) + 0.5)$^{\frac{1}{2}}$ are the common of the ratio transformations used. The orthogonal transformations include the two-dimensional Perpendicular Vegetation Index (PVI) of Richardson and Wiegand (1977) and the so-called Tasseled Cap Transformation or four-dimensional green vegetation index (GVI) of Kauth and Thomas (1976). Various vegetation indices along with the soil line index (SLI) of Wiegand and Richardson (1982) can be used to study the spectral characteristics of scene components. Our recent work on shrub-dominated rangelands show that the PVI departures from an established soil line are indicative of relative amounts of green vegetation (Wilson 1985).

These various indices offer potential for sensing scene parameters that will either directly or indirectly measure such woodland characteristics as productivity, biomass levels, vegetation cover, density and frequency, good seed years, and vegetation damage. This information must be correlated with certain kinds of ground data and/or data from large-scale aerial photographs. Then the result can be extrapolated to large land areas using the sampling efficiencies inherent in a multistage sampling approach (Heller 1978). The result of which is considerable savings by substituting costly field time for office and computer time.

What of other new remote sensing tools? The first of a new class of remote sensing instruments is the Airborne Imaging Spectrometer (AIS). This is a very specialized instrument capable of imaging 32 cross-track pixels simultaneously, each in 128 spectral bands in the 1.2 to 2.4 um region (Vane and others 1984). Such instrumentation allows the obtaining of almost a continuous spectrum for a site taken from an aircraft or spacecraft. Then, as more is learned about the spectral characteristics of the scene components it will be possible to extract the spectral information of interest to the resource manager. This, of course, will require high-speed digital computer capability with considerable data storage potential.

Microwave systems have a place in pinyon-juniper remote sensing from two viewpoints. First would be to use radar signals with specified look directions, angles of incidence, polarization, and frequency to study the structure of the vegetation. Second, the results of recent radar research indicate the effective depth influencing the radar backscatter in the soil varies between the top 5 and 15 cm of the soil. This has some obvious potential for following soil moisture changes using remote sensing (NASA 1989).

Yet another form of remote sensing is being tested on rangelands and for vegetation applications. Video infrared cameras with sensitivity in the visible and near-infrared offer potential to obtain near real-time data concerning several vegetation parameters, particularly plant stress (Everitt and Nixon 1985). While the resolution has been relatively poor some of the newer cameras offer considerably improved resolution. Video systems offer the manager the opportunity to examine a landscape in detail only minutes after the aircraft lands.

In summary, remote sensing types useful for the pinyon-juniper woodland consist of the following general categories: 1) aerial photography with a spectral range in the visible and near-infrared obtained in various formats and at various scales; 2) multispectral scanning with a spectral range including the visible, the near-infrared, the mid-infrared, and the thermal-infrared, the latter for heat sensing; 3) microwave sensors--primarily active systems (radar) with various angles of incidence look directions, polarizations, and wave lengths; 4) video cameras for near real-time remote sensing in visible and near-infrared wavelengths.

REMOTE SENSING APPLICATIONS

What then are some of the remote sensing studies that have been accomplished in the pinyon-juniper woodland? There are several. It is clear that the first serious application attempts were to map the woodland. There seems to be considerable feasibility to do this particularly with intermediate scale aerial photography. Scales between 1:10,000 and 1:30,000 would be optimum although some mapping could be accomplished on 1:60,000 and smaller scales. The 80m resolution of Landsats 1, 2, and 3 is not sufficient for accurate mapping of the type. This is particularly true if one is interested in obtaining data on tree density and species compositions, for example, are the stands pure pinyon, pure juniper, or mixed, and in what proportion? A 1:30,000 scale or larger would be required for tree species composition determinations. It is hoped that the higher resolution of the Thematic Mapper (30m) and other satellite systems such as SPOT (10m) will lead to accurate mapping of this resource. However, it should be remembered that intermediate and large scale aerial photography offer perhaps the most suitable and high-quality remote sensing medium for pinyon-juniper mapping needs.

Our early mapping of pinyon-juniper woodland on Landsat images resulted in relative poor classification accuracy (45 percent). However, it was quickly learned that this accuracy level could be elevated by looking at winter scenes (Halvorson 1974). In summer, the upper or high ecotone between the woodland and other mountain brush and high-elevation vegetation types was obscured. However, in the winter we were able

Table 2.--Success of identifying the pinyon/juniper-northern desert shrub ecotones in the Great Basin

Imagery	Percent Success[1]	Percent Close[2]	Percent Failure[3]	Total No. Evaluated
Landsat-1 Fall	39.4	45.5	15.1	33
Landsat-1 Fall (Color IR)	81.8	9.1	9.1	11
Landsat-1 Winter[4]	54.5	33.3	12.0	33
RB57F (1:110,000)	100.0	0.0	0.0	33
Total (ex. RB57F)	51.9	35.1	13.0	77

[1]the ecotone was correctly identified
[2]the ecotone was identified but differed somewhat in true location
[3]the ecotone was identified
[4]Winter scenes allowed 90 percent or better identification of ecotones at the upper elevational distribution of the pinyon-juniper

to map both the upper and lower boundaries of the woodland because the woodland was reflective in the infrared during the entire winter when compared with the other high-elevation deciduous vegetation types (Beeson 1974; Tueller and others 1979) (table 2.) With the photo interpretation of Landsat color infrared composites we found that less than 5 percent of the boundary locations were delineated incorrectly from Landsat-1 imagery. If areas of pinyon-juniper were continuous, densities as low as 41 trees per hectare were visible on this imagery with 80m resolution. Areas of pinyon-juniper as small as 25 ha were identifiable if there were at least 73 trees per hectare. Discontinuous areas of pinyon-juniper on complex landscapes could be identified only when tree density exceeded 18 trees/ha (Beeson 1974).

A more recent attempt to map pinyon-juniper woodland in western nevada pointed out similar problems in using Landsat digital data. The complex pixels tended to prevent accurate classification of the woodland types because of confusion with other forest types having similar spectral characteristics (Brass and others 1983). A study with early space imagery in Arizona showed confusion between pinyon-juniper woodland and open yellow pine forest (Sapp and others 1970). Mouat and Johnson (1978) also used Landsat digital data to map pinyon-juniper woodland in the Grand Canyon National Park.

Meeuwig and others (1979) suggested the use of 1:5,000 scale photographs to identify and measure pinyon and juniper. Regression equations were developed for estimating mass of various fuel components per unit crown area for both species with data derived from aerial photography. Techniques were described for using their equations for estimating fuel loading, fuelwood volumes, and potential slash production from aerial photographs.

Juniper density classes (2-20 percent, 10-30 percent and 30-50 percent) were used to evaluate Landsat-1 digital data (Daus and Senkus 1976). Sensitivity for the presence of juniper was not attained until relative cover percentages of 30 percent or greater were reached. The application of an option developed for use with a maximum likelihood classifier allowed a layered classification approach which gave an 89 percent reduction in the area considered during the second classification layer, significantly lowing classification procedure costs.

In 1970, Lorain completed studies on the use of large-scale color and color infrared photography for identifying and measuring individual pinyon and juniper plants in eastern Nevada. Both species were identified with relative ease (table 3). Textural differences are very apparent when interpreting these two species. Color differences on the infrared were also very different. At the same time we were able to count plant density not only for the pinyon and juniper, but for understory shrub species. Also, we were able to evaluate surface soil characteristics. Driscoll and Reppert (1968) also used 1:600 and 1:2400 color and color infrared photography to make similar measurements in the pinyon and juniper woodlands.

Table 3.--Correlation coefficients between photographic and ground measurements of pinyon and juniper trees for two film types and scales. Number of plants measured and their average size is given

Species	No. of Plants	Scale	Film Type	Size Range	Ave. Size	Corr. coeff.
Pimo/Juos	50	1:174	Infrared Prints	8" X 8" to 198" X 210"	38" X 46"	.9971
Pimo/Juos	50	1:750	Infrared Transparencies	8" X 8" to 198" X 210"	38" X 46"	.9953
Pimo/Juos	42	1:174	Infrared Prints	8" X 8" to 198" X 210"	38" X 46"	.9939
Pimo/Juos	42	1:750	Infrared Transparencies	8" X 8" to 198" X 210"	38" X 46"	.9963

Presently there seems to be little data nor a good understanding of the spectral characteristics of the pinyon-juniper woodland. One exception is the work of Dr. Ronald J. P. Lyon and his students at Stanford University who have acquired considerable spectral data for pinyon-juniper woodlands in western Nevada (Lyon 1985; Eaton and Lyon 1978; Elvidge and Lyon 1985). For example, the spectral characteristics of a molybdenum-bearing skarn in the Pine Nut Mountains of western Nevada were studied. Molybdenum and copper concentrations in the soil and vegetation were significantly higher within a spectrally anomalous area of pinyon and juniper. Landsat channel 7/channel 5 radiance ratios were correctly predicted to be higher in the anomalous region that outside the anomaly, especially during the summer months.

Milton (1978) obtained individual spectra with a Portable field Reflectance Spectrometer for both Pinus monophylla and Juniperus osteosperma in Utah. The spectra appear to represent typical green vegetation responses in the visible and near-infrared part of the spectrum. The green reflectance region in the visible part of the spectrum is noticeably depressed for the juniper. While the spectra of individual plants is important to know, most sensors look at much larger pixels than would be represented by a single plant. We must learn how to interpret the specral response of these integrated pixels.

A LOOK TO THE FUTURE

It is reasonable to expect greater utilization of remotely sensed data for the management of renewable resources in future. This seems to be assured. The form that the remote sensing will take is not completely clear. Continued use of aerial photography is assured. However, will aerial video cameras provide data of quality similar to emulsion based film and if so, how long will it be before the data stored on magnetic tapes will supplant the storage of film?

How soon will we known enough about the spectral characteristics of scene components so that it will be possible to analyze a woodland on demand in order to obtain data required for management decisions? In other words, how soon will it become commonplace and routine? Probably not for a while but it will surely come. Last year President Reagan announced that the design and development of a space station will proceed. Such space stations will eventually become permanent observation platforms in space. Observations will be made to understand the dynamic physical, chemical, and biogeochemical processes on the earth and to make this information readily available to managers back on the earth (Frost and McDonald 1984). One can easily visualize the manager of a stand of pinyon-juniper requesting certain kinds of information from scientists manning the space station and getting data in a matter of hours upon which a management decision can be based.

A future manager of pinyon-juniper woodlands might well receive over 75 percent of the information required for management from a series of sensors carried on board either an orbiting satellite or space station. This might be supplemented with data obtained periodically from a multispectral video system aboard an aircraft flown at various altitudes. The manager could, for example, interrogate his "on-line" computer terminal to extract information from the multispectral scanner on the space station. The manager may have already contracted to have the space station scientists turn on and point the scanner at the scene within designated coordinates on a prescribed periodic basis. The data he or she examines may indicate those sites with a high probability of a good seed or nut crop, areas with high proportions of young maturity classes for Christmas trees, and the location of stands dense enough with older maturity classes to provide sites appropriate for harvesting fence posts. The manager might dispatch the aircraft-borne infrared video systems to acquire information on the influence of a reported infestation of mistletoe in a pinyon stand or the

result of a wildfire. The scenes change and the examples could go on but the ideas are set and the potentials are real. The manager must orchestrate the costly ground data acquisition with the objectives of management and the potential use of the remotely sensed data.

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Silvics and Silviculture

Chaired by:

Milo J. Larson, Group Leader, Silviculture and Inventory, Southwestern Region, Forest Service, Albuquerque, NM

PINYON-JUNIPER SILVICS AND SILVICULTURE

Jerry D. Budy and Richard O. Meeuwig

ABSTRACT: The pinyon-juniper type, being more xeric than any other timber type in the United States, has unique silvical characteristics. The demand for products other than wood, particularly forage for livestock and wildlife habitat, may provide an opportunity to practice multiple-use silviculture. The development of efficient and appropriate silviculture systems is being facilitated by the increased research conducted in the pinyon-juniper type during the past 10 years.

INTRODUCTION

The pinyon-juniper woodland type covers more than 50 million acres in the western United States, mostly in Nevada, Utah, Arizona, New Mexico, Colorado, and California. The type occurs on foothills, mountain slopes, mesas, and plateaus at elevations generally ranging from 4,500 to 8,000 feet. Soils are derived from a wide variety of parent materials and are typically well drained.

Pinyon-juniper woodlands provide a variety of products. Pinyon nuts were a major food source for Indians for many centuries and are still harvested extensively (Lanner 1981). Throughout the Southwest pinyon-juniper woodlands have been major sources of fuelwood, fenceposts, and Christmas trees. The woodlands supplied most of the charcoal and fuelwood for the booming mining industry in the Great Basin during the latter half of the 19th century (Young and Budy 1979). Vast areas were clearcut near mining towns and other settlements. Throughout the rest of the woodlands most stands have been high-graded, leaving residual stands of inferior species and poorly formed trees.

After the turn of the century and until the energy crisis of the early 1970's, the availability of cheap fossil fuel reduced the demand for fuelwood from pinyon-juniper woodlands. The woodlands recovered as tree harvesting declined. Juniper and pinyon reoccupied most of the clearcut areas and, because of fire control during this time, moved into adjacent plant communities where recurring fires have previously excluded them.

Since the mid-1970's, the rapidly rising costs of fossil fuels have caused resumption of fuelwood cutting in the woodlands. The unexpected increase in demand for fuelwood has already created shortages around several urban areas (Gray and others 1982) and future demands may exceed production over most of the pinyon-juniper type.

The woodlands have been grazed by livestock for more than 100 years and some parts around the old Spanish settlements in New Mexico have been grazed for as long as 400 years. All too often, grazing was continuous and excessive, resulting in deteriorated range conditions (Springfield 1976). Grazing on most pinyon-juniper ranges has been brought under management in the past 70 years, but recovery of the range has been slow. The forage resource has declined drastically as trees reoccupied cutover areas and moved into adjacent fire subclimax shrub/grass communities.

In the past 35 years, extensive areas of pinyon-juniper have been cleared, usually by chaining, to increase forage production for livestock and big game. Some of these conversion projects were successful, but many others failed to increase carrying capacity for more than a few years and the treated areas have been reoccupied by young juniper and pinyon trees.

As a result of past use, the pinyon-juniper woodlands of today consist mainly of four general types of stands (Meeuwig 1984):

1. A few virgin stands in remote areas or on poor sites.
2. Old high-graded stands containing various proportions of old poorly formed trees -- trees up to 200 years old that were too small to cut when the stands were harvested in the 19th century, and trees less than 100 years old that came in after harvest.
3. Young stands that have reoccupied areas where virtually all tress have been eliminated either by clearcutting or type conversion efforts.

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Jerry D. Budy is Assistant Professor of Forestry, Department of Range, Wildlife & Forestry, University of Nevada-Reno, Reno, NV 89557; and Richard O. Meeuwig is Retired, Intermountain Research Station, Forest Service, U.S. Department of Agriculture.

4. Young stands that invaded adjacent communities because of fire protection.

The future pinyon-juniper woodlands will be largely affected by the current management objectives, just as the present woodlands are largely the result of past use.

MANAGEMENT OBJECTIVES

The management objectives depend upon the owner, public or private, of the forest and/or woodland. Since much of the pinyon-juniper woodlands fall under Federal ownership, the multiple-use objectives used for the National Forests are usually applied. The five multiple-use objectives include:

1. Timber production
2. Forage production
3. Wildlife habitat
4. Watershed protection
5. Recreation

Timber production is often the dominant use on commercial forestlands because of the economics involved. However, in pinyon-juniper woodlands the terminology does not even apply. The size, form, and growth rate of pinyon-juniper trees are such that the harvested trees do not qualify as industrial roundwood. Also, pinyon-juniper productivity is less than 20 cu.ft. per acre per year and, thus, the pinyon-juniper is classified as non-commercial forestland and commonly referred to as woodland. Fuelwood production, wood fiber production, or simply wood production best describes the objective in pinyon-juniper woodlands.

Since wood production is relatively slow in the pinyon-juniper woodlands and wood product values are relatively low, management using multiple-use objectives may be easier to accomplish than on commercial forestlands. The concept of multiple use has been in effect on National Forests for a long time. Timber production has always, or at least up to 1960, been the dominant use because of the economics involved. However, wood production is not always the dominant management objective in pinyon-juniper woodlands. Forage production has often been the dominant use in pinyon-juniper woodlands. However, the future management of pinyon-juniper woodlands may best be accomplished by using multiple use objectives rather than a dominant use.

MANAGEMENT ALTERNATIVES

Alternatives for managing pinyon-juniper woodlands include (Meeuwig 1984):

1. Type conversion for wildlife habitat or forage production;
2. Sustained yield management for wood production and other woodland products;
3. Custodial management where neither of the other management alternatives is cost effective.

Type Conversion

Type conversion involves destruction of unwanted dominant species to improve forage production either by seeding wanted species or by releasing suppressed preferred species (Everett and Sharrow 1985).

Chaining is the most commonly used method of type conversion. Seeding is almost always necessary in chaining projects. If the understory is good enough to respond adequately to tree removal, the trees are probably small or widely scattered and could be removed more cheaply by some other method. Chaining uproots and kills the larger trees but the smaller trees, particularly the junipers, usually survive. These survivors should be eliminated in some way for an efficient conversion. If they are left in place they will outcompete the forage species and form the nucleus of a new pinyon-juniper stand.

Prescribed burning is most effective in open stands that still have enough understory to carry fire, especially where the understory is dominated by grasses rather than shrubs. Prescribed burning may be used as a follow-up treatment on chained areas to eliminate debris and to kill the surviving trees. Such areas may respond best if burned several years after chaining when the seeded grasses are well established.

In scattered stands of small trees (old burns, old chained areas, other treated areas, and invasion areas), individual trees may be killed by burning when the fire danger is low, by herbicides applied by hand (Evans and others 1975), or by cutting with an axe or lopping tool. This type of treatment would retard the invasion and domination processes with little damage to the understory. As tree size and density increase, some other method such as broadcast burning might be more cost effective.

Of course, a careful economic analysis of costs and benefits should be made before any conversion project is undertaken. As much as possible, all costs and all benefits should be considered. Management decisions for each stand should be based on present and future resource demands, present vegetation and site characteristics, loss of wood production, probability of successful conversion, costs of conversion and

maintenance, and probable value and characteristics of the converted stand.

Sustained Yield

Pinyon-juniper woodlands have not been managed in accordance with silvicultural principles, except in a few isolated instances. Only 20 years ago, hardly anyone suspected that the demand for fuelwood would be as great as it is today. The wood resource was not considered to be worth very much and was often considered a liability. The type conversion activities of the past 30 years or so have destroyed a significant part of the fuelwood supply in many localities. Of course, much of the wood was salvaged on the conversion areas but most of these areas, even those where the conversion efforts failed, will not regain their fuelwood productivity for many decades.

The demand for pinyon-juniper fuelwood will probably continue to increase. Generally speaking, any pinyon-juniper woodland that is presently being harvested for fuelwood can be expected to become more valuable as a fuelwood source in the future and should be placed under a management system designed to provide fuelwood on a continuing basis at or near the maximum rate that the site is capable of producing.

For the most part, it is the old high-graded stands that contain enough fuelwood for economic harvest at present. These stands often contain old poorly formed trees and a disproportionally high percentage of juniper. Cutting systems for these stands should be designed to improve treeform and species composition and to maintain adequate growing stock. In most cases, the individual tree selection harvesting method should be used to maintain fuelwood productivity. Stand basal area should not be reduced below 40 ft^2/acre and spacing between leave trees should not exceed 30 feet to avoid reduction of future fuelwood yields. If the best nut-producing pinyons are left uncut, the long-term yields of nuts would be increased.

Harvesting operations should be carefully managed to minimize damage to residual vegetation, including advanced reproduction and shrubs. Slash burning should be limited to that needed to reduce fire hazards to acceptable levels. Slash burning damages residual vegetation and results in loss of nitrogen and other nutrients. Lopped and scattered slash provides partial shade for seedlings, reduces soil erosion, and gradually returns nutrients to the soil.

Christmas tree cutting should be confined to younger stands that have reoccupied old burns and other cleared areas. If Christmas trees are harvested in woodlands that are being managed for wood production, such harvesting should be closely supervised to avoid cutting trees that should be left to produce wood.

Custodial Management

Product values are presently so low throughout most of the pinyon-juniper type that intensive management is not practical for either wood or forage production. The bulk of pinyon-juniper woodlands are presently under custodial management and most are likely to remain so for a long time because slopes are too steep or productivity is too low to justify intensive management. Under custodial management with fire protection, forage for livestock and wildlife would continue to decline but most other values including fuelwood and nut production, watershed stability, recreation, and esthetics would remain constant or improve. Wood production on many sites could be expected to continue until enough volume accumulates to make sustained-yield management feasible.

Most pinyon-juniper woodlands have been protected from fire for more than 60 years. A managed fire policy is an alternative worth considering because fire control is expensive and because recurring fires were probably quite common in pinyon-juniper woodlands and are a natural part of the ecosystem. If fires started naturally were allowed to burn in appropriate stands under planned conditions, we might expect increased forage for livestock and improved habitat for some wildlife species. However, a great deal of care should be exercised in selecting locations where fire management areas are established. Many areas have not burned for so long they will not respond favorably to fire because many desirable species have been eliminated from the stand and soil seed reserves are depleted. Such areas would definitely require reseeding after fire, which could cost more in relation to net benefits obtained than continuous fire protection would have cost.

MANAGEMENT VS. SILVICULTURE

Most of the pinyon-juniper woodlands are probably being managed using one of the three management alternatives discussed previously. The main question is--are we practicing silviculture in the pinyon-juniper woodlands? The answer can be yes or no depending upon the management alternative. Since the main intent of type conversion management is to eliminate the trees, it is obviously not silviculture. Custodial management does not really qualify as silviculture either. Sustained-yield management for wood production can be considered an extensive type of silviculture because there is, at least, the intent to keep trees on the site. Simply stated, silviculture is growing trees and the sustained-yield management alternative does imply this.

Before going any further, the differences between management and silviculture should be noted. Management is the manipulation of a

forest, whereas, silviculture is the manipulation of a stand. The working unit in silviculture is the stand, whereas, forest management requires many stands. Management is the regulation and administration of a forest property to attain certain objectives. Silviculture is the tending, harvesting, and regenerating of a stand. The resulting stand usually has a distinctive form. This stand usually has certain characteristics, especially in terms of composition, structure, and function, which differ from the stand which would have resulted from natural succession (fig. 1).

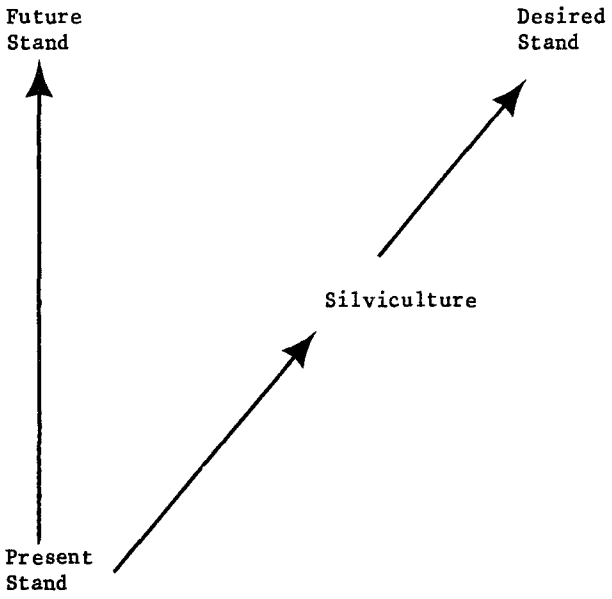


Figure 1.--The practice of silviculture implies a change in structure and composition of the future stand.

The actual practice of silviculture may be considered as a three-step process:

1. Understanding silvicultural principles;
2. Developing silvicultural prescriptions;
3. Conducting silvicultural practices.

On commercial forestland, silviculture following the steps above is well developed for the major forest types in the United States. However, practices conducted in the pinyon-juniper woodlands are not based on any established silvicultural principles. Silvicultural prescriptions involve the following three steps:

1. Specify the kind, intensity, timing, and cost of the treatment;
2. Justify the treatment;
3. Predict the likely consequences.

Few, if any, prescriptions have been written or developed specifically for pinyon-juniper woodlands. Past use of the woodlands has been with little regard for sound forestry or silvicultural practices developed for commercial forestlands. Thus, it appears doubtful if any of the current practices are based on field-tested prescriptions which have evolved from established silvicultural principles. The practice of silviculture in the pinyon-juniper woodlands is probably just beginning.

Accepting a rudimentary form of silviculture, the silvicultural strategy in pinyon-juniper woodlands may be more apparent. Spur (1979) listed five basic silvicultural strategies:

1. Exploitive;
2. Conventional extensive;
3. Conventional intensive;
4. Naturalistic;
5. Short-rotation.

Throughout much of Nevada, vast areas around mining towns were harvested during the 19th century for firewood, charcoal, and other wood products. Other areas have been high-graded more than once, leaving residual stands of low quality and poorly formed trees. This past use of the pinyon-juniper woodlands is usually referred to as exploitation because there was no consideration of regeneration during the harvesting. Actually, the practice of silviculture begins when the first consideration is given to regenerating a given species or forest type. The exploitive strategy is not really a silvicultural strategy, but more of a form of forest management without regard to sustained yield.

The conventional extensive strategy is probably the most widely used silviculture on our commercial forestlands. This strategy consists of harvesting stands using various silvicultural systems to encourage natural regeneration. The four basic systems which are named after the cutting method used for the final harvest include:

1. Selection;
2. Clear cutting;
3. Seed tree;
4. Shelterwood.

In addition to harvesting the stand using one of the above methods, the extensive strategy also includes one intermediate cut, such as, thinning. The intent of the thinning is to increase the diameter of the residual trees which will eventually be harvested. This conventional extensive strategy best fits the current sustained-yield management alternative. The

terminology, especially of the harvesting methods, makes understanding and/or application to the pinyon-juniper woodlands more difficult. For example, the selection method is recommended and used for those shade-tolerant species that grow in shade for most of their life. Pinyon, however, is considered a shade-intolerant species, but the selection method best describes the current practices under the sustained-yield management alternative. Also, uneven-aged management results from the selection system and this would best meet the intentions of the sustained-yield management alternative in the pinyon-juniper woodlands.

The other three harvesting methods, clear cutting, seed tree, and shelterwood, result in even-aged management. Although pinyon-juniper may be managed under even-aged or uneven-aged systems, there does not appear to be adequate information available to justify even-aged management. Again, the terminology provides confusion. When clear cutting is used in the pinyon-juniper woodlands, the intention is usually to eliminate the trees under type conversion management. Since there is no consideration of tree regeneration, the clearing does not fit even-aged management or silvicultural systems. The seed tree method does not really apply either because of the heavy, wingless pinyon seed. The seed tree method is usually used for shade intolerant species. The intention is to provide seed, but not shade. Pinyon seedlings, however, require shade, while the mature trees are very shade intolerant. The shelterwood method probably best describes the intention when used in pinyon-juniper, but the two or more partial cuts used to remove the mature stand do not appear to be economically feasible or even field tested. Current practices are probably best described as the shelterwood intention via the selection method where even-aged stands are encountered and the selection method in uneven-aged stands.

In terms of the other three silvicultural strategies, none fit or apply to the pinyon-juniper woodlands at the present time. Again, due to the slow rate of growth and low product values, pinyon-juniper silviculture and management will remain extensive. The conventional extensive strategy meets the current practices under the sustained yield management alternative. Also, it could be argued from a forestry standpoint that type conversion management follows the exploitive strategy. Lastly, under the custodial management alternative, wood production would be expected to increase over time until enough volume accumulates to make the conventional extensive silvicultural strategy feasible. At this point, the management alternative would change to sustained-yield management.

CONCLUSIONS

Since the bulk of pinyon-juniper woodlands are under custodial management, it follows that very little silviculture is actually being practiced at the present time. Although this view may not be appreciated, it does try to put things in perspective. In order to be really practicing silviculture, product values need to be high or benefits need to be greater than costs. In other words, the silviculture practices need to be cost effective. In order to develop silvicultural systems in pinyon-juniper, findings from both basic and applied research are needed. The following speakers will provide some of the important findings of present research which will lead to the development of silvicultural systems applicable to the pinyon-juniper woodlands.

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REGENERATION OF PINYON

Gerald J. Gottfried

ABSTRACT: The current emphasis on management of the pinyon-juniper woodlands has resulted in renewed interest in the regeneration characteristics of Colorado pinyon (Pinus edulis) and of singleleaf pinyon (P. monophylla). This information is vital for the development of sound silvicultural or range management prescriptions. However, our knowledge is incomplete, and the literature is occasionally contradictory. Most pinyon seedlings are observed in the shade of mature trees, shrubs, or of slash, and not in the spaces between trees, although pinyon is generally considered shade-intolerant. Seedling growth rates are low, but early release from shade can be fatal. The environmental requirements for successful germination and establishment have not been fully evaluated. Corvid birds are primary dispersal agents, but the importance of other seed dispersal pathways is unclear. Ecotypic variations should be anticipated within each of the two pinyon populations. More research is necessary before general management recommendations can be formulated.

INTRODUCTION

Pinyons are the common, most characteristic tree species of the pinyon-juniper woodlands, which cover more than 21 million hectares throughout the Southwest and the Great Basin (Barger and Ffolliott 1972). The pinyons usually grow in association with one or more juniper species. In Arizona and New Mexico, the Colorado pinyon (Pinus edulis Engelm.) is found in association with Utah juniper (Juniperus osteosperma (Torr.) Little), one-seed juniper (J. monosperma (Engelm.) Sarg.), Rocky Mountain juniper (J. scopulorum Sarg.), and alligator juniper (J. deppeana Steud.). Singleleaf pinyon (P. monophylla Torr. and Frem.) is the predominant species of the Great Basin, and is usually found in association with Utah juniper. The pinyon-juniper cover type is generally found at elevations between 1,372 and 2,286 m (Springfield 1976), over a wide range of soils, topography, and proposed habitat types. At the higher, more moist elevations, woodlands tend to be almost pure pinyon; while at the lower, drier elevations, they tend to be pure juniper (Springfield 1976; Tausch and others 1981).

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Gerald J. Gottfried is Research Forester, Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Flagstaff, AZ.

The pinyon-juniper woodlands have been used since prehistoric times as a source of fuelwood, building timbers, and pinyon nuts. The southwestern woodlands have been grazed by domestic livestock since Spanish colonial times. In the 1950's, the grazing resource was believed to be declining because of increased tree cover associated with the invasion of grasslands by pinyon and juniper. Arnold and others (1964) verified that forage production declined with increased tree cover. So, in the 1950's and 1960's, large areas of pinyon-juniper woodland were cleared in attempts to increase forage production; the wood and nut resources were usually ignored. Many cleared areas were soon occupied by surviving trees and by new seedlings, and anticipated increases in forage production were often not achieved (Clary and others 1974). The recent increase in fuelwood demands--more than 400 percent in Arizona between 1973 and 1978 (Ffolliott and others 1979)--has altered this situation. Land managers and researchers are currently attempting to develop growth and yield information and sound silvicultural prescriptions to place the woodlands under sustained yield forestry. At the same time, range managers are attempting to maintain the herbaceous cover and to control tree invasion on the more productive cleared sites. Achievement of both objectives, although they appear to be contradictory, requires an understanding of the silvical requirements of the pinyon and juniper species, especially the requirements for successful regeneration, such as seed dispersal, germination, and establishment. However, our knowledge is incomplete, and the literature is occasionally contradictory. Research on the woodland species has occurred sporadically since the late 1800's, and has intensified in recent years. This paper will review what is known about the regeneration of pinyon. Juniper regeneration, although also important, will not be reviewed here.

CONE AND SEED PRODUCTION

P. edulis begins to bear cones at about 25 years of age (Ronco, in press), while cone production for P. monophylla may be delayed until 35 years of age (Meeuwig and Budy, in press). Maximum seed production does not occur until a tree is between 75 and 100 years old. Cones of pinyon require almost three growing seasons to mature (Little 1938). Cone primordia start to form in the winter buds during August or September of the first growing season; this stage is complete by October. The strobili and cones emerge from the buds during the following May, and pollination occurs in June. This is followed by rapid cone and nut growth, which continues through

August. Growth resumes during the second May. Fertilization occurs in July, and the cones and nuts mature by September. Seed dispersal takes place from late September through October.

Pinyon is considered monoecious, with both male and female cones occurring on the same tree. The sexes are generally segregated, with more female cones occurring in the upper crown and more male strobili occurring in the lower crown (Lanner 1980). However, Floyd (1983) observed dioecy in several populations of Colorado pinyon in Arizona, Colorado, and Utah. She found that the youngest reproductive trees (averaging about 56 years old) produced mainly male strobili, slightly older trees (averaging between 74 and 80 years old) produced mainly female cones, while mature trees were characteristically monoecious. Floyd (1983) postulated that dioecy was an adaptation to the dry environment of the Southwest. Young trees might be less well established than older pinyon and more susceptible to moisture stress. The production of male strobili might require less energy than the production of female cones; also, the dioecy in younger trees might allow for more energy to go into physical growth.

Dioecy, or at least the inability of P. edulis to produce female cones, has been related to herbivory of the moth Dioryctria albovittella (Hust.) in northern Arizona (Whitham and Mopper 1985). Female cones are normally produced on terminal shoots near the top of the tree, while male strobili occur on lateral shoots. The moth larvae more frequently attack the terminal shoots, preventing female cone production, while lateral shoots are attacked considerably less often, allowing the successful formation of male strobili. Repeated herbivory will result in trees with prostrate, shrublike crowns, and relatively low growth rates. These trees will, however, resume normal cone production and growth if the moth population is reduced or eliminated.

Production of pinyon nut crops is highly variable. Colorado pinyon produces nut crops at intervals of 4 to 7 years, although shorter 3- to 5-year intervals have been reported (Barger and Ffolliott 1972). Meeuwig and Budy (in press) reported a 3- to 7-year interval for singleleaf pinyon. Even in poor years, there will usually be some local sites within the Southwest or Great Basin that produce good crops of seed. A cone will contain between 10 to 20 seeds, which average 4,190 seeds/kg. A large Colorado pinyon can produce more than 9.1 kg of seed in a good seed year (Ronco, in press), while a similar singleleaf pinyon will produce 5 kg (Meeuwig and Budy, in press). Trees with large, spreading crowns are considered the best seed producers. The size of the annual nut crop can vary from 454,500-909,000 kg to about 3.6 million kg in a bumper year (Barger and Ffolliott 1972).

Shorter intervals between good seed crops have been related to more favorable sites where pinyon flourishes (Barger and Ffolliott 1972). Forcella (1981) indicates that the production of pinyon cones may be related to below-normal maximum daily temperatures during the last week in August and the first week in September, when primordia are formed. An evaluation of temperature data and evidence of cone production from 30 woodland stands indicated one to two good crops every 10 years. Forcella (1978) indicates that irregular cone production may have the selective advantage of keeping insect predator numbers small during average years, ensuring predator satiation and seed survival when good crops occur. The same may hold true for dependent bird and rodent populations, which also eat large quantities of pinyon seed.

There are several insects that attack pinyon cones and seed. The western flower thrips, Frankliniella occidentalis (Pergande), is common on mature staminate cones and apparently feeds on the pinyon pollen (Little 1943; Furniss and Carolin 1977). Another thrips, Oxythrips pinicola Hood, has been found in pinyon flowers in Colorado. The cone moth, Eucosoma bobana (Kearfott), attacks both species of pinyon. Dioryctria albovittella, a cone moth, has been reported on P. edulis by Whitham and Mopper (1985) and on P. monophylla by Furniss and Carolin (1977). Chionodes periculella (Busck) mines in the seed cones of P. edulis in Colorado. Tricorynus conophilus Fall, Conophthorus edulis Hopkins, and C. monophyllae Hopkins are beetles that prey on pinyon cones. Some other pests on singleleaf pinyon are the cone borer, Ernobius montanus (Fall), and two cone sawflies (Xyela spp.).

SEED DISPERSAL

Pinyon seeds are heavy and wingless, and are not adapted to wind dispersal. Birds and rodents are considered to serve as the main dispersal agents. Four species of corvid birds are known to eat and to cache pinyon seeds--Clark's nutcracker (Nucifraga columbiana), piñon jay (Gymnorhinus cyanocephala), scrub jay (Aphelocoma coerulescens), and Steller's jay (Cyanocitta stelleri). Lanner (1981) indicates that piñon jays, which harvest seed from green cones, have the ability to differentiate between filled and empty or diseased seeds by using a combination of seed color, weight, and sound (by clicking the seed with their bills).

Vander Wall and Balda (1977) studied the coadaptation of Clark's nutcracker and P. edulis near Flagstaff, AZ. This species can harvest seed from green cones starting in August and will cache the seed in communal caching areas for later use. Clark's nutcracker has a sublingual pouch or expandable esophagus, which allows each bird to carry an average of 55 seeds on each trip. Vander Wall and Balda (1977) observed that these birds will travel up to 22 km between the pinyon seed source and the communal caching area. A flock of 150 birds can transport between 3.3 and 5.0 million seeds in the autumn of a good seed year. Seed are buried in clumps to a depth of 2-3 cm. The caches are usually on steep, south-facing slopes where snowmelt will occur earliest in the spring. Vander Wall and Balda (1977) indicate that pinyon cones and seeds have evolved with certain morphological characteristics, such as seed color

and cones that are oriented outward and upward, which tend to favor dispersal by birds. The trees benefit by having the birds disperse their seed, while the birds benefit by having a food supply during the most unproductive time of the year. In addition, Clark's nutcracker, which breeds in late winter or early spring, uses stored pinyon seeds to obtain energy necessary for reproduction (Vander Wall and Balda 1977).

Ligon (1978) conducted a similar study of the interrelationship of piñon jays and P. edulis in central New Mexico. This slightly smaller species can carry an average of 30 seeds in its sublingual pouch. Ligon (1978) estimates that a flock of 250 birds will transport 30,000 seeds in a day. Lanner (1981) reported that these birds will fly up to 10 km to the caching sites. Piñon jays also cache their seed on south-facing slopes or on the south side of vegetation, rocks, or debris. Ligon (1978) indicates that all buried seed will be consumed by the jays during average seed years, but some uneaten seed will remain to germinate during good seed years.

The relationship between either Steller's jay or scrub jay and pinyon has apparently not been studied as intensively. Steller's jay feeds on open pinyon cones, possibly because it has a shorter beak than the Clark's nutcracker or the piñon jay.

Rodents are generally considered less important than birds as dispersal agents. Phillips (1909) reported that mountain rats (Neotoma spp.) could store from 35 to 70 liters of good seed in their middens. However, seed concentrated in middens would provide a less ideal point for germination than the widely distributed caches created by birds. Utah cliff chipmunk (Eutamias dorsalis) and pinyon mice (Peromyscus truei) are two other species of pinyon seed-eating rodents (Ronco, in press).

Most regeneration in existing woodland sites is found under the crowns of older pinyon and juniper trees. It is logical to assume that at least part of the pinyon seedlings under an older pinyon tree developed from seed that fell from the overstory crown. A current study on a level site in New Mexico has shown that practically all of the viable seed that escaped the birds was deposited between the bole and the dripline of the parent tree. The occurrence of pinyon seedlings under junipers could be related to caching behavior or to seeds dropped by resting birds. It is uncertain what dispersal agent is responsible for the occasional seedlings found within the small gaps between trees. Some possible sources are seed dropped by birds or rodents, or seed carried by strong winds or by surface runoff. Gravity could be responsible on slopes. Emerson (1932) reported that on hillsides, considerable numbers of pinyon and juniper seedlings may become established in openings below parent trees.

GERMINATION AND ESTABLISHMENT

The environmental and physiological requirements for successful pinyon germination have not been fully evaluated. Tueller and Clark (1975), referring to pinyon, report that natural germination of pine seed usually takes place during the first spring after dispersal, but that seed may germinate during the summer or fall under favorable conditions. However, this appears to be a general statement referring to all pines and not specific to pinyon. Singleleaf pinyon has been observed to germinate in the spring following snowmelt (Lanner 1981); it is not clear if Colorado pinyon in the Southwest germinates in the spring, with the start of summer rains, as do most southwestern conifers, or during both spring and summer. Only summer germination has been reported; for example, Meagher (1943) found that pinyon germinated beginning on July 1 when spots were watered, and on August 17 when they were not watered. He did not study spring germination. Vander Wall and Balda (1977) observed pinyon germination during August on the Clark's nutcracker cache sites. However, spring germination of Colorado pinyon has been observed around Flagstaff and in northern New Mexico in 1985.

It is also unclear if seed dormancy is a factor in pinyon germination. Fresh pinyon seeds have a high initial viability (83 to 96 percent [Ronco, in press]), but this decreases rapidly after 1 year (Meeuwig and Bassett 1983). However, the storage life of seed from certain seedlots of both pinyon species may decline more rapidly (Meeuwig and Budy, in press; Gottfried and Heidmann, in press). Gottfried and Heidmann (in press) found that cold stratification, a common method of breaking seed dormancy, increased the speed of germination of pinyon from five central Arizona seed sources ranging in elevation from 1,689 to 2,195 m. Germination percentages were not affected, however. Although a test of six hydrogen peroxide treatments produced variable results, several treatments improved germination of a seedlot with poor initial germination percentages or energy (Gottfried and Heidmann, in press).

Not all seedlots reacted identically to these treatments. Ecotypic variability should be anticipated within the two major pinyon populations since they are found over such a wide range of sites throughout the West. For example, Gottfried and Heidmann (in press) found that seed from the most northern site and from the highest elevation site germinated in the laboratory in an average of 10.6 days, compared to 17.1 days for seed from the other areas.

Pinyon is considered intolerant to shade; however, most pinyon seedlings are found in the shade of older pinyon and juniper trees, brush, and slash. Germination will occur in the open if conditions are satisfactory, but establishment and subsequent survival appear to be less certain. Shade moderates the microclimatic factors, like solar radiation and wind effects, reducing moisture stresses and temperatures.

Moisture is probably the most critical factor controlling the distribution, composition, and density of pinyon-juniper woodlands. For example, there appears to be a direct relationship between the proportion and density of pinyon in a stand and a site's moisture characteristics. Meagher (1943) found that supplemental watering did not affect percent germination of P. edulis but did hasten germination by about 1-1/2 months, and also improved survival during the first 2 years. The addition of shade, which reduced moisture losses, further shortened the germination period by an additional 20 days. Rapid germination would benefit a seedling by allowing it to become established prior to the summer or fall drought periods. The faster the root system can become established, the better the chances of seedling survival. Pinyon is adapted to drought. Daubenmire (1943) found that pinyon seedlings had the most rapid root elongation of the six conifer species tested. Meeuwig and Budy (in press) report that singleleaf pinyon can develop a thick, 15-cm taproot within 10 days of germination. Pinyon seedlings can withstand up to 12 days of soil moisture below the wilting point in the laboratory without increased mortality because of its rapid rate of root elongation (Daubenmire 1943). However, more than 12 days of severe drought may be common on most sites.

Temperature is another vital environmental factor. It affects all biochemical reactions such as germination and transpiration and can cause tissue damage. Laboratory results should be applied to field conditions with caution. However, in the laboratory it appears that pinyon germination is best at temperatures close to 20° C. Kintigh (1949), working with an unknown pinyon species, found best germination and early growth occurs at a temperature of 21° C. Floyd (1983) found better germination percentages at 20° C than at 15°, 25°, or 30° C. Preliminary testing of pinyon with alternating day and night temperatures showed better germination with a 24-20° C range than with a 30-20° C range. Pinyon seedlings can withstand relatively high soil surface temperatures of 70° C, an obvious adaptation to the warm, dry conditions within the pinyon-juniper zone (Daubenmire 1943).

Although pinyon seedlings are usually found in shade, Meeuwig and Bassett (1983) indicate that the overstory foliage is usually not dense enough to reduce light intensities below tolerance levels for survival. Seedlings growing under shrubs that can be overtopped have the best chance of survival. Seedlings under trees must be released, but they often die, possibly because of the sudden exposure to more intense solar radiation, although the exact mechanism has not been determined. Size may be a factor since trees taller than 30 cm generally survive release. It is possible that degree of tolerance to release may be related to the amount of juvenile needles present, but this still needs to be confirmed.

The importance of the forest floor in the germination process is not known. Needles and duff would serve as mulch and provide a source of nutrients to the soil. Interspace areas are usually devoid of any litter or duff cover.

The effects of competition between herbaceous vegetation and pinyon seedlings have not been evaluated; however, it is assumed that pinyon has difficulty becoming established in the presence o dense, vigorous grass cover. Emerson (1932) observed that pinyon and junipers often become established in rocky areas where grass does not form dense stands. Once the seedling becomes established, competition should be less severe, especially once the tree roots grow below the top 30-40 cm of soil, the zone of competition with grass roots. Heavy grazing may reduce grass competition enough to permit establishment of bot pinyon and junipers (West and others 1975).

EARLY GROWTH

Top growth is very slow during the early years. In singleleaf pinyon, it may be less than 2.5 cm year. Diameter growth is less than 0.3 mm a year (Meeuwig and Budy, in press), but seedlings growing under shrubs tend to have greater diamete growth than those growing under tree crowns. Colorado pinyon saplings will put on 10-15 cm of annual top growth (Ronco, in press). Actual growth will vary depending on site conditions (habitat type), with best growth occurring on the more moist areas (Larson 1985).

DAMAGING AGENTS

Young trees are particularly susceptible to fire, although fire is relatively uncommon in most woodlands because of the lack of ground cover to carry a fire. Sufficient cover often occurs in young stands, lightly grazed stands, on better sites, and on habitat types with grassy understor plant associations.

Several insects affect young pinyon trees. The pinyon needle scale (Matsucoccus acalyptus) and the pinyon sawfly (Neodiprion edulicolus) attack foliage, as do a number of other insects (Meeuwig and Budy, in press). Cutworms (Noctuidae) have caused mortality in an experimental seeding in Arizona.

Pinyon dwarfmistletoe (Arceuthobium divaricatum) attacks both species of pinyon. Pinyon blister rust (Cronartium occidentale) may be a problem in some areas (Meeuwig and Budy, in press). Ronco (in press) indicates that pinyon is affected by several foliage diseases, including needle cast (Elytroderma deformans and Bifusella saccata) and needle rust (Coleosporium spp.).

The possibility of damage to pinyon regeneration by livestock has apparently not been studied. Trampling could be a problem. However, the successful regeneration on many cleared areas tha have received heavy livestock use would indicate that it is not a severe problem.

SUCCESSION

It appears that junipers, which have broader ecological amplitudes than pinyon, invade an area first, and are subsequently replaced by pinyon on better sites. Blackburn and Tueller (1970) studied woodland invasion in east-central Nevada and found that pinyon seedlings were more common than juniper seedlings in the closed communities than in relatively open communities. They indicated that pinyon numbers had increased by more than 68 percent over a 21-year period on these sites, and that the pine would eventually dominate the site. Tausch and others (1981) state that pinyon is responsible for most of the increases in tree density and dominance in the Great Basin over the last 150 years. A study on an Arizona site dominated by one-seed juniper showed a similar trend (Jameson 1965). Pinyon numbers increased by 46 percent over a 20-year period, while juniper numbers increased by about 10 percent. Pinyon height growth was also faster than juniper growth. Jameson (1965) concluded that pinyon should eventually become the dominant species in this stand. However, pinyons will rarely become established in the low-density juniper savannas that occur on lower elevation, drier sites.

Fire is the main natural disturbance in the woodlands. Arnold and others (1964) proposed a sere starting with annuals and progressing to full recovery of the woodlands. The trees would become reestablished during a shrub or a parallel, perennial grass stage. Barney and Frischknecht (1974) found that tree seedlings began to appear after 30 years of postfire recovery in central Utah, but that they would not dominate the site until after 70-80 years.

Many sites in the Southwest and the Great Basin have returned to woodland rapidly after cabling or chaining treatments designed to remove the woody vegetation in favor of forage production. However, most of the "new" trees were present prior to treatment, which failed to remove them because of their small size or because of operating procedures. For example, a site in eastern Nevada was dominated by pinyon trees within 15 years of treatment (Tausch and Tueller 1977), but only 1 percent were of posttreatment origin.

CONCLUSIONS

The current interest in managing the pinyon-juniper woodlands for a range of products has renewed interest in the regeneration characteristics of Pinus edulis and P. monophylla.

Although our knowledge is continuing to grow, there are still many questions that need to be answered or clarified. Some questions are concerned with the ability to predict good cone crops or to select areas that have more frequent good crops because of site or other characteristics. More intensive management will require an understanding of the genetic variability within the pinyon populations. Because birds are an important dispersal agent, it would help to understand what factors influence the selection of caching areas. Managers could use this information in planning for woodland regeneration needs, and to explain successional trends. The relative importance of the other dispersal agents should be evaluated.

Environmental and physiological requirements for successful germination and establishment have not been fully evaluated. There are still questions about the timing of P. edulis germination and about the environmental factors that initiate or delay the process. There are also many questions about the need for shade, and about the factors that enable larger seedlings to survive release. Understanding the reasons for the lack of regeneration in small gaps between trees, even when they receive partial shade, would help in the development of silvicultural prescriptions. The influence of competing vegetation on pinyon seedlings should also be defined.

A habitat type classification system is only just being prepared for the pinyon-juniper woodlands in the Southwest. The completion of this task will enable managers and researchers to identify sites where existing information can be successfully used to achieve pinyon regeneration, or where further research is necessary.

Understanding the requirements and mechanisms of pinyon regeneration provides an interesting goal and a pertinent one--the management of the pinyon-juniper woodlands.

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ESTABLISHMENT AND STAND DEVELOPMENT OF WESTERN JUNIPER IN CENTRAL OREGON

Lee E. Eddleman

ABSTRACT: Establishment and stand development of western juniper were studied in central Oregon. New individuals established primarily beneath the canopies of big sagebrush or juniper. No trees established prior to 1880, but had reached densities greater than 1,000 per hectare by 1980. Larger trees made up approximately 10 percent of the population. Basal area had reached 12.73 m^2 by the tenth decade of growth.

INTRODUCTION

Western juniper (Juniperus occidentalis Hook. Subsp. occidentalis) has been increasing its range at a phenomenal rate during the last 100 years (Adams 1975; Burkhardt and Tisdale 1969; Carahar 1977; Young and Evans 1981). Considerable speculation exists as to probable reasons for expansion of its range including fire control, overgrazing by domestic livestock, and climatic shifts (Burkhardt and Tisdale 1976); however, Mehringer and Wigand (1984) point out that on at least some "invaded" areas western juniper was present in prehistoric times.

Historically, western juniper invasion has been primarily into big sagebrush (Artemisia tridentata) communities and to a lesser extent into low sagebrush (Artemisia arbuscula) communities (Burkhardt and Tisdale 1969, 1976; Young and Evans 1981). Establishment may be facilitated by the presence of other woody plants since much of it takes place beneath sagebrush plants. Peak years of establishment were the late 1800s to early 1900s in northeastern California (Young and Evans 1981), early 1900s in southern Oregon (Adams 1975) and in the 1920 to 1940 period in southern Idaho (Burkhardt and Tisdale 1969). Densities of western juniper are variable depending on location, site factors, and stage of population growth. In those studies cited above, juniper densities ranged from 150 to 424 stems/hectare on big sagebrush sites and estimated at 28 stems/hectare on low sagebrush sites in northeastern California.

Western juniper is viewed by forest researchers as a slow growing conifer. Others frequently feel the plant suddenly appears and rapidly develops to maturity. Seedling growth rates of 1.4 to 3.4 cm height growth per year (Burkhardt and Tisdale 1976) and aboveground net productivity of approximately one-tenth that of western Oregon Douglas-fir forests (Gholz 1980) support the contention of slow growth.

Stand establishment and growth rates have a major impact on the economic use of the land surface. When the tree is viewed as a noxious weed, reducing available soil moisture and livestock forage, stand development characteristics determine the frequency and intensity of control treatments. When the tree is viewed as a natural resource for fuel wood, posts, boughs and wildlife cover, rates and character of stand development are also important.

Volume equations were determined for western juniper by Chittester and MacLean (1984), Chojnacky (1985) and Parker and Ziegler (1984) and detailed information on stand structure and development for pinyon-juniper (Pinus monophylla and Juniperus osteosperma) stands in the Great Basin has been reported on by Meeuwig (1979); no information is available on western juniper stand development characteristics for central Oregon. Since information from other areas did not appear to characterize central Oregon juniper stands, establishment locations, population growth, and tree growth characteristics were determined for an area in central Oregon near Prineville.

STUDY AREA AND METHODS

The study area is located 8.8 km southeast of Prineville, Oregon on an area locally known as Comb's Flat. Elevation ranges from 1,112 m to 1,220 m sloping gently to the north. Soils are clayey-skeletal Argixerolls and range between 38 and 60 cm deep. Average annual precipitation is 254 mm at Prineville, which is at 873 m elevation.

Western juniper appears as a dense forest in this area. Understory composition would place it in the mountain big sagebrush/bluebunch wheatgrass habitat type, although it has been degraded by grazing and western juniper encroachment. The present understory is dominated by native bluegrass (Poa sandbergii) in the interspaces between tree canopies and by a mixture of native bunchgrasses, annual and perennial forbs and cheatgrass (Bromus tectorum) beneath tree canopies. Sagebrush plants are scattered throughout the area and have a canopy cover estimated at three to five

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Lee E. Eddleman is Associate Professor of Range Ecology, Department of Rangeland Resources, Oregon State University, Corvallis, OR.

percent. Samples were taken in closed stands that gave the appearance of being mature and fully occupying the site.

Six 0.2-hectare blocks were selected for analysis, three of which were intensively studied. All stems were harvested and location of establishment relative to other plant species was noted. Basal diameter, height and age were determined for each tree. A cross-section from the base of each tree was taken to the laboratory and diameter growth increment determined for 10-year intervals. Measurements were taken along a radial best representing diameter growth (Meeuwig 1979) and diameter measurements were taken inside bark. Trees were grouped by decade of establishment for analysis. Near the upper elevation of the area, 12 dominant trees were cross-sectioned at one meter intervals to obtain an estimate of height growth rates for individuals least affected by intraspecific competition.

RESULTS

Establishment location was determined for 645 trees, seedling through adult. Individual trees for which the position of establishment could be determined show a strong association for sites in the shade of woody plants (table 1). Although big sagebrush appears to provide the greatest number of viable sites for establishment, it could simply be due to the higher density of big sagebrush plants relative to juniper during the earlier stages of stand development.

Examination of the litter at the base of even the oldest western juniper trees frequently revealed partially decomposed sagebrush stumps. Samples taken nearby but off the study area on site actively being invaded averaged 80 percent or more establishment of juniper taking place beneath big sagebrush canopies, which approximates the total percent establishment beneath woody plants found on the study site.

Table 1.--Establishment sites of western juniper

Location	Vegetation Type: Mountain Big Sagebrush	Vegetation Type: Ponderosa Pine
	%	
Beneath		
Sagebrush	52.3	0.8
Other Shrubs		32.0
Juniper	31.3	11.6
Ponderosa Pine		41.0
Bunchgrass	6.4	1.0
Other		
Bare	0.1	6.2
Rock Edge	1.9	2.2
Misc.[1]	8.0	5.2

[1] Misc. includes non-specified sites plus unknown.

Samples from five 0.4-hectare plots were taken a few miles from the study area in the ponderosa pine (Pinus ponderosa) mountain big sagebrush ecotone where big sagebrush was very sparse (table 1). Nearly 84 percent of western juniper establishment was beneath woody plant canopies. In addition to ponderosa pine and western juniper, bitterbrush (Purshia tridentata), gray rabbitbrush (Chrysothamnus nauseosus) and wax current (Ribes cereum) appeared to provide adequate conditions for western juniper establishment.

When age classes were examined, it became evident that in the last four decades most juniper seedling establishment took place under large juniper canopies. Only 2.5 percent of the trees less than six meters tall had regeneration beneath their canopies as compared to 52 percent of those trees six meters or more tall. The mean height of those trees with more than one individual beneath their canopy was 7.2 meters. As many as 72 small junipers were found beneath one large tree.

Oldest trees found on the sample plots were established in 1880 (fig. 1). In a careful search of the general area in which stumps and larger trees were aged, none were found which established before 1880. No dead trees were found in the area other than those cut down by man in recent years. Populations were doubling every 10 years to 1900, every 6.6 years from 1900 to 1910, followed by a gradual slowing of growth to a doubling every 10 years by 1940 and every 18 years by 1980. By 1980 the average western juniper density was 1018/ha.

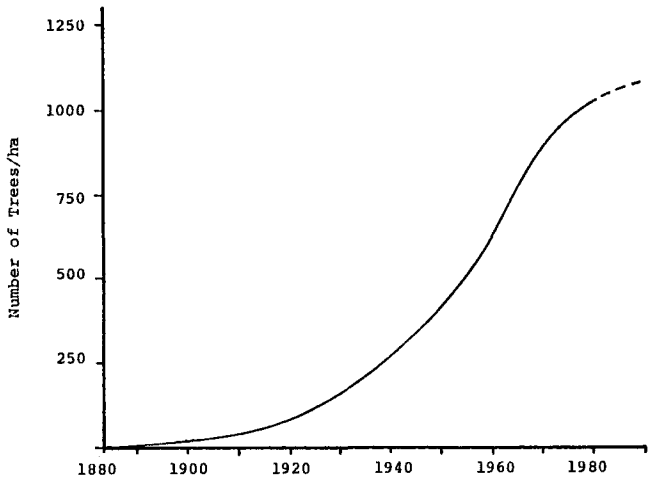


Figure 1.--Population growth curve for western juniper in central Oregon.

Large trees constitute a small portion of the present population. There were 102 trees/hectare over six meters in height (fig. 2) and only 107/hectare that were over 20 cm in diameter (fig. 3). Small trees made up the majority of the population. There were 560 trees/hectare (s=235) one meter or less tall and 748 trees/hectare (s=248) of five centimeters or less basal diameter, making up 55 and 73 percent of the population respectively. Large trees made up about 10 percent of the population.

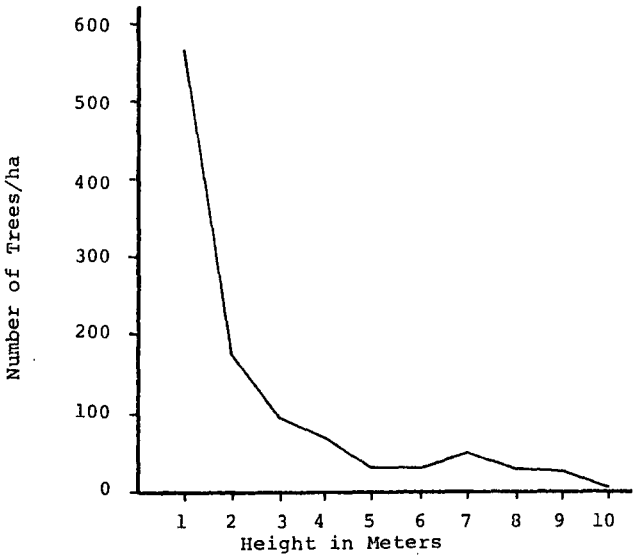


Figure 2.--Height class frequency distribution for western juniper.

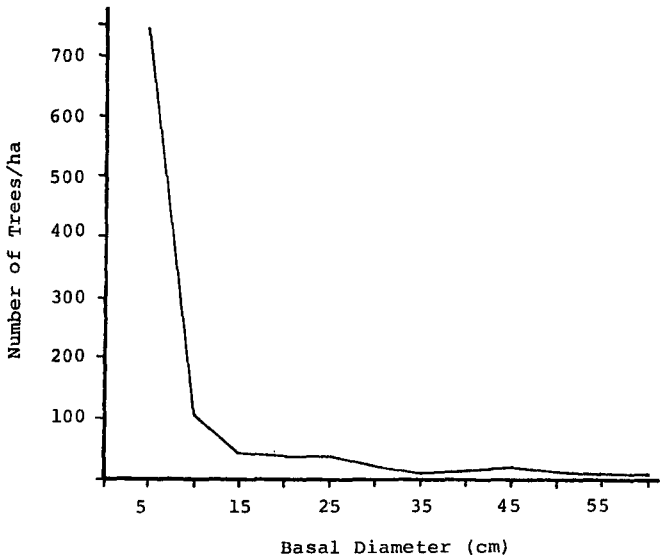


Figure 3.--Basal diameter size class frequency distribution for western juniper.

Height growth rates averaged over the life of the tree were fairly constant for trees initiated during the first four decades, dropped during the fifth and were again fairly constant though much reduced for trees initiated during the last five decades (table 2-a). Slower growth rates of later generations could be from intraspecific competition with older generations.

Trees greater than 60 years old, however, have been growing at a constant growth rate with no indication that height growth is slowing down (table 2-b). The reduction in growth rate observed from the fifth decade on (table 2-a) is probably therefore explained by later recruitment being suppressed by older age classes. The drop in growth rates

Table 2.--Height growth rate of western juniper (a--lifetime growth rate for trees initiated during each decade, and b--average years per meter of height growth and centimeters of height growth per year for each meter

	(a)	(b)		
Decade	Initiated in Each Decade	Dominant Trees 60 Years Old		
	(cm/yr)	Ht (m)	(Years/m)	(Cm/Year)
1	8.8	1	11.1	9.0
2	9.0	2	8.6	11.6
3	9.0	3	7.9	12.7
4	8.8	4	7.0	14.3
5	6.4	5	6.0	16.7
6	4.0	6	7.7	13.0
7	2.9	7	7.3	13.7
8	3.2	8	6.4	15.6
9	3.0	9	7.0	14.3
10	2.3			

corresponds to a time at which juniper density had reached 160 to 208 trees/ha.

Basal area began to increase rapidly after the fourth decade, rising to an estimated 12.7 m^2/hectare (s=2.25) by the tenth decade (fig. 4). Although the curve begins to flatten out after the tenth decade, indicating a slowdown in basal area growth, the value used for the eleventh decade was a projection from a set of values for the first few years of the decade and is therefore subject to question.

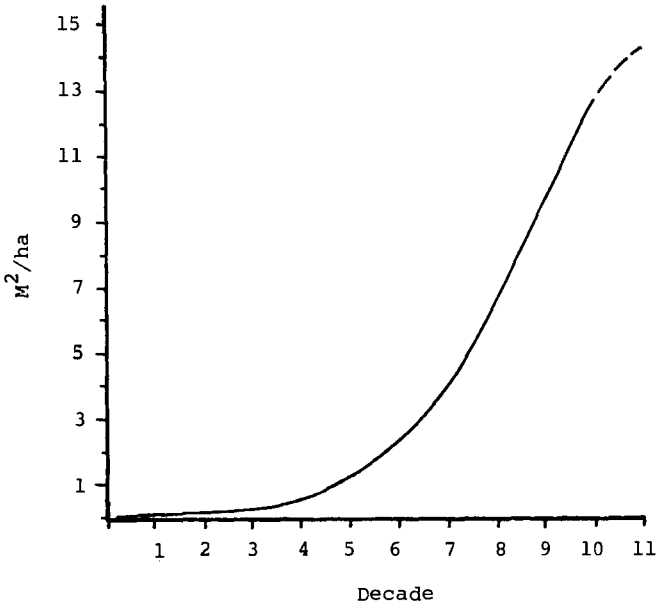


Figure 4.--Cumulative basal area for western juniper.

Ten-year periodic incremental diameter growth of older dominant trees increased steadily to approximately a 200 cm^2 increment per decade by the fifth decade and a peak of just over 250 cm^2 increment in the seventh through tenth decades (fig. 5). Those trees arising during the fourth decade, currently subdominant, are rapidly approaching the incremental basal area growth rates of the dominant trees. Those arising from the sixth decade and later show a slower rate of basal area increase; maximum basal area growth rates for these trees may not be known for several decades.

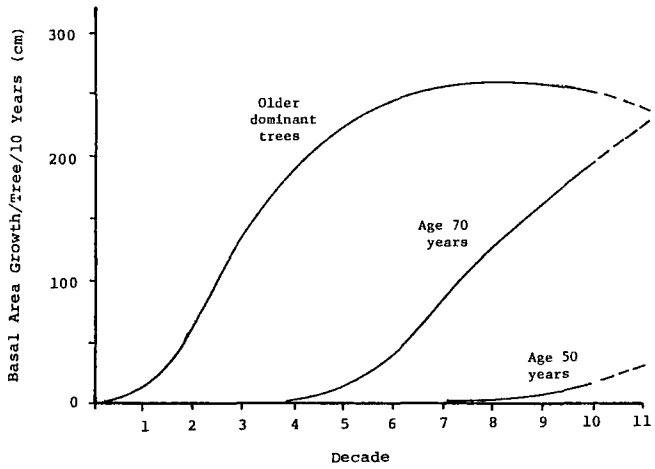


Figure 5.--Ten-year periodic increment in basal area growth for western juniper trees.

Table 3 gives summary stand characteristics for western juniper. The few dominant trees contribute most of the basal area and canopy cover. Subdominant trees, though greater in number, contribute much less to the basal area and canopy cover than do the dominant trees. Suppressed trees make up 90 percent of the population, 24 percent of the basal area and 29 percent of the juniper canopy cover.

Table 3.--Western juniper stand summary characteristics at the end of 10 decades of growth. Dominant trees are those over 30 cm in basal diameter and subdominant trees are those 20-30 cm in basal diameter

Trees	No/Ha	Ave Ht	Total Basal Area	Total Canopy Cover
		(m)	(m^2/ha)	(m^2/ha)
Dominant	40	7.5	6.27	1435
(Range)	(20-60)	(7.2-7.6)	(2.43-10.28)	(695-2250)
Subdominant	60	7.6	3.46	1025
(Range)	(10-110)	(6.9-8.7)	(0.49-6.62)	(240-1075)
Subtotal	100		9.73	2460
Suppressed	918		3.00	985
Total	1018		12.73	3445
(Range)	(830-1120)		(11.14-14.32)	(2430-4105)

SUMMARY AND CONCLUSIONS

Western juniper establishment on the study area began primarily beneath big sagebrush plants, but after development of sufficiently large trees, over seven meters tall, establishment began to take place beneath the existing juniper canopy. Increase in establishment beneath these larger trees is likely due to their production of considerable seed and the use made by the bird species of the berries as a food source and the tree as a perching site. Burkhardt and Tisdale (1976) found shrub understories to be a major establishment site for western juniper; however, establishment under juniper canopies was much less than found in this study. This may be partially explained by juniper canopy cover ranging from two to five percent in the southern Idaho study, well below the 34 percent cover encountered in central Oregon.

Woody plants may be acting as nurse plants for seedling western juniper, much as Phillips (1909) found for pinyon pine (Pinus edulis). Facilitation of establishment beneath a shrubby plant canopy is probably due to reduced soil surface temperature and increased shading (Burkhardt and Tisdale 1976) and perhaps aided by increased available moisture and nutrients near the base of the nurse plant.

Populations of junipers in the study area appear to have developed later than those in northeastern California (Young and Evans 1981) and those in southern Oregon (Adams 1975), but appear very similar in age structure to stands in southern Idaho (Burkhardt and Tisdale 1976). In each of these studies, however, age structure would be influenced by the proximity of the samples to leading edge of the expansion where younger trees would be expected and by proximity to long-lived trees on the upslope ridges which are the original and continuing seed source for downslope populations, in which case older age classes would be expected.

Density of trees is considerably higher than reported in most studies on western juniper; however, Burkhardt and Tisdale (1969) note some seral stands of western juniper contained over 2,000 adults/hectare. Apparently establishment is still proceeding at an active rate on the central Oregon site and not on the California site. It may be that the somewhat younger aged central Oregon stands contain more big sagebrush, have finer textured surface soil, and have a more favorable northerly aspect than the California site. Each of these factors has been found to be positively associated with juniper establishment (Burkhardt and Tisdale 1976).

Height classes found in the study area were markedly different from those in northeastern California where very few trees were less than 2.3 meters tall (Young and Evans 1982). Dominant and subdominant trees appear to maintain a fairly constant height growth. Competition with older, larger trees markedly reduced height growth of later generations. Although ring widths began to decline with age in the dominant trees, periodic increments in basal area declined little if any

with age. Diameter growth of suppressed later generation trees was markedly reduced, probably by competition with larger trees.

From the standpoint of post and fuelwood production western juniper trees reached 30 cm in basal diameter and seven meters in height between 70 and 80 years of age if they were not being suppressed by other juniper trees. On the other hand, rapid stand establishment and continued development create major control problems. A particularly serious problem is the very large population of small trees present under sagebrush and large juniper trees. Larger trees removed by fuelwood harvest or bulldozing would represent only a small portion of the population. Rapid stand development and full site occupancy would be expected to recur in a relatively short period of time.

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ASSESSMENT OF SITE QUALITY IN PINYON-JUNIPER WOODLANDS

Frederick W. Smith and Thomas Schuler

ABSTRACT: Various site quality estimators for southwestern pinyon-juniper woodlands were evaluated using data from sixty temporary plots. Anamorphic height-age site index curves were found to be useful in predicting volume when used in conjunction with stand density. Results indicated that regional growth equations for the species could be developed.

INTRODUCTION

The ability to assess potential productivity of lands covered by the southwestern pinyon-juniper forest is a critical element for improving the state of silvicultural practices. There is increased recognition of the importance of the type as a manageable, renewable resource and lessened emphasis on indiscriminate exploitation or type conversion. Increased interest in management is a result of the large area represented by the resource coupled with its value for resource production.

The pinyon-juniper forest type covers 4.29 million hectares in New Mexico, 4.94 million hectares in Arizona and 1.90 million hectares in Colorado. Woodlands are generally found between 1400 and 2300 m in elevation where annual precipitation is between 30 and 50 cm (Springfield 1976). The land base occupied by the type is variable with respect to climate where seasonal, latitudinal and elevational differences in precipitation occur (Jameson 1969), and geomorphology where soil texture, parent material and depth differ throughout the region (Springfield 1976). Vegetation classified as pinyon-juniper woodland can vary significantly in composition and structure (Pieper 1977). Across Arizona, New Mexico and southern Colorado, pinyon-juniper woodlands may be composed of combinations of three Pinus species and four Juniperus species. Also, disturbance histories including fire regimes and past human use add to the complexity of the vegetation composition of woodlands across the region (Meeuwig and Cooper 1981).

A reasonable estimate of site quality is an essential element of many forest management activities, especially yield forecasting and silvicultural prescription. At its most basic level, a site quality classification scheme ranks land according to relative potential to produce a given crop (Tesch 1981). More sophisticated schemes may use direct measurement of actual yields (Bradley and others 1966) or predict site quality from site environmental variables (Meeuwig and Cooper 1981). The precision and accuracy required of an estimator are largely determined by the value of the resource and the management intensity applied.

Site quality is specifically defined as the "amount of wood produced in a given time . . ." (Daniel and others 1979) and is a basic characteristic of the land itself. Since actual yields are influenced by management history direct estimators are rarely used. Rather, indirect estimators of site quality, such as site index, are much more common. Indices are based on an easily measured variable associated with the land or the current vegetation found on the land. Height of trees free of damage or the effects of severe competition adjusted to a common base age is the most frequently used index of site quality.

Despite the extensive coverage of the pinyon-juniper forest type in the southwestern United States, relatively little empirical growth information is available. This includes the lack of a generally applicable method for assessing site quality. The objective of this study was to test a variety of published and proposed approaches for estimating site quality in pinyon-juniper woodlands. The criteria for evaluating the various indices were correlation with productivity, independence from stand structure and ease of application. The methods tested were as follows:

1. Howell (1940) proposed that site determinations be "based on basal area at one foot when the stand above 4.5 feet high averages five inches in diameter one foot above the average ground level."

2. Meeuwig and Cooper (1981) found fairly constant basal area growth in well stocked stands and defined site index as "basal area growth per decade in fully stocked stands (stands in which undergrowth is less than 10 percent of the total plant cover)." An equation relating site index to site factors for use in stands not fully stocked was also presented.

3. Tausch (1980) suggested that a structural tree support theory derived by McMahon (1973) could be used in determining site quality. The constant of proportionality of a tree's crown volume or height

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Frederick W. Smith is Assistant Professor and Thomas Schuler is Graduate Research Assistant at the Department of Forest and Wood Sciences, Colorado State University, Fort Collins, CO.

to basal diameter showed differences between plots related to site quality. As with Meeuwig and Cooper's site index, the relationship may not hold for stands at less than full stocking so that an equation may be needed to estimate site index from other site factors.

4. Daniel and others (1966) defined site index as "the height to which a tree will grow on a particular site in the time it will take the tree to reach 10 inches in diameter" at one foot above ground level. Curves are presented to determine site index from the height and diameter of the dominant tree in the stand.

METHODS

Sampling was conducted to generate a region-wide data set to evaluate the several methods for assessing site quality. Sixty temporary plots were distributed in proportion to the land area of woodlands in Arizona, New Mexico and southern Colorado (table 1). One-third of the plots were located in each of three subjective site quality classes:

1. good sites evidenced by vigorous plants and no apparent limiting physical factors,

2. poor sites evidenced by reduced plant vigor and limiting soil or physical factors, and

3. Intermediate sites between good and poor.

Forty-five of the sixty plots were established in what appeared to be fully stocked woodlands and fifteen plots were established in less than fully stocked areas. Determination of full stocking was made with reference to understory cover where cover of 10% or less was taken as an indication of full overstory stocking (Meeuwig and Cooper 1981).

Table 1.--Geographic distribution of temporary sample plots by state and resource management unit

Location	Number of Plots	
New Mexico	24	
Santa Fe N.F.		11
Carson N.F.		6
Gila N.F.		7
Arizona	24	
Coconino N.F.		8
Tonto N.F.		3
Kaibab N.F.		6
Prescott N.F.		5
Apache-Sitgraves N.F.		2
Colorado	12	
San Isabel N.F.		2
Royal Gorge R.A., BLM		4
San Juan R.A., BLM		6
TOTAL	60	

Plots were not located in stands with evidence of disturbance within the last 20 years or in areas of infection by mistletoe.

Variable sized, rectangular, fixed-area plots were established to encompass approximately 20 live pinyon or juniper stems over 25 mm at stump height (SH) where stump height was taken as 15 cm above the root collar. Species, diameter at stump height (DSH), crown class, crown diameter and form, and total height were determined for each tree. For trees which forked below 15 cm, an equivalent DSH was determined as the square root of the sum of the squared individual stem diameters. Total age was determined on a disk taken from the base of two trees of each species present on or near the plot where each tree was considered to have been free of visible damage and free of abnormal competition. Percent ground cover by species was recorded along two line transects perpendicular to the long axis of each plot. A disk was taken from stump height from each tree in a plot. Sapwood area at stump height and diameter increment were determined on each sample disk.

From the plot data, a number of estimates were derived in accordance with published approaches for estimating site quality. Density of each stand was determined by a number of indices including basal area, stand density index (Reineke 1933), and total volume. Standing volume and basal area were estimated for each stand ten years prior to sampling. Volume estimates for each tree were calculated from the volume equations for pinyon and juniper reported by Clendenen (1979). Volume and basal area increments were determined by subtraction of past net volume and basal area estimates from current estimates. Volume increment was chosen as the standard of evaluation for performance of site quality estimation techniques.

RESULTS AND DISCUSSION

Techniques to estimate site quality for pinyon-juniper woodlands fall into three categories:

a. density of "fully stocked" woodlands,
b. crown measurements, or
c. height-age relations.

Site quality estimates based on these techniques were then evaluated with respect to their correlation with volume increments and ease of field application.

Basal area of "fully" stocked stands was proposed by Howell (1940) as an estimator of site quality. This technique relies on the assumption that, in the course of stand development, a site dependent asymptotic amount of basal area is reached and maintained through self-thinning and succession. To be useful in field applications, the point at which a stand becomes fully stocked must be evidenced by some structural characteristic other than tree density which does not vary from site to site. Understory cover was used as an indicator of overstory stocking where cover of 10% or less

was an indication of full stocking of the overstory. Summary stand statistics from sampled woodlands indicated that while fully stocked stands were generally more dense and basal area and volume increments were higher, there was considerable overlap between the two categories (table 2). Volume increment was not highly correlated with basal area stocking (fig. 1, table 3). The R^2 of the linear relation for fully stocked stands was 0.45.

This index favorably meets the criteria of ease of use in field applications and correspondence to common inventory techniques. However, it is useful only in woodlands that are fully stocked. The R^2 of the linear relation for less than fully stocked stands was 0.07. Also, the relatively poor correlation between volume increment and basal area suggests that it may not be a satisfactory index of potential productivity. There are two possible explanations for its poor performance. First, use of understory cover to determine full stocking may lead to erroneous classification of woodlands. Understory cover may be related to site as well as overstory stocking and woodlands are frequently grazed by domestic livestock and wildlife. In either case, inappropriate classification of stocking levels might result which would influence the relation between volume increment and basal area. Second, maintenance of a constant basal area over time after reaching an asymptotic stocking level may not be a characteristic of stand development (Long and Smith 1984) in pinyon-juniper woodlands.

Meeuwig and Cooper (1981) propose use of basal area growth in fully stocked stands as an index of site quality. For our data set, there was a high correlation between volume increment and basal area growth (table 3). The R^2 of this linear relation for fully stocked stands was 0.88. While the performance of this index may be satisfactory, the high cost associated with measuring basal area increment may be prohibitive for common application in inventory procedures and is limited in application to fully stocked stands. This index approximates a direct measure of site quality and may be useful in research applications where a measure of site quality is necessary to test the effectiveness of another index. As suggested by Meeuwig and Cooper (1981), basal area growth may be useful as a direct measure of site quality to verify other indirect estimators.

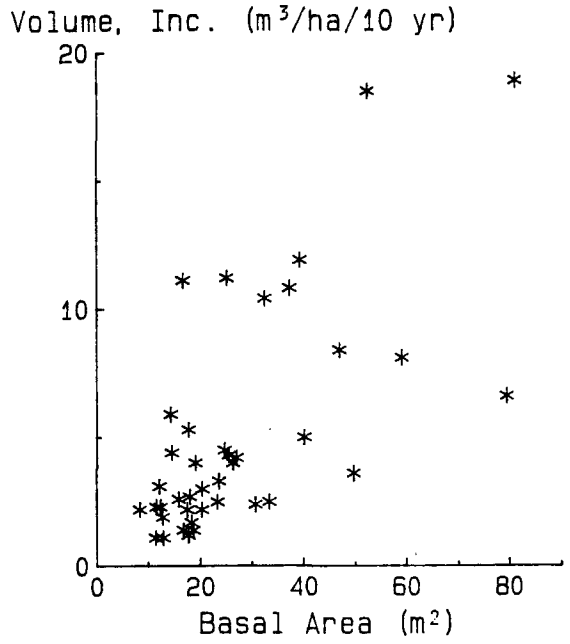


Figure 1.--The relation between volume increment and stand basal area for 41 fully stocked southwestern pinyon-juniper woodlands.

Application of allometric relations between tree diameter and crown size have been proposed by Tausch (1980) as a means of estimating site quality. He speculates that allometric relations between transpiring surface area and bole dimensions will change with differences in environment. A linear relation between leaf area and sapwood basal area has been documented in numerous studies (Grier and Waring 1974; Waring and others 1977; Kauffman and Troendel 1981) and there are indications that the relation may be site-dependen (Whitehead 1978; Grier and others 1984). For our test, we used total crown volume of fully stocked stands as an indicator of site quality.

The correlation between volume increment was significant but low where the R^2 was only 0.53 (table 3). This approach is limited by the same impediments to application in inventory procedures as other density-based indices which rely on a subjective assessment of full stocking. Also, measurement of crown dimensions is time consuming

Table 2.--Combined stand data summary

		Stems (ha)	Stand Density Index	Basal Area (m^2/ha)	Volume (m^3/ha)	Volume Growth (m^3/ha/10 yr)
Fully Stocked	Mean	1332	672	27.3	82.5	5.6
	S.D.	850	400	17.5	74.6	5.4
	Min.	188	220	8.3	9.3	1.1
	Max.	3571	1848	81.3	304.1	18.8
Less Than Fully Stocked	Mean	471	319	14.0	37.0	1.7
	S.D.	199	131	6.8	38.5	1.3
	Min.	242	126	4.4	7.3	0.5
	Max	950	600	28.0	150.5	5.2

Table 3.--The relationship between volume increment (m^3/ha/10 yr) and proposed estimates of site quality

Dependent Variable	Independent Variables	Regression Equation	R^2	SE
		FULLY STOCKED STANDS ONLY		
1. Volume Increment	Basal Area (m^2/hr)	$-0.2037 + 0.2092(X_1)$	.45	4.17
2. Volume Increment	Crown Volume (m^3/ha)	$0.8788 + .0208(X_1)$	.53	3.87
3. Volume Increment	Basal Area Increment	$-1.9440 + 3.6243(X_1)$	.88	1.93
		ALL STANDS SAMPLED		
1. Ln* (Volume Increment)	Stand Density Index	$0.2473 + .0016(X_1)$	.55	.56
2. Ln (Volume Increment)	SDI** (X_1), Site Index (X_2)	$-0.9583 + .0016\ (X_1) + .1722\ (X_2)$	.72	.45
3. Ln (Volume Increment)	Basal Area (m^3/ha)	$0.3685 + .0334\ (X_1)$	.45	.61
4. Ln (Volume Increment)	BA (X_1), Site Index (X_2)	$-0.8336 + .0333\ (X_1) + .0172\ (X_2)$	.62	.52

*Ln refers to the natural logarithm of the dependent variable.
**All SDI calculations are based on metric units.

during inventory. We suspect that the allometric relation between crown volume and diameter is responsive to changes in density as well as differences in environment.

Daniel (1966) proposed that height at a standardized diameter, rather than a base age, could be used as an estimator of site quality. We felt that the height-diameter relationship was influenced by density, so we attempted to derive a height-age relation which would be independent of stand structure. Graphical analysis indicated that height-age data for the pinyon site index trees was similar in form to that observed for most conifers (fig. 2). The Chapman-Richards function was fit to these data using a non-linear procedure. Guide curve development based on this function requires the estimation of parameters $theta_1$, $theta_2$, and $theta_3$ in the following equation (Clutter and others 1983):

$$H = theta_1\ [1 - \exp(-theta_2\ A)]^{[(1-theta_3)^{-1}]}$$

$theta_1$ = Height asymptotic level

$theta_2$ = Rate "$theta_1$" is approached

$theta_3$ = Allometric parameter

H = Tree height

A = Tree age

The parameters $theta_1$, $theta_2$, and $theta_3$ of the Chapman-Richards function were estimated using a non-linear regression procedure (Dixon 1983). The non-linear procedure minimized the residual sum of squares of the predicted values while producing unconstrained final parameter estimates:

$theta_1 = 7.63$

$theta_2 = 0.01353$

$theta_3 = 0.0621$

Residual sum of squares = 282

Error mean square = 2.91

When these estimates are substituted into the Chapman-Richards equation, the specific formulation of the guide curve is:

$$H = 7.63\ [1-\exp(-.01353A)]^{1.06628}$$

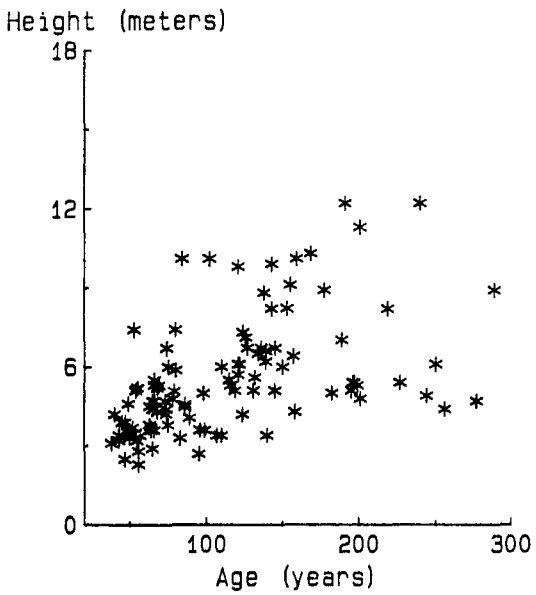


Figure 2.--The relation between total height and total age for pinyon pine site trees from 56 plots in southwestern pinyon-juniper woodlands.

A height-age curve for one site index given the age of reference (A_0) and the asymptotic level ($theta_1$) is as follows:

$$S = theta_1 \, [1-\exp(-.01353A_0)]^{1.06628}$$

Prediction of individual tree site index from height and age measurements (A_0 of 200) is determined from the following equation:

$$S = H \left[\frac{.93305}{1 - \exp(-.01353711\ A)}\right]^{1.06628}$$

These equations produce a family of anamorphic site index curves which can be used to derive an estimate of site index at base age 200 for pinyon pine from measures of S.H. age and total height (fig. 3). This system has the advantages of independence from density and stand structure and ease of application in standard inventory procedures.

Although site index alone was poorly correlated with volume increment, the correlation between volume increment and site index used in conjunction with a measure of density was relatively high (fig. 4, table 3). This is consistent with the interaction between site index and density that would be expected for other forest tree species.

The same procedure was attempted with similar data for juniper trees. Preliminary data analysis indicated that the relation between height and age for juniper was inconsistent with the assumptions necessary for construction of a height and age based site index system.

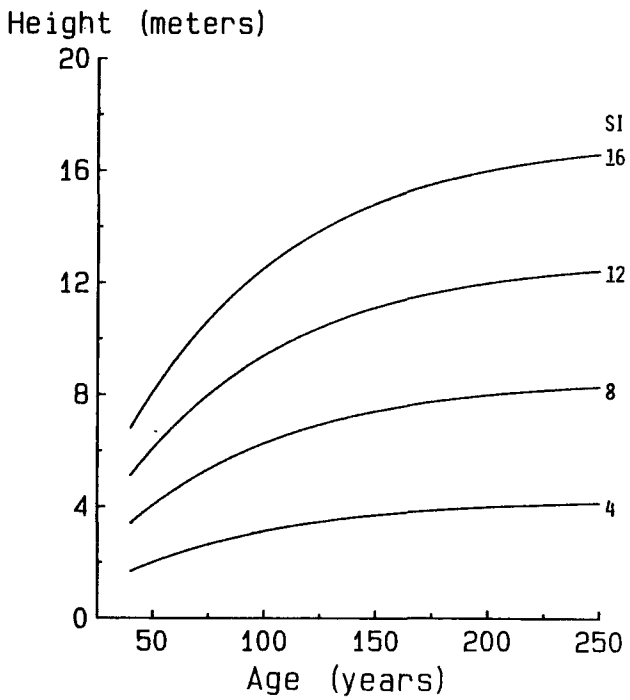


Figure 3.--Pinyon pine site index curves (base age 200) for southwestern pinyon-juniper woodlands derived from the Chapman-Richards equation fit to total height and age based on 100 trees in 56 stands.

SUMMARY

A variety of techniques which have been proposed for use as a means to estimate site quality in pinyon-juniper woodlands were tested with a regional data set from the southwestern United States. The indices tested were from three categories--density of fully stocked stands, allometric relations between crown and bole size and height-age site index.

Indices based on density of fully stocked stands were generally found to be poorly correlated with volume increment and are limited in application to undisturbed, high density stands. In addition, the process of classifying stands as fully stocked appears inexact as there was considerable overlap in density and increment between fully and less-than-fully stocked stands in our data set.

Indices based on allometric relations between crown and bole size may incorporate effects of stocking and environmental conditions and were thus modestly correlated with volume increment. However, application of this class of indices would require time-consuming measurements in inventory procedures.

Anamorphic height-age site index curves for pinyon pine appeared to perform well based on the criteria of correlation with volume increment and effectiveness for use in inventory procedures. When differences in density were accounted for, there was a high correlation between site index

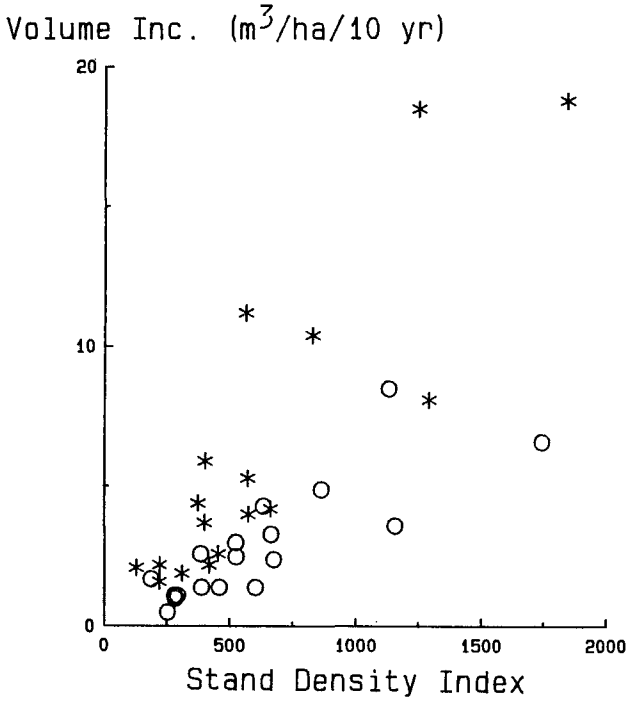


Figure 4.--The relation between volume increment and SDI for the top (*) and bottom (o) 1/3 of site index of 56 fully- and less-than-fully-stocked southwestern pinyon-juniper woodlands.

and volume increment of fully and less-than-fully stocked stands. This relation suggests utility of height-age site index for developing growth equations for the species. A set of anamorphic site index curves for base age 200 are presented for pinyon pine in the southwest.

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GROWTH CHARACTERISTICS AND THINNING RESPONSE FOR THE PINYON-JUNIPER WOODLAND TYPE IN NEW MEXICO

John M. Fowler and Jeff M. Witte

ABSTRACT: Twelve quarter-acre plots were constructed at four sites in New Mexico. Trees were measured and quality rated. There were 4,372 trees in this study. The plots were cleared on the basis of 0, 33, 67, and 100 percent of net crown cover. Fuelwood volume estimation equations were developed for each site and by species. Thinning treatments were used to determine the trade off between annual forage growth and wood fiber production. Production prices were determined and enabled alternative thinning practices to be analyzed. The results indicate that the 180-year planning horizon currently being used by land management agencies is too short.

INTRODUCTION

New Mexico has an estimated 17.2 million acres of pinyon-juniper (P-J) woodlands, which is the largest area of P-J in the southwestern states (Little 1977). Federal and state agencies estimate that nearly 10 million acres or 14 percent of the state's total land area is occupied by manageable P-J stock, where manageable is a function of accessibility and density (Fowler and others 1985). P-J woodlands constitute an important economic resource. Products include fuelwood, fence posts, Christmas trees, landscape design trees, and pinyon nuts. The land surface of this ecotype is used primarily for livestock grazing.

Dominant juniper species in New Mexico include oneseed juniper (Juniperus monosperma), Rocky Mountain juniper (J. scopulorum), alligator juniper (J. deppeana), and Utah juniper (J. osteoperma). The primary pinyon species in New Mexico is (Pinus edulis).

Increased energy costs have made fuelwood a viable alternative source of heat energy. Thinning provides fuelwood as well as freeing available water and nutrients for stimulated forage production. However, complete removal of tree stands can alter forage composition, especially where cool-season grasses are prevalent.

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John M. Fowler is Associate Professor, Dept. of Agricultural Economics and Agricultural Business, Jeff M. Witte is Research Specialist, Dept. of Agricultural Economics and Agricultural Business, New Mexico State University, Las Cruces, NM.

Increased fuelwood demand has accelerated the need for accurate supply estimates and growth rate patterns of P-J stands. Current inventory methods can be costly and time consuming. Information relating readily obtainable field measurements such as net crown cover and height to the more difficult measurements of volume, age, and gross crown cover is needed. The shrubby form of the P-J stands often precludes estimating many parameters that are more readily extractable from aerial photography.

Meeuwig and others (1979) state that crown area and crown diameter can be estimated with confidence from aerial photography. Research is also needed to determine forage response to different thinning ratios on the P-J ecotype. Forage and P-J typically compete for fixed resources. Obtaining an understanding of forage-fiber interactions could have important implications for future thinning practices on P-J woodlands.

The objective of this research include:

1. to determine econometric models relating easily obtained physical P-J growth parameters to key variables necessary for P-J woodland management.
2. to estimate long-run fuelwood growth curves for the uneven-aged P-J ecotype, and
3. to estimate appropriate thinning rates to maximize the value of forage-fiber production from the P-J woodland type.

SITE LOCATION AND DESCRIPTION

Four research areas with 12 quarter-acre plots at each site were established. Sites were located near Cloudcroft, San Lorenzo, Taos, and Cebolla, NM. Selection criteria for the research sites included presence of key target species, representative nature of the site to the general surrounding area, and the undisturbed nature of the site.

Detailed descriptions of the research sites established in Cloudcroft and Taos in 1981 are available (Fowler and others 1984). The site description included topographic features and listing of principal tree species and forb species.

EXPERIMENTAL DESIGN AND DATA COLLECTION

Research plots were established using a nested split-plot experimental design. All trees having a stem diameter (outside bark) greater than 2 inches at 1 foot above the groundline were measured. Variables included species, maximum crown diameter, minimum crown diameter, stem diameter (outside bark) at 1 foot above groundline, crown height and a subjective quality rating. The subjective quality rating was based upon: growth potential, form, vigor, disease or insect damage, and seed production. Dead trees received the lowest quality rating (1). Trees that were diseased or insect damaged were rated no higher than 2, and nicely formed, vigorous trees with evidence of seedling production were rated 5. Quality rating was used to aid in determining the thinning selection. When thinning treatments were assigned, the trees with the highest quality rating were left on the plots, except in clear-cut plots.

Measurement of trees with multiple stems posed a particularly difficult challenge in correlating data to an equivalent single-stem tree. The multiple-stem trees in Taos had from two to eight stems. The approximation for the Taos research site was found to be the sum of the largest and smallest stem diameters for each of the multiple-stemmed trees. The approximation at Cloudcroft was the sum of all the stems, pointing out the variation between the two sites. Multiple-stemmed trees were placed in models using the single-stem approximations.

A detailed map of individual plots was developed to scale showing crown cover and spatial position of each tree. The amount of crown overlap among trees was also indicated. Spacing for each tree was calculated by summing the distances to the four nearest trees. The map also indicated the number and location of seedlings and saplings within each plot. Chojnacky (1985) recommended such a procedure during his discussion of building better P-J volume equations.

Net crown cover for each tree was calculated by adjusting gross crown cover by the amount of overlap between adjacent trees. Total net crown cover was calculated. Plots were then stratified into three blocks based on their similarities in crown cover. Four thinning treatments (0, 33, 67, and 100 percent of net crown cover) were randomly assigned within each block.

Trees within each plot were sorted first by quality rating, and second by spacing. Trees with the lowest quality rating and closest spacing factor were removed in plots requiring thinning. This left the highest quality trees with maximum dispersion within the plots. In some cases tree selection was slightly modified after visual inspection of the site revealed that uniform dispersion would not be obtained.

INDIVIDUAL TREE ANALYSIS

To accurately determine volume and age figures, destructive sampling was conducted. It was felt that destructive sampling was necessary due to the earlier described problems with multiple stems, difficulty in increment boring, and large percentage error associated with visual segmentation techniques Chojnacky (1985). Merchantable fuelwood in cubic feet (2-foot logs at least 2 inches in diameter) volume was measured for each tree. Total cubic feet for each plot was converted to a cordwood measurement. The method of stacking incorporated air, wood, and bark, therefore, the proper cordwood conversion is 128 cubic feet per cord.

Table 1 provides characteristics of the Cloudcroft site. A total of 674 trees were destructively sampled. A similar table is available for the remaining sites. The San Lorenzo site had the fewest trees, where 421 of 736 total trees were destructively measured. The Taos site had 640 trees cut from 1,118 on the site. At the Cebolla research site 661 trees were cut of 1,213 total trees on this site. The data base for the four research sites were comprised of 2,396 trees destructively sampled of the 4,367 trees measured.

Table 1.--Cloudcroft research site characteristics

Plot	Number of trees	Number of tree cut	Thinning treatment	Total net crown	Net crown ranking	Fuelwood cut	Cord-wood equiv.
			(percent)	(Sq. ft)		(cubic ft)	(cord)
1	107	0	0	6,000	5	0	0
2	132	69	33	5,578	8	198	1.5
3	77	52	67	4,024	12	173	1.4
4	110	0	0	4,459	11	0	0
5	125	125	100	5,892	6	459	3.6
6	121	121	100	7,420	1	418	3.3
7	117	77	67	6,583	3	316	2.5
8	140	0	0	7,324	2	0	0
9	85	48	67	5,687	7	226	1.8
10	78	35	33	5,373	9	114	.9
11	91	91	100	5,170	10	394	3.1
12	117	56	33	6,256	4	172	1.3
Total:	1,300	674				2,470	19.4

ECONOMETRIC PROCEDURES

Gross Crown Cover (Individual Tree)

The land area covered by the crown of the tree and defined as gross crown cover is an important variable in determining density estimations of

woodlands. Determining gross crown cover by taking field measurements can be costly and time consuming. A simpler and less expensive method of measuring gross crown cover was desired. It was hypothesized that gross crown cover can be estimated from net crown cover. Net crown cover can be obtained from aerial photogrammetry. Height was another variable hypothesized to have explanatory capabilities, however, results were insignificant. Gross crown cover was plotted against net crown cover to determine the functional form of the model. Plotting indicated a linear relationship between between the two variables. The resulting models estimating gross crown cover for individual trees were as follows:

Cloudcroft:

$$G = 26.5 + .94N \quad F = 5186$$
$$[1.21] \quad [.01] \quad R^2 = .7996$$
$$(21.94) \quad (72.02) \quad n = 1300;$$

San Lorenzo: $G = 19.6 + 1.01N \quad R^2 = .89$

Taos: $G = 17.8 + 1.07N \quad R^2 = .84$

Cebolla: $G = 21.7 + .93N \quad R^2 = .91$

where: G = gross crown cover in square feet
N = net crown cover in square feet
[] = standard error of the estimate
() = t value of the parameter
n = number of observations.

Each research site had similar equation formats. That is, the intercept was approximately 20 square feet and the slope approximately equal to one. All parameter values in this, as well as other equations estimating gross crown cover, were statistically significant at the $\alpha = .0001$ level.

GROSS CROWN COVER (Plots)

Models were reformulated to predict gross crown cover from net crown cover on a plot basis. The equations for the Cloudcroft site were as follows:

Cloudcroft: $G = -988.11 + 1.60N \quad F_2 = 158$
$[752.36] \quad [.13] \quad R^2 = .94$
$(-1.31) \quad (12.57) \quad n = 12;$

Combined sites: $G = 235.01 + 1.31N \quad F_2 = 409$
$[351.98] \quad [.06] \quad R^2 = .90$
$(.67) \quad (20.22) \quad n = 48;$

where: G = gross crown cover in square feet
N = net crown cover in square feet.

These equations had higher predictive capabilities than those for individual tree measurements as indicated by higher R^2 values. The potential errors associated in estimation of individual trees may have balanced. F-values of the equations were statistically significant at $\alpha = .001$. The t-value for the slope parameter was also significant at this level.

The plot data were combined and one universal equation estimating gross crown cover from net crown cover was formulated. Dummy variables were used to determine structural differences between research sites. Analysis indicated that with gross crown cover estimations there was no structural difference on a plot basis. The universal equation for the combined sites explained about 90 percent of the variation in gross crown cover.

Volume Estimation (Individual Tree)

Fuelwood is an important revenue source from the P-J ecotype. Increased energy costs have made fuelwood a realistic alternative source of heat (Gray and others 1981). Increased demand for fuelwood has accentuated the need for forest management planners to accurately determine the supply of merchantable fuelwood. Econometric models predicting the relationship between volume and key explanatory variables were developed. Only clearcut plot tree data were used in this particular analysis because site representation would be appropriate only where all trees were cut. In other thinned plots, the best trees were typically left and this could bias the results. Additionally, models were stratified by species into pinyon and juniper classifications. The resulting models were as follows:

Cloudcroft:

Model 1: Pinyon and Juniper
$LnV = -6.2 + 1.22LnH + 1.06LnD + 0.33LnG \quad F = 312$
$[.33] \quad [.16] \quad [.11] \quad [.10] \quad R^2 = .7838$
$(-18.5) \quad (7.75) \quad (9.32) \quad (3.26) \quad n = 262;$

Model 2: Pinyon
$LnV = -4.9 + 0.9LnH + 1.5LnD \quad F = 41$
$[.73] \quad [.40] \quad [.39] \quad R^2 = .6588$
$(-6.69) \quad (2.27) \quad (3.98) \quad n = 37;$

Model 3: Juniper
$LnV = -6.57 + 1.41LnH + 0.95LnD + 0.38LnG \quad F = 272$
$[.39] \quad [.20] \quad [.13] \quad [.11] \quad R^2 = .7889$
$(-16.9) \quad (6.94) \quad (7.41) \quad (3.51) \quad n = 222;$

where: LnV = Natural log of volume in cubic feet
LnH = Natural log of height in feet
LnD = Natural log of diameter 1 foot above ground line, in inches
LnG = Natural log of gross crown cover in square feet.

Similar equations were developed for the other three sites; the equations had the same functional form with three exceptions. The Cloudcroft and San Lorenzo pinyon, as well as the Taos juniper model, did not have a statistically significant ($\alpha = .05$) gross crown cover variable. R^2 values ranged from .66 for pinyon trees in the southeast to .91 for pinyon trees in the northeast. The highest R^2 values were

in northern New Mexico where pinyon was the dominant species. Where juniper was the dominant species, the R^2 values for the juniper models ranged from .78 in the southwest to .87 in the northwest.

Volume Estimation (Plot)

Volume estimations were also developed on a plot basis. Data from clearcut plots at all sights were pooled. Total merchantable fuelwood volume was regressed against total net crown cover and average height. Analysis indicated that height was not a good explanatory variable for volume as it was not statistically significant at the $\alpha = .10$ level.

The universal volume estimation equation was:

$LnV = -1.98 + .93LnN \quad F_2 = 21$
$\quad [1.75] \quad [.20] \quad R^2 = .68$
$\quad (-1.13) \quad (4.56) \quad n = 12;$

The equation explained 68 percent of the variability in volume, and the independent variable net crown cover is readily obtainable through aerial photography (Meeuwig and others 1979).

Age/Volume (Individual Tree)

Determining the relationship between age and volume was essential in order to allow inferences to be drawn as to appropriate thinning rotations. Age was approximated by tree ring analysis. Volume was measured in cubic feet and represented the merchantable fuelwood produced by individual trees. Only data from clearcut plots were used in this analysis to obtain true age and volume relationships. Different functional forms of relationships between age and volume were analyzed. Equations using natural log relationships were used so that growth rates could be obtained. The resulting equations were as follows:

Cloudcroft:
$LnV = -10.27 + 2.08LnA \quad F_2 = 242$
$\quad [.67] \quad [.131] \quad R^2 = .4542$
$\quad (-15.26) \quad (15.56) \quad n = 293;$

San Lorenzo:
$LnV = -6.82 + 1.60LnA \quad R^2 = .3193$

Cebolla:
$LnV = -9.14 + 1.96LnA \quad R^2 = .5030$

Taos:
$LnV = -16.93 + 3.50LnA \quad R^2 = .6748.$

All parameters were statistically significant at the $\alpha = .001$. The best equation depicting the relationship between volume and age was for Taos. Age was not a good predictor of volume as indicated in the low R^2 values. Ideally, growth could be measured through time or simulated. However, in mixed and uneven stands of P-J, this estimation technique is adequate.

Rates of growth of tree volume over time can be derived by taking the first derivative of the formulated equations. To facilitate this, the equations were transformed from log form to exponential form. The transformed equations are as follows:

Cloudcroft $V = .000035A^{2.08}$

San Lorenzo $V = .00109A^{1.6}$

Cebolla $V = .000107A^{1.96}$

Taos: $V = 4.4 \times 10^{-8}A^{3.5}$

Taking the first derivative of the equations results in the rate of growth for each area. The rates of growth were as follows:

Cloudcroft: $\frac{\partial V}{\partial A} = .00007A^{1.08}$; n = 293

San Lorenzo: $\frac{\partial V}{\partial A} = .0017A^{.6}$; n = 156

Cebolla: $\frac{\partial V}{\partial A} = .00021A^{.96}$; n = 279

Taos: $\frac{\partial V}{\partial A} = 1.55 \times 10^{-7}A^{2.5}$; n = 258

The growth rate curve for Cloudcroft is presented in figure 1.

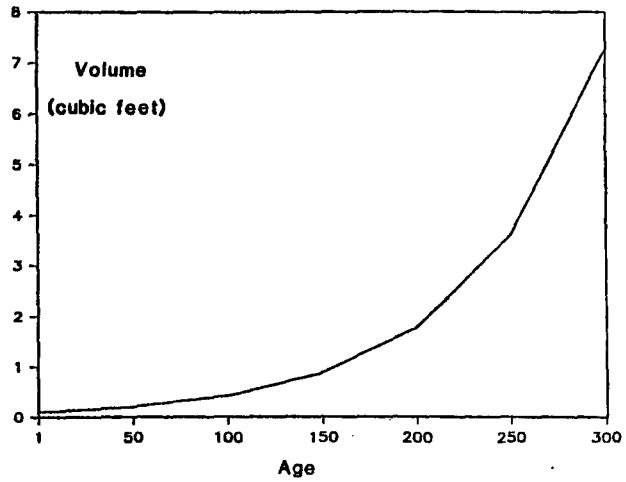


Figure 1.--Cloudcroft volume/age relationship.

The growth rates were on a per tree basis for each 1/4 acre plot. The equations were converted to an acre basis using the formula ($V = \frac{\partial V}{\partial A} 4(n)$). The average number of trees (n) was determined for each clearcut quarter-acre plot as follows: Cloudcroft 98; San Lorenzo 52; Cebolla 93; Taos 86. The resulting growth relationships were as follows:

Cloudcroft: $(.007A^{1.08})\ (4)\ (98) = .02744A^{1.08}$

Lorenzo: $(.0017A^{.6})\ (4)\ (52) = .3536A^{.6}$

Cebolla: $(.00021A^{.96})\ (4)\ (93) = .07812A^{.96}$

Taos: $(1.55 \times 10^{-7} 8A^{2.5})\ (4)\ (86) = .000053A^{2.5}$

FIBER RESPONSE

During the summer of 1984, the Cloudcroft and Taos stands were remeasured to obtain possible growth patterns. Individual trees were measured. Comparisons to original values were made and changes noted. The differences in measurements for height and diameter were then used to estimate volume growth of individual trees. The respective models for Cloudcroft and Taos P-J volume estimation presented earlier were used to estimate volume changes over the 4-year period. Table 2 depicts the cubic foot volume changes and their respective cordwood equivalents. Volume changes over the 4-year test period were minute. Slow tree growth rates make this analysis particularly difficult in the short run. A portion of the estimated changes in volume could have been due to sampling error as tree heights and crown cover were comparatively measured.

Table 2.--Cloudcroft cubic foot volume growth estimations by plot, 1984

Thinning treatment	Plot	Number of trees	Average volume change (per tree)	Total volume change per acre over 4 years	Cord/acre equivalent
(percent)			(cubic foot)	(cubic foot)	(cord)
0	1	107	.000412	.044084	.001377
	4	111	.002160	.239760	.007492
	8	140	.002282	.319523	.009984
33	2	135	.001000	.134897	.004220
	10	78	.000756	.058993	.001844
	12	117	.001491	.174455	.005452
67	3	77	.000402	.030918	.000968
	7	117	.000420	.049164	.001536
	9	85	.013136	1.116526	.034892

A positive relationship was expected between growth rates of individual trees and the progressiveness of the thinning treatment. Analysis did not support this expectation. There was no distinct pattern in the average growth rates of the individual trees. This analysis is premature, considering the slow growth rates of the species under study.

FORAGE RESPONSE

Forage Measurements

Permanent range transects were placed in each 1/4 acre plot. Two 40-foot lines were centered within each half plot. Forage species and production were measured over time. After plots were thinned, seeding treatments were randomly assigned to each half-plot. Seeding was done by hand broadcast. Seed mixture and application rates were predetermined by BLM and Forest Service personnel. Mixture and application rates were unique to each site. Transects were clipped at the end of each growing season. Forbs and grasses were oven-dried to determine dry weight.

Forage response to thinning treatment was monitored on a yearly basis. At the end of the growing season, range transects were clipped and dried weight of forage calculated. Changes in forage composition and weight were noted. The Cloudcroft and Taos research sites provided 4 years of forage growth data. Cebolla site had only been measured twice, and thus did not render sufficient information to formulate viable inferences. Extreme weather conditions and livestock grazing prevented the clipping of transects at the San Lorenzo site during the second year, therefore, only initial forage stands had been measured.

Cloudcroft

Forage response was variable (table 3). Forage production ranged from 17 lb/acre on the 33 percent plots in 1981 to 7,913 lb/acre on the 100 percent clearcut plots in 1985. There was no distinct trend in forage production for native grass species in response to thinning treatments. Native forage production on the 33 percent and 67 percent thinned plots remained below the levels on the control plots. Seeding was of little benefit on the control and 33 percent thinned plots. Seeding the clearcut and 67 percent thinned plot resulted in a substantial increase in forage production during 1984 and 1985.

Table 3.--Cloudcroft forage growth characteristics, 1981-1985

Year sampled	Forage type[1]	Yield (lb/acre) Thinning treatments (percent) 0	33	67	100
1981	Native	99	16	108	26
	Seeded	1	1	0	6
	Total	100	17	115	52
1982	Native	81	13	73	46
	Seeded	0	0	8	69
	Total	87	22	156	202
1983	Native	73	10	72	20
	Seeded	1	9	6	13
	Total	75	20	87	47
1984	Native	158	42	90	249
	Seeded	1	17	128	947
	Total	180	101	268	1,418
1985	Native	374	87	365	2,796
	Seeded	6	18	1,244	4,333
	Total	471	234	2,536	7,913

[1]Total forage included native grasses, seeded grasses and forbs.

The 1985 growing season produced large forage increases for all thinning treatments. A partial explanation for the increased forage growth could be the substantial increase in precipitation during both years. The average precipitation at the Mountain Park Weather

Station, which is the official weather station for the Cloudcroft area, was 18.48 inches per year. During 1984 the area received 29.10 inches of precipitation, 10 inches more than the yearly average. (Climatological Data Annual Summary Report, CDAS 1983, 1984; Kunkel 1984). Additionally, by the fourth year, the seeded species had time to establish on the 67 percent thinned and clearcut plots. On clearcut plots, seeded species amounted to nearly 60 percent of the total forage.

ECONOMIC CONSIDERATIONS

Two potential revenue sources from the typical P-J woodland type have been examined by this study: forage to be used for grazing and fuelwood to be used as an alternative energy source. Fuelwood was valued at the U.S. Forest Service stumpage price, which is the value in the field, of $7.50 per cord. A 4 percent real compound rate of interest was assigned to obtain the 1985 value of fuelwood taken in 1981. The economic values of fuelwood and forage production on a per acre basis are presented in table 4.

Forage was valued on the premise of increased forage production over the control plot (0 percent) and converted to an animal unit month (AUM) value. Seven hundred pounds of forage is required per AUM (Stoddard and others 1975). Forage value was based on the federal grazing fee of $1.86 in 1982, $1.80 in 1983, $1.37 in 1984 and $1.35 in 1985. All values in table 4

Table 4.--Cloudcroft economic analysis of thinning treatments, 1985

Thinning treatments	0 percent	33 percent	67 percent	100 percent
	----------1985 value per acre--------			
Value of initial thinning	0.00	43.20	66.68	117.00
Value of increased forage, '82	.23	.00	.18	.30
Value of increased forage, '83	.15	.00	.02	.00
Value of increased forage, '84	.35	.00	.17	2.39
Value of increased forage, '85	.91	.00	3.98	14.35
Value of 4-year fuelwood growth	.05	.03	.10	.00
Total	1.69	43.23	71.13	134.04

were presented in 1985 dollars. The value of forage increased substantially during 1984 and 1985 at Cloudcroft. This was especially relevant on the clearcut plots. At Taos, forage growth increased markedly in 1983 and 1985. Again, the clearcut plots had the largest increase.

The federal prices used in this study are regulated prices and not derived from the free market. The relative price ratio is the important determinant in moving toward sound resource management. It is necessary to use prices at the same bottom line, that is, prices that reflect the same net return. It would be inappropriate to use a market value of $100 per cord for the fuelwood, which is composed of cutting, hauling labor, splitting, marketing, and other value-additive inputs. It is also equally erroneous to value the forage at the processed red meat price. The stumpage value in field assumes the public fuelwood gatherer is supplying the labor, equipment, and capital and the public forage consumer is also absorbing the nonfee costs. Implicitly it is also assumed that the planning input into the management of the fuelwood and forage resources is roughly equivalent.

SUMMARY

The pinyon-juniper resource has long been managed on an acreage basis, rather than a volume basis. The models developed represent alternative formulations to allow resource managers to determine the fuelwood volume existing in mixed, uneven-aged stands of the P-J woodland type. Response statistics indicate how forage production can be enhanced with the removal of the fuelwood. Little change was observed when less than two thirds of the crown cover was removed. The largest response value was realized when the fuelwood resource was 100 percent utilized. Extremely slow growth rates in the P-J woodland type indicate P-J should be managed as a stock resource. Whereas the forage has flow characteristics and even when conservatively valued would suggest fuelwood harvesting should be accomplished by thinning at least two thirds of the net crown cover. The highest response was achieved by liquidating the fuelwood and capturing the increased forage production.

The long-run inference to be drawn is that the woodland is growing at such a slow rate that merchantable volumes cannot be attained until the stand attains at least 200 years of age. This implies that rotations in P-J of less than 200 years are gradually mining the resource and should be extended.

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SILVICULTURAL SYSTEMS FOR PINYON-JUNIPER

Richard L. Bassett

ABSTRACT: Silvicultural systems and cutting methods apply to pinyon-juniper stands. Each system and cutting method is described and the advantages and disadvantages compared. It appears that both the even- and uneven-aged silvicultural systems can be used to manage pinyon-juniper stands. The cutting methods that best apply are the single-tree selection and shelterwood. Regeneration may be more certain with the single-tree selection method. The clearcut method can be used when alligator juniper is in the stand. The land managers must select the appropriate cutting method that fulfills both the land manager's objective and the species silvical requirements.

INTRODUCTION

The pinyon-juniper woodland species that have been grouped together for discussion in this paper are Colorado pinyon (Pinus edulis Engelm.), one-seed juniper (Juniper monosperma (Engelm.) Sarg.), Utah juniper (J. osterosperma (Torr.) little), alligator juniper (J. deppeana Steud.) and Rocky Mountain juniper (J. scopulorum Sarg.).

Past management emphasis of pinyon-juniper woodland primarly has been to modify the woodland overstory so as to increase forage production for livestock grazing. As a result very little research has been done to identify the silvical characteristics, proper stocking levels or the silvicultural systems and cutting methods that are appropriate for pinyon-juniper regeneration and stand management.

There is a management shift from forage production as a primary emphasis to other woodland uses as the demand for other uses increase. Some other uses are to provide fuelwood, wildlife habitat, Christmas trees, posts, poles, pine nuts, recreation and aesthetics.

It appears in practice that no single silvicultural system or cutting method is best for all stand management situations. Both even- and uneven-aged silvicultural systems are appropriate for use in pinyon-juniper woodland, however not all cutting methods under each system are applicable in every stand, nor will every cutting method meet specific management objectives. The cutting methods that appear to apply best from a practitioner's point of view are the single-tree selection and two-step shelterwood. The stand clearcut can be used successfully in stands that have a significant component of alligator juniper or where stand objectives include a long term grass-forb stage.

The silviculturist or land manager must select the appropriate silvicultural technique (silvicultural system and method of cut) that favors the silvical requirements for the desired pinyon-juniper species mix and the stand structure to accomplish the land management direction. A silvicultural prescription should be written for each stand and, as a minimum, should describe the stand management objectives, the silvicultural technique and the timing of the first entry to treat the stand.

SILVICULTURAL SYSTEM AND CUTTING METHOD DEFINITIONS

A silvicultural system includes the entire process by which forest stands are tended, harvested and replaced. The system includes all cultural practices performed during the life of the stand such as regeneration cutting, fertilization, thinning, improvement cutting and use of genetically improved sources of tree seeds and seedlings (USDA Forest Service 1984). Silvicultural systems can be distinguished as either even or uneven-aged.

EVEN-AGED SILVICULTURAL SYSTEM

The even-aged system results in a stand of trees that are about the same age. The difference in age between trees forming the main crown canopy level will usually not exceed twenty percent of the rotation age. The rotation age can vary depending upon the land manager's objectives for a stand.

An even-aged stand of trees has a definite starting point or formation and an ending point or regeneration period when the entire stand is replaced with a new stand. The regeneration period may be abrupt or extended over a period of years depending upon the regeneration cutting method. The cutting methods used in the even-aged silvicultural system are clearcut, shelterwood and seed-tree.

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Richard L. Bassett is Regional Silviculturist, Southwestern Region, Forest Service, U.S. Department of Agriculture, Albuquerque, NM.

Clearcut Cutting Methods

The clearcut method is abrupt when an entire stand is cut. This method is called stand clearcut. The stand clearcut method may appear as a woodland range modification project. Removing the woodland overstory by mechanical methods has been done extensively in the past to increase understory forage production for livestock grazing. Stand clearcut and range modification differ; woodland regeneration is planned in a clearcut and not planned in a range modification project. It can be predicted, however, that most range modification projects will eventually return to woodland if not maintained.

There are several reasons for the eventual return of trees in a woodland conversion project: first, most range forage improvement projects do not completely eliminate the smaller trees; second, some live branches may be left on the juniper trees; third, birds and rodents disperse seeds; fourth, alligator juniper, if present, will sprout.

The stand clearcut method can be used when regeneration is relatively certain. A stand can be regenerated either naturally or artifically by planting. The following factors influence natural regeneration:

1. The invasion of new trees is not considered to be reliable because of the infrequency of good seed crops and the combination of climatic factors that influence high seed germination and tree survival.

2. The woodland species have a large, wingless seed. Adequate seed distribution is not considered a certainty because of the unpredictable factors of seed dispersal by birds and rodents.

3. Regeneration will occur naturally from alligator juniper sprouting as well as seed (Barger and Ffolliott 1972). Jameson and Johnson (1964) found that alligator juniper has three types of sprouts: epicormic (trunk), basal and root (suckers). Basal sprouts occur more often than the other types. They also found that sprouting decreases as stem diameters increase; no sprouting was observed on trees 31 inches and larger in diameter when cut. There must, however, be an adequate component of alligator juniper in the stand to get proper stocking.

The strip and group clearcut methods are variations of clearcutting that extend the stand regeneration period over several years, perhaps as many as 40 years for a 200-year rotation period. The stand is progressively clearcut in strips or groups until the entire stand is cut and regenerated. The strips and openings should be no wider or larger than twice the average height of the mature trees in the stand. These methods are seldom, if ever, used; however, they may be appropriate to keep cover during the regeneration cutting period for certain wildlife species.

Shelterwood Cutting Method

The shelterwood method is implemented in steps over a period of years at the end of the rotation. The shelterwood method establishes a new stand under the protection of the old by opening the crown canopy enough to encourage seed production and allow light for new seedling establishment and growth.

The shelterwood method typically has a series of three steps in unmanaged stands that are called preparatory, seed and removal cuts. The recognized silvicultural objectives for the preparatory cut are to develop windfirmness in leave trees, develop good quality seed-bearing trees and accelerate breakdown of a deep duff layer. None of the objectives appear to be necessary for most pinyon-juniper stands; therefore, the preparatory cut is not recommended.

The seed cut is required to select the best seed producing trees except when adequate advanced regeneration is already present.

The objective of the removal cut is to provide improved growing conditions for the newly established seedlings and saplings by removing the sheltering seed trees in one or more removals that completely free the new stand. It would appear that only one removal cut, a final removal, would be necessary. The period of time between the seed cut and the final removal cut may be as long as 40 years for a stand with a 200-year rotation age or twenty percent of the established rotation age of the stand.

The two-step shelterwood method (i.e. the seed and final removal cuts) is being used in Northern New Mexico by leaving the best and biggest trees as seed trees in a stand on an average spacing of 20 by 20 feet (109 trees per acre). All other merchantable trees are removed. An average spacing of 30 by 30 feet (48 trees per acre) and 40 by 40 feet (27 trees per acre) has also been tried in other areas in New Mexico. An average spacing between 20 feet and 40 feet is probably an acceptable range for leave seed tree spacing in the two-step shelterwood. Site quality and desired regeneration stocking are two factors that will influence the seed tree spacing. The seed trees will be removed in the final removal cut after seedling establishment and growth.

An option is also available in the removal cut of the shelterwood method to leave some seed trees for pine nut production if pinyon pine is present in the stand. Little (1940) found by looking at the cones under a pinyon pine tree, the best nut producers could be selected.

There is a variation of the shelterwood method called simulated shelterwood (Alexander and Edminster 1980). This method removes the overstory in one or more removal cuts from a fully stocked understory of advanced regeneration. The regeneration was not planned but already exists. Again, one final removal would appear to be necessary.

Seed-Tree Cutting Method

The seed-tree method removes all but a few seed bearing trees left singly or in small groups in the stand.

This method is primarily a stand clearcut with a few remaining trees (between 8 to 15 for many timberland forest cover types) distributed over each acre in the stand. The silvical characteristics of the pinyon-juniper species practically eliminates the seed-tree as an acceptable regeneration method to establish a properly stocked stand. The pinyon-juniper species have heavy, nonwinged seeds that tend to fall under or very near the parent tree and apparently must have shade for germination and early growth.

Intermediate Treatments

All stand treatments between the time a stand is formed and the regeneration cut are called intermediate treatments. Precommercial thinning for stocking control has not been a common practice and will probably not be in the future unless for a specific management objective.

Intermediate treatments such as commercial thinning, and salvage are appropriate but will probably not be used unless the small volumes can be removed by fuelwood cutters. Christmas trees can be harvested as a commercial thinning.

Sanitation cuts are appropriate to control dwarf mistletoe in pinyon pine. Dwarf mistletoe is found in pinyon pine and not in the juniper species. True mistletoe is found in junipers but not in pinyon pine. It is suggested that the same management strategies that are used to control dwarf mistletoe in ponderosa pine (Beatty 1982) will work for pinyon pine.

UNEVEN-AGED SILVICULTURAL SYSTEM

The uneven-aged silvicultural system involves the manipulation of a stand to simultaneously maintain continuous high-forest cover, recurring regeneration of desirable species, and the orderly growth and development of trees through a range of diameter classes.

Stands that are managed under the uneven-aged system do not have an established management rotation age. Management objectives are met by controlling growing stock. Growing stock is regulated by setting the following stand conditions:

1. The Residual Stocking Level After Harvest. The stocking level is expressed as basal area, usually at root collar. Stand basal area should not be reduced below 40 square feet per acre (Meeuwig 1983).

2. The Diameter of The Largest Tree. The maximum tree size to be left after harvest depends upon site productivity and species. The diameter is usually measured at root collar.

3. The Number of Trees Desired in Each Diameter Class. It is essential that all sizes of trees be represented in balanced proportion, and that those trees be able to reach their growth potential.

There is an acceptable approach to determine the number of trees in each diameter class by defining the characteristic inverse-J-shaped curve for the uneven-aged stand (Danial and others 1979). The slope of the curve is defined by the diminution quotient q, which expresses the ratio of the number of trees in any diameter class to the number in the next higher diameter class. The diameter class is usually two-inch, but may be a four-inch class for pinyon-juniper stands.

Stands with a small q value have a relatively higher proportion of the growing stock in the larger diameter classes. A high value of q results in a stand with a greater proportion of small trees (Danial and others 1979).

The period between cuttings in an uneven-aged stand is defined as cutting cycle. In a balanced uneven-aged stand there is theoretically a stable equilibrium between growth, harvest yield, and regeneration (Smith 1962). In practice, growth should remain constant and regeneration should occur continuously or periodically. A cutting cycle between 10 and 30 years would be realistic for many timberland forest cover types but not for pinyon-juniper because of slow growth and low volumes. Cutting cycles should be long, usually 50 to 100 years, to avoid excessive administration and harvest costs (Meeuwig and Bassett 1983). This would also mean larger harvest volumes and less ground disturbance. A 40 year cutting cycle may be appropriate for woodland stands that are capable of producing 10 or more cubic feet of wood per year.

Regeneration cutting methods that develop and maintain uneven-aged stands are single-tree and group-selection.

Single-Tree Selection Cutting Method

The single-tree (individual-tree) selection method periodically removes the less desirable trees from specific size classes over the entire stand to regulate growing stock. This method works well for woodland regeneration and growth.

Group-Selection Cutting Method

The group-selection method completely removes small groups of trees over the entire stand with the sizes of the groups held to an area small enough to assure that the site will be protected by the surrounding trees. The openings should be no larger than twice the average height of the mature trees in the stand. The group-selection method would seldom, if ever, be used for uneven-aged woodland stand management because it is difficult to locate and track the small groups and administer wood removal.

Intermediate Treatments

Intermediate treatments do not apply to uneven-aged stand management. All diameter classes must be cut in each entry to maintain the inverse-J-shaped curve determined for a stand.

THE ADVANTAGES AND DISADVANTAGES OF THE MOST APPROPRIATE WOODLAND CUTTING METHODS

EVEN-AGED SILVICULTURAL SYSTEM

Woodland stands tend to establish and grow with many different ages and sizes of trees (Barger and Ffolliott 1972). This occurs because of the species silvical characteristics favoring seedling establishment under the shade of older trees or in some instances under shrubs. However, woodland species are generally intolerant to shade when they are older and grow best in full sunlight. A stand with many different ages can be manipulated to an even-aged stand.

Stand Clearcut Cutting Method Comparison

The quickest method to create an even-aged stand condition is the clearcut. The prescribed treatment would be to remove all merchantable trees at the same time.

The stand clearcut method has the following advantages:

1. There is immediate control over the size and shape of the future stand. The stand size and shape can be manipulated to meet management objectives, especially to create the grass-forb seral stage.

2. This is the best method to temporarily increase livestock forage and browse for wildlife. The forage and browse production benefit could last up to 30 years.

3. Horizontal diversity for certain wildlife use can be created when this method is used interchangeably with other cutting methods.

4. This is the simpliest method to apply, requires the least amount of silvicultural skill and sale preparation and administration time.

5. Prescribed burning can be used if there are adequate fine fuels to carry a fire and the burning is done before alligator juniper sprouting.

6. This method is the most effective method to control dwarf mistletoe in pinyon pine.

The stand clearcut method has the following disadvantages:

1. Natural regeneration can be obtained with certainty if there is an adequate component of alligator juniper in the stand to get proper stocking from sprouting. Sprouting will not occur with the other woodland species.

2. Artificial regeneration (planting) is an uneconomical option at the present time.

3. The site is exposed to direct insolation, and wind and water erosion.

4. This method is the least desirable esthetically, unless intermingled with other cutting methods. Even then, it may not meet visual quality objectives.

5. This method provides no verticle diversity.

Two-Step Shelterwood Cutting Method Comparison

The two-step shelterwood cutting method appears to be an effective method for woodland even-aged stand management.

The two-step shelterwood cutting method has the following advantage:

1. There is good control over site conditions for natural regeneration.

2. This method can be used with heavy, wingless seed species.

3. There is good site and soil protection from insolation, and wind and water erosion.

4. The stand appearance is generally esthetically acceptable over the majority of the stand rotation.

5. This is the most flexible method, especially if there is a fully stocked existing understory. The final removal cut of a simulated shelterwood can be implemented.

6. There is an opportunity to manipulate the species composition in the stand.

7. Some horizontal diversity can be created between stands with different ages.

8. Dwarf mistletoe in pinyon pine can be controlled.

The disadvantages of the two-step shelterwood cutting method are as follows:

1. Higher technical skills are required in prescribing and marking than the stand clearcut method.

2. Damage can occur to regeneration and/or residual trees during the cutting and removal operation if not given adequate administration.

3. There is a limited amount of vertical diversity within the stand.

4. There are higher costs in sale preparation (marking leave seed trees) and sale administration.

5. Forage production for livestock and browse production for wildlife is less than with the clearcut method. The grass-forb seral stage is nearly eliminated; present only during the regeneration period.

6. Prescribed burning is not an option.

7. There is a tendency for a stand to become overstocked resulting in slower growth and even stagnation since products removed during intermediate treatments may have a low value.

8. Adequate stocking of natural regeneration may not occur within the recognized regeneration period for the established stand rotation age.

UNEVEN-AGED SILVICULTURAL SYSTEM

Since existing woodland stands tend to be in an all aged arrangement it appears that a logical cutting method available to develop an uneven-aged stand is the single-tree selection method.

Single-Tree Selection Cutting Method Comparison

The single-tree selection method has the following advantages:

1. It is the best method to fit the natural stand conditions for regeneration. Regeneration is favored for the large, wingless seed species with available tree shading for seedling establishment and early growth.

3. The site is protected with less exposure to direct insolation, wind and water than the other methods.

4. There is maximum vertical diversity within the stand, more than any other method.

5. Species composition can be easily manipulated in the stand.

6. This method is esthetically desirable.

The disadvantages of the single-tree selection method are as follows:

1. This method requires the greatest skills to manage, especially in the areas of diameter distribution and proper stocking levels.

2. The cost of preparing a sale and administering the removal is higher than other methods.

3. Residual stand damage can be high during product removal without proper administration.

4. Forage production for livestock and browse production for wildlife is always lower then other methods. The grass-forb seral stage is nonexistent.

5. There is a tendency to lose control over the management by not treating the stand on the proper cutting cycle frequency.

6. There is no horizontal diversity for wildlife if the stands are large and continuous. All stands would appear about the same.

7. Prescribed burning is not an option because of species sensitivity to fire.

8. This method is the least desirable to control dwarf mistletoe in pinyon pine.

SILVICULTURAL TECHNIQUE SELECTION

The silvicultural systems and cutting methods (i.e., techniques) have not been tested by research in pinyon-juniper woodland stands (Meeuwig and Bassett 1983). Except for a few instances up until now, Meeuwig (1983) states pinyon-juniper woodlands have not been managed according to silvicultural principles.

It is reasonable to state, however, that silviculture techniques do apply to and can be implemented in, woodland stands. Silviculture, generally, is the art and science of cultivating (i.e., reproduction, establishment, care and development) forest crops in a stand, based on the knowledge of silvics and a stated land management objective.

Land management objectives (stand objectives) are derived from an approved or accepted long-range plan that identifies the product(s) that will be produced from a given area of land. Some examples of products may be forage, wildlife habitat, fuelwood, recreation, poles, posts, pine nuts, and Christmas trees.

It appears in practice that no single silvicultural system or cutting method is best for all land management situations. The silviculturist or land manager must select the appropriate silvicultural technique that fulfills both the selected land management objective and the species silvical requirements. Some of the silvical requirements are habitat conditions, regeneration and growth characteristics and shade tolerance. It is mandatory to know management direction and the silvical characteristics of each woodland species before prescribing a silvicultural treatment.

The prescriptionist must look at the existing stand condition and project what the stand will look like in the future after cutting.

A written stand prescription should be prepared, and as a minimum should describe the stand management objectives (i.e., land management direction), the silvicultural techniques and the timing of the first treatment or cutting for the stand.

CONCLUSION

More research is needed to test the even- and uneven-aged silvicultural systems for woodland stand management. It appears, however, in practice that both systems apply but not all cutting methods in each system, nor will each method meet specific management objectives.

The regeneration cutting methods used in the even-aged silvicultural system are clearcut, shelterwood and seed-tree. The stand clearcut and two-step shelterwood methods appear to work best for even-aged stand management. The stand clearcut method requires less skills to apply and is not restricted when adequate alligator juniper is present in the stand. The two-step shelterwood method requires more skill to apply, is not restricted by species, but the stand may become overstocked before the shelterwood seed cut is made. Removal in the simulated shelterwood can be used when there is an existing, fully stocked understory of advanced regeneration.

The seed-tree method does not work well because of the large, wingless seed characteristics of the woodland species.

The regeneration cutting methods used in the uneven-aged shelterwood system are single-tree and group-selection. The single-tree method works best but requires the most skills to apply, has no species restrictions, is most like the natural all-aged stand condition and allows more frequent control over stocking with each entry of the cutting cycle.

The group-selection method does not work well because the groups would be small and difficult to track, and regeneration is difficult to get in openings.

The land manager or silviculturist must select the appropriate silvicultural technique to meet both the land management direction and the species silvical requirements.

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A MANAGEMENT STRATEGY FOR WOOD PRODUCTION FROM PINYON-JUNIPER WOODLANDS

Milo Larson

ABSTRACT: Application of principles of forest management is suggested as an appropriate management strategy. Inventory is essential and stratification should include size class, stocking, and site quality estimates. Projection or estimates of growth are also needed. Harvest scheduling can then be done using a formula rule or harvest scheduling model. Shelterwood regeneration methods without intermediate cuts appear to be a feasible management strategy.

INTRODUCTION

A management strategy can be defined as manipulating the course of events so that a desired outcome is reached. For the purpose of this paper the desired outcome is presumed to be a sustained yield of wood fiber with concurrent production of other multiple uses.

To exert the proper control of harvest and growth in woodlands we need to know certain things, such as:

1. How much do we have?
2. How fast does it grow?
3. How can it be regenerated?
4. How it is to be utilized?
5. How does fiber production relate to other uses?

Many will say that we do not have sufficient or well documented information in any of these areas. Perhaps not, but we do have enough information about each of them to develop a basic approach to the problem. The approach suggested here includes three steps:

1. Inventory
2. Growth projection
3. Harvest scheduling through a planning model.

INVENTORY

In recent years there has been fairly rapid development of inventory techniques ranging from LANDSTAT satellite data (Ambrosia and others 1983), aerial photos (Moessner 1962), line intercept transects (Meeuwig 1978), Zig Zag transects (Sauerwein 1976), and fixed or variable plots with equations developed from woodland segmentation procedures (Born 1981). The latter approach seems to be finding general acceptance in the Southwest.

An inventory must consist of more than plot taking techniques or volume estimates. Meaningful strata must be developed that will permit projection of growth and estimation of changes in size or age classes as time passes. Cover type and size class should be considered the minimum breakdown that would permit adequate projection. For example, the Southwestern Region of the Forest Service recognizes woodland cover types that include Arizona cypress, mesquite, juniper woodland, oak woodland, pinyon-juniper, and Rocky Mountain juniper. Size classes used for pinyon and juniper are nonstocked, seedlings and saplings (4 inches tall to 2.9 inches DRC [diameter at root collar]), small woodland (3.0 to 8.9 inches DRC) and large woodland (more than 9.0 inches DRC) (USDA Forest Service 1984).

Additional breakdowns in stratification that are often useful include accessibility, stocking or slope classes. Use of some measure of site quality is very desirable also because the range of productivity in pinyon-juniper is relatively broad. It ranges from sites capable of producing little more than juniper shrubs up to sites that can produce trees more than 30 inches in diameter at stump height (Barger and Ffolliott 1972). Some of the pinyon or juniper stands on a given ownership are likely to be impractical to manage for wood products of any kind due to low productivity, while others have relatively good potential for management. The disadvantage to adding more levels to the stratification is that the large number of strata greatly increase costs of both the inventory and the operation of a harvest scheduling model.

GROWTH PROJECTION

Growth Projection is difficult but information and methodologies do exist. Howell (1940) produced growth tables for site quality estimated from basal area at one foot above the ground. Fowler and others (1984) used volume and age to develop growth models for two areas in New Mexico. Smith (1985) has developed a conventional site index for pinyon and productivity estimates based on height and age. These relationships are expected to find their way into newer growth projection models (Edminster 1985).

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Milo Larson is Group Leader, Silviculture and Inventory, Southwestern Region, Forest Service, U.S. Department of Agriculture, Albuquerque, NM.

Regardless of data sources or methodology, the strategist must estimate how the various woodland strata will change as the years pass. The volume of the existing strata and the growth of each strata provide the yield information needed in the operation of a harvest scheduling model.

Growth is dramatically affected by site quality and stocking. Productivity ranges from approximately 2 to more than 30 cubic feet per acre, per year on well stocked, good sites. (Barger and Ffolliott 1972; Smith 1985). Managers have to determine a productivity level at which sites should be excluded from consideration for management that calls for periodic removal of wood fiber.

The growth projection should also be part of the analysis of the management regimes and rotation ages that will be used in harvest scheduling. In addition each manager will have to consider the local situation and make some estimate of minimum product size and minimum volume that could constitute a harvest as well as the time necessary to reach the first two conditions.

If a harvest scheduling model is used, the manager must provide data for a range of rotation ages and a proposed regeneration method. In the southwest, managers commonly select rotation ages between 180 and 220 years using a shelterwood regeneration method.

Other regeneration methods carried forward to the harvest scheduling models often include selection and clearcutting. In practice, selection tends toward high grading because market factors favor removal of the larger and better trees, while clearcuts tend to be difficult to regenerate. A common irony appears to be that range managers have a difficult time preventing regeneration of pinyon and juniper once they have cleared it while foresters can't seem to get seedlings started in the clearings they want restocked with trees.

HARVEST SCHEDULING

Methods

A basic forestry question is what the annual harvest of pinyon and juniper will be for a given Forest or area. Landowners must somehow determine a level of harvest that best meets their objectives. The possible methods to do this range from simplistic formula rules to highly complex computer programs that all but defy comprehension.

Area Control

Use of area control is not recommended because available volume is the most critical factor to users. An equal area harvested each year is likely to produce substantial variation in harvest volume. However, if area control is used, the simplest approach is to divide the area of pinyon-juniper by the chosen rotation age. The result is an acreage to cut each year.

Volume Control

Volume control is recommended because users and markets tend to become dependent on volumes made available from Federal lands and most other interests seem to be concerned about volume removed rather than area cut. It can be calculated using samples taken to estimate the total inventory and the strata that comprise it.

Formula rules.--A simple method is to use Von Mantel's formula.

$$A = \frac{2\,(G)}{R}$$

Where
A = Annual Allowable Cut
G = Total Growing Stock Volume
R = Rotation Age in Years

Other formula rules (Davis 1954) that may have applicablility include Hundeshagen's formula, the Austrian formula, Hanzlik's formula, and the volume summation formula. These offer some refinement over Von Mantel's, but are relatively simplistic in their approach to the problem. Even so they can be recommended as a first approximation for a management strategy. The manager should review each formula and select the one that best meets the local situation and the available information.

Resource allocation models.--More recently, linear programming has been adapted to resource allocation models such as timber RAM (Navon 1971). Use of such a model greatly improves the degree to which the manager can manipulate changes in the growing stock to meet his objectives. Schedules of pinyon-juniper harvests that maximize yields now or in the future can be routinely tested. Allocations of pinyon-juniper woodlands to uses incompatible with production of wood fiber can be modeled to test the probable effect on annual harvest levels. Decisions about which strata to treat first and to what degree can be evaluated without actually carrying out the treatments in the field.

The most recent versions of the FORPLAN model (Gilbert and others 1982) represent the ultimate in the ability to project management scenarios and to test alternatives against wood fiber production and other criteria. Both quantitative and financial responses of alternatives can be tested. If the relationships and values are known, almost any combination of resources can be evaluated.

The problems with the modeling approach are manyfold. Good inventory information is necessary, and it needs to be more site specific than customary in the past. The relationship between production of wood and the response of grasses and forbs to reductions of tree stocking needs to be established for the major community or habitat types. Other relationships for resources as diverse as water yield and recreation need to be established. Values for all resources concerned need to be established if economic evaluations are desired.

The number of possible allocations and resource combinations rapidly approaches infinity, thus creating a need for a very large computer and a wizard to communicate with it. And finally, the complexity of the answer makes it difficult to administer in the field.

In spite of the difficulty, the FORPLAN approach is desirable for application at least to National Forests. The general use of this model for timberlands and other resources makes increased use of its potential in pinyon-juniper woodlands almost inevitable. Advances in inventory technique, site classification, habitat typing, and growth estimation documented at this conference provide a beginning for response information needed to operate the model. Additional research will permit gradual strengthening of information on relationships between resources.

Developing the management strategy.--The range of management strategies applied to pinyon-juniper woodlands is extremely diverse because of different objectives among owners or administering agencies and changing needs of society itself.

Conversion of woodlands to grasslands at as rapid a rate as practical may be the favored strategy for a rancher. Preservation in a relatively undisturbed state may be the strategy favored in a park or research area. Between these two extremes, a host of management strategies can be devised. The overall strategy on a large Federal ownership will undoubtedly include a variety of management within an overall multiple use strategy. This could include preservation, type conversion, wood production, production of pinyon nuts, maintenance of wildlife habitat, maintenance of visual quality and protection of watersheds.

If the manager knows for certain what is wanted and where it should be produced, it is a relatively simple matter to calculate a harvest schedule. When it is less certain, trial allocations to the various uses need to be made. Harvest schedules must be developed for each alterative so that a rational decision can be based on the comparative differences.

Regardless of the methods used to determine harvest levels, a good deal of calculation can be involved. The need for lots of calculations adds to the appeal of computerized approaches. Use of the computerized planning models permits the manager to look at probable results of a variety of management strategies. In addition, the models can calculate an optimum harvest schedule for a given objective such as: maximize sustained yield of wood fiber, or maximize present net value.

Current management.--Even though importance of pinyon-juniper woodlands has increased dramatically in recent years, productivity and values are relatively low. This situation has caused the current managers to favor a low intensity management strategy which typically consists of shelterwood regeneration at a rotation age of about 200 years. Intermediate cuts are not usually scheduled. If uneven-aged management is favored, cutting cycles tend to be long, often 50 years. Where grazing is important, clearcutting is sometimes favored with an allowance made for a long interval for regeneration to become established. In no case does tree planting to enhance wood fiber production appear economically feasible. In most cases, development of road access for harvest of pinyon-juniper is impractical unless it is coincidental to development of roads to more valuable timberlands or for other resource uses. The poorest sites and steepest slopes are typically allocated to uses which are incompatible with wood fiber production.

Management strategy should by no means be constant. Twenty years ago, wood from these lands was essentially worthless and conversion of pinyon-juniper woodlands to grasslands was the basic management strategy for the type. If future changes in demand cause increases in value of the wood or other products, more intensive management strategies may be appropriate.

CONCLUSIONS

Wood fiber production will continue to be important in pinyon-juniper types. Management strategies for wood production should be based on inventory, growth projection, and a harvest scheduling methodology. Methods commonly used to develop management strategies for timberlands are applicable to woodlands and should be used.

Productivity and values are low which causes managers to select strategies consisting of low management intensity. Poor or difficult to harvest sites are being allocated to resource uses which do not require production of wood fiber.

Future changes in demand for wood from these lands may change management strategies. Research and experience are improving the probability of development of improved management strategies in the future.

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FIELD TESTING OF THE POINT SAMPLING METHOD IN PINYON-JUNIPER WOODLANDS

Jack Sheffey

ABSTRACT: Utilizing a point sampling volume estimation method for pinyon-juniper woodlands by means of a slope-compensating stick type angle gauge is an efficient, accurate technique. This paper deals with field testing of the method in northwest Colorado.

INTRODUCTION

In the White River Resource Area, Colorado, where the majority of all commercial forest acres are composed of pinyon-juniper woodlands, it is desirable to acquire a fast, accurate field method for volume estimation.

Meeuwig and Budy (1981) outline a method that seemed to meet the requirements. The method is based on a variable plot point sample which tallies pinyon based on basal area and juniper based on crown area. The details and methodology are clearly explained in the report and need not be repeated in this paper; only the most pertinent points will be discussed.

Most stands encountered in our Resource Area are old growth pinyon-juniper with closed canopies and little understory vegetation. Therefore, we use the point sampling method and this discussion is confined to it.

Meeuwig and Budy (1981) used data collected from singleleaf pinyon-Utah juniper (Pinus monophylla-Juniperus osteosperma), whereas this article is prepared from data from Colorado pinyon (Pinus edulis) and Utah juniper; however, results were very comparable.

Point sampling selects tally pinyons utilizing a Slope-Compensating Stick-Type Angle Gauge (Meeuwig 1977). This angle gauge is adjustable by basal area factor. Meeuwig and Budy state that it is desirable to tally at least one pinyon on every point, and preferable to tally two or three to improve sample intensity. We discovered, on the average, that this could be accomplished using BAF 40 only in very well-stocked stands (10+ cords/acre pinyon). In most instances, reducing the BAF to 20 will ensure having tally trees on every point, in average-to-good stands. After sale layout, if the first several points were tallied on both the BAF 40 and 20, then the proper choice could be made of which BAF to use on the particular stand.

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Jack Sheffey is Forester, White River Resource Area, Bureau of Land Management, U.S. Department of the Interior, Meeker, CO.

GAUGE CONSTRUCTION, USE

Angle gauge construction is not difficult and very inexpensive. Any yard stick, meter stick, or handmade reasonable facsimile will suffice, with the easiest choice being to acquire a Biltmore cruising stick, with a hole for the crossarm already drilled. The crossarm is built from standard hardware items including metal sheeting, 1/4-inch brass bolt, 1/4-inch washers, 1/4-inch wingnut, and silver solder. Crossarm width is determined by BAF selected and distance on the angle gauge from eye to cross arm (formulas are shown in Meeuwig and Budy [1984]). Changing crossarms from one BAF to another requires only a few seconds (fig. 1-4).

In the field, the angle gauge is quick and easy to use. Sighting on stems at stump height (6 inches above ground) allows a clear view to select tally pinyons. As with all variable plot methods, tally trees are chosen on the basis of relationship of stem diamter to distance from point center. Borderline trees will be encountered. Therefore, it is necessary to prepare limiting distance tables and measure all borderline trees and tally only "in" trees. The limiting distance tables in this paper (from the formula in Meeuwig and Budy [1981]) are calculated in tenths of feet, and measured from point to stem center, not stem face. Of course, a separate limiting distance table is required for different basal area factors (tables 1 and 2).

USING THE METHOD

Junipers are tallied on the basis of the relationship between crown diameter and distance to point center. A juniper is tallied if the distance from the sampling point to nearest portion of its crown is no greater than one-half its average crown diameter. This is equivalent to the stem center being within one crown diameter of the sampling point. After extensive use in the field, we found that this latter requirement is somewhat easier to visualize on the ground, and it was utilized as the basis for tallying juniper.



Figure 1.--Stick-type Angle Gauge components.

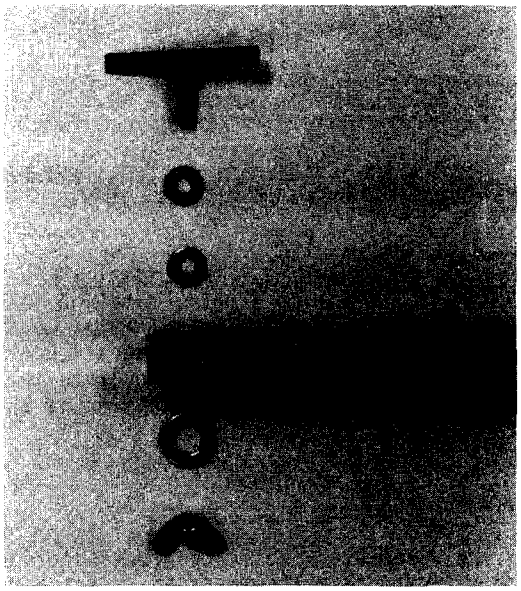


Figure 2.--Finished crossarm in proper sequence for mounting on Biltmore Stick.

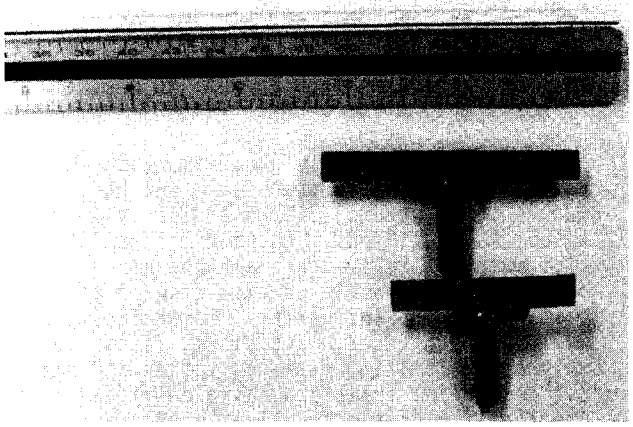


Figure 3.--Finished crossarms for BAF 40 and 20 angle gauges. Top: BAF 40 crossarm, width = 2.3 inches. Bottom: BAF 20 crossarm, width = 1.63 inches.

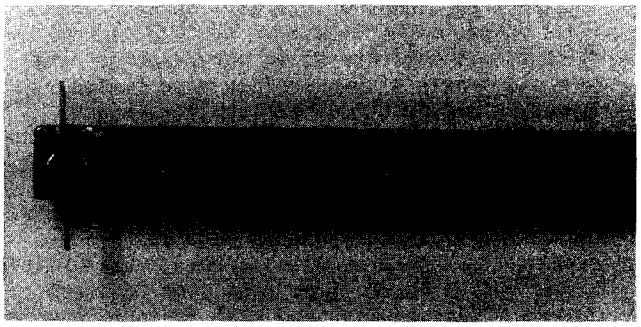


Figure 4.--Crossarm properly mounted on Biltmore Stick.

After a stand is designated for a point sample cruise it is necessary to prepare point sample locations within the stand. In an effort to acquire an adequate sample intensity and sample all areas of the stand equally, while selecting all sample points at random, we decided to use a grid system for on-the-ground implementation. Typically for smaller stands (up to 10 to 15 acres) a 2x2 chain spacing satisfies the requirements. In larger stands a 3x3 chain spacing is very adequate. Greater distance between point samples allows less field time to cruise a large stand; however, when significant diversity of size and age classes is encountered within the stand, a smaller spacing is likely to give a better representation of average stand volume.

The next step after selecting a stand and deciding on cruise strategy is to become familiar with the actual data gathering and recording procedure. With the sighting eye positioned directly over the point sample, sight down the angle gauge at every pinyon in view. The crossarm should be perpendicular to the angle gauge stick (Biltmore stick) unless there is noticeable slope. When slopes are encountered, follow directions in Meeuwig and Budy (1981). When sighting on a pinyon, place the end of the angle gauge against your face,

Table 1.--Limiting Distance Table for use with BAF 20 angle gauge

Stump(6") Diameter	Limiting Distance	Stump(6") Diameter	Limiting Distance	Stump(6") Diameter	Limiting Distance
8.0	15.5	15.4	29.9	22.8	44.3
8.1	15.7	15.5	30.1	22.9	44.5
8.2	15.9	15.6	30.3	23.0	44.7
8.3	16.1	15.7	30.5	23.1	44.9
8.4	16.3	15.8	30.7	23.2	45.0
8.5	16.5	15.9	30.9	23.3	45.2
8.6	16.7	16.0	31.1	23.4	45.4
8.7	16.9	16.1	31.3	23.5	45.6
8.8	17.1	16.2	31.5	23.6	45.8
8.9	17.3	16.3	31.6	23.7	46.0
9.0	17.5	16.4	31.8	23.8	46.2
9.1	17.7	16.5	32.0	23.9	46.4
9.2	17.9	16.6	32.2	24.0	46.6
9.3	18.1	16.7	32.4	24.1	46.8
9.4	18.3	16.8	32.6	24.2	47.0
9.5	18.4	16.9	32.8	24.3	47.2
9.6	18.6	17.0	33.0	24.4	47.4
9.7	18.8	17.1	33.2	24.5	47.6
9.8	19.0	17.2	33.4	24.6	47.8
9.9	19.2	17.3	33.6	24.7	48.0
10.0	19.4	17.4	33.8	24.8	48.2
10.1	19.6	17.5	34.0	24.9	48.3
10.2	19.8	17.6	34.2	25.0	48.5
10.3	20.0	17.7	34.4	25.1	48.7
10.4	20.2	17.8	34.6	25.2	48.9
10.5	20.4	17.9	34.8	25.3	49.1
10.6	20.6	18.0	35.0	25.4	49.3
10.7	20.8	18.1	35.1	25.5	49.5
10.8	21.0	18.2	35.3	25.6	49.7
10.9	21.2	18.3	35.5	25.7	49.9
11.0	21.4	18.4	35.7	25.8	50.1
11.1	21.6	18.5	35.9	25.9	50.3
11.2	21.7	18.6	36.1	26.0	50.5
11.3	21.9	18.7	36.3	26.1	50.7
11.4	22.1	18.8	36.5	26.2	50.9
11.5	22.3	18.9	36.7	26.3	51.1
11.6	22.5	19.0	36.9	26.4	51.3
11.7	22.7	19.1	37.1	26.5	51.5
11.8	22.9	19.2	37.3	26.6	51.6
11.9	23.1	19.3	37.5	26.7	51.8
12.0	23.3	19.4	37.7	26.8	52.0
12.1	23.5	19.5	37.9	26.9	52.2
12.2	23.7	19.6	38.1	27.0	52.4
12.3	23.9	19.7	38.3	27.1	52.6
12.4	24.1	19.8	38.4	27.2	52.8
12.5	24.3	19.9	38.6	27.3	53.0
12.6	24.5	20.0	38.8	27.4	53.2
12.7	24.7	20.1	39.0	27.5	53.4
12.8	24.9	20.2	39.2	27.6	53.6
12.9	25.0	20.3	39.4	27.7	53.8
13.0	25.2	20.4	39.6	27.8	54.0
13.1	25.4	20.5	39.8	27.9	54.2
13.2	25.6	20.6	40.0	28.0	54.4
13.3	25.8	20.7	40.2	28.1	54.6
13.4	26.0	20.8	40.4	28.2	54.8
13.5	26.2	20.9	40.6	28.3	54.9
13.6	26.4	21.0	40.8	28.4	55.1
13.7	26.6	21.1	41.0	28.5	55.3
13.8	26.8	21.2	41.2	28.6	55.5
13.9	27.0	21.3	41.4	28.7	55.7
14.0	27.2	21.4	41.6	28.8	55.9
14.1	27.4	21.5	41.7	28.9	56.1
14.2	27.6	21.6	41.9	29.0	56.3
14.3	27.8	21.7	42.1	29.1	56.5
14.4	28.0	21.8	42.3	29.2	56.7
14.5	28.2	21.9	42.5	29.3	56.9
14.6	28.3	22.0	42.7	29.4	57.1
14.7	28.5	22.1	42.9	29.5	57.3
14.8	28.7	22.2	43.1	29.6	57.5
14.9	28.9	22.3	43.3	29.7	57.7
15.0	29.1	22.4	43.5	29.8	57.9
15.1	29.3	22.5	43.7	29.9	58.1
15.2	29.5	22.6	43.9	30.0	58.3
15.3	29.7	22.7	44.1		

For BAF 20: Limiting Distance(in feet)= $\frac{\text{Stump(6") Diameter(in inches)}}{12}$ x 23.3

Table 2.--Limiting Distance Table for use with BAF 40 angle gauge

Stump(6") Diameter	Limiting Distance	Stump(6") Diameter	Limiting Distance	Stump(6") Diameter	Limiting Distance
8.0	11.0	15.4	21.2	22.8	31.4
8.1	11.1	15.5	21.3	22.9	31.5
8.2	11.3	15.6	21.4	23.0	31.6
8.3	11.4	15.7	21.6	23.1	31.8
8.4	11.5	15.8	21.7	23.2	31.9
8.5	11.7	15.9	21.9	23.3	32.0
8.6	11.8	16.0	22.0	23.4	32.2
8.7	11.9	16.1	22.1	23.5	32.3
8.8	12.1	16.2	22.3	23.6	32.4
8.9	12.2	16.3	22.4	23.7	32.6
9.0	12.3	16.4	22.5	23.8	32.7
9.1	12.5	16.5	22.7	23.9	32.9
9.2	12.6	16.6	22.8	24.0	33.0
9.3	12.8	16.7	23.0	24.1	33.1
9.4	12.9	16.8	23.1	24.2	33.3
9.5	13.1	16.9	23.2	24.3	33.4
9.6	13.2	17.0	23.4	24.4	33.5
9.7	13.3	17.1	23.5	24.5	33.7
9.8	13.5	17.2	23.6	24.6	33.8
9.9	13.6	17.3	23.8	24.7	34.0
10.0	13.7	17.4	23.9	24.8	34.1
10.1	13.9	17.5	24.1	24.9	34.2
10.2	14.0	17.6	24.2	25.0	34.4
10.3	14.2	17.7	24.3	25.1	34.5
10.4	14.3	17.8	24.5	25.2	34.7
10.5	14.4	17.9	24.6	25.3	34.8
10.6	14.6	18.0	24.8	25.4	34.9
10.7	14.7	18.1	24.9	25.5	35.1
10.8	14.8	18.2	25.0	25.6	35.2
10.9	15.0	18.3	25.1	25.7	35.3
11.0	15.1	18.4	25.3	25.8	35.5
11.1	15.3	18.5	25.4	25.9	35.6
11.2	15.4	18.6	25.6	26.0	35.7
11.3	15.5	18.7	25.7	26.1	35.9
11.4	15.7	18.8	25.8	26.2	36.0
11.5	15.8	18.9	26.0	26.3	36.2
11.6	15.9	19.0	26.1	26.4	36.3
11.7	16.0	19.1	26.3	26.5	36.4
11.8	16.2	19.2	26.4	26.6	36.6
11.9	16.4	19.3	26.5	26.7	36.7
12.0	16.5	19.4	26.7	26.8	36.8
12.1	16.6	19.5	26.8	26.9	37.0
12.2	16.8	19.6	26.9	27.0	37.1
12.3	16.9	19.7	27.0	27.1	37.3
12.4	17.0	19.8	27.2	27.2	37.4
12.5	17.2	19.9	27.4	27.3	37.5
12.6	17.3	20.0	27.5	27.4	37.7
12.7	17.5	20.1	27.6	27.5	37.8
12.8	17.6	20.2	27.8	27.6	38.0
12.9	17.7	20.3	27.9	27.7	38.1
13.0	17.9	20.4	28.1	27.8	38.2
13.1	18.0	20.5	28.2	27.9	38.4
13.2	18.1	20.6	28.3	28.0	38.5
13.3	18.3	20.7	28.5	28.1	38.6
13.4	18.4	20.8	28.6	28.2	38.8
13.5	18.6	20.9	28.7	28.3	38.9
13.6	18.7	21.0	28.9	28.4	39.0
13.7	18.8	21.1	29.0	28.5	39.2
13.8	19.0	21.2	29.1	28.6	39.3
13.9	19.1	21.3	29.3	28.7	39.5
14.0	19.2	21.4	29.4	28.8	39.6
14.1	19.4	21.5	29.6	28.9	39.7
14.2	19.5	21.6	29.7	29.0	39.9
14.3	19.7	21.7	29.8	29.1	40.0
14.4	19.8	21.8	30.0	29.2	40.1
14.5	19.9	21.9	30.1	29.3	40.3
14.6	20.1	22.0	30.2	29.4	40.4
14.7	20.2	22.1	30.4	29.5	40.6
14.8	20.3	22.2	30.5	29.6	40.7
14.9	20.5	22.3	30.7	29.7	40.8
15.0	20.6	22.4	30.8	29.8	41.0
15.1	20.8	22.5	31.0	29.9	41.1
15.2	20.9	22.6	31.1	30.0	41.3
15.3	21.0	22.7	31.2		

For BAF 40: Limiting Distance(in feet)= $\frac{\text{Stump(6") Diameter(in inches)}}{12}$ x 16.5

just below the sighting eye. If the tree trunk (at 6 inches above the ground) can be clearly seen on both sides of the crossarm, the tree is tallied. If the crossarm extends beyond the tree trunk on both sides, the tree is not tallied. If there is any doubt, or if the tree cannot be seen clearly, distance and diameter must be measured and judged against the limiting distance table.

We found it easiest to proceed in a clockwise direction from the cruise bearing and record all tally pinyons first, then record junipers, as already described. Junipers, by this method, are always tallied in the same manner, regardless of the BAF utilized for selecting pinyons. After all tally trees are selected and recorded, individual tree data is collected. For calculations in Meeuwig and Budy (1981),

diameter at stump height (6 inches), average crown diameter, and the total height are needed for all pinyons, diameter at breast height and average crown diameter are needed for all junipers. Total height can also be recorded for stand description purposes. It should be noted that if the goal of the point sample cruise is to estimate volume only, the individual tree data require only crown diameter and total height for pinyon, diameter at breast height and crown diameter for juniper. From this, it should be clear that if the proper BAF is selected (points average two to three trees), and minimal time is spent collecting individual tree data, this is a very quick method of field cruising.

Additional information may be gathered to prepare a more intensive stand description. Dead standing and dead down trees are measured as if reconstructed to live form. The live total height and crown diameter must be estimated on tallied dead trees as this information is required for volume determination. A Biltmore stick is especially useful for measuring diameters of downed trees, and standing multiple-stemmed junipers, as a diameter tape is difficult to employ in these situations.

When initiating this point sample method total heights and crown diameters should be measured accurately. Meeuwig and Budy (1981) defined the average crown diameter as the maximum crown diameter averaged with the diameter perpendicular to the maximum diameter. In time, with sufficient experience, pinyon-juiper heights and crown diameters can be accurately estimated without instruments, which further increases the efficiency of the method.

From the field data collected, average volumes per acre by species can be calculated in a few simple steps. These procedures are detailed in Meeuwig and Budy (1981). In addition to volumes, if the proper field data are collected, trees-per-acre, slash, aboveground biomass, foilage and fine fuels, stand basal area, and growth rates can also be estimated through this method.

TESTS OF THE METHOD

In the summer of 1982, approximately 400 acres of pinyon-juniper woodlands were cruised utilizing the point sample method for the purpose of layout of commercial firewood sales. Of the acreage laid out, six firewood sales, totaling 4,123 cords in approximately 311 acres, were advertised and sold. Average volume per acre for pinyon was 8.5 cords; it was 5.0 cords for juniper. No adverse reaction to volume estimates was received by successful bidders, most of whom are experienced commercial firewood operators.

Field work was completed by three experienced timber cruisers, all with degrees in forest management. After initial learning and experimentation, implementing the point sample method progressed very smoothly. On the average, after stand designation, boundary marking, and deciding on cruise strategy, points could be completed in 5 to 15 minutes, averaging 7 to 10 minutes, including pacing between plots, by a two-person crew. Significant diversity was encountered, with tally pinyons ranging usually from one to six; junipers averaged less. With this method it is very possible and practical for one person to complete the cruise, which is very difficult with other methods.

Convinced that the point sample method was a very efficient way to intensively cruise pinyon-juniper woodlands, it became desirable to test the accuracy of the volume estimates produced for this region. We believed that the ideal test would be to actually count all firewood harvested from a newly contracted commercial sale cruised by the point sample method and then compare results. This, however, posed some overwhelming problems. The best way to count cords of firewood is to have it staked in 4x4x8-foot units, by species. This procedure would involve a great deal of extra labor above and beyond normal logging operations. Therefore, this experiment was not implemented. In preference to this idea, we decided to test the point sample method on the basis of square one-acre tracts. These tracts were located in areas with good accessibility with volumes comparable to commercial sales. In addition, test tracts were located throughout the Resource Area and were not limited to one area.

The test tracts were laid out as one-acre squares, 208.7 x 208.7-feet, with hand-held compass and 200-foot tape. Corners and boundaries were well marked. The point sample cruise was implemented starting at one corner on a 1x1 chain grid, which results in a very equal distribution and sampling of the test tract. Data were collected in exactly the same manner as for all commercial firewood sales.

After field work was completed, arrangements were made to have the test tracts harvested. Cutting requirements were the same as commercial sales. In addition, it was required that all wood harvested be blocked and staked in one cord piles, 4 feet wide, 4 feet high, and 8 feet long, within the test tract boundary, separated between pinyon and juniper. Boundaries and corner stakes were to remain intact and no wood was allowed to be removed from the test tract until tallied and confirmed by a BLM representative.

CONCLUSIONS

Field work has been completed on six test tracts, and more are planned; however, at the time of preparation of this paper only two test tracts have been completed. We believe that results from additional test tracts will further confirm the estimation accuracy of the point sample method in pinyon-juniper woodlands.

The point sample method is a fast, efficient, and accurate procedure for cruising pinyon-juniper woodlands. We recommend that, before

implementing the method, field testing be conducted on a local basis to determine the comparability of volume tables supplied in Meeuwig and Budy (1981). The "Discussion" section of this report offers some explanations and suggestions regarding this issue.

This article is in full agreement with Meeuwig and Budy in supporting the thought that woodlands will become increasingly more important in the future, not only to supply forest products, but also for range, wildlife, and watershed management, and therefore a method which makes efficient use of field time while yielding accurate and useful information will be a great asset to woodland managers.

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EVOLUTIONARY SORTING OF PINYON PINE TAXA IN ZION NATIONAL PARK, UTAH

David J. Gafney and Ronald M. Lanner

ABSTRACT: Singleleaf pinyon (Pinus monophylla) grows on the floor of Zion Canyon, while its closely related congener Colorado pinyon (Pinus edulis) grows on the surrounding high plateau. The two species are known to hybridize. Population samples of both species were made along 2 transects ranging from 1,219 m to 2,134 m elevation. Based on percent of monophylly and needle resin canal number, it is concluded that hybrids occur throughout the elevational ranges of both parents. Distribution of the taxa was closely correlated with bedrock geology. Hybrids of these species occur widely throughout their ranges, including areas of Arizona not heretofore reported. Detailed studies of the site relationships of hybrids are needed in order to predict their behavior under different land management regimens.

INTRODUCTION

The pinyon-juniper woodland community is the most extensive forest association of the western United States, covering some 190,000 square kilometers (Lanner 1981). It consists of junipers and pines of several species. The singleleaf pinyon (Pinus monophylla Torr. & Frem.) which ranges mainly within the Great Basin, and the Colorado pinyon (Pinus edulis Engelm.), a tree of the Colorado Plateau and foothills of the southern Rocky Mountains (Critchfield and Little 1966), form the pine component of this woodland in most of the southwestern United States.

Lanner (1974) reported natural hybridization occurring between these two species where they are sympatric. He delineated major zones of hybridization: the Utah Plateaus-Great Basin interface, running from north central to southwestern Utah; the drainages of the Colorado River in southern Utah and northern Arizona; and the mountain complex south of the Mogollon Rim.

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David J. Gafney is Visiting Instructor, University of West Florida, Pensacola, Florida. Ronald M. Lanner is Associate Professor, Department of Forest Resources, Utah State University, Logan, Utah.

Lanner suggested that further investigation might disclose the presence of additional areas of introgression and hybrid swarms, particularly in the Colorado River drainages. Indeed, later analysis by Lanner (unpublished) of material collected in northwestern Arizona indicates the presence of pinyon hybrids in a number of locations along the Colorado River and in the Arizona Strip (Jacob's Well, Snap Point, Poverty Mountain, Trail Canyon, Mount Trumbull, Bob Cat Tank, Tapeats Amphitheater, Tobar Terrace); as well as farther south along highway US 66 (Williams, Seligman, Peach Springs). Thus it is clear that hybridization between these taxa is indeed widespread geographically, and significant biologically.

The most obvious morphological difference between the two species is the number of needles per fascicle. P. monophylla is the only member of the genus Pinus with 1-needled fascicles. P. edulis has mostly 2-needled fascicles, with varying proportions of 3-needled fascicles in some areas. A second quantitative character which can be used to differentiate the species is leaf resin canal number. P. edulis almost without exception has 2 resin canals per leaf (Harlow 1947; Lanner 1974), while P. monophylla has 2-17 (Lanner 1974). Hybrid trees have varying proportions of 1- and 2-needled fascicles and are intermediate in resin canal number (Lanner 1974). The species also differ in several cone and seed characters, but percent monophylly and leaf resin canal number are sufficiently diagnostic to allow reliable identification of species and hybrids.

Both species occur in Zion National Park. Nelson (1976) reported the presence of Colorado pinyon on the canyon slopes and plateau where it often intermingles with ponderosa pine (P. ponderosa Dougl ex Laws.). She stated that singleleaf pinyon is almost as common, but does not extend as high in elevation. Lanner (1974) established three sample plots in the area and reported mixed populations, i.e. stands containing trees of hybrid origin. On the floor of Zion Canyon, sample trees averaged 85.8% 1-needled fascicles, while at Mt. Carmel Junction, 30 km to the east and higher in elevation, sample trees had a mean of only 7.2% 1-needled fascicles. Smith Mesa, a site intermediate to those in elevation, had 78.1% of monophyllous fascicles.

The recombinants resulting from natural hybridization are believed to be most likely to persist where environmental conditions are intermediate between those required by the parental forms (Anderson 1949; Stern and Roche 1974)--that is, in a "hybridized habitat" (Grant 1971). Roche (1969) suggested it would be highly unlikely that hybrids "could successfully compete in the ecological niche occupied by either parent, for the parental forms will almost certainly be better adapted to their respective environments than the hybrid form." This hypothesis is supported by Salisbury's (1940) study of two species of European oaks. Quercus robur L. prefers heavy calcareous soils, while Quercus petraea (Mattuschka) Liebl. occupies lighter, more acidic substrate. Hybrids, however, were able to survive only in a transitional zone between the two soil types. Roche (1969) investigated cone scale morphology of Engelmann spruce (Picea engelmannii Parry) and white spruce (Picea glauca (Moench) Voss) in British Columbia. Hybrid swarms were found in the altitudinal transition between montane white spruce and subalpine Engelmann spruce forests. A gradational change of cone scale morphology was observed from one parental form to the other across the swarms. Benson and others (1967) studied a hybrid swarm of shrub live oak (Quercus turbinella Greene) and blue oak (Quercus douglasii Hook and Arn.). Hybrids on the south and southwestern slopes had hybrid index values close to that of Q. turbinella, while hybrids with a north to northeastern aspect had values most similar to that of Q. douglasii. Characters varied clinically with aspect.

In all those studies hybrids became established in ecological zones intermediate between those of the parent species. This study differs from those, however, by examining a hybrid swarm that is spread across three discrete substrates, without transitional zones. There is continuous change in elevation within and between soil types, so climatic variation is probably continuous, but the abruptness of the changes in substrate appears unusual in studies of natural hybridization between tree species.

METHODS

Sample plots were located along two line transects in Zion National Park, from the floor of Zion Canyon to the surrounding high plateau. Extremely rugged terrain (fig. 1) forced the location of several plots, preventing equal elevational intervals along the transects. Sixteen plots fell along a 6 km long transect (Transect A) from the canyon bottom (elev. 1219 m) to the summit of Deertrap Mountain (2134 m). Nine plots were on Transect B, extending 7 km from the canyon bottom to the top of Checkerboard Mesa (1234-2033 m).

Zion Canyon is carved into a plateau made up of horizontal layers of sedimentary rock, and the transects crossed three major rock formations (Gildart 1984). The lower 5 plots on Transect A (A-1 through A-5) and the lower 3 on Transect B (B-1 through B-3) fell on the Kayenta formation, a water-deposited sandstone. Intermediate plots were on "slickrock" formed by the erosion of the Navajo formation, the vertical walls of which

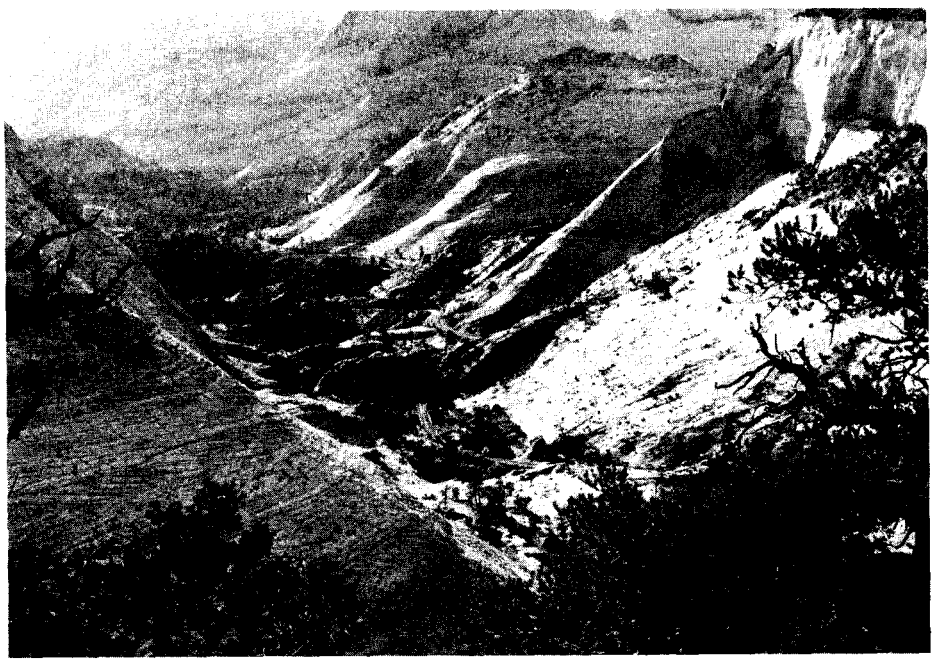


Figure 1.--View from Summit of Checkerboard Mesa showing terrain similar to that of the transects, and pinyon pines distributed at all elevations.

limited the number of plots that could be placed on it. The caprock of the Zion Canyon plateau is the Carmel limestone formation, upon which plots A-12 through A-16, B-8, and B-9 were located. All plots except those on the level plateau had a southwesterly aspect.

A plot consisted of an area large enough to contain at least 5 scattered trees. From each of these, 5 first-order shoots containing two year's growth were removed. All of the needle fascicles on the sample shoots were scored for needle number. Resin canals were counted on free-hand sections from mid-needle of the needles of 10 fascicles per tree per year, using a stereomicroscope. Trees were classified in the following categories: P. monophylla--at least 98% 1-needled fascicles; P. edulis--no more than 2% 1-needled fascicles; hybrid--between 2 and 98% 1-needled fascicles (Lanner 1974).

RESULTS

Plots along the lower 300 m of both transects averaged 94-100% monophylly and 2.7-3.4 resin canals per leaf. The 7 plots on the plateau top, by contrast, averaged only 4-32% monophylly and had resin canal means of 2.0-2.4 (table 1, table 2).

The highest elevation at which pure P. monophylla was found was 1,860 m. The lowest elevation at which pure P. edulis was encountered was 1,660 m. Hybrids were found in 24 of the 25 sample populations. One low elevation plot (B-3) consisted solely of P. monophylla, and 4 plots (A-12, A-14, B-6, B-7) consisted entirely of hybrid trees. The only plot that had representatives of both parental types plus hybrids (A-7) was located very close to the midpoint of the elevational gradient (1,660 m.).

When individual trees were tallied separately for each bedrock type, hybrids were found on all three rock types. P. monophylla was not found on Carmel limestone sites, and P. edulis was missing from the Kayenta formation (table 3). Mean percent monophylly and mean resin canal number were inversely correlated with elevation (r^2 = .75 and .68 respectively), but the curves were not significant at the .05 level (figs. 2, 3).

Table 1.--Elevations and needle parameters of plots on transect A, between Zion Canyon Junction and Deertrap Mountain

Plot	Elevation (m)	Percent monophylly Mean	Percent monophylly Range	Resin canal number Mean	Resin canal number Range
1	1,219	98	92-100	3.2	2.0-4.8
2	1,295	96	88-99	2.9	2.3-3.8
3	1,372	99	98-100	3.4	2.0-5.0
4	1,463	94	76-100	2.7	2.0-3.2
5	1,554	94	79-100	2.2	2.0-3.0
6	1,600	97	87-100	3.3	2.0-5.6
7	1,661	63	1-100	2.2	2.0-2.9
8	1,722	87	65-99	2.6	2.0-3.5
9	1,768	66	5-99	2.4	1.9-3.2
10	1,859	89	77-99	2.0	2.0
11	1,905	56	0-46	2.0	2.0
12	1,950	32	4-85	2.0	2.0
13	1,980	21	0-93	2.4	2.0-3.8
14	2,012	18	4-49	2.0	2.0
15	2,073	11	0-26	2.0	2.0
16	2,134	8	0-29	2.0	2.0-2.2

Table 2.--Elevations and needle parameters of plots on transect B, between base of Watchman Trail and Checkerboard Mesa

Plot	Elevation (m)	Percent monophylly Mean	Percent monophylly Range	Resin canal number Mean	Resin canal number Range
1	1,234	97	91-100	3.3	2.2-6.1
2	1,329	98	89-100	2.9	2.3-3.6
3	1,494	100	100	2.7	2.2-3.9
4	1,585	88	69-100	3.1	2.8-3.7
5	1,692	74	15-99	2.2	2.0-2.6
6	1,768	86	72-94	2.2	2.0-2.6
7	1,829	60	18-94	2.6	2.0-4.0
8	1,950	14	0-61	2.0	2.0
9	2,033	4	0-17	2.1	2.0-2.3

Table 3.--Distribution of Pinus edulis, P. monophylla, and hybrids on the three major rock formations of Zion Canyon

Species	Kayenta Sandstone	Navajo Sandstone	Carmel Limestone
		Number of Trees	
P. edulis	0	3	12
Hybrids	13	30	23
P. monophylla	27	17	0

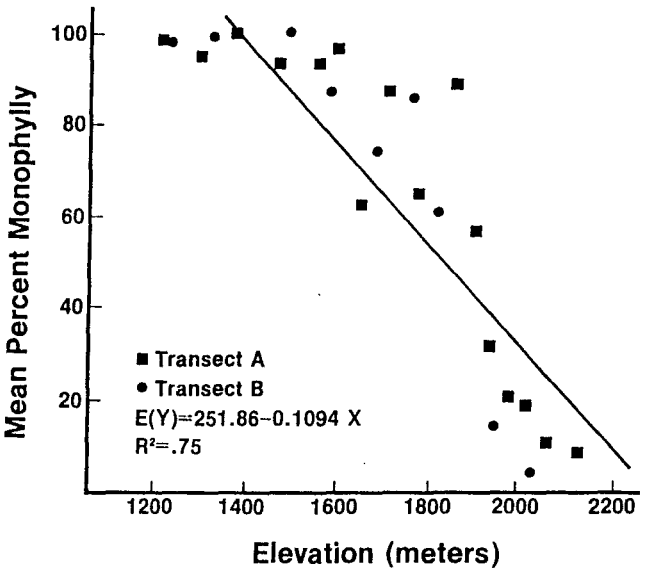


Figure 2.--Relationship between mean percent monophylly and elevation for plots on two transects from the floor of Zion Canyon to the top of the adjacent plateau.

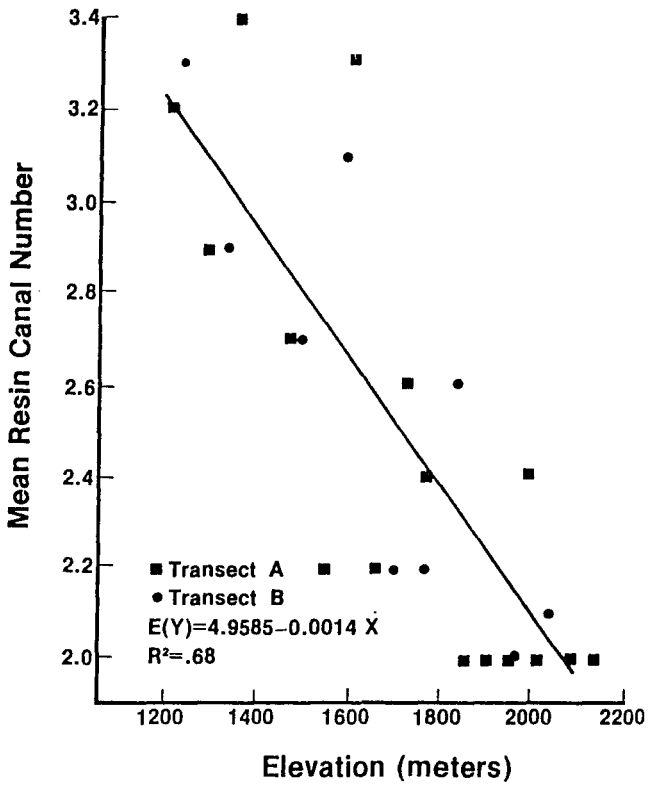


Figure 3.--Relationship between mean resin canal number and elevation for plots on two transects from the floor of Zion Canyon to the top of the adjacent plateau.

DISCUSSION

The occurrence of a wide assortment of trees intermediate in both characters, as well as both pinyon species in relatively pure form, is not unexpected. This pattern--assumed to be the result of natural hybridization--has consistently appeared in all areas where Colorado pinyon and singleleaf pinyon are sympatric, and is absent in areas where they are not (Lanner 1974). These populations appear to typify what Drake (1980) has termed "successful hybridization." According to Drake's concept of hybridization success, plant hybridization comprises three phases: hybrid establishment, development and expansion of hybrid populations, and an evolutionary outcome. The evolutionary outcome is, rarely, the appearance of a new taxon; and is, presumably, more often an introgressed species pair. The general trend of decreasing monophylly and leaf resin canal number with increasing elevation is also consistent with earlier work: wherever these species are sympatric, Colorado pinyon extends higher in elevation and singleleaf pinyon extends to lower elevations. This does not explain the absence of singleleaf pinyon on the limestone caprock, however. Elsewhere singleleaf pinyon frequently grows on basic substrate (Tueller and Clark 1975), including dolomitic limestone (St. Andre and others 1965) exceeds elevations of 2700 m on many of its sites (Lanner 1981).

The commonness of hybridization between these taxa points to the need to study their silvical and ecological requirements in the light of their genetic makeup. Seed germination and seedling establishment characteristics, for example, cannot be safely assumed to be unvarying even within a relatively small area along the species' broad interface. Any silvicultural treatments imposed on the woodlands should be done with due consideration for the high level of genetic variability that may be present.

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GERMINATION AND FIELD ESTABLISHMENT OF JUNIPER IN THE SOUTHWEST

James T. Fisher, Gregory A. Fancher and Robert W. Neumann

ABSTRACT: Studies were conducted to determine reliable methods for germinating and establishing Juniperus monosperma. Poor germination is caused by a germination inhibitor in the seed coat and physiological dormancy. Germination rate and value were significantly improved when seeds were leached 48 hours with H_2O, or treated with ethephon or H_2O_2 plus GA_3 before stratification at 4° C.

Establishment studies at three New Mexico sites evaluated the effects of planting date, mulch, drip irrigation, fertilizer and rodent protection on juniper seedling survival. Two years after planting, survival rates for the best treatment combinations ranged from 70 to 99% among sites. July was the superior planting date for the site near Raton, New Mexico. Drip irrigation proved superior to mulch. Plastic mesh was essential and was more effective than animal repellant for rodent protection.

INTRODUCTION

Pinyon-juniper (P-J) woodlands occur extensively in the West and are frequently razed by mining operations, particularly coal stripping. In New Mexico, topography of surface-mined land ranges from flat to rolling hills. Many areas include badlands formed by steep-walled gullies separated by rugged rock ridges. Revegetation can reduce erosion and restore aesthetic values, but restoration is difficult because of low rainfall, wide temperature extremes, animal depredation and rugged topography (Schubert 1977). Because native plants are well adapted to regional conditions, native plant species often can be established more easily than introduced species (Balzar 1975). Establishing native P-J woodlands speeds the progression from early seral stage vegetation (annuals and herbaceous perennials) to longer lived woody species (Wagner and others 1978). Also, it is becoming increasingly apparent that P-J woodlands should be conserved for their renewable products and uses (Jensen 1972; Lanner 1977; Short and McCulloch 1977).

Revegetation programs in the Southwest have rarely included one-seed juniper (Juniperus monosperma) because of unreliable seed germination in nurseries and a lack of information on establishment techniques. Efforts were begun in 1979 in cooperation with the U.S. Forest Service to identify reliable pregermination treatments and subsequently in 1981 to develop revegetation practices. Because greenhouse culture of containerized one-seed juniper varies little from that routinely used to grow other junipers, seedling production was omitted as a research objective. The studies conducted will be highlighted following brief reviews of information available from other sources.

JUNIPER SEED GERMINATION

Seed Production and Germination Properties

One-seed juniper trees produce seed when 10 to 20 years old. Flowering occurs from January to June and the fruit is formed by the fusion of a fleshy female flower into an indehiscent strobilus commonly called a berry (Johnsen and Alexander 1974). Large seed crops are produced every 2 to 5 years and ripen in August or September of their first year within blue or purple berries.

The seed coat consists of an outer fleshy layer of pectic substances, a thick lignified stoney layer and a thin inner membranous and suberized layer. In several juniper species the hard coat interferes with moisture uptake (Johnsen and Alexander 1974). The fleshy white endosperm of these seeds is made up of thick cells with large amounts of cellulose and is surrounded by an outer layer of suberized cells (Pack 1921). Embedded within this is a straight embryo with two to six cotyledons (Johnsen and Alexander 1974).

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James T. Fisher is Associate Professor of Silviculture and Tree Physiology, Department of Horticulture, New Mexico State University, Las Cruces, NM; Gregory A. Fancher and Robert W. Neumann are, respectively, Associate Manager and Research Forester, Mora Research Center, Mora, NM.

Germination is delayed in most junipers by embryo dormancy and occasionally by impermeable seed coats, immature embryos or the presence of inhibitors (Barton 1951; Djavanshir and Fechner 1976; Pack 1921). Moisture uptake through the hilum of J. scopulorum and J. virginiana seed is apparently obstructed by a covering of vascular tissues from the fruit base. One-seed juniper seeds are reported to have dormant embryos and impermeable seed coats (Johnsen and Alexander 1974).

Johnsen (1962) reported that J. monosperma germination improved following a 48-hour soak in several changes of distilled water. He attributed this to the leaching of seed germination inhibitors. High temperature stratification (cyclic 20-30° C) or H_2O_2 was used to improve permeability while chilling was required to break embryo dormancy (Barton 1951; Djavanshir and Fechner 1976; Van Haverbeke and Read 1976). High temperature or H_2SO_4 without chilling, H_2O_2, removal of seed coats, dilute acids and increased oxygen pressure, light and carbon dioxide were ineffective in promoting germination of unstratified seeds (Pack 1921).

The most common treatment for breaking seed dormancy, particularly physiological dormancy, is stratification of fully imbibed seeds at low temperatures (0.5°-5° C) for up to six months. This generally improves germination percent and rate, and widens the temperature range over which germination will occur. For one-seed juniper, stratification at 5° C for 30 to 120 days has been recommended (Johnsen 1962), but may be unnecessary for some seedlots (Johnsen 1962; Riffle and Springfield 1968). However, cold stratification reduces the nurseryman's flexibility and exposes seed to microfloral degradation.

NMSU Cooperative Studies on Seed Treatments

Tests were conducted with seeds harvested in north central New Mexico in October 1979 to evaluate the effects of several pregermination treatments on J. monosperma seed germination (table 1). Cones were depulped by a procedure described by Van Haverbeke and Barnhart (1978). Debris and void seed were removed by flotation and a South Dakota seed blower. Seeds were X-rayed and subjected to a tetrazolium salt test at the National Tree Seed Laboratory to determine percent viable seed per lot.

Tests evaluated germination percent after a 40-day period, germination rate and germination value. The highest daily rate (peak value) was used as an index of germination rate. Germination percent and the sum of the daily germination rates were used to compute germination value as described by Djavanshir and Pourbeik (1976).

Table 1.--Pregermination experiments conducted at New Mexico State University (O'Brien 1980)

1. Leaching (48 hrs)
   A. w/ or w/o leaching , no strat.
   B. Leach before 0, 30, 60, 90 dy strat.
2. GA_3 (48 hr soak)
   A. 0, 100, 150, 200, 250, 300, 350, 400 ppm before 90 dy strat.
   B. 125, 250, 500, 1000 ppm after 90 dy strat.
3. Ethepon (Ethrel)
   A. 48 hrs 0, 200, 400, 800, 1600 ppm after 90 dy strat.
   B. 48 hrs 300, 600, 1200, 2400 ppm or 24 hrs ethephon (same rates) + 24 hrs 250 ppm GA_3 before 0, 30 or 90 dy strat.
4. Trts applied before 0, 30, 60, 90 dy strat.
   A. GA_3 (48. hr soak in 250 ppm)
   B. Kinetin (" " " " 25 ")
   C. H_2O_2 (" " " " 5 % soln.)
   D. 24 hr kinetin (25 ppm) + 24 hr GA_3 (250 ppm)
   E. 24 hr kinetin (25 ppm) + 24 hr H_2O_2 (5%)
   F. 24 hr H_2O_2 (5%) + 24 hr GA_3 (250 ppm)
   G. 24 hr H_2O_2

Preliminary tests determined: the time required to complete water imbibition at 24° C; the effect of imbibition temperature (4° C vs. 24° C) before a 90-day stratification on germination; and effects of germination chamber photoperiod (8 hr light vs. no light) and temperature (20-30° C vs. 20-35° C). Studies showed that seed were fully imbibed after 16 hrs, that germination percent, rate and value were significantly higher after warm imbibition (24° C), and that seed germinated best when subjected to an 8-hr photoperiod, 16 hrs at 20° C and 8 hrs at 30° C. Results of these studies were applied to pregermination tests.

Chemical induction tests involved placing seeds in 20-ml solutions containing the respective chemical. Seeds were maintained at 24° C for the times indicated in table 1.

Leaching significantly improved germination percent, rate and value. Leached seeds germinated rapidly to a high percent while control seeds germinated more slowly (fig. 1). In addition, there was a positive linear response as stratification after leaching increased from 0 to 90 days (fig. 2). Applied before or after a 90-day stratification, GA_3 had no detectable influence on germination. However, H_2O_2 plus GA_3 (250 ppm) resulted in almost total germination of viable seeds. Germination percent, rate and value increased in a linear manner as ethephon concentration

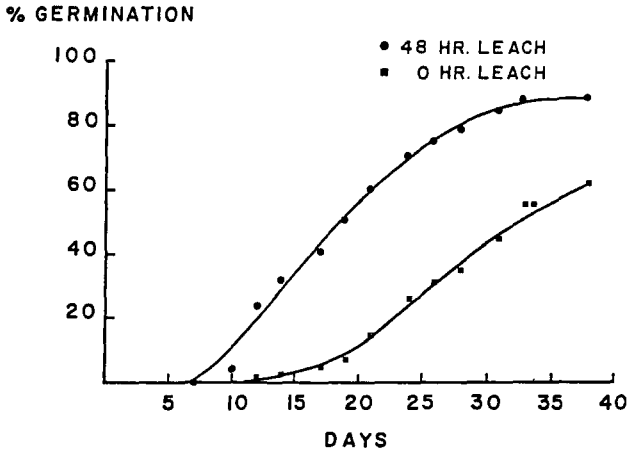


Figure 1--Cumulative germination rates of non-stratified J. monosperma seed leached for 0 and 48 hours.

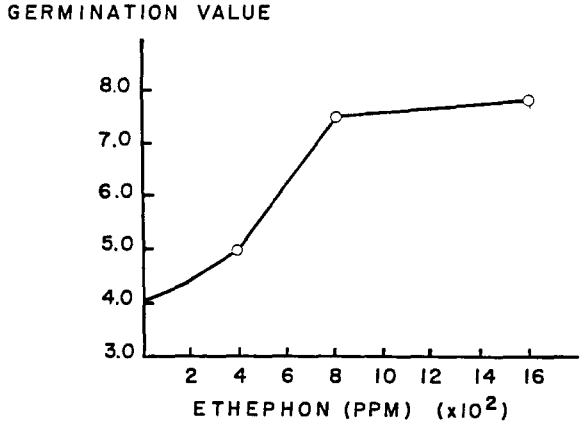


Figure 3--Ethephon effects on germination value of J. monosperma seed stratified 90 days before treatment.

increased (fig. 3). The combination of ethephon and GA_3 was ineffective. The germination percent of chemically treated seeds was not improved by cold stratification. However, value was highest when the H_2O_2 plus GA_3 and ethephon-only treatments were applied in conjunction with 30 days of cold stratification, as shown for the former in figure 4. Kinetin plus H_2O_2 improved percent germination only and, overall, was less effective than GA_3 plus H_2O_2.

Results indicated that poor germination may result from the presence of a germination inhibitor in the seed coat and physiological dormancy. Gibberellic acid-only treatments probably failed because the thick seed coat disallowed uptake. Apparently H_2O_2 sufficiently scarified seed to permit GA_3 uptake, or oxidized inhibitory substances to the extent that GA_3 could function effectively. The treatment combining 24 hr exposures to ethephon and GA_3 apparently did not allow sufficient time for ethephon uptake. Among ethephon-only treatments, high concentrations apparently gave best results because of greater absorption.

Recommendations drawn from these studies are that seed should be leached with water at 20-24° C and cold stratified for 90 days or, for a shortcut treatment, be subjected to H_2O_2 plus GA_3 or ethephon-only applied before 30 days cold stratification. The method chosen will therefore depend upon circumstances and available materials.

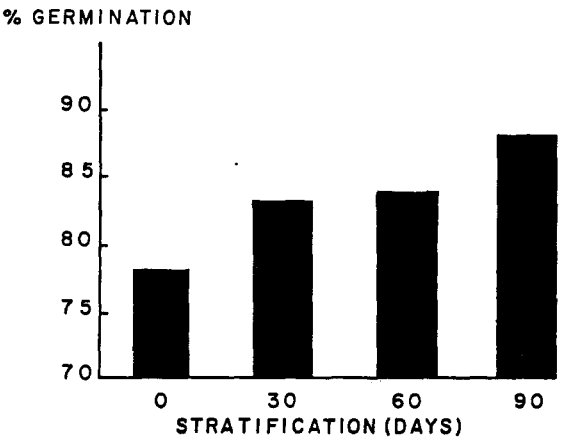


Figure 2--Germination percent of J. monosperma seed leached for 48 hours and cold stratified for 0, 30, 60 and 90 days.

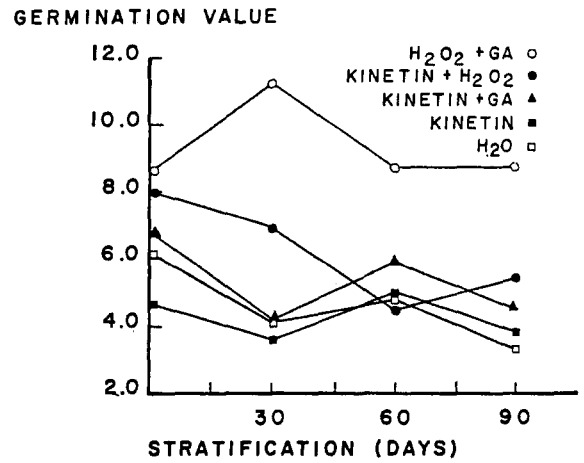


Figure 4--Chemical and cold stratification treatment effects on germination value of J. monosperma seed.

FIELD ESTABLISHMENT OF JUNIPER

Woody Plant Revegetation in the Southwest

In New Mexico, transplant survival is determined largely by moisture availability (Aldon and Springfield 1973). Cultivation, certain types of mulches and drip irrigation can improve infiltration. Cultivation also incorporates organic matter, promotes aeration and helps roots penetrate heavy soils (USDA 1979). Mulches often improve tree and shrub survival (Springfield 1972; Carpenter and others 1978) because moisture is conserved. Mulches routinely used are wood chips or straw applied at a rate of about 3,360 kg/ha. Straw is a common standard against which other materials can be evaluated (Berg 1972). The effective life of straw and hay mulches varies with climatic conditions, but is usually about 1 year. Wood residues last longer, are easier to apply, carry no weed seeds and resist wind movement (USDA 1979). Wood chips are often applied to steep slopes (20% or more) where straw mulches are less effective in preventing erosion.

Incorporating straw into soil to a depth of 5 cm retards wind removal. Applied too heavily, a thick cover of organic mulch causes considerable water loss by intercepting precipitation and subsequent evaporation (Hodder 1974). Straw mulch greatly increases the organic matter content of relatively sterile spoil material. Organic matter also increases soil porosity and aggregation (Hodder 1974).

Supplemental irrigation has significantly increased woody plant survival in western revegetation plots (Lang 1971). Drip irrigation increased survival of Juniperus scopulorum (Williamson and Wangerud 1980), and Atriplex canescens (Aldon 1978). Directed watering reduces weed problems, soil erosion and the total volume of water used. Portable systems can be designed to meet the needs of remote sites (Garcia 1979).

The two elements most commonly deficient on disturbed land are nitrogen (N) and phosphorus (P) (Berg 1972). Transplants often fail because soil is so deficient in P that plants do not extend their roots enough to exploit an adequate moisture supply (USDA 1979). Topsoils may contain adequate N, but subsoils and geologic materials are usually deficient (USDA 1979). Conventional fertilizers have given erratic results in arid regions because their salts often injure transplants. Slow release formulations may be less injurious and provide nutrients for many months. Because release rate is temperature dependent, more nutrients are available when higher soil temperatures are also conducive to root growth. Transplant root growth can be greatly increased by providing slow-release fertilizer and superphosphate (Whitcomb 1977).

Seedling containerization reduces transplant shock and permits planting when summer rains occur in the Southwest. Preliminary studies in northern New Mexico indicate that planting container seedlings in late August and September results in less survival and growth than in July plantings (Fisher and Neumann, unpublished data). For some conifer species, planting in late summer and fall apparently does not allow adequate root development before low soil temperatures reduce further root extension.

Steps are often required to protect transplants from animal browsing. Because poisons, repellents and trapping are either hazardous or unreliable, lightweight polypropylene netting or meshed tubes that physically protect each tree have been developed and appear effective (Campbell 1969). Tubes are marketed in a variety of gauges and dimensions, and they photodegrade in the field in 3 to 5 years.

NMSU Cooperative Studies on Revegetation Practices

Experiments were begun in 1981 to determine reliable methods for routine revegetation of juniper on mined sites. Specific objectives were to relate establishment success to planting date and treatments including drip irrigation, mulch, protective polypropylene mesh (50 mil) tubes and fertilization. Research objectives were tailored to each of three test sites in compliance with the most urgent needs and the available resources. Site descriptions, methods and results are fully described elsewhere (Fisher and others, in press). This paper will summarize two of the three studies.

The Raton site (2,194 m elev.) is 98 km west of Raton, New Mexico. It occurs within a major coal field occupying dissected plateau country. Mineable lenses ranging from 1 to 4 m thick are extracted by underground and surface mining. Good stands of native vegetation occur on all sites except those with shallow soil. Douglas-fir and ponderosa pine are located on north-facing slopes; P-J woodlands reside on the more xeric sites. Mean annual rainfall is 360-460 mm. Soils are derived from sandstone and shale and have a pH of 8.2-8.8. The experimental site is level to moderately sloping with 31 to 51 cm of topsoil covering spoil material.

The Grants site (2,194 m elev.) is on La Jora Mesa within the Cibola National Forest. The test site is surrounded by P-J woodlands and is an abandoned uranium spoil. Annual precipitation is 130 to 230 mm, and soil pH is about 8. The soil is derived from Dakota sandstone, a prominent mesa soil in the area (Griswold 1971).

At the Raton site, a split-plot randomized block design with six replications was used. Main plots were drip irrigation and straw mulch. Six

subplots (three planting dates X two fertilizer regimes) were randomly assigned within each main plot. Planting dates were July and August 1981, and May 1982. Fertilizer treatments were 20 kg/m^3 Osmocote (18-6-12) slow-release fertilizer plus 11 kg/m^3 triple-superphosphate (0-46-0) mixed with soil in the planting hole versus no supplemental fertilizer. Each subplot contained 38 seedlings spaced 0.5 m X 0.9 m. The 13-month-old seedlings were grown in 160-cm^3 Ray Leach tubes according to procedures described by Tinus and McDonald (1979).

The study site was roto-tilled before planting to improve moisture infiltration and remove weeds. Seedlings were auger-planted. Straw mulch was spread by hand and incorporated into the top 5 to 10 cm of soil to avoid wind displacement. The drip system supplied each seedling with enough moisture to wet the soil around it to a depth of 30 cm. Drip plots were irrigated bi-monthly from May through September. Weeds were controlled by hand cultivation.

The Grants test evaluated Osmocote (18-6-12) and 0-46-0 triple-superphosphate (TSP) fertilizers along with wood chip mulch or the lack of it. Specific treatments are identified in table 2. Fertilizers were applied in shallow pockets--about 6 cm deep and 10 cm to each side of the trees. All seedlings, except those in one of the controls, were protected from rodents with a lightweight polypropylene mesh (6 mil) that was much less rigid than the 50 mil mesh tubes used at Raton and which could be cut to the desired length and attached to the trees before planting.

Results were as follows: At the Raton site, July planting resulted in the highest survival (73%) and was statistically superior ($p<0.05$) to May at 55% and August at 48%. The drip/no fertilizer subtreatment was significantly better than all other subtreatments for each planting date, except August where it was equivalent to mulch/no fertilizer (fig.5). Drip-irrigated

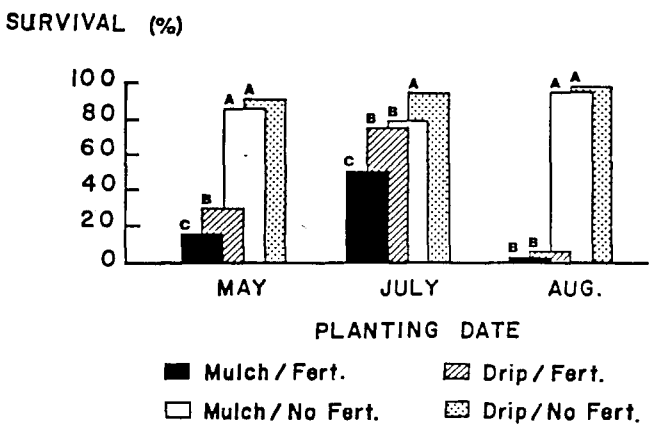


Figure 5--Survival percent for J. monosperma seedlings planted at Raton. For each planting date, treatment values with the same letter are not significantly different ($p<0.5$).

Table 2.--Treatment effects on one-year survival of one-seed juniper seedlings planted near Grants, New Mexico

----------Treatment----------		Survival (%)
Mulch	Fertilizer	
Wood Chips	21 g/tree TSP[1]	98.8 A[2]
	10.1g Os.[3] + TSP	97.5 A
	20.2 g Os.+ TSP	93.9 AB
	none	92.5 AB
No Mulch	21 g/tree TSP	83.8 B
	10.1g Os. + TSP	88.8 AB
	20.2 g Os.+ TSP	95.0 AB
	none	88.8 AB
	none/no protection[4]	85.0 B

[1] Triple-superphosphate (0-46-0)
[2] Values with the same letter are not significantly different at $p<0.05$.
[3] Osmocote (18-6-12)
[4] Treatment lacked rodent protection.

plots (84% survival) were superior to mulched plots (64% survival) for the July planting. Fertilization significantly decreased seedling survival within each planting date. Respective survivals for fertilized versus unfertilized plots were 22% versus 88% for May, 62% versus 86% for July, and 3% versus 95% for August.

At the Grants site, the TSP-only or 10.1 g Osmocote + TSP treatments applied with mulch were superior ($p<0.01$) to TSP-only plots not mulched. Mulched plots showed significantly higher ($p<0.05$) survival (96%) than the non-mulched plots (89%). Although survival was 85% for seedlings without protection, nearly all had been severely browsed by rodents. The plastic mesh used in all other treatments protected the trees from serious animal damage.

Revegetation studies showed that containerized seedlings can be planted with satisfactory to excellent success on spoil banks. Planting date was significant at Raton indicating that seedlings should be planted in time for root growth before ground freeze. In a similar study conducted near Gallup, New Mexico at a lower elevation (2,070 m) and latitude, August planting was superior to September and November (Fisher and others, in press). Although the optimum planting time will vary with site, Raton and Gallup results clearly show that high survival can be achieved if the June drought is avoided.

Dryland plantings in arid regions require some method, like organic mulching, to conserve soil moisture. Mulch clearly improves survival and without severe drought may produce results equivalent to irrigation.

Fertilization can provide a benefit, especially if combined with irrigation. Fertilizer should be applied in shallow pockets near the tree, not directly into the planting hole.

Seedling protectors are essential for success on sites where rodent populations are substantial. The lighter weight, smaller guage (6 mil) mesh used at the Grants site is recommended over rigid 50 mil tubes because the mesh is less expensive, can be attached before going to the field, stays in place longer and photodegrades in about 1 year. Twelve mil mesh is available and would extend protection beyond 1 year.

In summary, we are confident that use of the germination and revegetation practices developed can be joined with existing seedling production technology to successfully restore disturbed or over-exploited juniper woodlands. In addition, it is probable that denuded and severely eroded juniper lands in other countries (for example Pakistan) could be restored through similar techniques.

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Woodland Conversion

Chaired by:

Earl F. Aldon, Project Leader, Rocky Mountain Forest and Range Experiment Station, Forest Service, Albuquerque, NM

CONTROL, PLANT SUCCESSION, AND REVEGETATION IN WESTERN JUNIPER WOODLANDS

Raymond A. Evans and James A. Young

ABSTRACT: Juniper control methods, successional dynamics of herbaceous vegetation, and revegetation of sites following juniper and sagebrush control have been studied for 10 years on western juniper (Juniperus occidentalis Hook.) woodlands in northeastern California. Juniper trees were controlled by picloram (4-amino-3,5,6,-trichloropicolinic acid), picloram with limbing or removal of trees, mechanical clearing and burning, and wood harvesting. Big sagebrush (Artemisia tridentata Nutt.) was controlled with 2,4-D and herbaceous weeds by an atrazine-fallow method. Seedings of intermediate wheatgrass [Agropyron intermedium (Host) Beauv.], alfalfa (Medicago sativa L.), and sainfoin (Onobrychis viciaefolia L.) were made with a rangeland drill. A multi-faceted weed control-revegetation approach was essential for successful improvement of juniper woodlands for increased cattle production and enhancement of wildlife values.

INTRODUCTION

During the last century, a pronounced change in the distribution, density, and age structure of virtually all juniper (Juniperus spp.) woodlands has occurred in the western United States (Johnsen 1962; Arnold and others 1964). Western juniper (Juniperus occidentalis Hook.) woodlands of the northwestern Intermountain Region have undergone dramatic changes since 1875, including invasion of western juniper into sagebrush communities, increased density of trees, and maturation of stands with complete dominance of sites by juniper trees (Young and Evans 1981; Eddleman 1984).

Increase of junipers is usually at the expense of desirable browse and forage species. Therefore, control of juniper trees for increased forage necessitates reestablishment of perennial grasses and other desirable species. Juniper woodlands seldom have uniform stands of trees. Differences in time of establishment and level of dominance create a patchwork of dense trees interspaced with shrub-dominated openings. Under such conditions, control of trees, shrubs, and in some instances herbaceous weeds may be necessary in order to establish desirable forage species.

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Raymond A. Evans and James A. Young are Range Scientists, Agricultural Research Service, U.S. Department of Agriculture, Reno, NV.

STUDIES

We conducted studies in western juniper woodlands in northeastern California on: (1) efficacy and cost of alternative treatments for control of juniper trees; (2) plant succession of herbaceous vegetation following tree control; and (3) revegetation of the sites with forage species (Young and others 1982; Evans and Young 1985; Young and others 1985). The aforementioned studies were conducted in near mature western juniper woodlands where trees or shrubs have almost completely occupied the environmental potential of the site. The average density of western junipers was 150/ha, average height was 9.2 m, and average diameter at the soil level was 0.5 m. The tree cover, in specific areas, had virtually eliminated the woodland understory of herbaceous and shrub species. Other areas had scattered trees with big sagebrush (Artemisia tridentata Nutt.) dominating the sites.

In a fourth study, we combined juniper and sagebrush control with seeding of intermediate wheatgrass [Agropyron intermedium (Host) Beauv.] sainfoin (Onobrychis viciaefolia L.) and alfalfa (Medicago sativa L.) (Evans and Young 1986). This site was 20 acres of big sagebrush that had 60 small juniper trees (3 ft. or less in height) and a scattering of pole sized junipers (5 to 8 ft. tall). In this instance, junipers had not yet dominated the site, but without control probably would have developed into a thicket within a few years.

Control of Western Junipers

A study was conducted to evaluate four alternative control technologies in maturing western juniper woodlands. The alternatives were: (1) to control the trees by the use of picloram (4-amino-3,5,6-trichloropicolinic acid)[1] pellets applied at 0.5 oz per 3 feet of tree height of 10% a.i. material with no further treatment; (2) to use picloram for tree control combined with sufficient limbing or removal of trees to allow seeding with a rangeland drill; (3) to clear juniper trees with a bulldozer and then burn them; and (4) to cut down the trees with chain saws and stack the wood for burning (Young and others 1982).

[1] Picloram is a restricted-use herbicide that is registered for juniper control in California and Oregon by the Environmental Protection Agency.

Herbicidal, mechanical, and multi-harvesting methods were equally effective for control of western juniper trees, but were progressively more expensive. In terms of 1982 prices: the picloram treatment costs $31/acre; picloram with limbing costs $179/acre; mechanical clearing and burning of trees costs $237/acre; and wood harvesting and slash disposal, $832/acre. Wood harvesting, because of its labor-intensive nature, was only economically feasible when the wood was used on the ranch or where local wood markets existed. Transportation costs made this method of tree control invalid when markets were more than 100 miles away.

Plant Succession Following Control of Western Junipers

Successional dynamics of herbaceous vegetation after control of western juniper trees with picloram was studied for a 7-year period (Evans and Young 1985).

The juniper trees had almost completely dominated some areas of the site virtually eliminating herbaceous and shrub understories. In other areas, both trees and shrubs were dominant with little or no herbaceous understory. The sudden killing of the overstory trees without physically disturbing the site initiated a series of complex successional changes in species composition and biomass of the herbaceous plant communities under and between the standing dead trees.

Cheatgrass (Bromus tectorum L.) rapidly dominated areas under dead trees with an accompanying yield increase from almost none to 1250 lb/A at the edge of the tree canopies within 4 years after treatment and from none to over 1400 lb/A midway under the tree canopies 7 years after tree control. Near the base of the trees, yield increased to 350 lb/A by the end of the study. In areas between tree canopies, dramatic changes in botanical composition and yield of herbaceous vegetation occurred with tree control. Initially, cheatgrass and annual broadleaf plants increased. In subsequent years, medusahead [Taeniatherum asperum (Sim.) Nevski] became the dominant herbaceous species on the plot area regardless of tree control. Yield of herbaceous vegetation between live juniper trees consistently averaged about 130 lb/A throughout the study. Between picloram-treated trees increases of herbaceous yield varied from almost none to 1200 lb/A after 7 years. In areas of low tree and high shrub cover little increase in herbaceous yield occurred while in areas of high tree and low shrub cover maximum yield increases occurred after tree control. This was an expected response since there was no shrub control included in the treatments.

Available soil moisture through the active growing period, accelerated litter accumulation and decay, and increased nitrogen in the surface layer of the soil after tree control with picloram were important factors affecting herbaceous vegetation. Relations among these factors and botanical composition and yield of herbaceous vegetation were especially apparent under tree canopies.

The dramatic response of understory annual herbaceous vegetation after control of western junipers emphasizes the need for developing a comprehensive range improvement plan for western juniper woodlands. Integrated control of all layers of this vegetation is necessary for establishment of desirable forage and browse species.

Weed Control and Revegetation Following Western Juniper Control

A study was conducted to evaluate weed control and revegetation techniques for rehabilitating western juniper woodlands following control of the tree overstory by herbicidal, mechanical, or wood-harvesting procedures (Young and others 1985).

As has been discussed previously, control of juniper trees releases shrub and herbaceous vegetation from dominance of the tree overstory. Therefore, revegetation of the woodland with desirable forage and browse species requires weed control of both shrub and herbaceous species.

Picloram pellets were applied to kill juniper trees with subsequent tree limbing to allow the passage of an 8-foot wide rangeland drill. This treatment was compared with mechanically clearing with a bulldozer and wood-harvesting where trees were cut at or near the soil surface. Slash resulting from the treatments was allowed to dry 1 year to permit disposal by burning. A low volatile ester of 2,4-D [(2,4-dichlorophenoxy) acetic acid] at 2 lb/acre a.e. was used to kill sagebrush and atrazine [2,chloro-4-(ethylamino)-6-(isopropylamino)-s-triazine] at 1 lb/acre a.i. for herbaceous weed control. The atrazine treatment was designed to create a herbaceous fallow for 1 year before seeding (Eckert and Evans 1967). Both herbicides were applied with a trailer-mounted boom sprayer modified for rangeland use (Young and others 1979). All plots were seeded with a modified rangeland drill (Asher and Eckert 1973). Seeding mixture consisted of intermediate wheatgrass, sainfoin, and alfalfa. In addition, 2-year-old seedlings of bitterbrush (Purshia tridentata DC.) mountain mahogany (Cercocarpus ledifolius Nutt.) and fourwing saltbush [Atriplex canescens (Pursh) Nutt.] were transplanted into the wood-harvested and picloram-limb plots.

The methods of tree control profoundly influenced subsequent weed control-revegetation options in the understory. Physical constraints imposed by the standing dead trees of the

picloram-limb treatment limited the use of both boom sprayer and rangeland drill making weed control and seeding difficult. In addition, accumulation of juniper litter reduced the efficacy of atrazine for annual grass control on both picloram-limb and wood-harvest plots.

Establishment of forage species was most successful on the mechanically cleared plot; acceptable stands resulted on wood-harvest plots with only marginal stands of grasses and legumes on picloram-limb plots.

Juniper woodlands provide cover and forage for large and small herbivores. Grazing and browsing pressure from these herbivores negated attempts to establish browse species in these trials.

Integrated Range Improvement in Scattered Western Juniper Stands

A weed control-revegetation study was conducted in an area of scattered, young western juniper trees in the general area of the previous trials (Evans and Young 1986). The study site (20 acres) was dominated by big sagebrush with a sparse stand of young junipers, mostly 3 feet or less in height with a scattering of trees 5 to 8 feet tall. This area was surrounded by larger trees and without control would have been a thicket of juniper trees in a few years. The sparse herbaceous understory was dominated by cheatgrass.

The western juniper trees were controlled by individual tree application of picloram in the fall of 1980. In the spring of 1981, 2,4-D was applied with a ground rig sprayer for control of big sagebrush. In the next spring, one third of the area was seeded with 'Greenar', 'Tegmar', or 'Oahe' intermediate wheatgrass mixed with alfalfa and sainfoin by use of a rangeland drill pulled through the standing, dead western junipers and sagebrush.

At the end of the growing season of 1985, an area where western juniper and big sagebrush control was integrated with wheatgrass and legume seeding, forage yield varied from 1260 to 2300 lb/A depending on cultivars of wheatgrass. In contrast, the untreated check areas yielded 200 lb/A. Protein content of the forage was also increased from 7.7% on the untreated check to 10.7% with intermediate wheatgrass-legume mixtures.

DISCUSSION

The aforementioned field trials indicate that many options are open to the rancher or land manager for vegetation manipulations in western juniper woodlands. Results of these trials emphasize the complexity of these communities and the necessity to consider all components of the vegetation when improvement technologies are employed.

Manipulations in Mature Stands

A rancher or land manager who wants to improve western juniper woodlands for increased forage production or improved wildlife habitat has the choice of herbicidal, mechanical, or wood harvesting methods as means of tree control. In terms of cost, herbicides provide the lowest labor and capital investment (Young and others 1982). Labor-intensive harvesting of fuel wood from the woodlands is the most expensive.

When employing improvement technologies in juniper woodlands, a choice of methods and design must also be made in terms of aesthetics and subsequent management of the area. When increased forage production is the primary goal of woodland manipulation and temporary visual disruption is of little importance, area-wide mechanical control followed by seeding is a logical choice. When aesthetics are important and when multiple-use is going to be made of the resources in a specific area, another alternative might be more desirable. Opening up a woodland by creating sunspots or small clearings of 1 or 2 acres gives the illusion of no disturbance or very little disturbance when viewed horizontally. This can best be done by wood harvesting or with picloram. Of course, when using a herbicide the standing dead trees remain which also can be unsightly.

Among the advantages of creating sunspots in a woodland are: the creation of high quality wildlife habitat with diverse vegetation; an increase in forage for livestock grazing; and only slight disturbance of the woodlands. Probably the chief disadvantage to the sunspot concept is the extreme difficulty in establishing forage and browse plants in small areas, especially when wildlife pressure is high.

Unfortunately, controlling juniper trees does not automatically lead to dominance by desirable forage and browse species. Disturbance in juniper woodlands leads to dominance of brush and undesirable herbaceous weeds. This can be construed, in terms of sustained forage productivity, as greater environmental degradation than tree dominance. It is necessary to manipulate all subordinate layers of vegetation after tree control subsequent to seeding of desirable forage and browse species.

The method of tree control influences opportunities for control and manipulation of subordinate layers of vegetation. Controlling trees with herbicides and leaving standing dead trees limits subsequent weed control and seedbed preparation. Limbing of herbicide-killed trees to permit access of spray equipment and drills is difficult and expensive. Mechanical clearing

and disposal of trees provides a clear seedbed, but only temporarily. A delay in revegetation, which might be necessary for drying of the downed trees before burning, will permit establishment of weeds and necessitate herbaceous weed control before seeding.

Manipulations in Young Stands

Many of the difficulties facing land managers when improving mature stands of western junipers do not exist with scattered stands of young trees. With mechanical removal of mature trees, the disposal of aerial biomass of 75 tons per acre with three times that weight in root crowns and associated soil makes juniper tree clearing difficult and expensive. With scattered stands of young trees disposal of huge amounts of biomass is not a problem.

In effect, chemical control of young juniper trees can be likened to preventative medicine. These young trees, if not controlled now, will become an ever increasing problem for the land manager who wants to increase forage and browse production through range improvement.

Rangelands that support big sagebrush and western juniper are, potentially, excellent sites for forage productivity and good candidates for range improvement because of deep soils and relatively high precipitation but unique problems exist with tree, brush and herbaceous weed control and subsequent seeding.

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BIOLOGICAL AND ECONOMIC EFFECTIVENESS OF SEVERAL REVEGETATION TECHNIQUES IN THE PINYON-JUNIPER-SAGEBRUSH ZONE

Warren P. Clary and Fred J. Wagstaff

ABSTRACT: A variety of techniques were used by the Forest Service and Bureau of Land Management to revegetate major portions of two wildfire burns in central Utah. The techniques included aerial seeding with single chaining, aerial seeding with double chaining, aerial seeding with quadruple chaining, rangeland drilling, and land imprinting. Production of seeded plants, when viewed across the range of seeding techniques and ecological site conditions, varied from 170 to 971 kg/ha. The costs associated with seeding these sites varied from $42 to $84/ha. Economic effectiveness was determined by comparing the value of the forage increase with the cost of seeding.

INTRODUCTION

Only a limited amount of seeding information in the pinyon-juniper-sagebrush zone has been published in the last 10 years. Most addresses forage species adaptation (Lavin and Johnsen 1975, 1977a, 1977b; Stevens 1983); little deals with the issue of seeding or revegetation techniques. An earlier article by Lavin and others (1973) discussed intensive revegetation techniques that involved prespraying, spraying, undercutting, plowing, surface drilling, and furrow drilling, but did not report the effectiveness of less intensive techniques such as broadcast seeding with chaining, cabling or railing, or broadcast seeding alone. Their work showed that different combinations of season, seedbed preparation, and planting are required for best results with different plant species.

Several reports from Utah (Ralphs and Busby 1978, 1979) suggest that seeding effectiveness was less with chaining than with drilling, but no direct comparisons were made. An economic analysis was reported for only one of six demonstration areas. An evaluation of Forest Service chainings showed average production of 297 kg/ha of seeded grasses following treatment (Payne and Busby 1980). Several other reports did not differentiate between seeded perennial grasses and other plants, thus the relative contribution by seeded grasses was not apparent (Clary 1983; Phillips 1977).

Koniak (1983) studied eight pinyon-juniper stands that had been broadcast seeded after wildfire. Results were affected by variation in aspect, elevation, precipitation, and livestock grazing and showed that at least in some circumstances adequate stands of seeded grasses could be obtained by broadcasting. However, in most instances above-normal precipitation was a necessary ingredient to achieve a reasonable stand by broadcast seeding. In National Forests of the Forest Service's Intermountain Region, the best results from broadcast seeding have been on rocky soils (Davis 1986). Astroth and Frischknecht (1984) reported that broadcast seeding was most successful on sagebrush sites in the fall following plowing. However, the most consistent results were obtained by deep-furrow drilling in the spring on plowed areas.

A WILDFIRE SEEDING CASE HISTORY

In July 1981 two major fires were ignited by lightning in the Canyon Mountains area of central Utah (fig. 1). These fires, the Clay Springs and Little Oak Creek burns, covered approximately 25,000 ha in the pinyon-juniper and big sagebrush vegetation types. The lands burned were predominantly under Federal management--Forest Service and Bureau of Land Management (BLM).

Revegetation Work

Revegetation efforts by the management agencies began in the fall of 1981. A variety of techniques were utilized depending upon site conditions, agency approach, and some special study situations. The techniques included aerial seeding with single chaining, aerial seeding with double chaining (usually with a modified chain), a special case of aerial seeding with a strip of multiple chaining, rangeland drilling, land imprinting, and no seeding. The implement for imprinting was described by Johnson (1982). It includes a seed box mounted to drop seed ahead of the rollers.

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Warren P. Clary is Supervisory Range Scientist, Intermountain Research Station, Forest Service, U.S. Department of Agriculture, Boise, ID; Fred J. Wagstaff is Range Economist, Intermountain Research Station, Forest Service, U.S. Department of Agriculture, Provo, UT.

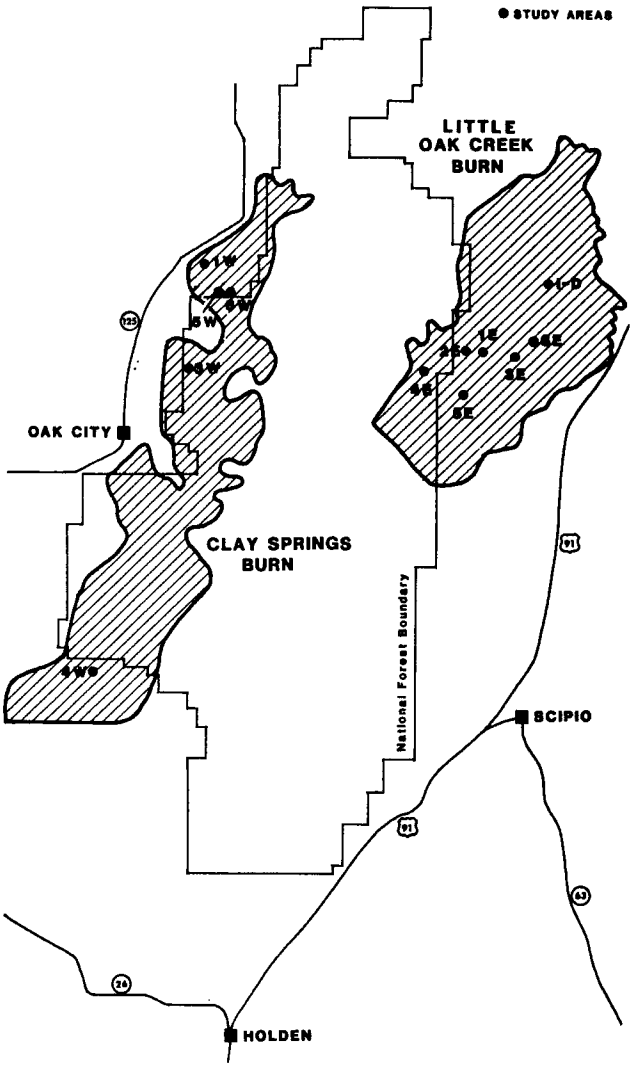


Figure 1.--Location of the Canyon Mountains burns and the study areas.

On the National Forest portion of the burns all seeding was from the air at a rate of 11.3 kg/ha. The seeding species and amounts were:

Fairway crested wheatgrass	1.7 kg
Standard crested wheatgrass	1.7 kg
Intermediate wheatgrass	1.7 kg
Russian wildrye	1.7 kg
Manchar smooth brome	1.1 kg
Ladac alfalfa	2.0 kg
Small burnet	1.1 kg
Yellow sweetclover	0.3 kg

On the areas revegetated by the BLM (rate of 9.0 kg/ha) the seeding species and amounts were:

Fairway crested wheatgrass	4.5 kg
Luna pubescent wheatgrass	1.7 kg
Russian wildrye	2.2 kg
Ladak alfalfa	0.6 kg

Most of the BLM seeding was drilled, although some areas were seeded from the air. In addition to the seed mix, 0.6 kg/ha of fourwing saltbush seed was applied from the air across the general BLM seeding area. In several drilled locations severe wind erosion occurred due to high wind velocity, light-textured soils, and lack of cover. These areas were redrilled in 1982 using the following seed mixture:

Fairway crested wheatgrass	4.5 kg
Luna pubescent wheatgrass	2.2 kg
Fourwing saltbush	1.1 kg
Winter rye	2.2 kg
Yellow sweetclover	1.1 kg
Ladak alfalfa	1.1 kg

Rainfall for the three water-years following seeding, based on weather records from the nearby communities of Scipio and Oak City, was 160, 171, and 172 percent of normal for 1982, 1983, and 1984, respectively. However, for the important April to June period, rainfall the first year after seeding (1982) was only 68 percent of normal. Conversely, in 1984 when these study data were collected, rainfall during these same months was 180 percent of normal.

Study Methods

The objective of this study was to examine the biological and economic effectiveness of the different techniques used to revegetate the Clay Springs and Little Oak Creek burns. Study areas were sampled by 20 to 90 transects of ten 1-m^2 plots located 3 m apart. On each 1-m^2 plot weight estimates were made by individual species. Vegetation on two plots per transect was clipped, ovendried, and weighed to provide a basis for converting estimated green weight to dry weight. A total of 2,900 plots were measured (tables 1, 2, and 3).

Because of the unplanned nature of the large wildfires and the large-scale revegetation efforts by the management agencies, little opportunity existed to establish a rigorous study design for evaluating the revegetation efforts. The imprint, drill, and no seed comparison was, however, established as a replicated design. Sampling in other areas was conducted primarily to document conditions of different situations on the burns. In two instances paired comparisons were made on either side of a line separating two revegetation techniques on approximately similar sites and with similar seed mixtures. The other areas sampled represent individual situations which can only be collated and interpreted in an approximate fashion.

Results

Comparisons among treatments generally indicated a greater production of seeded grasses for revegetation practices that do a good job of covering the seed or compacting the seedbed. This is consistent with past experience (Jordan

Table 1.--Comparisons of plant production (kg/ha) on the Canyon Mountains burns and some characteristics of study areas

Plant type, area characteristic	Drilled vs aerial seeded and single chained (areas 1E and 2E)	Aerial seeded and multiple chained vs aerial seeded (areas 5W and 6W)	Imprinted vs drilled vs unseeded (area I-D)
Perennial native grass	366a vs [1]408a	3a vs 2a	62a vs 69a vs 98a
Perennial seeded grass	348a vs 101b	229a vs 22b	890a vs 777a vs 15b
Annual grass	43a vs 100b	3a vs 96b	10a vs 35ab vs 77b
Perennial native forbs	6a vs 16a	0a vs 0a	1a vs 1a vs 0a
Perennial seeded forbs	66a vs 29a	49a vs 1b	54a vs 16b vs 1b
Annual forbs	10a vs 14a	1a vs 41a	1a vs 2a vs 12a
Native shrubs	13a vs 24a	48a vs 100a	0a vs 0a vs 0a
Total	852a vs 692b	333a vs 262a	1,018a vs 900a vs 203b
	Some characteristics of the study areas		
Elevation	1,660 m	1,620 m	1,550 m
Precipitation zone	38 cm	36 cm	28 cm
Soil	Fine sandy loam to gravelly fine sandy loam, moderately deep.	Very gravelly sandy clay loam to very cobbly sandy clay loam, very deep.	Stony or very fine sandy loam, or silt loam, very deep to shallow.
Plot numbers	400	200	900
Seeding comments	Soil not frozen	Soil frozen	Soil not frozen, moist

[1]Values within rows of the same column followed by different letters are statistically different at $P<0.05$.

n.d.; Plummer and others 1968; Reynolds and Springfield 1953). A highly significant increase in production of seeded grasses occurred where drilling was compared with aerial seeding-single chaining (table 1). A similar increase in production of seeded plants occurred on an aerial seeding-multiple chaining area that was compared with an aerial-seeding-only area. This study area was on a steep hillside where a modified chain had been pulled downhill at least four times on a circular travel route while the surrounding area was unchained. A striking increase in seeded grass establishment and production occurred as a result of severe soil disturbance. A significant increase in seeded forbs also occurred in this comparison. This aerial seeding was done on frozen soils, thus the severe disturbance by multiple chaining may have been more important here than in some situations.

In the three-way comparison of imprinting, drilling, and no seeding the production of seeded grasses was similar between the imprinted and drilled areas. This is of some interest because 2 years earlier the initial

establishment of seedlings was over three times as great in the imprinted area as in the drilled area (Clary and Johnson 1983). It appears that after 3 years of growth, larger plant sizes in the drilled area compensated for the greater density of plants in the imprinted areas. The perennial seeded forb (alfalfa) continued to produce more in the imprinted area than in the drilled area. Total production on the seeded areas was four to five times that of the unseeded area. Surprisingly few annuals were present on the unseeded area even though 3 years had passed since the fire.

In all three comparisons in table 1, the treatments producing the most seeded grasses produced the least annual grasses. However, the presence of seeded grasses did not significantly decrease production of native perennial grasses. There were no significant differences in native perennial grasses within individual comparisons even though substantial differences in seeded perennial grasses occurred (table 1).

The remaining sample locations on the Little Oak Creek and the Clay Springs burns generally represented individual situations; however, the same trend in seedling establishment was

Table 2.--Plant production (kg/ha, $\bar{x}$±se) on individual sample locations, Little Oak Creek burn, and study area characteristics

Plant type, area characteristic	Drilled (area 3E)	Drilled redrilled 1982 (area 6E)	Aerial seeded and double chained (area 4E)	Aerial seeded and single chained (area 5E)
Perennial native grass	12±3	6±5	310±45	20±8
Perennial seeded grass	956±110	806±55	174±51	76±36
Annual grass	16±5	2±1	119±26	156±12
Perennial native forbs	1±1	0±0	19±8	3±1
Perennial seeded forbs	171±34	98±16	1±1	0±0
Annual forbs	33±12	0±0	3±1	2±1
Shrubs	2±2	0±0	54±18	53±10
Total	1,191±108	912±53	680±53	310±27
Some characteristics of the study areas				
Elevation	1,585 m	1,570 m	1,854 m	1,707 m
Precipitation zone	30 cm	30 cm	41 cm	38 cm
Soil	Fine sandy loam to gravelly fine sandy loam, moderately deep.	Fine sandy loam to very fine sandy loam, moderately deep to shallow.	Very stony sandy loam, deep.	Stony fine sandy loam, moderately deep.
Plot numbers	200	200	200	200
Seeding comments	Soil not frozen	Soil not frozen	Soil not frozen, good coverage	Soil not frozen

Table 3.--Plant production (kg/ha, $\bar{x}$±se) on individual sample locations, Clay Springs Burn, and study area characteristics

Plant type, area characteristic	Aerial seeded and double chained (area 4W)	Aerial seeded and double chained (area 3W)	Aerial seeded and single chained (area 1W)
Perennial native grass	11±4	4±2	15±5
Perennial seeded grass	335±47	214±38	239±29
Annual grass	28±9	76±13	104±18
Perennial native forbs	0±0	0±0	1±1
Perennial seeded forbs	10±3	14±4	66±12
Annual forbs	30±13	17±6	4±2
Shrubs	8±5	68±22	8±6
Total	422±35	393±26	437±27
	Some characteristics of the study areas		
Elevation	1,620 m	1,680 m	1,580 m
Precipitation zone	33 cm	36 cm	33 cm
Soil	Fine sandy loam, deep.	Stony or very cobbly sandy loam, deep.	Clay loam, very deep.
Plot numbers	200	200	200
Seeding comments	Soil not frozen, precipitation during back chain, good coverage.	Soil frozen a.m., fair coverage	Soil frozen, poor coverage.

apparent. That is, the more intensive the effort to place and cover seeds, the greater the success. The drilled areas produced considerably more seeded forage than aerial-seeded and chained areas (table 2 and 3). Greater establishment of seeded grasses and forbs in the drilled areas resulted in less production of annual grasses than in chained areas. Drilled areas also had more total production as a result of establishment of seeded grasses even though those sites are at a lower elevation and are in a lower rainfall zone than the chained areas (table 2 and 3). Similarly, the areas that had been double chained produced more seeded forage on the average than the areas that had been only single-chained, but the single-chained areas produced more annual grasses.

When the areas were grouped according to general categories of revegetation technique, a noticeable trend of increased production of seeded species occurred as treatment intensity increased (table 4). These generalized groupings do not represent a direct comparison of revegetation techniques because some site and situation differences were involved; for example, aerial seeding-chaining was a

technique often applied to steeper and rockier terrain than was drilling or imprinting. However, in instances when drilling was compared to aerial seeding-chaining on similar sites, drilling resulted in superior stands of forage species. In study area 1W the terrain was level and the soil was deep and rock free. This was an obviously "drillable" site, yet treatment by chaining resulted in production far below similar drilled areas. It should be noted 1W was one of the sites treated when the soil was frozen. Perhaps future revegetation criteria should limit treatment activity to periods when soils are not frozen.

Economic Effectiveness

The procedure for evaluating the economics of these methods was to consider the cost to provide additional grazing of seeded species (marginal cost) in relation to the value of that grazing (marginal value product). In a study of appropriate values for use in analysis of range improvements, it was found in the Oak Creek area that $6.23 was a reasonable estimate of the annual value of an animal unit month (AUM) (Wagstaff and Pope, in preparation). When this is discounted at an 8 percent interest rate, assuming a 20-year project life with benefits beginning the third year, the net present value of an AUM is $48.70. This value can be directly compared with revegetation costs.

The aerial seeding-single chaining cost $228 to increase forage production by 568 kg annually and thus to increase grazing potential one AUM annually (table 4). This far exceeded the net present worth or capitalized value of an AUM as did the cost of $185 for aerial seeding-double chaining. The problem was the limited biological effectiveness of the chaining option. It should be pointed out that several hundred kilograms per hectare of new forage were produced in 1984 on sites that were often too stony to be revegetated by drilling or imprinting. In addition, the argument can be made that it is necessary to get seed on as many burned acres as possible regardless of seeding technique, and satisfaction is gained in knowing an attempt was made to revegetate and protect a maximum amount of area. However, the success in plant establishment via the seeding-chaining technique was too low to be economically justified on the basis of increases in grazing values alone. Others have reported average increases in seeded forage species of 297 kg/ha (Payne and Busby 1980) to 395 kg/ha (Christensen and others 1966) following chaining or cabling. Nevertheless, under the current benefit-cost structure, the livestock forage values alone would not compensate for the revegetation costs on those areas either if similar results were obtained following wildfire.

Perhaps chaining treatments could show economic feasibility if economic considerations allow use of a higher annual value and a low rate of interest for capitalization. However, both the value of an AUM and the selection of an interest rate should reflect current economic and market conditions, otherwise the analysis would be biased. When other costs such as the costs of water development or fencing are also incurred,

Table 4.--Economic comparisons of revegetation treatments

Treatment[1]	Average production seeded species, kg/ha	Hectares treated/AUM of grazing capacity	Treatment cost/ha	Cost/ AUM of grazing capacity	Net present worth/AUM of grazing capacity
Seed-single chain	170	[2]3.3	[3]$69	$228	[4]$48.70
Seed-double chain	256	2.2	84	185	48.70
Imprint	[5]971	0.6	67	40	48.70
Drill	836	0.7	42	29	48.70

[1]Calculations for aerial seeding only are not presented because an insignificant area was treated.

[2]An AUM is assumed to equal 568 kg of total forage (341 kg consumed at 60 percent use).

[3]Treatment costs are based on typical costs for the Intermountain Region, National Forest System (Davis 1986).

[4]Based on a discount rate of 8 percent, and assuming a 20-year project life with benefits beginning the third year.

[5]Imprinting production is assumed to be 1.2 times the drilling production mean, based on the side-by-side comparison.

economic feasibility is less likely. In this case study, water developments and fencing were also required to allow grazing of the forage, so the cost per gained AUM was greater than the seeding cost alone. Currently, the cost of revegetation by chaining can be justified only if a substantial portion is charged to noncommodity factors such as improvements in soil protection, wildlife habitat characteristics, preclusion of unwanted plants, or enhancement of visual quality.

Drilling and imprinting were the only revegetation techniques that provided new AUM's of grazing at costs less than the apparent gain in value (table 4). This suggests that, when site conditions permit, drilling or imprinting should be selected to obtain the best revegetation result for the dollars invested following a wildfire. When redrilling was necessary because of severe wind erosion, the total cost of the revegetation effort was not fully compensated by gains in livestock grazing capacity alone and would have to be partially justified on the basis of resource protection. This redrilling perhaps could have been avoided if rapidly developing nurse crop species, such as the winter rye and sweetclover planted in the second drilling, had been planted in the first drilling.

In some instances where a substantial amount of native perennial grasses is present, such as occurred on study areas 1E, 2E, and 4E (table 1 and 2), there may be little justification for incurring seeding costs. Recovery of the native perennials should provide an adequate forage resource and soil protection (West and Hassan 1985).

CONCLUSIONS

Revegetation by drilling or imprinting techniques was economically justified based on the increase in livestock grazing values. When redrilling was required, part of the total cost would have to be justified on the basis of resource protection or other noncommodity considerations.

The increased value of livestock grazing did not provide sufficient economic justification for using the aerial seeding-chaining technique. Application of such a revegetation technique may have to be justified to a substantial degree by noncommodity considerations.

Several factors that may have reduced revegetation success on the Canyon Mountains burns were: seeding on frozen soils in some instances; encountering below-normal rainfall the first spring after seeding; and not using a rapidly developing nurse crop in areas susceptible to wind erosion.

ACKNOWLEDGMENT

Acknowledgement is given for the assistance of Benton Smith in location of appropriate study sites and for information on conditions occurring during revegetation work.

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REHABILITATION OF WESTERN JUNIPER RANGELAND: A CASE HISTORY

Thomas E. Bedell

ABSTRACT: The Bonnieview Ranch in central Oregon (Crook County) economically increased beef production and drastically improved environmental diversity at the same time. Paper describes why and how it happened.

SITUATION

Absentee owner, Jack Parker, and resident manager, E. J. Kropf, made the decision in 1978 that to increase production from the 43,000 acre Bonnieview Ranch would be more economical than additional land purchase. This was a fortuitous decision given the change in land values and interest rates since that time. The ranch lies from 3,300 to 6,000 feet elevation in a 10-17 inch annual precipitation zone. About 20,000 acres are a ponderosa pine (Pinus ponderosa)-grass type and 17,000 acres a bunchgrass type largely invaded by western juniper (Juniperus occidentalis). Much of the area had deteriorated to cheatgrass (Bromus tectorum) dominance. An additional 6,500 acres was in the Ochoco National Forest, primarily ponderosa pine-bunchgrass.

In spring cattle were grazed on the cheatgrass-bunchgrass-juniper ranges as early as possible to take advantage of the nutritive value of cheatgrass. In June some cattle would go on the National Forest and the remainder onto deeded forested range. Livestock water limited good cattle distribution. Fall grazing occurred mostly on limited acreages of irrigated lowlands. A total of 400 cows could be handled, 225 of which were on National Forests for two months.

There is an inadequate hay base in relation to rangeland. Economic analysis showed attempting to increase hay production or to purchase hay to be uneconomic. Cows are moved to leased winter pasture in California. Greatly improved weaned calf production was the livestock goal, since it was deemed uneconomic to put yearlings back on range in the spring.

This examination of alternatives to improving productivity showed juniper reduction to be mandatory. At that time, Parker and Kropf did not realize all the additional benefits to controlling juniper. As time passed, these realizations caused modified management plans.

METHODS AND MANAGEMENT DECISIONS

Oldest juniper trees were/are probably 60-90 years of age with age classes all the way down to seedlings. Most were invaders from the old "climax" trees on the rocky ridges. Broadcast burning was not feasible due to lack of sufficient ground fuel. Chemical means were not effective. Kropf did not want to employ chaining due to steep topography and potential degree of soil disturbance. His options were either sawing or bulldozing. Because chain sawing would have been slower than dozing, a combination of two D-6 Caterpiller and two 60 horsepower crawler tractors with 6-way dozer blades were used to push and pile the trees. Smaller trees were pushed by the smaller tractors to improve efficiency. Cost-sharing with Agricultural Conservation Program funds helped reduce total cost.

Some use of chain saws and follow up piling with a smaller tractor was made. Little trees were impossible and impractical to bulldoze out. Although they are susceptible to fire, broadcast burning has not been used yet. Concern exists that fire would destroy more diversity than it would gain, since juniper control releases many browse plants especially at higher elevations.

Sites with the greatest potential and the poorest stands of perennial grasses were planted with crested wheatgrass (Agropyron desertorum). No grass was seeded on higher elevation sites. Crested wheatgrass is more competitive than resident perennial grasses. It was planted both to increase forage productivity on depleted sites and to complement the much larger acreage of rangeland that was not seeded. Its best use was planned for very early spring before native perennials had made much growth.

RESULTS

Kropf observed that although forage productivity increased fairly soon following clearing, there appeared to be some hazard of grazing too soon unless stock could be carefully controlled. Consequently, the conscious decision was made to defer grazing for 2-3 years to allow some stability to occur. The ranch is being managed under Holistic Resource Management principles with the appropriate mix of grazing, animal impact, fire, rest and technology. All management tools used passed the criteria of cause/effect and economic returns for each dollar spent.

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Thomas E. Bedell is Extension Rangeland Resources Specialist, Oregon State University, Corvallis, Oregon 97331.

A total of over 5,000 acres have been cleared at a cost to the ranch of $21 per acre during the 1979-82 period (fig. 1). Large changes in forage and beef production, water flow, and wildlife have occurred. Until the additional forage is efficiently used, no more clearing will be done. Another 8,000 acres of juniper could be cleared.

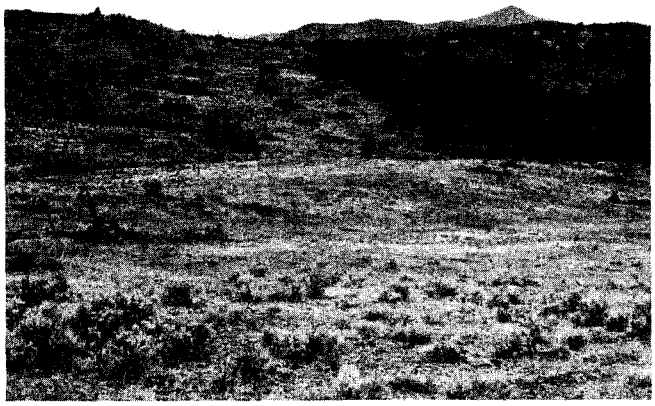


Figure 1.--Juniper cleared in the 1978-79 period. Some piles in mid-ground were burned. Photo taken summer 1985.

Desirable native perennial plants, mostly bunchgrasses, are rapidly gaining on cheatgrass. One 1,200 acre broadcast seeding to crested wheatgrass failed. Although some other seedings succeeded, Kropf found that seeding often was not necessary nor desirable economically and ecologically.

Production changes were documented at improving from 19 acres per AUM to as much as 2.7 acres per AUM on native range. The average now is about 3 acres per AUM. For beef production over the whole ranch, 600 cows are now run with steer calf weaning weights of 582 pounds in 1984 compared to 400 cows with 425 pound steer weaning weights in 1977. Some of the production difference is due to improved genetics, but a substantial part is due to improved forage.

With the advent of increasing perennial grasses, most pastures are grazed 2-3 times; in April, in mid-June, and again in the fall. When care is taken not to overgraze plants, Kropf finds very positive responses.

Several new pasture subdivisions using non-electrified high tensile smooth wire have been made. This fence is less expensive to build and to maintain than conventional barbed wire fences. Currently 150 miles of fence exists on Bonnieview Ranch. In-line wire tighteners are loosened each fall so wire will not break during winter when cattle are not in the pastures.

Grazing management and pasture subdivisions on the 6,500 acre National Forest permit raised stocking rates from 200 cows for 2 months (400 AUM) to 225 cows for 3 1/3 month (800 AUM). One pasture contains the major riparian system which permits special management if needed.

Water production improved greatly (fig. 2). Horse Heaven Creek ran dry each summer. Its entire watershed is on the ranch. Snow now reaches the ground instead of lodging in juniper trees and possibly sublimating. Springs run profusely. Horse Heaven Creek no longer runs dry. Looking at precipitation records indicates that precipitation changes could not possibly account for the improvement in spring and creek flow. Kropf fenced out large portions of the creek into riparian pastures. Not only does this now give him more grazing stability, the streamside vegetation responded quite positively minimizing bank erosion and shading the stream. This action is beneficial to ranch production as well as the fishery.



Figure 2.--This stock pond was dug following control of juniper to impound water formerly used by juniper.

Soil erosion decreased dramatically. Junipers were piled in some gullies but not in live streams. More water appears to be stored in the soil. Some big sagebrush appear to be dying with the changed soil-water relations.

In the latter years of the 5 year clearing project, small one to two acre areas of trees were left. These provided hiding areas for deer. Not all juniper piles were burned and those remaining provided excellent cover for birds and small game (fig. 3). Currently the ranch wildlife populations include antelope, mule deer, elk (which have never been seen before), ducks and geese, quail, chuckars, and dove. Diversified environment and a relative abundance of water not only in the stream but also in the uplands were a result of proper planning and management.



Figure 3.--Cleared juniper trees are pushed into draws to provide both upland wildlife habitat and a buffer to soil erosion via water movement.

CONCLUSIONS

Managing juniper provides benefits not only to Bonnieview Ranch (more beef) and improved cash flow, but to downstream water users and certainly to the society as a whole through a diversified wildlife population. Reduced soil movement and a stabilized watershed resulted through planned upland management. Manager Kropf intends to manage so that minimal opportunity will exist for new juniper seedlings to survive and grow. No definite strategy to accomplish this has yet been adopted. But, as ecological evidence develops, Kropf will be utilizing it to advantage in relation to the whole ranch operation.

SHRUB SELECTIONS FOR PINYON-JUNIPER PLANTINGS

Stephen B. Monsen

ABSTRACT: Planting limitations of pinyon-juniper woodlands have decidedly influenced shrub seeding success. Species adapted to broadcast seeding have generally excelled. Inability to discern site adaptability requirements of individual shrubs has resulted in misplanting, particularly of species with limited distribution. Various subspecies and ecotypes of big sagebrush and rabbitbrush and numerous ecotypes of antelope bitterbrush have proven to be well adapted to pinyon-juniper sites, providing a diverse array of selections with different useful features. Selections of fourwing saltbush, common winterfat, and forage kochia, species naturally occurring in other plant communities, have been developed for pinyon-juniper woodlands. To date, five shrub cultivars with superior vegetative characteristics have been developed for wildlife habitat, including pinyon-juniper sites. These selections, 'Rincon' fourwing saltbush, 'Hatch' winterfat, 'Immigrant' forage kochia, 'Lassen' antelope bitterbrush, and 'Bighorn' skunkbush sumac have advanced the usefulness of these shrubs.

INTRODUCTION

Shrubs are a principal component of the pinyon-juniper vegetation type throughout most of the Great Basin (Beeson 1974; Young and others 1976; Tueller and others 1979). Although valuable for livestock grazing, watershed protection, and esthetics, shrubs are particularly important for big game habitat (Tueller 1979). To date, shrub selection and revegetation research have emphasized wildlife needs--forage and cover (Plummer and others 1968). However, the values and integral relationship of other resources cannot be ignored, and have strongly dictated shrub research and management.

Shrub research has progressed concurrently with the development of herbaceous plants. Grasses and broadleaf herbs have been most reliably established by direct seeding of pinyon-juniper sites and are important to game (Tueller 1979; Kufeld and others 1973; Ferguson 1983) and livestock foraging (Hull and Holmgren 1964; Hassell and others 1983; Asay 1983; Rumbaugh 1983). In most circumstances, shrubs grow in association with herbs. Thus, attempts to establish shrubs must be planned in the context of a mixed community. To a large extent, introduced grasses have been used to plant pinyon-juniper woodlands. The compatibility of the introduced grasses and native shrubs has regulated planting mixtures. Thus, progress in the use of shrubs has been closely related to the advancement of herbaceous species. More important, the invasion of pinyon-juniper trees is often responsible for a decrease in preferred browse (Tueller and Monroe 1975). Plummer and others (1970) found mixed herb-shrub seedings better able to control tree establishment than shrubs planted alone. Thus, conversion of pinyon-juniper woodlands has been dependent upon the development of both shrubs and herbs.

The use of shrubs to revegetate big game winter ranges in Utah was initiated following high animal mortality during extremely harsh winters, particularly 1947-48 and 1951-52. Game managers determined that animal losses were accentuated by poor forage conditions, particularly on sites occupied by closed stands of pinyon-juniper (Robinette and others 1952). Studies were initiated by personnel from the Utah Division of Wildlife Resources and the Intermountain Research Station to determine woody species that could be successfully established and maintained to provide habitat for big game animals. Shrubs now regarded as most successful for pinyon-juniper revegetation resulted, in part, from research priorities established 30 to 40 years ago. This paper provides an assessment of shrub performance from artificial plantings conducted within pinyon-juniper sites in Utah during the past 30 years.

FACTORS LIMITING SHRUB USE

Seven primary factors have been found to influence success of shrub plantings of pinyon-juniper sites. Other conditions are also important, but the following factors strongly influence shrub performance and current use of woody plants in major revegetation projects.

Plant Culture

Factors associated with rearing and field planting largely determine plant performance (Holmgren and Basile 1959). Some shrubs respond satisfactorily without special culture; others need specific attention (Medin and Ferguson 1972; Vories 1981; Shaw 1984; U.S. Department of Agriculture 1985).

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Stephen B. Monsen is Botanist, Intermountain Research Station, Forest Service, U.S. Department of Agriculture, Provo, UT.

Species that establish easily have received the most attention. Poor or erratic seedling establishment is the primary weakness that limits shrub use. Woody plants are often not seeded, or substitute species are used because of expected poor seeding success. Transplants have been used to circumvent problems associated with direct seeding, but this technique has limited application. As seedling establishment problems are solved, shrub plantings will progress quickly.

The primary shrubs currently used in large pinyon-juniper restoration projects are described by Plummer and others (1968). Rearing traits and features that limit or promote species usefulness are also described by these authors.

Site Differences and Shrub Adaptability

Pinyon-juniper sites normally support a diverse array of woody and herbaceous species (West and others 1978). The potential plant composition can be disrupted by grazing or poor management (Tueller and Monroe 1975). Fires can also change the species present and plant composition (Arnold and others 1964; Everett and Clary 1985). Density of pinyon and juniper trees is also influenced by seasonal temperature and moisture (Tueller and others 1979). Age of the stand also influences plant composition.

The potential of individual sites within a pinyon-juniper stand to support specific shrubs or understory herbs is not adequately known. Attempts to seed a homogenous mixture of shrubs and herbs over a variety of sites are not always successful. Some shrubs including mountain big sagebrush (Artemisia tridentata ssp. vaseyana), antelope bitterbrush (Purshia tridentata), and Douglas or low rabbitbrush (Chrysothamnus viscidiflorus ssp. viscidiflorus) are widely adapted to pinyon-juniper sites. Compared with less-adapted species, including Martin ceanothus (Ceanothus martinii), blueberry elder (Sambucus cerulea), and green ephedra (Ephedra viridis), they have been more successful in rehabilitation plantings. However, if species of naturally limited distribution are planted on adapted sites, satisfactory stands often develop.

Usually, less prevalent shrubs are not well represented in most seed mixtures. Consequently, an adequate amount of seed is not planted in areas where these shrubs would likely occur. Thus, species with limited distribution are frequently considered difficult to establish, but in reality, they have not been adequately planted or planted on adapted sites. If site differences within the pinyon-juniper community were better understood, shrub selection and survival could be significantly improved.

Competition of Weedy Annuals

The presence of understory herbs, including weedy annuals, decidedly influences shrub planting success (Koniak 1983) and natural recovery (Everett and Ward 1984). The invasion of cheatgrass (Bromus tectorum) has reduced shrub seedling survival on many pinyon-juniper sites. This annual weed is extremely competitive and limits not only shrub establishment, but subsequent growth.

The presence of cheatgrass frequently masks site potential and has created annual grass-dominated communities on sites that were once shrublands (Hull and Pechanec 1947). Cheatgrass competition can be reduced by spring or fall tillage (Hull and Holmgren 1964), burning to destroy the seed crop, and by planting in scalps or strips cleared of weed seeds. However, control measures are not always effective or feasible. Consequently, weed control must be considered with shrub plantings on many pinyon-juniper sites. Failure to recognize this situation has resulted in planting failures.

Limited Access

Pinyon-juniper woodlands often occupy steep, irregular sites, limiting use of equipment for site preparation and planting. Tree removal and seeding techniques are normally restricted to a few practices--chaining (Plummer and others 1968), burning, and broadcast seeding (Everett and Clary 1985). Removal of competition and seedbed preparation are normally completed in one operation, which favors some species and limits others. Only species that establish with minimal site preparation can be reliably planted with the few techniques available--big sagebrush, Wyeth eriogonum (Eriogonum umbellatum), and low rabbitbrush. The inability to properly treat irregular terrain and soil conditions accounts for limited planting success of many shrubs--mountain snowberry (Symphoricarpos oreophilus), Woods rose (Rosa woodsii), and black common chokecherry (Prunus virginiana ssp. melanocarpa) (Plummer and others 1957).

Inadequate Planting Equipment

Current seeding practices do not always reflect the full potential of shrub seedings. Most seeding operations on pinyon-juniper sites favor grasses. Few seeders or planting devices have been developed to plant small or irregularly shaped seeds including many shrub species. Seeds of most shrubs are planted using equipment designed for grass seeds. Most equipment used for extensive plantings cannot be regulated to properly control planting depths and seeding rates of most shrub seeds (Long and others 1984).

Shrubs are usually seeded in mixtures with other plants, including grasses. Grass seedlings grow more rapidly and frequently outcompete shrubs. To be successful, shrubs must be planted in rows or spots separate from herbaceous plants (Holmgren and Basile 1959; Giunta and others 1975; Monsen and Shaw 1983). Planting equipment and seeding practices must be improved to accommodate planting seeds of multiple species.

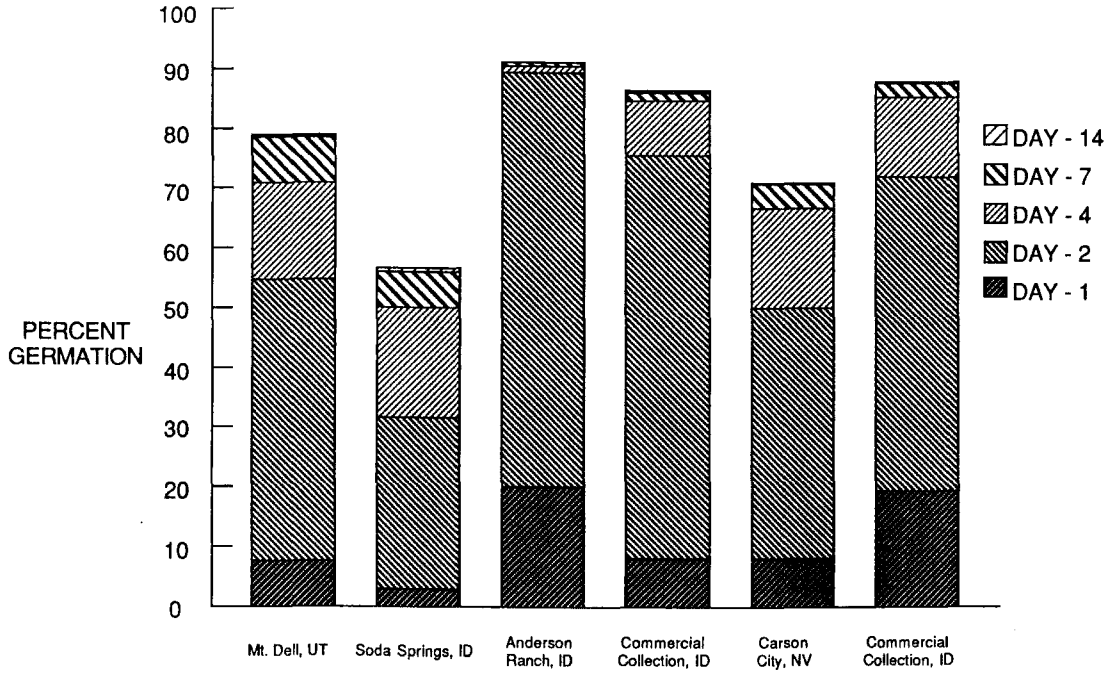


Figure 1.--Cumulative germination of six sources of antelope bitterbrush following 24-hour soak at 2 °C stratification (adapted from Meyer and Allen 1985).

Seed Quality

Seed of most native shrubs is usually acquired from wildland collections. Seed quantity and quality varies among years of collection and locations (Gross 1984). Seed germination and seedling vigor are influenced by climate and condition of the mother plant. Seed cleaning and storage also affect seed quality (Stevens and others 1981). Seed germination and quality standards have not been developed to regulate marketing. Consequently, erratic stands often occur from large plantings as seed quality varies among seed lots purchased and seeded (Monsen and McArthur 1985).

Seed germination of some shrubs is more predictable and uniform than others. Seeds of antelope bitterbrush normally germinate readily, yet vary somewhat among collection sites (fig. 1). Seeds of Saskatoon serviceberry (Amelanchier alnifolia), Woods rose, and black common chokecherry germinate erratically and vary greatly among collections.

Determination of adequate seeding rates and planting methods depends upon the specific lot of seed planted. Care must be exercised to assure the use of good quality seed. Until specific seed standards can be developed and maintained, shrub planting success will likely be quite erratic.

Animal Depredation

Rodent foraging of planted seeds (Everett and others 1978) and established plants (Julander and others 1959) can decimate large plantings. Rodents (Bradley 1968) and insects (Haws and others 1984) definitely prefer seeds of certain species, and entire plantings can be disrupted by these animals. Plummer and others (1957) reported that nearly half of the 20 shrub species commonly used in pinyon-juniper seedings are eaten by rodents, causing damage to large plantings. Species most eagerly sought by rodents include squawapple (Peraphyllum ramosissimum), antelope bitterbrush, Saskatoon serviceberry, black common chokecherry, and bittercherry (Prunus emarginatus). Seeds of some species not used by rodents are fourwing saltbush (Atriplex canescens), winterfat (Ceratoides lanata), sagebrush (Artemisia spp.), and rabbitbrush (Chrysothamnus spp.). Shrub seedings can be established when rodent populations are low; however, rodent numbers may increase as a result of chaining or other treatments (Turkowski and Reynolds 1970). Seeding certain shrubs, including those mentioned above, without controlling rodents or protecting the seed is extremely hazardous.

Grazing by big game and livestock can also be detrimental to young shrub plantings. Some shrubs require a number of years to fully establish. During the interim period, plants are susceptible to grazing. Monsen and Shaw (1983) reported cattle grazing reduced establishment of antelope bitterbrush over a 7-year period following seeding. Deer grazing frequently restricts shrub survival and herbage production (fig. 2). Medin and Ferguson (1980) found deer preference and concentrated use of antelope bitterbrush resulted in mortality of new plantings. Seeding small areas without controlling animal numbers has resulted in the loss of planted shrubs. The size and configuration of the planting can affect animal concentration and use. Reintroduction of palatable plants onto heavily used game ranges

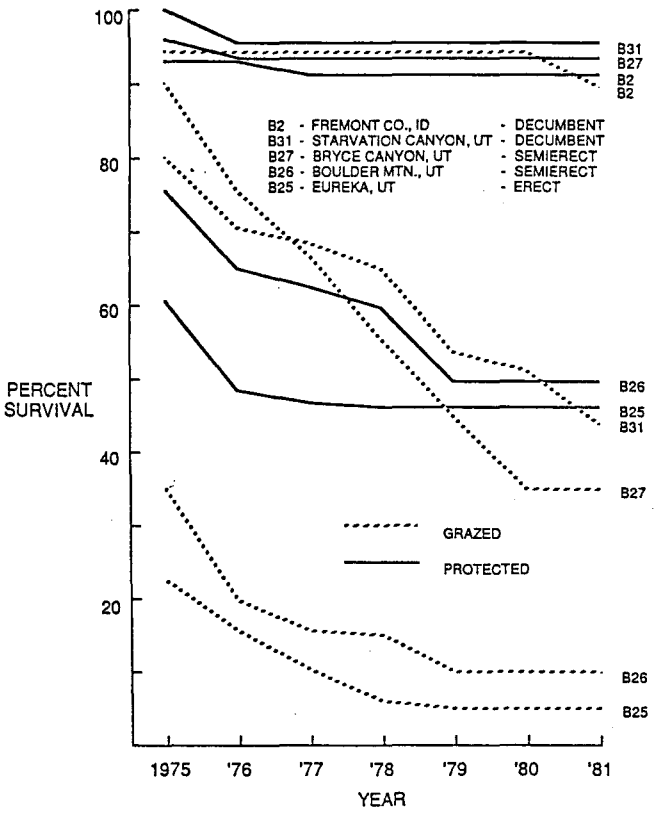


Figure 2.--Influence of deer browsing upon survival of five accessions of antelope bitterbrush from two separate planting sites in south-central Idaho.

is not advised unless grazing can be dispersed or reduced (Plummer and others 1957). Small plantings often serve to concentrate grazing animals, resulting in abnormal impacts. The expected survival of seeded species and recovery of remnant plants must be considered in determining the size, location, and design of pinyon-juniper plantings.

PROGRESS IN SHRUB DEVELOPMENT

Various shrubs have been evaluated for planting pinyon-juniper sites, including species that naturally occur within the woodlands or other closely related plant communities. To date, shrubs considered to be important forage plants for big game animals have been selectively tested. The most promising species are discussed in the following sections.

Prominent Species

Artemisia and Chrysothamnus.--A number of species and varieties of Artemisia and Chrysothamnus occur within the pinyon-juniper woodlands of the Great Basin (West and others 1978; McArthur 1983). The widespread distribution of both genera includes plants adapted for nearly all circumstances encountered in the pinyon-juniper type. Black sagebrush (Artemisia nova) and varieties of big sagebrush; basin big sagebrush (A. tridentata ssp. tridentata), Wyoming big sagebrush (A. tridentata ssp. wyomingensis), and mountain big sagebrush (A. tridentata ssp. vaseyana) usually occur in distinct, but overlapping, areas (McArthur 1983). However, when planted within the pinyon-juniper type all appear to express a broad range of adaptation.

Segregation and eventual elimination of less-adapted varieties and ecotypes of big sagebrush will occur if they are planted in extremely different circumstances. Yet, no other taxa is as universally adapted to the pygmy forest sites as big sagebrush.

Selections of big sagebrush provide considerable variability in growth form, productivity, forage quality, and spreadability (McArthur and others 1979; McArthur and Welch 1982; Davis and Stevens 1986). The palatability and forage quality of sagebrush has often been regarded as low for game and livestock (Voight 1975). However, considerable progress has been achieved in identification and selection of ecotypes of basin, Wyoming, and mountain big sagebrush that are quite palatable, high in crude protein (Welch and McArthur 1979), and low in monoterpenoids (Welch and McArthur 1981). Palatable ecotypes of Wyoming big sagebrush adapted to semiarid regions have been recognized and found adapted to pinyon-juniper sites. In addition, a highly palatable and nutritious selection of mountain big sagebrush has also been developed and will likely be released as a named cultivar (McArthur and others 1985).

Palatability is regarded as the principal weakness of most species of rabbitbrush. Low rabbitbrush is recognized as somewhat better than most varieties of rubber rabbitbrush (Chrysothamnus nauseosus). McArthur and others (1979) rank C. nauseosus ssp. albicaulis and ssp. hololeucus acceptable to grazing animals and recommend their use for game restoration. To date, no single accession of low or rubber rabbitbrush has emerged that exhibits superior forage traits over other collections tested. However, various accessions of low rabbitbrush and two accessions of rubber rabbitbrush obtained from Ephraim Canyon, UT, and Hardware Ranch, UT, are selectively browsed. Studies indicate considerable improvement could be achieved through further selection (McArthur and others 1979).

Seedling establishment and natural spread of big sagebrush and rubber rabbitbrush are important traits that promote their use (Stevens 1986). However, artificial seeding of both species through drills or other seeding equipment is often difficult. Seeds are not easily cleaned, and uncleaned seeds cannot be properly metered or carried through most seeders. Seed placement (Stevens and others 1986) and shallow planting are essential to seedling emergence. Broadcast planting is often more successful than drill seeding. Consequently, aerial broadcasting followed by chaining is a successful means of seeding both sagebrush and rabbitbrush.

Seedlings of big sagebrush and rubber rabbitbrush usually are able to establish and persist when planted with grasses on most pinyon-juniper sites. Grass competition does not prevent the development of a desired number of shrubs. In addition, plants of both species attain maturity within 2 to 4 years and then spread by natural seeding. Shrubs cannot always be established throughout a planting site by artificial seeding. Natural spread must often be relied upon to compensate for erratic stands (Monsen and Richardson 1984). Few other shrubs are able to spread naturally as well as big sagebrush and rubber rabbitbrush. Consequently, site preparation and seeding costs can be reduced if these species are planted.

The number of individual plants of big sagebrush and rabbitbrush to establish by direct seeding can be determined by regulating seeding rates. Simply stated, "the more seed sown the more plants established." This does not apply to most other shrubs. Big sagebrush and rubber rabbitbrush can also be established under extremely harsh circumstances by broadcast seeding. Sagebrush is not well adapted to mine disturbances and exposed substrata, but both species can be established when proper procedures are observed (Luke and Monsen 1984; Monsen and Richardson 1984).

The rapid development of browse is an important consideration in many wildlife plantings. The growth rate of big sagebrush, fourwing saltbush, winterfat, and rubber rabbitbrush exceeds most other shrubs, and young plants are able to survive browsing. Planting these shrubs with slower growing shrubs is a means of providing forage very quickly, and allowing slower developing species time to establish.

Purshia-Cowania-Cercocarpus.--As a group, the related species of antelope bitterbrush, Stansbury cliffrose (Cowania stansburiana), alderleaf cercocarpus (Cercocarpus montanus), and curlleaf cercocarpus (C. ledifolius) perform well from artificial seeding (Monsen and Davis 1985). Antelope bitterbrush is most abundant and has been more thoroughly investigated. Numerous ecotypes with genetically different growth habits, growth rates, and forage qualities have been identified (Davis 1983). Although some ecotypes are only adapted to certain soil conditions and elevational zones, these differences are less pronounced when plantings are established within pinyon-juniper communities. Attempts to plant high-elevation collections on pinyon-juniper sites have not been successful, but many other selections do well within the tree type.

Bitterbrush and other related species have evolved to occupy a wide range of sites and express considerable diversity (McArthur and others 1983; Winward and Findley 1983). Since most ecotypes are quite well adapted to pinyon-juniper sites, important features can and have been incorporated in wildland plantings. Selections that express good drought tolerance have been successfully planted on shallow soils and arid sites. In addition, upright growth forms have been used to provide concealment to game animals and to maximize production of understory herbs. Forage production has also been increased by using highly productive growth forms. Different ecotypes of antelope bitterbrush do not respond as satisfactorily when planted in the big sagebrush or mountain brush plant types. The universal adaptability of most ecotypes of antelope bitterbrush to the pinyon-juniper sites significantly increases their usefulness. Few other shrubs have the same potential to improve game and livestock resources within the pinyon-juniper woodlands. Ecotypes with promising features are described in table 1.

A number of selections of antelope bitterbrush have been developed for wildlife plantings. An upright ecotype from central California has been released as 'Lassen' antelope bitterbrush (Shaw and Monsen, in press). The selection is well suited to neutral and slightly acidic soils throughout northern California and the Pacific Northwest. Plants grow rapidly, retain overwintering leaves resulting in higher levels of protein (Welch and others 1983), and grow well with understory herbs. A selection from Sanpete County, UT, has survived better and produced a greater amount of forage than any other accession planted throughout the pinyon-juniper woodlands. Further testing is required before a formal release is made of this selection.

Seeds of antelope bitterbrush are easily processed and planted. If rodent damage can be controlled, seeding is normally successful (Holmgren and Basile 1959; Nord 1965; Plummer and others 1968; Everett and others 1978). Seedlings survive rather harsh situations, but will succumb to herbaceous competition. Natural spread can be prevented by an understory of annual weeds and seeded perennials (Monsen and Shaw 1983).

Stansbury cliffrose, as well as curlleaf and alderleaf cercocarpus, occur on more restricted areas within the pinyon-juniper type than does antelope bitterbrush. However, when planted on adapted sites, these shrubs develop satisfactorily. All three shrubs exhibit similar weaknesses--low seedling vigor and slow initial growth rates. Under favorable planting conditions, these features do not restrict plant establishment and survival. However, improvement of these traits would better assure planting success. The growth rates of the three species lag behind antelope bitterbrush (fig. 3). Without grazing, 3 to 5 additional years are required for these plants to attain mature stature. The time may be critical as young plants are usually browsed quite heavily, increasing mortality and often delaying or preventing growth to maturity. The delay also enhances understory competition, further suppressing shrub growth.

The most promising development attained with Stansbury cliffrose has been the performance of progeny from a natural hybrid between cliffrose and antelope bitterbrush. Seedlings from open

Table 1.--Selected features recognized among different collections of antelope bitterbrush

Characteristics	Collection sites	
	Positive correlation	Negative correlation
Adaptation to edaphic features		
Acidic soils	Ada Co., ID; Reid Ranch, Payette NF, ID	Washoe Co., NV; Mt. Pleasant, UT
Basic soils	Fairview, UT; Eureka, UT	Idaho City, ID; Ada Co., ID
Coarse-textured soils	St. Anthony, ID; Stein's Mtn., OR	
Elevational adaptation		
(elevation 6,000 feet)	Starvation, UT; Oaks Ephraim Canyon, UT	Snow Canyon, UT
Compatability with herbs	Middleton, ID; Fountain Green, UT	
Drought tolerance	Mono Lake, CA; Bell Rapids, ID	
Evergreen	Lassen, CA	Maybell, CO
Fire tolerance	Wenatchee, WA	Fountain Green, UT; Ada Co., ID
Grazing tolerance	Soda Springs, ID; Spring City, UT	
Growth form		
Erect	Mt. Pleasant, UT; Lassen, CA	
Semierect	Bryce Canyon, UT; Soda Springs, ID	
Decumbent	Starvation Canyon, UT; Craters of the Moon, ID	
Growth rate	Lassen, CA; Fremont Co., ID	Boulder Mtn., UT
Herbage production	Ada Co., ID; Holden, UT	
Layering	Oaks Ephraim Canyon, UT; Sawtooth NF, ID	Maybell, CO; Boise Basin, ID
Seed production	Ada Co., ID; Middleton, ID	
Susceptible to insects	Pringle Falls, OR	Boise Basin, ID; Ada Co., ID

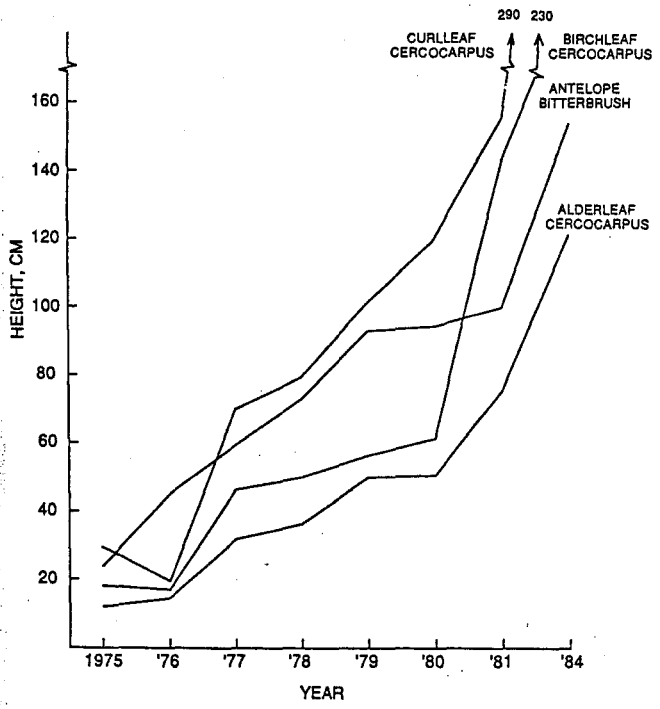


Figure 3.--Mean annual growth rate of planted and protected shrubs growing at selected study site, south-central Idaho.

pollination of a hybrid plant have survived and demonstrated adaptiveness to almost all pinyon-juniper sites. The progeny have evergreen leaves, a feature of cliffrose, with good seedling growth rate and a wide area of adaptation--traits of the antelope bitterbrush parent. Backcrossing the hybrids with suspected parents, occurring at the collection site, or crossing with other populations could further enhance desirable traits. Although hybrids may not possess some desirable characteristics, hybridization is a viable means of enhancing these two shrubs (Stutz and Thomas 1964; McArthur and others 1983).

Collections of curlleaf and alderleaf cercocarpus have been under investigation for nearly 40 years, but no single selection or population demonstrates superiority. Seedlings of all selections grow rather slowly, and attempts to improve this feature have been given priority. Most selections of both plants appear adapted to sites within the pinyon-juniper type, but new plantings must be protected from grazing to assure survival.

'Montane' alderleaf cercocarpus has been released for wildland plantings in Colorado and New Mexico (U.S. Department of Agriculture 1979). Although not widely tested throughout pinyon-juniper woodlands, the selection germinates easily. Plant survival and early growth rate does not appear to exceed other selections, but the germination feature is an important characteristic than can enhance seedling establishment.

Rhus-Amelanchier-Prunus.--Skunkbush sumac (Rhus trilobata), Saskatoon serviceberry, and chokecherry occupy areas throughout the pinyon-juniper forests. Natural stands persist under heavy grazing. Plants frequently survive encroachment of pinyon and juniper trees and can exist both with and without a dense understory of herbs. These shrubs often occur in nearly pure stands,

or they may be intermixed with a variety of species.

Seeding success for each of these species on pinyon-juniper sites has been quite variable. Germination is erratic, and growth is often unpredictable. Initial establishment and early growth appear to affect subsequent growth. New seedlings succumb to drought and some plants that are stunted for 1 or 2 years fail to recover. Growth is often slow for 3 to 5 years, then growth increases dramatically (fig. 4). Competition from other species is destructive to small seedlings, particularly on semiarid sites. However, dramatic differences occur under moist conditions. Both serviceberry and chokecherry persist and grow very well amid herbaceous competition if soil moisture is adequate. Competition for space, light, and nutrients does not appear to limit shrub growth in these circumstances.

Under nursery conditions chokecherry growth is rapid, serviceberry moderate, and skunkbush sumac only fair. Close spacing of skunkbush sumac seedlings in nursery beds reduces growth even when the beds are heavily fertilized and irrigated. Nursery growth rates tend to confirm performance of field plantings for the three shrubs.

Although these shrubs are slow and difficult to establish, once in place the plants persist and furnish excellent game habitat. Long-term evaluation indicates that all three species may require 10 to 20 years to attain mature size.

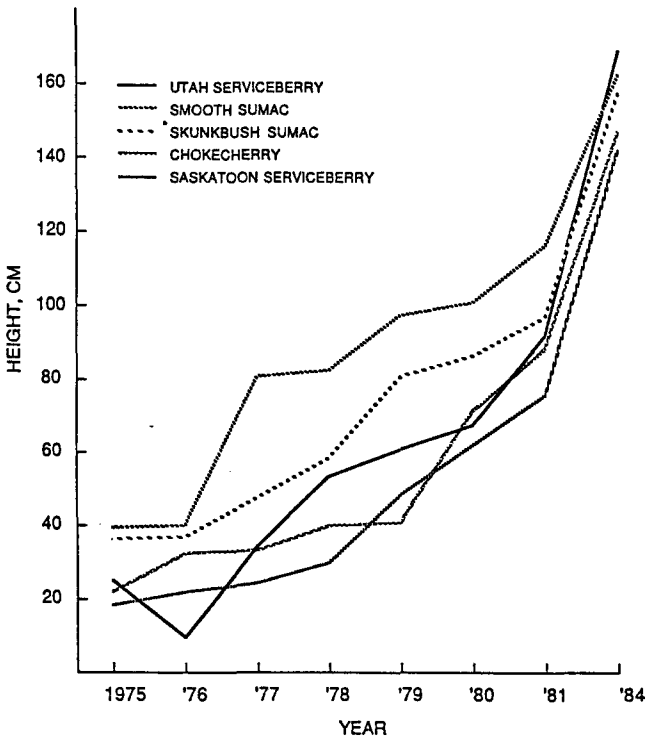


Figure 4.--Mean annual growth rate of planted and protected shrubs growing at a study site, south-central Idaho.

However, plants are long lived and once established are not likely to disappear or require replanting. Although these shrubs usually produce a large seed crop, natural seeding is infrequent. All species survive fire and heavy grazing. Plants grow well with understory herbs and appear to favor the growth of shade-tolerant species. Competition of mature plants with understory species is unique. Dense, mature stands of these shrubs can be easily seeded to improve the understory herbs without affecting shrub performance. Sites occupied by chokecherry and serviceberry often are highly productive, and usually support a mixed understory of broadleaf herbs and grasses. These areas are particularly important to big game during the early spring and winter periods. Seeding alfalfa (Medicago sativa) with chickpea milkvetch (Astragalus cicer) and other palatable forbs can improve these shrublands. Although areas occupied by the shrubs may be relatively small compared to other plant communities, they are vital to game habitat.

Attempts to enhance seed germination and seedling growth rates have been a principal objective of research on all three species. Specific collections of chokecherry from southwestern Montana are easier to germinate than most other selections, and skunkbush sumac accessions from west-central Idaho have excellent drought tolerance. However, plants have not been adequately evaluated for other traits.

'Bighorn' skunkbush sumac was released by the U.S. Department of Agriculture, Soil Conservation Service, in 1979, as a selection for wildland and conservation plantings (USDA 1979). It excels in emergence, stand establishment, and growth rate. It appears adapted to all sites where the species grows as a native, but has not been fully evaluated for pinyon-juniper woodlands.

Species With Restricted Distribution

Growing within the pinyon-juniper type are additional shrubs with distinct areas of occurrence. Plants confined to restricted areas are vital to animal habitat and should be used in revegetation projects. Examples include Martin ceanothus, green ephedra, and blue elderberry (Sambucus cerulea). These species do not grow together, but occur on quite different sites. Seedlings are sometimes difficult to establish, and must be planted on adapted sites to survive. However, Martin ceanothus has been able to grow on sites different from its natural environment.

Green ephedra is very site specific. Plants have survived when seeded "offsite," but are less vigorous and fail to spread by natural seeding. Seeds germinate uniformly, but young plants grow slowly and do not survive if subjected to herbaceous competition.

Blue elderberry is distributed throughout many pinyon-juniper sites, usually as single individuals or small groups. Attempts to seed this

species throughout large areas have not been successful, but plantings confined to areas of adaptation do very well.

Progress has been made in developing culture techniques required to grow these shrubs. Martin ceanothus and blue elderberry establish very well, seedlings are quite vigorous, and seeds can be planted with conventional equipment.

All three shrubs persist and recover well from heavy grazing. Martin ceanothus is usually browsed by wintering animals, but like blue elderberry is also grazed in the summer. Blue elderberry produces many stems, shoots, and leaves that persist for only one season. Unlike many other shrubs, heavy grazing of current growth is not detrimental to the plant.

These shrubs not only produce diversity, but provide available forage during periods of heavy snowfall. Martin ceanothus and green ephedra occur on exposed sites that usually are not covered with snow. Blue elderberry is an erect shrub, not likely to be covered with snow.

A few promising ecotypes of each of the three species have been selected from wildland populations. A collection of Martin ceanothus from central Utah has a wide range of adaptation. Plants from a blue elderberry source in south-central Idaho appear adapted to dry sites, with possible use in the lower pinyon-juniper and big sagebrush communities. No specific collection of green ephedra has excelled over others under test.

Expansion of Species From Closely Related Communities

Considerable research has been directed to the development of shrubs for pinyon-juniper plantings of species that occur in closely associated plant communities. Some shrubs that are prevalent in big sagebrush, salt desert shrubland, and mountain brush types often extend into pinyon-juniper sites. Desirable shrubs have been screened and evaluated to determine their adaptability to pinyon-juniper communities. The most promising candidates have been winterfat, fourwing saltbush, black sagebrush, and desert bitterbrush (Purshia glandulosa). Also included in this group is forage kochia (Kochia prostrata), a foreign introduction.

From the group, three advanced cultivars have been developed, primarily for planting pinyon-juniper, big sagebrush, and other big game winter ranges. The cultivars include 'Hatch' winterfat (Monsen and others 1985), 'Rincon' fourwing saltbush (McArthur and others 1984), and 'Immigrant' forage kochia (Stevens and others 1985). These cultivars have some similar attributes--easily established by direct seeding, rapid growth, highly productive, resistant to grazing, excellent winter forage, and good natural spread.

'Hatch' winterfat was developed from a high-elevation collection obtained in Garfield County, UT. The selection coexists with pinyon-juniper and ponderosa pine (Pinus ponderosa) at elevations over 6,000 ft (1 829 m). Plants are distinctly more robust and larger than any other selection evaluated. Seedling vigor and growth rate exceed all other accessions tested (Stevens and others 1977). Plantings have been maintained at numerous pinyon-juniper sites for nearly 30 years without decline in vigor. Artificial plantings and natural seedings are quite vigorous and survive amid herbaceous plants. Seedlings of few other shrubs are as competitive as this plant, thus enhancing its use in mixed seedings.

'Rincon' fourwing saltbush is one of a number of selections that are well adapted to pinyon-juniper communities. Plantings demonstrated that ecotypes obtained from the southwestern States were not cold tolerant in the Intermountain region (Monsen and Christensen 1976). Consequently, collections from northern climates and higher elevations have been emphasized for pinyon-juniper plantings. In addition, sources that produce a high percentage of viable and easily germinated seeds were sought. 'Rincon' fourwing saltbush possesses these traits, including high forage quality.

Most fourwing saltbush selections establish quite well, but variable results can occur (Clary and Tiedemann 1984; Frischknecht and Ferguson 1984; Monsen and Richardson 1984; Stevens and Van Epps 1984). Seeds germinate erratically, usually as a result of impermeable bracts (Springfield 1970). Utricles can be fractured to facilitate germination. Seedlings are susceptible to frost; consequently, spring plantings may be recommended (Plummer and others 1968). However, genetic control (Stutz and others 1976) and inhibitors (Nord and Van Atta 1957) affect germination.

Fourwing saltbush is able to establish when seeded with herbs, as young plants grow rapidly, but planting in separate rows is recommended (Monsen 1980). When seeded with grasses, 2- or 3-year-old plantings usually can be grazed without damage to the shrub (Klineman and others 1984). Fourwing saltbush is compatible with most grasses and broadleaf herbs recommended for pinyon-juniper projects. Plants are adaptable to different soils and a single ecotype can be planted throughout a large area. Plants persist when subjected to heavy grazing, yet rabbit and rodent grazing can kill seedlings. Because of the diverse characteristics expressed through hybridization of closely related species, this taxa is important to the pinyon-juniper type (Stutz and others 1984).

Both black sagebrush and desert bitterbrush occur intermixed within the pinyon-juniper type on well-drained soils and arid sites. Consequently, they have been important in revegetation of adverse areas. Both shrubs provide useful winter forage.

Black sagebrush is normally quite palatable. It is prevalent on shallow rocky soils, often occurring in pure or dominant stands. However, nearly all collections tested demonstrate

adaptability to different site conditions, and can be seeded throughout pinyon-juniper sites. Plants persist well and spread naturally. Seedlings are more vigorous than big sagebrush and grow well with herbs. To date, research has identified plants that excel in seed production and forage yields.

Desert bitterbrush possesses a number of traits usually not encountered in antelope bitterbrush--fire tolerance, evergreen leaves, tolerance to heat and drought. However, seedlings of desert bitterbrush do not survive and grow as well as antelope bitterbrush. Also, plants are less widely adapted. Consequently, hybridization of the two shrubs has been the most successful means of advancing desert bitterbrush traits. Although desert bitterbrush survives when planted within the pinyon-juniper type, its performance does not equal that of antelope bitterbrush. Even under conditions where desert bitterbrush should excel, antelope bitterbrush responds more favorably.

Perhaps the most favorable shrub introduction for pinyon-juniper sites is forage kochia (McArthur and others 1974). Native to southern Eurasia (Keller and Bleak 1974), the plant demonstrates adaptability to conditions throughout the pinyon-juniper type. Plants also produce relatively high levels of crude protein (Davis and Welch 1984). Stevens and others (1985) have determined the cultivar, 'Immigrant,' excels in forage production and palatability over other accessions tested. This selection is recommended for range and wildlife seedings.

Seed germination diminishes rapidly unless freshly collected seeds are dried to about 7 percent moisture and maintained in cold storage (Jorgensen and Davis 1984). Seeds are small and can be planted too deeply. However, plants can be established from broadcast seeding. The shrub is palatable, yet withstands heavy grazing. It is useful in grass-shrub plantings for livestock grazing (Ostyina and others 1984). New seedlings develop from existing plants, and seedlings are able to spread onto sites occupied by halogeton (Halogeton glomerata) and cheatgrass. The shrub grows well on heavy textured soils and soils having a high salt content (Ostyina and others 1984). This valuable forage plant is able to exist on harsh sites where few other species occur.

CONCLUSIONS

Pinyon-juniper sites normally support a number of shrub associations. Areas occupied by dense stands of trees can be successfully seeded with shrubs and herbs, but successful planting practices are very limited. Species that require minimal seedbed preparation have excelled. However, many other shrubs have promise, but require special care in planting. The use of shrubs has not only been hindered by lack of planting techniques, but also by inability to protect small seedlings and failure to properly define areas capable of supporting specific species.

A number of shrub cultivars have recently been developed as forage plants for livestock and big game habitat. Numerous other shrubs demonstrate potential for revegetation but are not widely used because of weaknesses associated with seed germination, establishment, or growth performance.

Plant selection programs have been employed to acquire and develop collections with superior traits. Progress has been achieved using this approach.

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USING HERBICIDES FOR PINYON-JUNIPER CONTROL IN THE SOUTHWEST

Thomas N. Johnsen, Jr.

ABSTRACT: Pelleted picloram or tebuthiuron are being used to kill individual trees, to maintain chained or bulldozed areas, and to restore recently invaded grasslands on southwestern pinyon-juniper ranges. Good control of Utah juniper (Juniperus osteosperma) and pinyon (Pinus edulis), and variable control of one-seed juniper (J. monosperma) and alligator juniper (J. deppeana) have been obtained. Broadcast applications have been limited to experimental and demonstration trials but both herbicides successfully controlled Utah juniper and pinyon. Tebuthiuron severely damaged cool season grasses; picloram did little damage to grasses. Tebuthiuron controlled understory shrub live oak (Quercus turbinella) and picloram did not.

INTRODUCTION

Although attempts have been made to control junipers on southwestern rangelands since the beginning of this century, most control efforts have been made during the last 30 years. A total of about 1 1/2 million acres of pinyon-juniper ranges was chained, cabled, or bulldozed in Arizona alone during the 1950s and early 1960s (Cotner 1963). Many of these areas are now being reinvaded and junipers are still encroaching on Arizona grasslands (Johnsen and Elson 1979). A renewed interest in pinyon and juniper wood products has resulted in a need for methods to manage stands by selective thinning. Use of mechanical control methods is limited by increased energy and labor costs, limited suitable areas, and aesthetics. Therefore, interest in the use of herbicides to control junipers has increased.

This paper briefly reviews herbicidal control of alligator juniper (Juniperus deppeana), one-seed juniper (J. monosperma), and Utah juniper (J. osteosperma) and some of the problems of using herbicides on southwestern juniper stands. Herbicide terminology follows that suggested by the Terminology Committee of the Weed Science Society of America (Harger and others 1985).

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Thomas N. Johnsen, Jr., is Research Agronomist for U.S. Department of Agriculture, Agricultural Research Service, 2000 East Allen Road, Tucson, AZ 85719.

BACKGROUND

Juniper Characteristics

Junipers are difficult to control with chemicals; Johnsen (1963, 1967) has reviewed characteristics which cause this. Many juniper anatomical and morphological characteristics offer resistance to foliage applied herbicides. The compact, low-growing juniper crowns limit spray droplet penetration into the canopy, resulting in poor, uneven coverage. Mature juniper leaves are small, appressed, scalelike, and vertically oriented, which makes spray droplet impingement difficult. The exposed leaf surfaces have thick, waxy cuticles and a layer of fibers under the outer epidermis which resist herbicide penetration into the leaf. Stomata and thin epidermal layers are located on protected inner surfaces of the appressed leaves and are difficult for sprays to reach. A large resin gland is located inside the small leaf and may absorb herbicides which enter the leaf and prevent movement out of the leaf.

All junipers have dormant epicormic buds which grow rapidly when the top growth is damaged. Alligator juniper also has dormant basal and root zone buds which grow profusely when top growth is damaged (Jameson and Johnsen 1964) making this species particularly difficult to kill. Sprouts from these dormant buds normally break dormancy and grow for only a short period in the early spring and are resistant to short-persistence herbicides.

Junipers have a widespread shallow lateral root system. Johnsen (1962) found that lateral roots of one-seed juniper were often twice as long as the tree height. Thus the lateral root system would be readily exposed to soil-applied herbicides. Herbicides entering the roots would be translocated throughout the tree crown by the younger sapwood of the trunk.

Herbicide Trials

The results of efforts to control junipers and pinyons with herbicides during the past half century were summarized previously (Johnsen 1966a, 1966b; Evans and others 1975). Many herbicidal chemicals were tested but few were effective. Promising agents were: arsenic salts; AMS; 2,4-D; 2,4,5-T; polychlorinated benzoic acids; fenuron; picloram and karbutilate. Of these only picloram is still available to control junipers on rangelands. In more recent trials another herbicide, tebuthiuron, has been effective on Utah junipers (Johnsen 1977, 1979; Clary and others 1985).

HERBICIDES CURRENTLY USED

Picloram

Picloram has been used on junipers in the southwest since 1963 as either foliage sprays or soil applications. It has controlled a variety of juniper species, including Ashe juniper (J. ashei) (Dalrymple 1969), eastern redcedar (J. virginiana) (Dalrymple 1969; Buehring and others 1971), one-seed juniper (Johnsen 1966a, 1967; Johnsen and Dalen 1984), redberry juniper (J. pinchottii) (Schuster 1976; Ueckert and Whisenant 1982), rocky mountain juniper (J. scopulorum) (Fisser 1967), Utah juniper (Fisser 1967; Johnsen 1966a, 1967; Clary and others 1974; Johnsen and Dalen 1984), and western juniper (J. occidentalis) (Young and others 1982). Picloram gave variable control of alligator juniper (Johnsen 1967; Johnsen and Warskow 1966; Clary and others 1974; Johnsen and Dalen 1984). Although picloram has been effective as both spray and pelleted formulations, only the pelleted product containing 10 percent picloram is currently being used to control junipers.

Tebuthiuron

Tebuthiuron has been tested on junipers in the southwest since 1972 but is generally ineffective on all but a few juniper species. Western juniper (Britton and Sneva 1981), eastern redcedar (Scifres and others 1981), and redberry juniper (Ueckert and Whisenant 1982) were not controlled by tebuthiuron. Utah juniper has been controlled by tebuthiuron (Johnsen 1977, 1979; Clary and others 1985). One-seed juniper and alligator juniper have been controlled by high rate of tebuthiuron applied to individual trees but not by broadcast applications in Arizona (Brock 1985; Johnsen data on file).

APPLICATION METHODS

Individual Tree Treatment

Individual tree treatment is used to kill small junipers to maintain chained or bulldozed areas and to restore recently invaded grasslands in the southwest. Pelleted picloram or tebuthiuron is sprinkled over the top of small trees or under the canopy of larger trees to obtain uniform coverage around the tree within the canopy drip line. This treatment is most suited to small trees under 6-feet tall in stands of less than 200 trees per acre. Larger trees vary in response to this treatment and denser stands may require broadcast applications. Applications should not be made onto frozen or saturated soils as the herbicide may be moved away from the treated tree before it can enter the ground. Very little damage has been observed on plants away from trees treated with picloram. However, tebuthiuron may kill grasses and forbs several feet away from the tree, especially with high application rates on slopes.

Applications in the southwest have been made on the basis of tree height units. Earlier work with other herbicides indicated that applicators were better able to judge tree height more quickly than crown diameter, stem diameter, or crown area. There is also good correspondence between tree height and crown volume for the smaller trees, but larger trees often have irregular canopy shapes and foliage densities resulting in a poor relationship between tree height and amounts of live top growth.

Differences in soil and site characteristics including clay content, organic matter, slope, rooting depths, top growth density, and herbicide application uniformity may cause variations in responses to these herbicides.

Individual Utah junipers have been controlled equally well with picloram or tebuthiuron (Johnsen and Dalen 1984; Johnsen data on file). Rates as low as 0.7 g active ingredient of either herbicide per 3 feet of height control Utah juniper trees up to 9-feet tall. High rates, 3.6 g or more per 3 feet of height, of picloram or tebuthiuron kill one-seed juniper and alligator juniper but lower rates of 1.4 g or less per 3 feet of height have given erratic results. Johnsen and Dalen (1984) developed linear regression equations to determine the relationship between tree height and amount of picloram needed to control Utah juniper, one-seed juniper, and alligator juniper. The equations indicate that 1.8 g of picloram will kill a 4.5-foot tall alligator juniper, a 3-foot tall one-seed juniper, or a 7.5-foot tall Utah juniper. Picloram is superior to tebuthiuron for controlling one-seed juniper, but both herbicides control pinyons and alligator juniper equally well. Herbicide effects are quicker with picloram than tebuthiuron. Alligator juniper may regrow several times from dormant buds before the tree dies.

An average of about 13 percent of the trees in pilot trials were not treated, ranging from 1 to 27 percent (Johnsen and Dalen 1984), which is less than the 40 percent average reported by Ueckert and Whisenant (1982) when treating very small junipers. Most of the missed trees were under 2-feet tall, because small junipers blend into the natural colors of the area and are difficult to find. The fewest trees were missed when applicators moved systematically through treatment areas, erratic hunting for trees often resulted in entire groups of trees being bypassed. Marking treated trees along treated strip edges helped reduce the number of missed trees and saved time as applicators returned across the area. Johnsen and Dalen (1984) reported it took from 0.14 to 0.81 worker-hour to treat an acre. Treatment times varied with the size of treated areas, tree density, crew organization, crew attitudes, treatment thoroughness, weather, and terrain. Per acre treatment times were less for smaller areas than for larger areas with similar tree densities.

The amount of herbicide needed for individual juniper treatment projects is readily determined from the size of the area, average number of trees per acre, and the average tree height. The average dosage per tree times the number of trees on the area determines the amount of herbicide needed.

Broadcast Application

Experimental broadcast applications of picloram and tebuthiuron have controlled Utah juniper but responses have been variable with alligator and one-seed junipers. In Arizona, aerial applications of pelleted picloram and tebuthiuron at 0.8 or 0.9 pounds per acre, respectively, killed 80 percent of the Utah junipers. At these rates, picloram killed all of the pinyon but none of the shrub live oak, while tebuthiuron killed 67 percent of the pinyon and 85 percent of the oak. Applications of 2 pounds or more picloram or 1.6 pounds or more tebuthiuron per acre killed more than 90 percent of the Utah junipers. Only 17 percent of the shrub live oak was killed with 3.6 pounds of picloram per acre; 87 percent of the pinyon was killed with 4.4 pounds of tebuthiuron per acre. Variations in individual pinyon responses to broadcast tebuthiuron may be due to variations in pinyon root distributions, especially on rocky sites, and to limited movement of tebuthiuron in soils. Neither herbicide killed many alligator junipers with broadcast applications.

Both herbicides readily killed junipers on ridges and along slopes but left trees undamaged on deep soils or bottom land sites, particularly at the lower application rates. Thus, junipers may not be eliminated from large areas. This is similar to the results reported by Clary and others (1985) from tebuthiuron treatment of Utah juniper in Utah. Picloram usually has maximum effects within 2 years of application to junipers, whereas tebuthiuron may take as long as 4 years to achieve maximum effects.

Effects on Associated Vegetation

Grasses in Arizona, mainly blue grama and sideoats grama, present on aerially treated plots, were not damaged by either picloram or tebuthiuron. In smaller, hand-applied broadcast trials, up to 4 pounds picloram per acre did not damage established grasses. Tebuthiuron did not damage established perennial grasses with applications of 2 pounds or less per acre; however, rates of 4 pounds or more per acre killed cool season grasses. The lower rates of tebuthiuron delayed cool season grass establishment for several years. Current label directions restrict tebuthiuron application to no more than 2 pounds per acre, thus its use should harm few established grasses. Generally, if a residual stand of grass was present, good stands of grasses developed within 5 years on both picloram and tebuthiuron treated areas without reseeding. Crusted, bare soils remained bare indefinitely. Increased grass production resulted from release of established plants from juniper competition and establishment of new plants under and between dead trees. Few forbs or half-shrubs grew on picloram or tebuthiuron treated areas.

Treated areas open to grazing are closely grazed. Grazing management is needed to avoid overuse by both livestock and wildlife following herbicide broadcast treatment of junipers.

ACCEPTANCE OF HERBICIDES

In order to be used, an herbicide must be accepted both by potential users and the interested public. Generally, this means the herbicide must fill a need and be: 1) safe, 2) acceptable to the public, 3) effective, and 4) selective.

Need for Herbicides

In the past, numerous areas of southwestern pinyon-juniper were chained, cabled, or bulldozed. Concern about maintaining these areas, restoring newly invaded grasslands, and managing juniper woodlands caused examination of ways to control junipers. Limitations of other control methods, including increased costs, have stimulated interest in herbicides.
Chaining and cabling, the most widely used juniper control methods, are suited to mature, even-aged, nonsprouting junipers in stands of about 250 trees per acre or less. Small trees and dense stands are not suited to chaining or cabling. Excess debris and soil disturbance also limit public acceptance of chaining and cabling. Moreover, most areas in the southwest suited to these methods have already been treated.

Crushing nonsprouting junipers with specialized equipment is effective for mature, even-aged stands but may not kill small trees, has become costly, and is limited to rock free soils on relatively smooth, level sites. A mulch of crushed tree left on the ground is visually acceptable.

Bulldozing is effective on small to medium sized junipers in stands of up to 150 trees per acre but is costly and debris and soil disturbance may be excessive. Soil disturbance by mechanical control of junipers may cause weeds and undesirable half shrubs to dominate the sites preventing forage plant establishment or increased production by existing forage plants.

Burning individual trees is effective on nonsprouting junipers but is no longer used because of high fuel costs and the limited times it may be used. Grass fires have killed small junipers in experimental burns but have been used infrequently. Burning juniper stands has been successful but many mature stands do not have enough ground fuel to carry a fire. The main use of fires in juniper control has been to reduce slash left from chaining or bulldozing.

Hand cutting junipers with axes or power saws is effective on small to medium sized, nonsprouting junipers in light density stands but the cost is

high and few workers are willing to do this work for more than a few days at a time. However, fuel wood harvesting has been used to remove large trees. Returns from the sale of cutting permits pay part of the costs of controlling the smaller trees by cutting, bulldozing, or herbicide applications.

Picloram or tebuthiuron control junipers by either individual tree or broadcast applications. Individual tree treatments are suited to trees under 10-feet tall in stands of less than 150 tree per acre. Such stands are on newly invaded areas and reinvaded treated areas. Selective thinning of juniper stands for wood production might also be done this way. Small dead trees cause little visual impact, especially after the foliage has fallen. Broadcast applications are suited to dense stands of all sizes of trees. Dead trees in dense stands can be visually distracting and may have to be removed by burning, crushing, or wood harvesting after establishment of the replacement vegetation.

Safety

The toxicology, degradation, movement, and dissipation of picloram have been reviewed by Mullison (1985) and of tebuthiuron by Elanco (1983). Much research has been done on the characteristics of picloram since 1963 and of tebuthiuron since 1972. All indications are that hazards to the environment, animals, or people are minimal if label directions for these herbicides are followed.

Both herbicides are of low toxicity to animals with no indication of biological magnification. Ingested picloram is rapidly excreted unchanged; ingested tebuthiuron is rapidly metabolized and excreted without accumulating in the body. Picloram is degraded by exposure to sunlight and by soil microorganisms. Tebuthiuron is degraded by soil microorganisms and by growing plants. Both herbicides can be moved by soil water several feet into the soil; however, a high percentage of each herbicide is found within the surface two feet of soil. Both herbicides are lost from the soil most rapidly when plant growth conditions are favorable but may be detected for several years after application. Small amounts of these herbicides may leave an area in surface runoff water, mainly in the initial runoff after application. The herbicides are rapidly diluted to biologically insignificant or nondetectable levels as runoff water passes through untreated areas.

Picloram is a restricted-use herbicide which may be sold only to Certified Applicators because of a concern for possible damage to desirable off-site plants, not because of any danger to animals or people. Tebuthiuron is a general use herbicide and its sales are not limited to Certified Applicators. Both herbicides are registered in Arizona and New Mexico for controlling junipers and pinyons. Various use limitations are listed on the different labels for each herbicide so care must be taken to fully understand and to follow directions on current labels.

Public Acceptance

Since the Agent Orange controversy, some members of the public have been critical of using herbicides, especially on public lands. As this is being written, herbicides have not been used on federal lands in Arizona since early 1984. Arizona is under the jurisdiction of the U.S. District Ninth Circuit Court which has banned any herbicide use on federal lands as a result of a suit about the adequacy of a Worst Case Analysis for spraying 2,4-D on Federal lands in Oregon and parts of Washington. This has not limited herbicide usage on non-federal lands in Arizona and herbicides continue to be used on federal and non-federal lands in New Mexico which is not in the Ninth Circuit Court jurisdiction. Hopefully, public education about herbicides and their careful use by applicators will eventually result in a more favorable attitude towards using herbicides on range and forest lands.

Effectiveness and Selectivity

Effective control of one or more juniper species has been obtained with both picloram and tebuthiuron by individual tree or broadcast applications. Even with delayed responses, especially with tebuthiuron, acceptable control has been obtained. Picloram exposed to sunlight may be decomposed and rendered ineffective. Tebuthiuron is very stable and is not rendered ineffective after application.

Individual tree treatments are selective due to herbicide placement under the tree. Plants adjacent to treated trees may be damaged if their roots are in the treated area or the herbicide is washed off the treated area. Broadcast applications of either picloram or tebuthiuron will damage or kill susceptible non-target plants on the treated areas. Established perennial grasses have not been damaged by picloram at rates recommended to control junipers in the southwest; however, similar rates of tebuthiuron can damage cool season grasses.

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HERBACEOUS PLANT MATERIALS FOR PINYON-JUNIPER RENOVATION PROJECTS

Wendell G. Hassell and Wendall R. Oaks

ABSTRACT: Thinning or removal of pinyon-juniper (P-J) trees will usually increase grass and forb species for forage production. Reseeding with more desirable and higher producing cultivars will improve renovation projects. The USDA Soil Conservation Service, Forest Service, Agricultural Research Service, and other cooperating state and federal agencies develop plant materials to improve and add new plant cultivars for P-J renovation.

Adapted species include basin wildrye, bluebunch wheatgrass, blue grama, galleta, Indian ricegrass, western wheatgrass, and Lewis flax. Other species have been tested that fit ecological niches in the P-J vegetative zone. High-quality varieties can improve establishment and production on P-J lands.

INTRODUCTION

Pinyon-juniper vegetation occupies extensive areas in the southwestern United States. Fifteen Major Land Resource Areas (MLRA) show P-J as a major vegetation type (Soil Conservation Service 1981). P-J occupies an estimated 51 million acres in the five states: Arizona, Colorado, Nevada, New Mexico, and Utah (Moessner 1962). Management of P-J woodlands to improve herbaceous plant production involves many alternatives of which seeding is one. The right species will improve the resource, and benefit rangeland and wildlife.

ADAPTED HERBACEOUS SPECIES

Herbaceous understory vegetation can be useful in determining adapted species for reseeding. Understory vegetation varies considerably among P-J stands based on canopy cover and site. Several studies have been conducted to identify understory species in P-J stands (fig. 1).

Several pinyon-juniper communities or subtypes have been recognized (Springfield 1976). Utah juniper is the dominant species in three of four subtypes recognized in northern Arizona and New Mexico (west of the Continental Divide) by Jameson (table 1). According to Jameson, high-producing areas are in the higher elevations of the warm, moist zone, where grasses such as sideoats grama and bottlebrush squirreltail are common. Low-producing areas are in the cool, winter-dry zone, characterized mainly by blue grama (Springfield 1976). Table 1 lists understory herbaceous species for different sub-types.

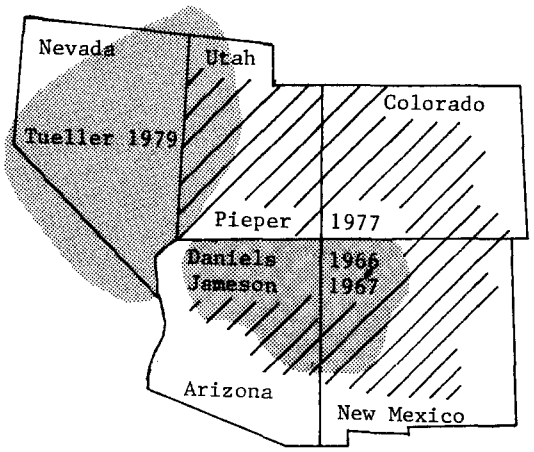


Figure 1.--Studies that have been conducted to identify understory species in pinyon-juniper stands.

Important herbaceous species are listed by Pieper (1977) referring to the States of Arizona, Colorado, New Mexico, and Utah (table 2).

Ecological studies of 71 P-J sites in northern Arizona and northwestern New Mexico identified the following principal understory species (Daniel and others 1966):

Species and Percent of Composition	
Blue grama	42.2
Snakeweed	9.8
Big sagebrush	4.8
Galleta	4.6
Squirreltail	3.5
Black sage	2.6
Indian ricegrass	1.5
Muttongrass	1.5

Major herbaceous species were identified on 66 of the approximately 200 major mountain ranges in the Great Basin of eastern Utah and Nevada (Tueller and others 1979).

Table 3 indicates the grass and forb species showing 10 percent or higher in sampling of 482 plots (Tueller and others 1979).

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Wendell G. Hassell, is Plant Materials Specialist, USDA Soil Conservation Service, Denver, CO. Wendall R. Oaks, Plant Materials Center Manager, USDA Soil Conservation Service, Los Lunas, NM.

Table 1.--Description of four subtypes in pinyon-juniper woodland in northern Arizona and New Mexico (west of the Continental Divide) as recognized by Jameson 1/

Subtype	Climate	Soils	Understory
1. Utah juniper-pinyon-sagebrush	Cold or warm, dry summer	Sandstones in cooler areas; limestone, basalt or granite if in warmer areas	Indian ricegrass
2. Utah juniper-pinyon-sagebrush-muttongrass	Cool, moist	Kaibab limestone, basalt	Cliffrose, muttongrass (*Poa fendleriana*)
3. Utah juniper-pinyon-alligator juniper-chaparral	Warm, moist	Sandstones, redwall limestone, granite, basalt	Sideoats grama, squirreltail, western wheatgrass, black dropseed (*Sporobolus interruptus*), Junegrass
4. One-seed juniper-pinyon-blue grama	Cool, dry winter	Kaibab limestone, tertiary sands and gravels, basalt	Blue grama, galleta, western wheatgrass

1/ Jameson, Donald A. 1967. Productive potential of sites in the pinyon-juniper type. (Establishment and progress report on file at Rocky Mt. For. and Range Exp. Sta., Flagstaff, AZ)

Table 2.--Important herbaceous species in the understory on pinyon-juniper from different areas

Northern Region	Southwestern Region	Southeastern Region
Poa longiligula Longtongue muttongrass	Muhlenbergia emersleyi Bullgrass	Bouteloua gracilis Blue grama
Oryzopsis hymenoides Indian ricegrass	Piptochaetium fimbriatum Pinyon ricegrass	Muhlenbergia pauciflora New Mexico muhly
Stipa speciosa Desert needlegrass	Eragrostis erosa Chihauhau lovegrass	Stipa neomexicana New Mex. feathergrass
Bouteloua gracilis Blue grama		Lycurus phleoides Wolftail
Hilaria jamesii Galleta		Aristida spp. Threeawn

Table 3.--Plant species encountered in study and percent of the plots where each species was observed (constancy)

Scientific name	Common name	Constancy
		Percent
GRASSES		
Agropyron spicatum	Bluebunch wheatgrass	30.7
Bromus tectorum	Cheatgrass	35.5
Elymus cinereus	Wildrye	13.4
Hilaria jamesii	Galleta	9.7
Koeleria cristata	Junegrass	16.1
Oryzopsis hymenoides	Indian ricegrass	53.5
Poa sandbergii	Sandberg bluegrass	57.2
Sitanion hystrix	Squirreltail	79.8
Stipa comata	Needleandthread grass	16.3
Stipa occidentalis	Western needlegrass	16.3
FORBS		
Arabis holboellii	Rockcress	39.2
Astragalus purshii	Pursh locoweed	14.1
Astragalus sp.	Locoweed, Milkvetch	10.4
Balsamorhiza sagittata	Arrowleaf balsamroot	15.8
Chaenactis douglassii	Chaenactic	10.5
Collinsia parviflora	Blue eyed mary	10.7
Crepis acuminata	Tapertip hawk's beard	15.1
Cryptantha flavoculata	---	13.9
Eriogonum caespitosum	Mat wildbuckwheat	18.5
Eriogonum ovalifolium	Cushion wildbuckwheat	11.7
Gilia leptomeria	Gilia	12.4
Lupinus alpestris	Mountain lupine	11.9
Machaeranthera canescens	Hoary machaeranthera	13.1
Machaeranthera leucanthemifolia	Machaeranthera	13.1
Phlox diffusa	Spreading phlox	25.6
Phlox longifolia	Longleaf phlox	23.1
Phlox stansburyi	Stansbury phlox	23.1
Senecio multilobatus	Lobeleaf groundsel	11.9

Table 4.--Selected herbaceous species for P-J sites

Plant name	Seedling vigor 1/	Longevity 2/	Season of use	Herbage production 3/	Forage quality 4/	Improved cultivars	Elevation 5/	Ann'l PPT (in)	Soils 6/ Depth	Soils 6/ Texture
GRASSES										
Basin wildrye	F	L	Spring-Summer	H	F	Magnar	5,000-10,000	14-18	D	Silty
Bluebunch wheatgrass	F	L	Spring	H	G	Whitmar, Secar	4,500- 9,500	12-16	M-D	Silty-clayey
Blue grama	G	L	Summer	M	F	Lovington, Hachita	3,700-10,500	10-14	S-M	Sandy-clayey
Galleta	G	L	Summer	L-M	F	Viva	3,600-10,500	10-14	S-M	Silty-clay
Indian ricegrass	F	M	Spring-Fall	L-M	G	Paloma, Nezpar	4,000- 9,500	10-16	M-D	Sand-silt
Little bluestem	G	L	Summer	M-H	F	Pastura, Cimmeron	3,500- 9,500	14-18	M-D	Sandy-silty
Sheep fescue	P	L	Spring	M	F	Covar	6,000-13,000	12-16	M	Silty-clayey
Sideoats grama	E	L	Summer	H	G	Vaughn, Niner, and others	3,500- 7,500	12-16	M	Sandy-clayey
Spike muhly	P	L	Summer	L-M	G	El Vado	5,000- 9,600	14-18	M	Sandy-silty
Western wheatgrass	F	L	Spring	M	F	Barton, Arriba, Rosana	3,600-10,000	12-16	M	Silty-clay
FORBS										
Lewis flax	G	S	-	L	G	Appar	4,800- 9,400	10-23	M	Sandy-clayey
Palmer penstemon	G	M	-	M	F	Cedar	3,900- 9,000	12-16	M	Sandy-clayey
Rocky Mtn. penstemon	G	M	-	M	F	Bandera	6,000-11,000	14-18	M	Sandy-silty

1/ Seedling vigor - Ratings are relative. Excellent (E); Good (G); Fair (F); and Poor (P)

2/ Longevity - Short-lived (S) stands begin to decline dramatically after 3 or 4 years. Long-lived (L) stands do not begin to decline for at least 5 to 7 years, and usually last 10 to 20 years with proper management on adapted sites; Medium (M) stands last 4 to 7 years, but may regenerate with new seedlings.

3/ Herbage production - Ratings are relative. Production of herbage varies by site, season, use, and other factors, in addition to inherent capability.

4/ Forage quality - Ratings are relative. Good (G) and Fair (F)

5/ Elevation - Minimum and maximum elevation data from Colorado and Utah data in Plant Information Network (PIN) data base.

6/ Soils - Very shallow (S)-less than 10 inches; moderate (M)-10 to 40 inches; deep (D)-greater than 40 inches.

CULTIVARS FOR RESEEDING

Specific site information must be considered before recommending species for reseeding P-J. The following native species have potential for use in P-J renovation and improved cultivars have been developed (table 4).

Description of Native Herbaceous Species

Basin Wildrye.--Basin wildrye (Elymus cinereus) is a hardy, robust, long-lived native perennial bunchgrass found along river ravines, slopes, and flood plains. It often grows in association with Agropryon sp. (wheatgrass), Chrysothamnus sp. (rabbitbrush), and Artemisia sp. (sagebrush). 'Magnar' adapts to a broad soil texture range, except for coarse-texture deep sands and shallow soils, it needs deep soils. It has salt tolerance similar to tall wheatgrass (Agropyron elongatum).

Various ecotypes are tolerant of strongly saline-nonsodic and saline-sodic soils. Basin wildrye is better adapted to winter-wet and summer-dry climates than summer-wet and winter-dry climates (Wasser 1982). It performs best in overflow and sub-irrigated range sites of over 15 inches. Basin wild-rye is tolerant of fair soil drainage, short-term winter flooding, and water table intermittently in top foot of soil (Wasser 1982). Basin wildrye has moderate grazing resistance, but can be damaged by intense early spring grazing. It starts growth before crested wheatgrass.

The only cultivar 'Magnar' was selected for high seed germination and good plant performance and was cooperatively released in 1979. Magnar basin wildrye produces high forage yields. Plot samples on good irrigated land have shown production of 20 tons/acre dry matter. Fall growth left standing over winter gives good protection for cattle calving and wildlife. Early spring growth provides good quality forage. Seed is commercially available.

Bluebunch and Beardless Wheatgrass.--Bluebunch wheatgrass (Agropyron spicatum and A. spicatum inerme) is native on drier areas over the western United States. It is known for its drought tolerance, especially on deep soils. Bluebunch wheatgrass retains its feed value and palatability late into the summer and fall.

'Secar' is a bluebunch wheatgrass selection from a native plant collection near Lewiston, ID. Secar is a densely tufted bunchgrass with abundant, narrow leaves; numerous fine stems; small seeds; and divergent awns. It is early maturing, drought tolerant, and persistent under adverse conditions. Secar generally proved equal or superior to other strains in drought tolerance, forage production, spring recovery, ability to establish and provide ground cover, root and crown production, dryland seed yield potential, and irrigated seed yield potential. In nearly all tests below 14 inches of annual rainfall, its performance exceeded that of 'Whitmar' beardless bluebunch wheatgrass.

'Whitmar' beardless wheatgrass is an ecotype selected from the Palouse climax bunchgrass prairie. Good stands are obtained from spring seedings where moisture is available. If land preparation is less intensive or plantings are on Sierozen soils, fall seedings are more successful (Hafenrichter and others 1979). Seed should be treated with an insecticide to prevent wireworm damage. This grass usually requires 3 years to establish before grazing.

Blue Grama.--Blue grama (Bouteloua gracilis) is the most drought tolerant of the major grasses and has the ability to become semi-dormant with increasing drought; it renews growth quickly with available moisture (Wasser 1982).

'Hachita' was originally collected in southern New Mexico. The site was described as semi-desert plains invaded by mesquite, also associated with tobosa grass, vine-mesquite, burrograss, and three-awns. The elevation was estimated at 4,400 feet and annual precipitation was 10 inches. Hachita blue grama was selected from 21 other accessions for drought tolerance and seed production. In test plots, it had more seedling vigor, produced more herbage, and is more drought resistant than 'Lovington.' Hachita has equivalent seed production to Lovington.

Hachita has been tested throughout New Mexico, and plantings were located near Hurricane, UT; Pueblo and Walden, CO; and Odessa, TX. Preliminary data from a planting near Colby, KS, indicate adequate if not superior performance by Hachita. Commercial seed is available.

'Lovington' blue grama is from a bulk field collection made near Lovington, NM, at 3,900 feet in an area with 14 inches mean annual precipitation. It was selected for its outstanding seedling vigor and forage production. It is well adapted for use on upland sites on medium-textured to fine-textured soils in eastern New Mexico, northwestern Texas, and southeastern Colorado (Thornburg 1982).

Galleta.--Galleta (Hilaria jamesii) is one of very few grasses adapted to the heavier, moderately saline desert soils. However, it thrives on well-drained sandy soils and fractured rockland sites in the Colorado plateau region (Wasser 1982). One of the most characteristic features of the species is its tough, woody rhizomes. The rhizomes also probably aid galleta to greatly resist trampling, heavy grazing, and drought (West 1972).

'Viva' galleta was evaluated at the Los Lunas, NM, Plant Materials Center and at field locations in Colorado and New Mexico. Original seed was collected in 1944 from a native stand near Newkirk, NM. Viva was selected for seed production and seedling establishment and released in 1979.

Indian Ricegrass.--Indian ricegrass (Oryzopsis hymenoides) is a densely tufted perennial with upright stems. It is widely distributed over the West where it is one of the most drought-enduring native range grasses. It is most abundant from low, semi-arid ranges up through the pinyon-juniper zone. It grows on semi-deserts, sand dunes, sandy plains, canyons, hillsides, foothills, exposed ridges, and dry sandy, rocky, or granulated shale sites. It is one of the first species to become established on disturbed sandy sites. Indian ricegrass is both attractive and palatable to all classes of livestock, and is one of the more important forage grasses of semi-arid ranges. The nutritious forage cures well and has special value on winter ranges. This species has excellent seedling vigor and is easily established by fall seeding. There is considerable eco-typic variation in this species, and plantings must be made from adapted seed sources.

'Nezpar' Indian ricegrass was selected for its unusually low percentage of hard seeds and excellent seedling vigor. It is recommended for use throughout the Northwest and Intermountain area of the West. It is adapted at elevations above 6,000 feet in southern states.

'Paloma' Indian ricegrass was collected near Pueblo, CO. It is used for range seeding and soil stabilization in Arizona, Colorado, and New Mexico, and general performance is best at elevations below 6,500 feet.

Little Bluestem.--Little bluestem (Andropogon scoparium or Schizachyrium scoparium) is a major species of the Central Great Plains plant growth region, but is also important from Canada to southern Texas. Little bluestem grows on drier sites. Several cultivars are available for the Central and Northern Great Plains plant growth regions. Two cultivars that are adapted to the P-J region are: 'Cimarron' little bluestem is a composite from many sites in southwestern Kansas and the panhandle of Oklahoma. It has shown good performance in central New Mexico. 'Pastura' little bluestem was developed from a collection made at about 6,500 feet near Rowe, NM, in a 14-inch mean annual precipitation zone. It is well adapted to extremes in temperature and precipitation, and establishes well under adverse range conditions.

Sheep Fescue.--Sheep fescue (Festuca ovina) is a durable low-growing grass. It is slow to establish but is durable and competitive once it is established. It does best on deep soils and at higher elevations.' 'Covar' may be seeded in the fall (late October to mid-November) or spring. Fall seeding is preferred in the low rainfall areas. Seed not over 3/8-inch deep, on a firm seedbed. Covar was developed from material collected in Konya, Turkey. It was compared with numerous other fescue strains. In one 6-year herbage production study, it produced an average 850 pounds of forage per acre, equaling Idaho fescue, a native species. Trial plantings in the northwest region show Covar is an aggressive competitor that forms an attractive drought-tolerant, erosion-control cover. It is a more desirable groundcover than Sherman big bluegrass, Durar hard fescue, creeping red fescue, or crested wheatgrass in 10- to 14-inch annual rainfall areas. Covar is well adapted for roadbanks, terraces or diversions, as dryland turf, in waterways, on steep slopes planned for permanent cover, and other critical areas subject to erosion. It was not selected as a forage plant or for grazing, although it is palatable to livestock.

Sideoats Grama.--Sideoats grama (Bouteloua curtipendula) is a major warm-season, slightly spreading bunchgrass. It is distributed over much of the eastern and central United States. The primary use of sideoats grama is in the Central and Northern Great Plains plant growth regions; but it grows in the Southern Plains, Southern Plateaus, and Southern Rocky Mountains plant growth regions. It is usually seeded in mixtures on lighter textured soils and rocky sites. There are numerous cultivars available.

'Vaughn' and 'Niner' are two cultivars originating from the most westerly areas of the southwest and recommended for P-J sites. Vaughn was released in 1940, and Niner in 1983. Niner produces 50 percent more seed than Vaughn and has been equal to or better than Vaughn in seedling establishment.

Spike Muhly.--Spike muhly (Muhlenbergia wrightii) is a warm-season tufted native bunchgrass with short rhizomes. It grows 8 to 20 inches tall. It is adapted to a wide variety of soil types of the upper pinyon-juniper and ponderosa pine vegetation zones at 3,800 to 9,000 feet in Colorado, New Mexico, Utah, Arizona, and Nevada. It is an excellent soil binder. Spike muhly is palatable to all classes of livestock and is excellent forage for deer and elk throughout the year.

'El Vado' spike muhly was originally collected west of Parkview, NM and released in 1973. El Vado was superior or equal in seed production, seedling vigor, and forage production in almost every comparison to other spike muhly strains at Clovis, Las Cruces, and Los Lunas, NM. This species is a good soil binder. El Vado can be used for soil stabilization and revegetation where vegetation has been reduced or destroyed by surface mining, construction activities, brush control, overgrazing, or fires.

Western Wheatgrass.--Western wheatgrass (Agropyron smithii) is an aggressive, sod-forming species most common in the Northern Great Plains plant growth region, but grows south into Texas and throughout the Intermountain region. In many areas it is the dominant species. It is widely used in range seedings, surface mine reclamation, and critical area stabilization. Western wheatgrass is best adapted to a mean annual precipitation of 14 to 20 inches but performs well in the 10- to 14- inch zone. It is best adapted to soils that are silt or clay but performs satisfactorily on sandy soils. It tolerates soils that are weakly basic to strongly saline. Western wheatgrass ecotypes vary in forage and seed production, color, coarseness, and other characteristics. Other wheatgrasses and other species of grasses are better adapted in areas with predominantly winter-wet and summer-dry climates (Thornburg 1982). Several cultivars have been developed and are available commercially.

'Arriba' western wheatgrass, selected from a collection made in Colorado, is adapted for New Mexico, Colorado, and Utah. Arriba is an aggressive spreader on the better sites.

'Barton' western wheatgrass, developed from a collection in Kansas, is adapted to use in Kansas and Nebraska and adjacent states.

'Rosana' western wheatgrass, a selection from Rosebud County, MT, is adapted to Montana and Wyoming, and can be used in northern Pinyon-Juniper zones. Rosana appears to be more palatable than Barton and Arriba in eastern Colorado.

Lewis Flax.--Lewis flax (Linum lewisii) is a hardy, relatively short-lived native perennial forb. It is well adapted for use in mixtures on variable sites. It has been successfully used as a component in seed mixtures planted for P-J range restoration.

'Appar' was selected because of its outstanding vigor, beauty, and competitiveness with understory grasses prevalent on sites where it was collected. It was named in honor of A. Perry Plummer, U.S. Forest Service (retired), who selected the original plant material in the badlands of the Black Hills region of South Dakota. Appar was released in 1980 and is especially well adapted to the Intermountain Region of southern Idaho and northern Utah and Nevada. Annual precipitation should be 10 inches or more. Best growth is obtained on well drained soils. It is not an understory species.

Deep blue flowers develop profusely for about 6 weeks beginning in mid-May. Appar is non-toxic and very palatable to wildlife and livestock in early stages of growth. Birds consume the seed and capsules in fall and winter. Appar should not be grazed until the second growing season

after planting. It will survive heavy grazing after it is well established. It has a life span of from 5 to 7 years. Plants must develop at least one mature seed crop during this period to perpetuate themselves.

Palmer Penstemon.--Palmer penstemon (Penstemon palmeri) is one of the most beautiful species of Penstemon. It is a short-lived perennial with attractive white corollas fringed with pink. Basal leaves remain green throughout the winter. It grows mainly at elevations of 3,500 to 6,500 feet in washes and along roadsides in the sagebrush and pinyon zones from Utah and Arizona to California. Palmer penstemon shows promise of providing good cover on eroding sites. Game animals browse the plant.

'Cedar' Palmer penstemon was released in 1984. Cedar was selected for its ability to establish, persist, and provide forage diversity when seeded in mixtures on winter, spring, fall, and summer game and livestock ranges. It produces a considerable amount of succulent foliage during the spring and summer growing periods. A large percent of the basal leaves remain green during the summer and winter months, consequently allowing foraging animals to graze the plants during critical periods. The plant provides high-quality forage during the winter. Small birds, big game, and livestock selectively use Cedar. It provides good ground cover for erosion control and stabilization of disturbed sites and burns. Cedar is also useful for horticultural and landscape plantings because of the abundant flowers, pleasing aroma, and persistent foliage.

Mature plants are long-lived for penstemons, living 5 to 7 years. Extensive regeneration can occur by natural seeding. An abundance of seed is normally produced even during adverse years. Seeds are small and may persist in the soil for a number of years, allowing for natural spread and stand maintenance. Cedar does best in open stands, but will grow in association with grasses, low shrubs, and intermediate shrubs like big sagebrush and antelope bitterbrush. Complete range of adaptation has yet to be determined, but Cedar should do well in Utah, Arizona, New Mexico, Colorado, Idaho, and Nevada.

Rocky Mountain Penstemon.--Rocky Mountain penstemon (Penstemon strictus) thrives on rocky, sandy loam soils usually in open shrublands and woodlands, often on rather thin soils.

'Bandera' Rocky Mountain penstemon is a herbaceous, long-lived, perennial, flowering plant useful for beautification, soil stabilization, and ornamental landscaping.

This variety was released in 1973. The original collection of Bandera was made in the ponderosa pine zone northwest of Mountainair, NM. The natural range of Rocky Mountain penstemon is central and northern New Mexico, Colorado, southern Wyoming, Utah, and northeastern Arizona at elevations from 6,000 to 11,000 feet. It is found on rocky to sandy loam soils.

Bandera has an abundance of dark, shiny green leaves. The lower leaves form a basal rosette. The stems are coarse and range from 8 to 28 inches in height. The abundant flowers range from blue to violet in color. Most of the flowers were produced between mid-May and mid-June at Los Lunas, NM, where the initial testing was done.

This variety can be established from seed or from plant sprigs obtained by dividing the base of older plants. Each sprig needs some roots and a few leaves for best results. Basal portions of the stems layer (grow roots) readily in moist soil. Seedling vigor is good for plants established from seed. Bandera should be fall seeded for best results.

Fusarium wilt reduced seed production of Bandera after 2 years on a flood-irrigated sandy loam soil. This disease has not been observed on plants growing on clay or clay loam soil. Plants with low vigor were occasionally attacked by scale insects.

Description of Introduced Grass Species

There are 3 new introduced grass varieties that have been released and show high potential for use on pinyon-juniper areas.

'Bozoisky-select' Russian wildrye (Elymus junceus) was selected by the Agricultural Research Service for improved seedling vigor and forage production. This cultivar was released in 1984. Russian wildrye greens up earlier in the spring and stays green through the summer. Bozoisky-select has higher yields than 'Vinall' Russian wildrye in low rainfall areas of the West. Bozoisky-select is a long-lived bunchgrass originating from the USSR. It is adapted to 8 to 14 inches annual precipitation zone.

'Hycrest' crested wheatgrass (Agropyron cristatum) is a hybrid between fairway crested wheatgrass and standard crested wheatgrass. It has improved seedling vigor and becomes very competitive with cheatgrass (Bromus tectorum) on dry sites. Hycrest is adapted to the same area as other crested wheatgrasses, but yields about 20 percent more forage than Nordan. This cultivar was developed by ARS at Logan, UT, and released in 1984.

'Paiute' orchardgrass (Dactylis glomerata) was introduced into the United States from Turkey. It was selected by the Forest Service at Ephraim, UT, for its ability to establish and persist in P-J areas. Paiute is more drought tolerant than other orchard varieties and has persisted for as long as 20 years on arid rangelands in Arizona, New Mexico, Idaho, and Utah. Areas of greatest adaptability are sagebrush grass and pinyon-juniper communities. Paiute was released in 1983 as a persistent bunchgrass developed for quality forage on arid rangelands. It will green up earlier than Fairway crested and remains greener in the fall. Good management practices are needed to maintain high production stands.

CONCLUSIONS

Pinyon-juniper woodlands are increasing in economic importance. Management is shifting from chaining large areas for increased forage production to joint production of wood, cover, and forage (Smith 1985). Reseeding with adapted perennial species can speed up successional stages on P-J sites. In studies by Erdman (1970) at Mesa Verde, CO, succession after fires followed the basic successional stages (Erdman 1970):

Fire - skeleton forest/bare soils	0 years
Annual vegetation	2 years
Pennial grass/forb stage	4 years
Shrub stage	25 years
Shrub/open tree stage	100 years
Climax P-J forest	300 years

Soil moisture availability is a major factor controlling plant community patterns in the P-J zone and must be considered with any renovation-reseeding project.

Under given conditions of climate and geologic parent material, soil texture slope, and rockiness determine the presence and distribution of woodland and grassland communities in the pinyon-juniper zone. Trees prevail on the coarser, rockier sites, whereas herbaceous vegetation characterizes the finer textured soils. Grasses and forbs, with fibrous, compact, and generally shallower root systems may also grow on coarse, rocky sites, but are much better adapted than are most woody species to fine-textured soils.

Cultivars that have been selected for seedling vigor, forage production, and erosion control uses can improve success of establishing herbaceous species. These species have been field-tested and information assembled on specific areas of adaptation and performance.

Seeding adapted perennial species can improve productivity of P-J lands and help protect this range resource. Composition of vegetation can be improved by using ecological site information, good establishment techniques, and improved plant materials, resulting in resource benefits over many years.

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ECONOMIC AND SOCIAL ASPECTS OF PINYON-JUNIPER TREATMENT--THEN AND NOW

Raymond S. Dalen and William R. Snyder

ABSTRACT: Since 1950, about 550,000 acres of pinyon-juniper woodland on the National Forests in the Southwest have been mechanically treated to improve forage production. Management emphasis of pinyon-juniper woodland has shifted to fuelwood and wildlife, but if forage production is to be maintained, retreatment is needed. Treated areas are in various stages of regrowth with residual and new trees varying from 10 to over 250/acre. The age of the clearing, forage site productivity, tree density, height distribution, and composition are important factors in selecting retreatment projects. A pinyon-juniper regrowth model was developed to help select the better retreatment sites. Retreatment is most cost efficient on high forage production sites where tree density is between 25 to 125 trees/acre and 85 percent of the trees are 6 feet tall or less.

INTRODUCTION

The National Forests in Arizona and New Mexico contain about 6,835,000 acres of pinyon-juniper (PJ) woodland. Approximately 4,495,000 acres of this ecosystem are considered suitable for grazing by domestic livestock accounting for about 45 percent of the total livestock use on National Forests in Arizona and New Mexico. The PJ woodland type is characterized primarily by pinyon pine (Pinus edulis Englem.), Utah juniper (Juniperus osteosperma (Torr.) Little), one-seed juniper (J. monosperma (Englem) Sarg.), alligator juniper (J. deppeana Steud.), and Rocky Mountain juniper (J. scopulorum Sarg.)

During the 1950's and 1960's, the demand for forage production exceeded demand for tree products obtained from PJ woodlands, and trees were removed to increase forage production for livestock. The high cost of harvesting and the slow growth rate of pinyon and juniper discouraged the management of these trees for wood products (Arnold and others 1964).

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Raymond S. Dalen is Range Improvement Specialist, U.S. Department of Agriculture, Forest Service, Albuquerque, NM; William R. Snyder is Director of Range Management, U.S. Department of Agriculture, Forest Service, Albuquerque, NM.

This paper presents a brief history of PJ treatments since 1950 and current management emphasis of PJ woodlands. Is retreatment of these older PJ project areas an economic practice? An economic evaluation method is presented to aid in the selection of retreatment sites.

HISTORY OF PINYON-JUNIPER TREATMENT

Since 1950, tree removal treatment has been applied to about 550,000 acres of National Forest PJ woodland in Arizona and New Mexico. During the 20 year period, 1950 to 1969, 463,100 acres were treated. This accounts for 84 percent of the total PJ woodland acres treated by tree removal. Only 85,100 acres of PJ woodland have been treated since 1969 (table 1).

Tree removal treatment methods were almost exclusively mechanical and included cabling, chaining, pushing, and crushing.

Cabling was the primary method of treatment during the early 1950's. This method utilized two large crawler tractors linked together with 300 feet of heavy cable. Cabling removed the larger trees but allowed the smaller trees to survive. It worked best in open stands of mature juniper with 100 to 150 trees/acre. In dense stands with small trees the cable would raise and slide over the trees. Cabling normally removed only about 50 to 60 percent of the trees. The results on heavy clay textured soils were poor and cabling alligator juniper was not effective.

Table 1.- -Pinyon-juniper treatment 1950 to 1985. National Forest land in Arizona and New Mexico. Approximate acres

	Treatment Clearing Method					
Period	Cabling	Pushing	Chaining	Tree crushing	Other[1]	Total
	Thousand acres					
Before 1950	1.8					1.8
1950 - 1959	126.9	122.0			0.7	249.6
1960 - 1969	20.5	65.0	64.0	61.5	2.5	213.5
1970 - 1979		27.5	17.5	15.0	2.5	62.5
1980 - 1985		22.6				22.6
Total	149.2	237.1	81.5	76.5	5.7	550.0

[1] Includes burning, hand cutting, and herbicides.

Chaining was first used in 1960. An anchor chain weighing 90 lb/foot was used in place of a cable. During the 1960's chaining costs averaged $7.50/acre compared to cabling at $2.85/acre. However, the heavier anchor chain was considered more effective in removing trees and cabling was phased out during the early 1960's.

Pushing has been the most widely used method totaling 237,100 acres (table 1). Here individual trees were bulldozed, and often piled and burned. During the early 1950's an effort was made to find the best equipment for pushing. Both wheel and crawler tractors with the dozer blade modified with a pusher bar were used. The pusher bar was designed to push the tree over and the dozer blade caught the roots, lifting the tree out of the ground. The wheel tractor was best for trees 4 to 8 feet tall but the power of a crawler tractor was needed for larger trees. Pushing was accomplished in open stands with 20 to 75 trees/acre. Utah and one-seed was easier to push than alligator juniper. During the 1950's pushing costs averaged $5.25/acre and were higher than cabling costs at $2.25/acre, but the results were considered more effective. During the 1960's and 1970's pushing costs were higher than chaining. Even though some small trees were missed when pushing the results in overall tree kill were better than chaining.

The LeTourneau Tree Crusher was first used in 1965 in New Mexico. This machine weighed 80,000 pounds, had three 6-foot drums with cutting blades spaced 18 inches apart, and cut a 16-foot swath. The LeTourneau Tree Crusher was effective in dense stands of mature trees, but small pinyon or juniper trees less than 4 feet tall were too pliable for effective treatment. In one project, 40 percent of the trees survived. However, the cutting drums did provide a good seedbed and all slash was flattened. Some tree crushing was accomplished in the late 1970's using a modified Fleco brush roller. This employed a 16-foot wide drum pulled by a large tractor. Results were similar to the LeTourneau Tree Crusher.

Historically, considerable effort and investment was made to increase forage production in the PJ woodland type. Where the residual grass stand was considered inadequate, project areas were often seeded to forage grasses. Forage production was often increased between 700 and 900 lb/acre on the more productive sites and as much as 400 to 600 lb/acre on the moderate sites, but forage response on some PJ woodland soils was negligible (O'Rourke and Ogden 1969). It is estimated the increased forage production produced about 140,000 animal unit months (AUM) of grazing capacity on National Forest lands in Arizona and New Mexico. Regrowth of the surviving trees and establishment of new trees on previously treated areas has reduced the net gain to an estimated 110,000 AUM's.

The economic benefit associated with PJ woodland treatment was primarily increased forage production for livestock, which resulted in increased grazing use on some allotments and maintenance of grazing use on others. There is no significant change in water yield following mechanical treatment of PJ woodland (Clary and others 1974) and until the 1970's much of the debris was burned and little was used for fuelwood.

There is little evidence that economic evaluations were used in project site selection for PJ woodland treatment. Cabling was probably phased out in the early 1960's because the expected benefit was not consistent with costs. Chaining and pushing was most likely cost efficient only on the most productive sites. Based on 1972 data, range economic benefits and costs came out about even for the more successful juniper control projects. Benefits in increased forage production were marginal or not equal to the costs where PJ woodland sites had only poor or moderate forage production potential (Clary and others 1974).

In many cases, social benefits associated with woodland treatment were more positive than the direct economic benefits. In this aspect many of the projects were considered cost effective when the social and economic benefits were combined. A cost-effective project is where the returns or benefits, both quantifiable and nonquantifiable exceed the overall costs. Social benefits include maintaining traditional lifestyles, employment, community stability, and stability of ranch operations where the permittee affected is dependent upon public lands for livestock grazing. Permittee dependency on livestock forage from National Forest land in Arizona and New Mexico averages 47 percent. Past PJ woodland treatment activities were carried out to improve forage productivity, which in turn contributed to the social and economic well being of people and communities that depended on rangelands for their livelihood.

CURRENT MANAGEMENT EMPHASIS

Management Direction

Pinyon-juniper woodlands are now being managed to emphasize a variety of uses, and management priority includes fuelwood production and wildlife habitat enhancement as well as grazing use. Pinyon pine and juniper are preferred fuelwood species and, in accessible areas, their availability is becoming limited. Between 1977 and 1979, fuelwood sales increased 62 percent (USDA 1983). Preliminary information developed for Forest Land Management Plans indicates about 135,000 acres of PJ woodland in Arizona and New Mexico will be harvested for fuelwood during the 10-year life of the Forest Plans. The fuelwood harvest methods depend on specific stand characteristics and are designed to insure natural regeneration. Shelterwood harvest is the most common method and involves removing the overstory trees in two or more cuttings. Because of overstory canopy reductions from fuelwood harvests, forage production is expected to increase for a significant period following harvest (Jameson 1971). The amount of increased forage production depends on site productivity.

Under current management, the emphasis for PJ woodland is retreatment of areas previously cleared during the 1950's, 1960's, and 1970's (table 1). Retreatment to maintain forage production will be accomplished on the most productive sites in a

cost-effective manner and must be consistent with standards and guidelines in the Forest Plans. Approximately 115,000 acres will be retreated during the 10-year life of the Forest Plans. Tree removal may still be used for forage improvement objectives consistent with Forest Plans. However, the project must be cost effective and located in areas where demand for fuelwood is light and access is limited both now and into the foreseeable future (USDA 1983). New openings designed primarily to increase forage production are projected to cover only about 7,000 acres during the 10-year life of the Forest Plans.

Current Retreatment

Close to 80,000 acres of the initial 550,000 acres of PJ work has had some type of retreatment. About 42,140 acres have been retreated since 1980, mostly by pushing, individual plant treatment using pelleted herbicides, and some prescribed fire and handcutting (table 2).

Chaining or tree crushing is not an effective retreatment method, but pushing has been used with costs averaging $20.30/acre. Specific information for analysing variable costs of pushing previously treated woodland stands has not been developed, but they are associated with tree density, composition, and height class distribution.

A program was started in 1977 on the Prescott National Forest in Arizona to manually apply picloram 10 percent active ingredient (a.i.) pellets around the base of individual pinyon and juniper trees on previously cabled, chained, and pushed areas. This method was generally used on trees less than 6 feet tall. Between 1978 and 1981, herbicide demonstration plots were established at seven locations in Arizona and New Mexico to determine control results on different tree species by height class on several soil types (table 3). The herbicides used include picloram pellets (10 percent a.i.), tebuthiurom pellets (20 percent a.i.), and hexazinone in the liquid form, all applied using the individual plant treatment method at two rates. Based on

Table 2.- -Acres of previously worked pinyon-juniper areas retreated during the period 1980 to 1985 and approximate costs

	Clearing Method				
	Pushing	Herbicide[1]	Prescribed fire	Hand cutting	Total
	Acres				
	20,575	17,055	3,820	690	42,140
	Dollars per acre				
Low	13.70	6.25	2.50	30.00	
High	29.60	18.75	4.00	49.30	
Average	20.30	11.50	3.25	40.75	

[1] Individual plant treatment.

information learned from the demonstration plots, about 17,055 acres have been treated with picloram pellets since 1980 (table 2). Costs ranged from $6.25/acre to $18.75/acre for an average of $11.50/acre. This cost is less than pushing, because herbicide applications were generally in stands where the tree density varied from 60 to 150 trees/acre with only trees 6 feet tall or less being treated. Aerial application of pelleted herbicides has not been used on a project basis because the total cost at 1 lb/acre a.i. is about $36/acre.

Use of prescribed fire has been limited because livestock use must be deferred for at least one growing season to allow fuel accumulation. Success is generally limited to trees less than 4 feet tall (Springfield 1976). Prescribed fire under proper burning conditions is relatively inexpensive and an effective removal method for pinyon, one-seed, and Utah juniper where at least 60 percent of the trees are 4 feet tall or less and sufficient fine fuels exist to carry the fire.

ECONOMIC EVALUATION OF RETREATMENT

Trees are regrowing in the previously cleared areas and forage gains are gradually being reduced. Retreatment of some previously treated areas may be cost efficient. The rest of this paper deals with the economic efficiency of retreating historic tree removal sites.

A PJ regrowth model was developed to predict the increase in percent crown canopy over time "with" and "without" retreatment based on existing tree density, composition, and height class. The understory forage production associated with changes in overstory is converted to AUM's and assigned a benefit value which is discounted over time to calculate present value of range related benefits. The retreatment cost is calculated based on the retreatment method and existing stand characteristics. A benefit-cost ratio and present net value of a retreatment project can then be determined. The model is designed to help in the economic evaluation and selection of the most cost-efficient sites for retreatment.

Modeling Crown Canopy Regrowth

There is little information available on the regrowth characteristics of PJ overstory crown canopy following cabling, chaining, or pushing. Arnold and others (1964) report that the average crown canopy of PJ following cabling and pushing on 29 sites in Arizona increased from less than 0.5 percent to slightly over 2.0 percent, a rate of 0.6 percent/year over 3 years. They report that PJ grows back very slowly where clearing is thorough, but on cabled areas the small trees that are missed respond rapidly to release when the larger overstory trees are removed. Barney and Frischknecht (1974) report that Utah juniper crown cover increased slowly during the first 46 years following fire in west-central Utah. The trees began to dominate the study sites 46 to 71 years after burning.

Several studies report on crown canopy growth in untreated stands. Jameson (1965) reports that in a young stand of pinyon and one-seed juniper in northern Arizona the crown canopy increased at the rate of 0.31 percent/year over a 20-year period. Jameson (1971) also reports that the rate of change in crown canopy regrowth of PJ based on 21 study sites in Arizona and New Mexico is associated with existing percent crown cover of the stand. In stands where the crown canopy is greater than 3 percent, the average mean annual change of crown canopy was 0.420 percent, but only 0.123 percent in stands with less than 1 percent canopy. There was no apparent relation between tree cover changes and any site characteristics. Stands with few trees had low growth rates as did over mature stands. Cover increase was greatest for stands with 10 to 35 percent crown canopy. Howell (1940) reports that growth is slow in the woodland type with little variation in growth rate for individual trees between good and poor sites.

The previously treated PJ stands vary in site productivity, age since treatment, tree density, composition, and height. The approach used to model change in percent crown canopy was to establish average height growth rates by 1-foot height classes by tree species. As the trees increase in height, a height-crown area ratio is applied to calculate crown canopy. The height growth rate for both pinyon and juniper is based on Howell (1940), but the rate for juniper was increased slightly based on Jameson (1965) and Myers (1962). Starting the first year and at 25-year intervals the height-crown canopy ratio was used to calculate gross crown canopy (ft^2/acre) based on the predicted increased height growth and the average number of trees per acre in each height class. Gross crown canopy was adjusted to net tree crown canopy to account for tree canopy overlap. The tree height-crown ratio is based on measurement of 227 pinyon trees, 427 alligator junipers, and 173 one-seed junipers at two treatment sites in New Mexico. A weighted average calculated from the alligator and one-seed juniper measurements is used to represent all junipers. The one-seed juniper height-crown ratios are similar to those reported by Howell (1940).

Most of the crown canopy regrowth is from existing trees. On older project sites this includes trees that survived the original treatment and new trees that have become established. The age of project site treatments vary but it is assumed that new trees will continue to become established. The number of new trees which may become established is variable and difficult to predict but generally relates to existing tree density. A conservative estimate was used based on Arnold and others (1964), Jameson and Johnson (1964), Jameson (1965), Aro (1971), and Tausch and Tueller (1977). The interval in which new trees are established is 33 years based on Barney and Frischknecht (1974). The newly established trees with their relatively slow growth rate comprise only about 7 percent of the overstory after 75 years. The predicted regrowth in crown canopy of a PJ stand with 100 trees/acre is illustrated in figure 1.

Modeling Overstory-Understory

Previous studies have shown the relationship between overstory crown canopy and understory herbage/forage production. Perennial understory vegetation generally is greatest where there are few trees. The decrease in perennial grasses and forbs is proportional to the increase in overstory of PJ (Arnold and others 1964; Jameson 1967, 1971; Clary and others 1974; Clary and Jameson 1981). Forage production associated with overstory crown canopy cover between 0 and 70 percent is displayed in figure 2.

Project Site Parameters Modeled

Project site parameters modeled are based primarily on information from the herbicide demonstration plots (table 3). The parameters include tree composition, density, height class distribution, and site forage productivity.

Tree composition.--Tree composition includes a pure juniper stand (one-seed, Utah, and alligator juniper are combined) and a 50/50 mixed PJ stand.

Table 3.- Pinyon-juniper tree density, composition, and percent distribution by tree height class on pelleted herbicide demonstration plots established 1978 to 1981 on previously cleared areas

Project	Forest	State	Clearing method	Year originally cleared	Surviving tree species: Pinyon pine	Juniper: One-seed	Juniper: Utah	Juniper: Alligator	Juniper: Rocky Mountain	Total	Height class (feet): 0-3	4-6	7-9	10+
					Trees per acre						Percent			
McInturf	Tonto	AZ	Pushing	1955				701		701	60	28	8	4
Alma Mesa	Apache/ Sitgreaves	NM	Pushing	1958	11		9	194		214	45	40	13	2
Mud Tanks	Coconino	AZ	Pushing (hand cutting)	1959 (1962)			11	51		62	47	43	9	1
13-Mile Rock	Coconino	AZ	Pushing	1963			50	53		103	57	29	12	2
Cedar Flat	Coconino	AZ	Chaining	1965			81			81	33	49	11	7
Bonito	Cibola	NM	Tree crusher	1966	110		83			193	20	59	20	1
Rowe Mesa	Santa Fe	NM	Tree crusher	1968	64		19		39	122	55	36	4	5

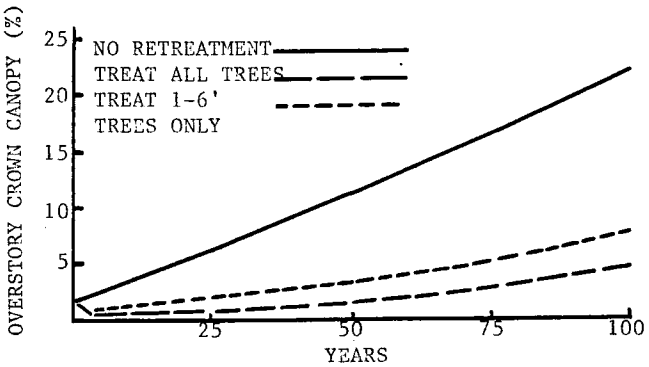


Figure 1.--Average crown canopy regrowth of a previously treated 50/50 mixed pinyon-juniper stand with short height class "without" and "with" retreatment. "With" retreatment includes treating all trees or only trees 6 feet tall or less.

Tree density.--Modeled tree densities range from 10 to 250 trees/acre. Tree density is based on stands considered most appropriate for retreatment. At six locations the number of trees ranged from 62 to 210 trees/acre (table 3) and represent many of the treatment projects in Arizona and New Mexico. The McInturf site in Arizona, pushed in 1953, had the highest density of trees at 701/acre but is not considered typical of stands suitable for retreatment.

Tree height distribution.--The distribution of trees by height class is important in selecting retreatment sites. In developing the model, two typical stand distribution classes were selected based on the height class data in table 3. One is referred to as a short height class stand where trees 3 feet tall or less dominate the stand. Trees in this height class are the easiest and least expensive to control. The second stand distribution is referred to as average height class because mid-size trees 4 to 6 feet tall dominate the stand. The percent of trees by height class for the short and average stand distribution is shown in table 4.

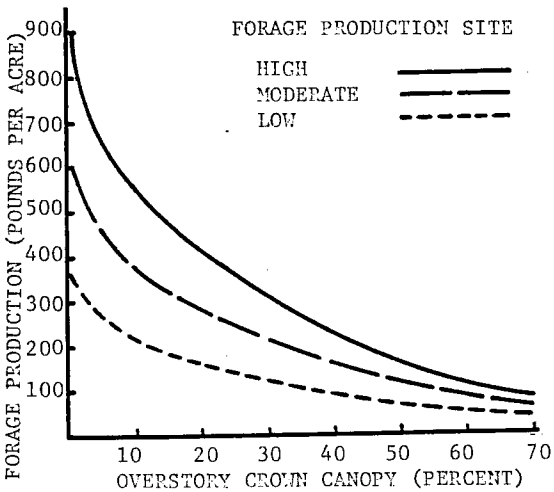


Figure 2.--Average understory forage production capability relationship to pinyon-juniper overstory crown canopy for three forage production sites.

Table 4.- Percent distribution of pinyon-juniper trees by tree height class (feet) in a short and average stand

Tree height class	Stand distribution height class	
	Short	Average
Feet	-- Percent --	
0-3	55	30
4-6	30	50
7-9	12	15
10+	3	5

Forage productivity.--For modeling purposes, three site classifications relating to soil production potential are used. A high classification represents a site capable of producing an average peak standing forage crop of about 900 lb/acre when all of the tree overstory is removed. A moderate site will produce about 600 lb/acre and a low site only about 350 lb/acre. The forage production associated with tree overstory percentage for each site class is shown in figure 2. Forage production rates are based on average annual climatic conditions.

Economic Analysis and Assumptions

A computer spread sheet program was developed to calculate cost efficiency of retreating PJ sites based on predicted change in tree regrowth in percent crown canopy "with" and "without" retreatment. In this paper, only retreatment using individual plant treatment with pelleted herbicides is analyzed because variable cost data tended to be more readily available. However, similiar information could be developed for mechanical retreatment and prescribed fire. The economic analysis is designed to select the most cost-efficient site and the break-even point based on tree densities of 10 to 250 trees/acre in a pure stand of juniper or a 50/50 mix of pinyon and juniper for two stand distribution height classes and three forage productivity sites. The program was also designed to compare the current practice of treating only trees 6 feet tall or less with treating all trees.

The assumptions used in the economic analysis are listed below.

"With" and "without" project.--"With" project includes both treating all trees in the stand and treating all trees that are only 6 feet tall or less. "Without" project is no retreatment and trees will continue to grow and increase in crown canopy (fig. 1).

Forage-AUM production.--Forage production associated with the change in tree overstory for each production site classification is converted to AUM's based on forage intake of 600 lb/AUM, and 40 percent allowable use. Grazing intensity and management is assumed to be constant.

AUM benefit value.--An AUM is assigned a benefit value of $9.67. This is a Regional average based on the Economic Research Service Livestock Budget Study (Gee 1981) completed for each National Forest in Arizona and New Mexico. An AUM benefit value of $5.22 is also used based on the Regional average of the appraised market value of grazing on public rangelands adjusted for advance payment (USDA, USDI 1985).

Retreatment costs.--Retreatment costs are based on individual plant treatment using pelleted herbicides. Herbicide cost is $28.80/lb a.i. Application cost includes travel time on foot to reach each tree, treatment time, and project travel mileage. Treatment travel time per acre from Cotner and Jameson (1959) was adjusted based on several current treatment projects. Current labor rates are used. Permittee application costs may vary slightly. Herbicide rates vary with tree species and height class. Taller trees require more material than shorter trees. Pinyon and Utah juniper are the most sensitive to picloram. Alligator juniper is moderately resistant and one-seed juniper is the most resistant (Johnson and Dalen 1984). Total treatment costs per acre in a 50/50 mixed PJ stand with an average height class where all trees are treated varies from $1.97/acre at 10 trees/acre to $35.14/acre at 250 trees/acre (figure 3). Costs of the original treatment are not considered and are treated as sunk costs.

Tree survival rate.--Ten percent of the pinyon trees in all height classes, 10 percent of the juniper trees in the 0 to 6 feet height class, and 20 percent of the juniper trees in the 7 feet or greater height classes are expected to survive. The survival rate is primarily from application error and is based on results from the demonstration plots and recent projects.

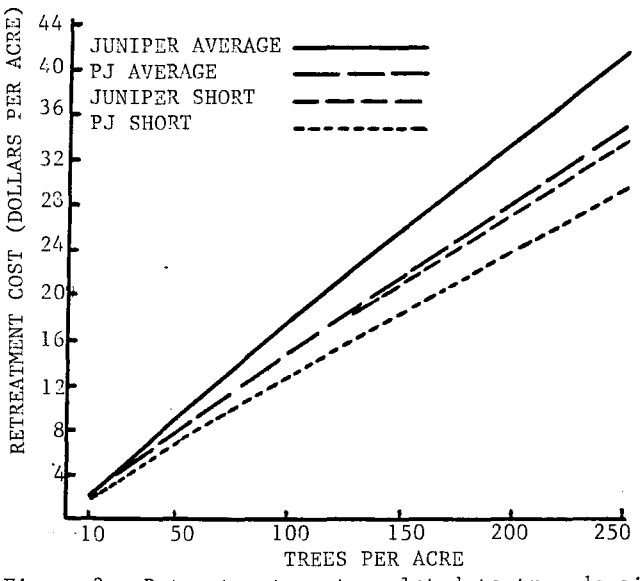


Figure 3.--Retreatment costs related to tree density using individual plant treatment with pelleted herbicides. All trees are treated in a 50/50 mixed pinyon-juniper and pure juniper stand with short and average height class.

Discount rate and project life.--A real discount rate of 4 percent is used for long term projects (USDA 1985). The project life is expected to be 50 years based on the survival rates. No increased benefits occur the first 3 years following treatment. Benefits are discounted beginning year 4 until year 50. Only one retreatment is expected so costs are assumed to occur in year zero and are not discounted.

Economic investment criteria.--Present net value (PNV) is used to determine retreatment project cost efficiency. Present net value is the difference between the discounted or present value of the benefits and costs (USDA 1985). A positive PNV indicates the benefits from retreatment exceed the costs. The break-even point is where the present value of the benefits (PVB) equals the present value of the costs (PVC). All costs and benefits are on per acre basis.

Results

The results of the economic analysis indicate that of the site parameters modeled, tree density and forage site productivity are significant evaluation criteria in selection of retreatment sites. Tree species composition and height class of the stand are less significant. For example, when analyzing only benefits, the PVB at equal tree densities are similiar for a pure juniper and 50/50 mixed PJ stand with either the short or average tree height class. In contrast, the PVB on the high productive site varies from $6.37/acre to $29.34/acre at 10 to 250 trees/acre when all trees in a 50/50 mixed PJ stand are treated (fig. 4). Present value of the benefits decreases by about 30 and 60 percent when moderate and low productive sites are retreated.

The general range of acceptable retreatment costs for various tree densities and forage site conditions is illustrated in figure 4. For example, with 150 trees/acre the cost break-even point is $24.20/acre at a high forage production site. The treatment cost must not exceed

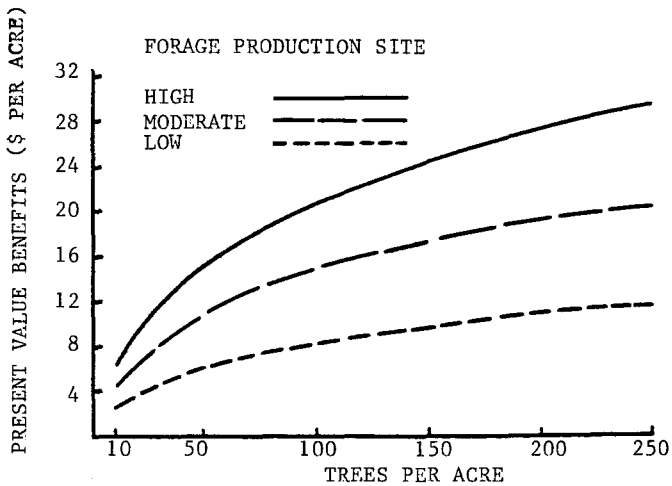


Figure 4.--Present value of benefits related to tree density when treating all trees in a 50/50 mixed pinyon-juniper stand with a short height class at three forage production sites. AUM benefit value is $9.67 discounted at 4 percent for 50 years.

$16.92/acre at a moderate site and $9.69/acre at a low forage production site. If the cost of retreatment can be accomplished at less than these figures, the PNV will be positive. With a higher cost the PNV will be negative and retreatment will not be cost efficient.

Retreating PJ woodland on high forage production sites with tree densities between 25 and 125 trees/acre is the most cost efficient and produces the highest PNV ranging from about $7.04 to $8.62/acre (fig. 5). On sites with more than 50 trees/acre the PNV decreases as the tree density increases and site productivity decreases. On moderate forage production sites the highest PNV ranges from $2.72 to $3.95/acre at 10 to 75 trees/acre. On low forage production sites the highest PNV is $.76/acre but only at 10 trees/acre (fig. 5).

The break-even point in a 50/50 mixed PJ stand with a short height class on a highly productive site when all trees are treated is 250 trees/acre. The break-even point is reduced to a tree density of 130/acre and 35/acre on the moderate and low sites (table 5).

These results indicate that retreatment of PJ on low forage production sites is generally not cost efficient. Retreatment is cost efficient on moderate and high sites when the treatment costs are reasonable and consistent with tree density and site conditions. Individual plant treatment is generally cost efficient on high and moderate productive sites when tree densities do not exceed 200 and 110 trees/acre, respectively.

The current practice of retreating stands with pelleted herbicide by individual plant treatment has normally been limited to trees 6 feet tall or less because costs are less than when treating the

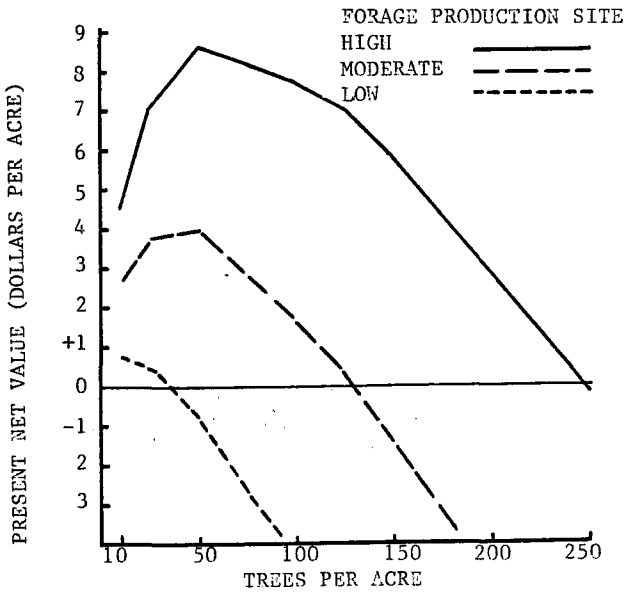


Figure 5.--Present net value related to tree density when treating all trees in a 50/50 mixed pinyon-juniper stand with a short height class at three forage production sites. AUM benefit value is $9.67 discounted at 4 percent for 50 years.

Table 5.- -Break-even point in trees per acre for retreating pinyon-juniper stands using individual plant treatment with pelleted herbicides when all trees are treated

Stand characteristics		Forage site productivity		
Compositon	Height[1] class	High	Moderate	Low
		-- Trees per acre --		
50/50 pinyon-juniper	Short	250	130	35
Pure juniper	Short	205	105	30
50/50 pinyon-juniper	Average	205	105	30
Pure juniper	Average	160	85	25

[1] Distribution by height class shown in table 4.

taller height classes (fig. 3). However, when treating all trees in the stand at tree densities and sites that provide a positive PNV, the incremental benefits exceed the incremental costs of treating all trees instead of only trees 6 feet tall or less. For example, a PJ stand with 100 trees/acre and an average tree height distribution at a high forage production site, the PNV of treating all trees is $7.03/acre compared to $2.48/acre for treating only trees 6 feet tall or less for an incremental increase of $4.55/acre.

The results of the regrowth model and the assumptions used in the economic analysis are not absolute but are expected to be relative to the site parameters modeled and reasonably accurate for its intended purpose. However, the assigned AUM dollar benefit value has more effect on the investment criteria than accuracy of the PJ regrowth predictions. For example, if the assigned AUM benefit value is reduced to $5.22, the break-even point for retreating a 50/50 mixed PJ stand with a short tree height class on a high forage production site is a stand with 75 trees/acre. The break-even point with an assigned AUM value of $9.67 is 250 trees/acre. In this case the AUM benefit value is reduced 46 percent but the break-even point in retreating a stand based on tree density is reduced 70 percent. By comparison, if results in the regrowth model were reduced 46 percent, the break-even point would be 135 trees/acre.

Conclusions

Preliminary results from the regrowth model indicate the model should be helpful in selecting stands for retreatment. More work is needed in defining social benefits and in gathering additional site specific cost data on mechanical retreatment and prescribed fire methods so they may be better compared to individual plant treatment with pelleted herbicides in the site selection process.

The cost of PJ retreatment can be predicted fairly accurately but the benefits are more difficult to determine. In this paper only range grazing use converted to AUM's has been identified and valued. The assigned AUM benefit dollar values are based on various studies (Gee 1982, USDA-USDI 1985) which suggest different benefit values. If future retreatment costs remain constant or slightly upward and the trend in AUM value is downward, it will be increasingly difficult to justify PJ woodland retreatment based only on cost efficiency. Then, social concern, multiple-use objectives, and other nonpriced benefits would have to outweigh cost efficiency to proceed with PJ woodland retreatment projects.

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Nutrient Cycling

Chaired by:

Jeffrey M. Klopatek, Assistant Professor, Department of Botany and Microbiology, Arizona State University, Tempe

NUTRIENT ACCUMULATIONS IN PINYON-JUNIPER ECOSYSTEMS--MANAGING FOR FUTURE SITE PRODUCTIVITY

Arthur R. Tiedemann

ABSTRACT: Pinyon and juniper trees function similarly to other shrubs and trees in their capacity to accumulate nutrients from adjacent openings and enrich the area beneath their canopies. This accumulation may occur at the expense of the nutrient capital of areas away from the influence of tree canopies. Invasion of pinyon and juniper trees into areas previously occupied by shrubs, grasses, and forbs may result in substantial shifts in the distribution of nutrients among biotic and abiotic ecosystem compartments. Incorporation of a greater proportion of the total site nutrient capital into aboveground biomass has important implications for the management of these stands from the perspective of future site productivity.

INTRODUCTION

Maintaining adequate levels of essential plant nutrients is a critical factor in the productivity and stability of any plant community. The pinyon-juniper (Pinus edulis, P. monophylla-Juniperus spp.) and juniper habitats throughout the Western United States have been managed in the past largely without regard for potential site productivity consequences of nutrient depletion associated with management activities. Forage production and wildlife management goals in pinyon and juniper ecosystems have typically been achieved by chaining or cabling, with the resultant residues piled or windrowed and burned (Valentine 1980). Broadcast burning of chained or cabled trees has also been used to remove residues. Burning has the potential for causing substantial losses of nitrogen (N) and sulfur (S) that are contained in tree foliage, stems, branches, and litter (DeBell and Ralston 1970; DeBano and Conrad 1978; Tiedemann and Anderson 1980). Burning piles or windrows of trees also concentrates some elements such as calcium (Ca), potassium (K), and iron (Fe) beneath the burned piles. This results in a long-term redistribution of these nutrient elements from areas occupied by the trees to a relatively small portion of the total area. Increased erosion after treatment may result in accelerated solution and sediment losses of essential plant nutrients (Tiedemann 1981).

International concern has developed for possible reductions in site productivity associated with losses of nutrients accompanying whole tree harvest and burning of residues (Kimmins 1977; Wells and Jorgensen 1979). Scientists and land managers should have the same concern for future site productivity of arid and semi-arid shrub and tree ecosystems. Current and projected demands for fuelwood indicate that interior west woodlands such as pinyon and juniper will become increasingly important for this purpose. It is conceivable that a future goal will be to manage these woodlands for fuelwood production if the value for that product outpaces other values such as range forage production.

As management of semi-arid woodlands such as pinyon and juniper is intensified, the future site productivity consequences of nutrient depletion associated with management activities should be examined. If a substantial proportion of the total site nutrient capital is contained in the vulnerable aboveground biomass, care should be exercised to retain as much of that nutrient capital on the site as feasible.

Nutrients should be viewed as a finite resource. Replenishment of already limiting nutrients may occur too slowly to keep up with losses that occur as a result of harvest, burning, erosion, and leaching. This may be particularly applicable to N and S--both are lost by burning and both are mobile in the soil. Replenishment of nutrients that originate from the parent material such as phosphorus (P), (Ca), and (K) may also limit productivity if management creates losses that exceed the rate of replacement.

My goal in this paper is to consider future site productivity in pinyon-juniper and juniper ecosystems from the perspectives of nutrient accumulation patterns and basic knowledge of effects of management on nutrients contained in biomass. The hypothesis to be explored is that invasion of grass/forb and sagebrush/grass

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Arthur R. Tiedemann is Principal Range Scientist, USDA Forest Service, Pacific Northwest Research Station, La Grande, OR.

ecosystems by pinyon and juniper trees is accompanied by a shift in nutrient accumulation patterns whereby a greater proportion of total site nutrients is contained in biomass components. An increase in the proportion of nutrients in biomass (including litter and dead material) increases the vulnerability of the ecosystem to management activities, such as burning, that remove or redistribute nutrients. Nutrient depletion may be manifested as reduced productivity of the remaining species or a shift in species composition to those more tolerant of the diminished nutrient regime.

NUTRIENT CYCLING DYNAMICS OF ARID AND SEMI-ARID WOODLANDS

Understanding the effects of management on nutrients and site productivity is important to an understanding of the way trees such as pinyon and juniper accumulate and cycle nutrients. Many shrub and tree species of arid and semi-arid woodlands of the intermountain west and southwest that have been studied have similar nutrient accumulation patterns. Nutrients are accumulated in the area beneath the canopies of individual shrubs or trees creating islands of soil more fertile than the adjacent interspaces (Garcia-Moya and McKell 1970; Tiedemann and Klemmedson 1973; Barth and Klemmedson 1978; Doescher and others 1984). Enrichment of the soil beneath the canopies of trees and shrubs presumably occurs at the expense of the nutrient capital of the adjacent openings by the action of lateral roots (Tiedemann and Klemmedson 1973). For species with a taproot, nutrients are also likely translocated from deep in the soil to the surface.

The magnitude of accumulation of nutrients by different arid and semi-arid shrubs and trees varies among species. Tiedemann and Klemmedson (1973) observed that total N and total S were three times greater in the surface 4.5 cm of soil beneath mesquite (Prosopis juliflora (Swartz.) DC) trees than in the surface soil of adjacent openings. Barth and Klemmedson (1978) found that total N in soil was two times greater under canopies of mesquite and palo verde (Cercidium floridum Benth.) than in soil from open areas. They also showed that there were differences in spatial patterns of soil properties between Sonoran desert and Chihuahuan desert shrubs. In north-central Washington, total N and S were three times more concentrated in the surface 5 cm of soil beneath mature bitterbrush (Purshia tridentata (Pursh) DC) than the same soil layer in areas away from the shrub canopies (Tiedemann 1983). In curlleaf mountain mahogany (Cercocarpus ledifolius Nutt.) communities in northwest Nevada, Tiedemann and Furniss (1985) observed six-fold greater concentrations of total N in surface soils (upper 3 cm) beneath canopies than in open areas (0.72 percent compared with 0.12 percent). Trees in the study area ranged from 30 to 145 yr of age. Doescher and others (1984) found significant differences in accumulations of total N in the surface 10 cm of soil beneath the canopies of big sagebrush (Artemisia tridentata Nutt.) compared with the same soil layer in adjacent interspaces. The magnitude of differences, however, was not as great as that observed in many other studies.

Our understanding of nutrient accumulation and cycling patterns of pinyon-juniper and juniper ecosystems is just emerging. The available literature indicates that pinyon-juniper and juniper ecosystems have developed accumulation patterns for nutrients similar to those displayed by other semi-arid and arid shrub and tree species. Soil nutrient concentrations are generally greater beneath the canopies of trees than in adjacent open areas. Evidence of tree root distribution patterns suggests that this enrichment occurs at the expense of the nutrient capital of adjacent open areas (Everett and others in press; Young and others 1984.) In the study by Everett and others, lateral roots of singleleaf pinyon (Pinus monophylla Torr. and Frem.) extended beyond the edge of the canopy to a distance of at least one-third the canopy radius and occupied all soil horizons. Lateral roots of western juniper (Juniperus occidentalis Hook.) were found 6 m from the bases of trees (Evans and others 1984). The author has observed dense concentrations of small (< 1 mm)) feeder roots at depths of 5-10 cm in the soil of interspaces (5 to 10 m from the crowns) between Utah juniper (Juniperus osteosperma (Torr.) Little) trees in central Utah.

Thran and Everett (this proceedings) showed that the upper 10 cm of soil from beneath singleleaf pinyon contained 1.5 times more total N than in soils from interspaces. Klopatek (this proceedings) observed that total N was 5.5 times greater in soil from areas under canopies of pinyon and juniper than from adjacent interspaces.

The influence of the pinyon tree is even more pronounced for available nutrients. Barth (1980) found 16-fold greater sulfate-S and 19-fold greater available P concentrations in soil from the surface 10 cm beneath pinyon (Pinus edulis Engelm.) than in soil from adjacent shrub-dominated areas. For nitrate-N, the difference was 2.4-fold. Major cations, Ca, magnesium (Mg), K, and sodium (Na) (ammonium acetate available) were 5 to 13 times greater in pinyon soil than soil from shrub-dominated areas. Barth (1980) also demonstrated a direct relationship between tree age and amounts of available Ca, Mg, K, and nitrate, sulfate, and sodium bicarbonate extractable P up to about 400 yr. Everett and others (in press) observed enrichment patterns in the surface 10 cm of soil under singleleaf pinyon for mineralizable N (2X), available P (1.8X), and sulfate-S (16X) compared with areas beyond the canopy edge. Exchangeable Fe, Zn, K, and Na were also enriched in soil of the canopy location compared with open areas. Thran and Everett (this proceedings) found a

3.5 fold difference in available P between canopy and open locations of singleleaf pinyon in the surface 10 cm of soil.

In contrast to results of studies conducted with pinyon pine, Brotherson and Osayande (1980) found a small, but significant ($P < 0.05$), difference in concentration of total N between areas under Utah juniper canopies and open soils (0.049 percent compared to 0.044 percent). Comparisons for available P and cations were not significant.

Bunderson and others (1985) related foliar nutrient concentrations in Utah juniper to soil concentrations of the same elements. Their findings suggest that this tree may be a sodium sensitive species with high concentrations of Na limiting N utilization. Low levels of P in the soil may be even more limiting than N to the growth of Utah juniper. Their results also indicate that K may be limiting for juniper growth.

Comparisons of nutrient levels in soils with adequate levels of total and available nutrients (Tiedemann and Lopez 1982) indicate that some nutrients in the pinyon-juniper ecosystem are at marginal or limiting levels. In Barth's (1980) study, soils from areas beneath pinyon canopies and adjacent open areas were marginal for nitrate-N (15.7 and 6.5 p/m). Soils from shrub-dominated open areas were deficient in available P (6.7 p/m). Available P in intercanopy areas in the study by Thran and Everett (this proceedings) (18 p/m) is at a marginal availability level to support normal plant growth. Soils from 17 Utah juniper sites (Bunderson and others 1985) were also below marginal levels for available P. In most studies where total N was reported, levels were near the low end of the range considered sufficient for wildland soils (0.05 to 0.5 percent). Total N in soils away from the influence of tree canopy ranged from 0.044 percent in Utah juniper stands (Brotherson and Osayande 1980) to 0.09 percent (Thran and Everett, this proceedings).

NUTRIENT ACCUMULATION IN PINYON AND JUNIPER BIOMASS AND POTENTIAL EFFECTS OF MANAGEMENT ON FUTURE SITE PRODUCTIVITY

The hypothesis that pinyon and juniper invasion results in a greater proportion of total site nutrients contained in biomass than the previous plant communities was evaluated by developing three N distribution profiles. The first is a low shrub/grass/forb setting from southern Washington. Grasses and forbs predominate on the site with low shrubs comprising only 10 percent of the total vegetal cover. The second is a sagebrush/grass ecosystem from southern Idaho. For the pinyon and juniper ecosystem, the N distribution profile is a composite from several studies. A search of the literature revealed no information on N distribution among biomass components and soil for pinyon or juniper at any specific location. Although the profile is presented from the perspective of invasion of pinyon and juniper, the effects of management on nutrients should be similar for climax communities.

Nitrogen was selected as an example nutrient for developing this hypothesis for several reasons. There is more information on accumulation and distribution patterns available for N than for any other nutrient element. Of the nutrients examined in wildland ecosystems to date, N is the nutrient most commonly found to be in marginal or limited supply. Last, and perhaps most important, N is probably more vulnerable to losses associated with management activities than are most of the other nutrients. As previously discussed, N contained in plant materials volatilizes readily upon combustion. After disturbance such as harvest and burning, mineralization accelerates the conversion of organic N to nitrate-N (Vitousek and Melillo 1979). Nitrate-N is highly mobile in the soil and is easily lost by leaching (Black 1968).

Data for N distribution in a low shrub/grass/forb ecosystem (fig. 1) were developed from Tiedemann and Klock (1977) and Tiedemann (data on file with the author) for an Artemisia rigida (Nutt.) Gray/Stipa occidentalis Thurb./Phlox diffusa Benth. community from Meeks Table Research Natural Area (RNA). Root biomass was estimated from the root:shoot ratio of 2:1 considered average for herbaceous species (Troughton 1957). The aboveground N contained in biomass is 7.5 kg/ha or about 0.13 percent of the soil-plant-litter total. Most of the N (99.6 percent) is contained in the soil. Roots comprise only a small portion of the total system N (0.2 percent).

In the sagebrush/grass (Artemisia tridentata/ Gramineae) ecosystem of Mayland and Murray (1979), the amount of system N in the aboveground biomass components is substantially greater than the low shrub/grass/forb ecosystem on Meeks Table RNA--115 kg/ha or 2.4 percent of the system total (fig. 2).

The salient feature of the biomass N distribution in low shrub/grass/forb and sagebrush/grass ecosystems is the relatively small proportion contained in the aboveground biomass. In these settings, less than 5 percent of the total system N can be influenced by management activities at any given point in time. Removal of the aboveground biomass by grazing, fire, or sagebrush elimination will remove only a small portion of the total system N.

The N distribution profile for a pinyon-juniper ecosystem shown in figure 3 is a composite of information from several studies. Data for biomass of foliage, branches (including dead material) and wood (stems and branches > 76 mm) are from Meeuwig (1979). Litter and root values were developed from data in Young and

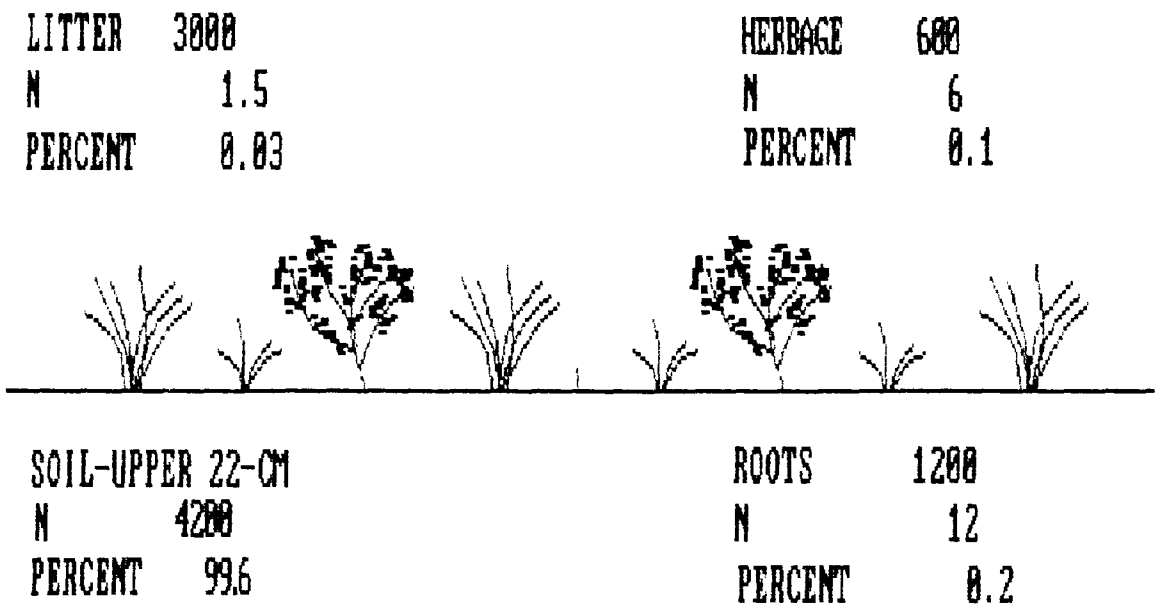


Figure 1.--Distribution of biomass and nitrogen (kg/ha) in a low shrub/grass/forb ecosystem on Meeks Table Research Natural Area, Washington. Percent values refer to the proportion of the total nitrogen capital contained in each biomass component and soil.

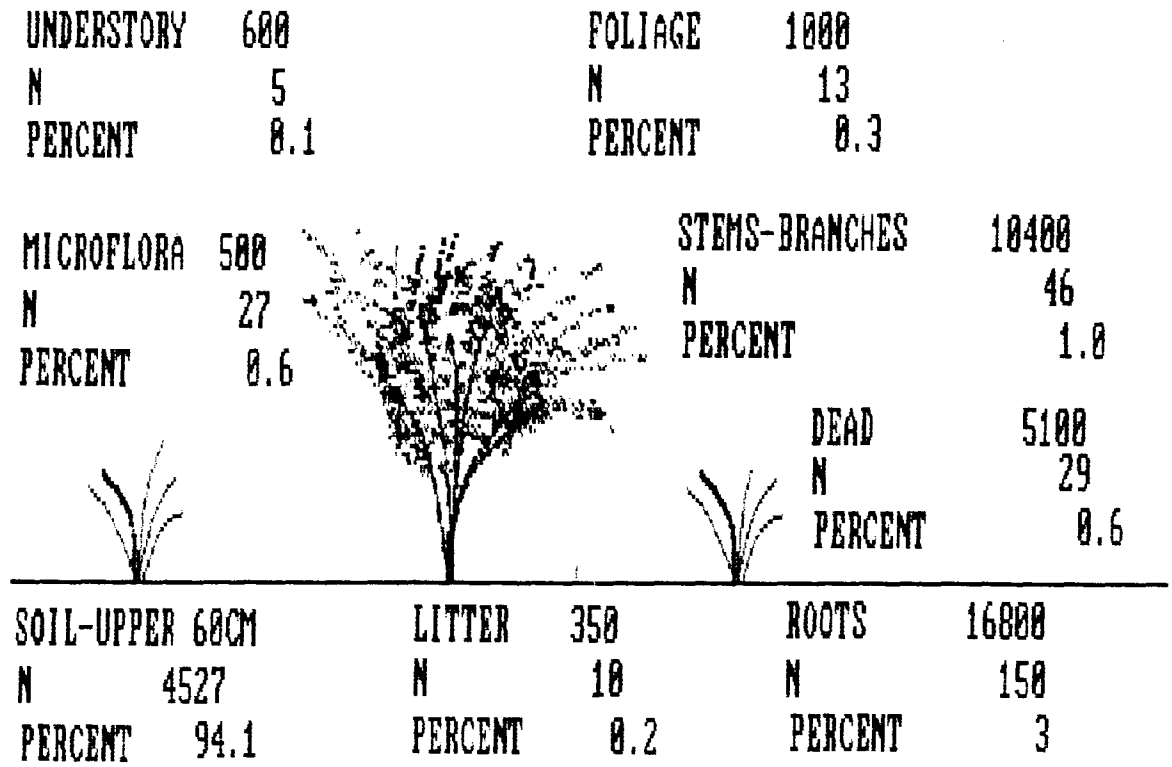


Figure 2.--Biomass and nitrogen distribution in a sagebrush/grass ecosystem in southern Idaho (kg/ha). Percent values refer to the proportion of the total nitrogen capital contained in each biomass component and soil.

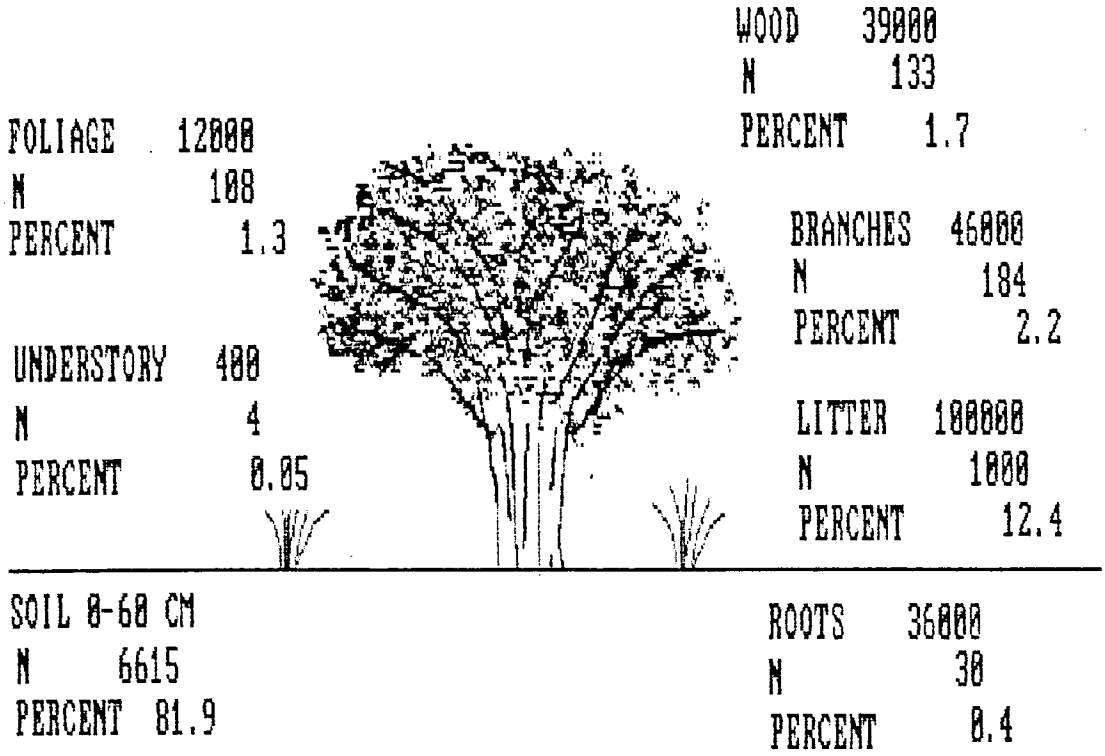


Figure 3.--Biomass and nitrogen distribution in a pinyon-juniper ecosystem (kg/ha). Percent values refer to the proportion of the total nitrogen capital contained in each biomass component and soil.

others (1984). Understory biomass is from Hall (1973) for a western juniper ecosystem. Nitrogen concentrations used to convert biomass to N contained in biomass were as follows: pinyon-juniper foliage (Bunderson and others 1985); wood and branches (Clayton and Kennedy 1980 for Pinus ponderosa Laws.); litter (Rodin and Bazilevich 1967); understory (Tiedemann and Clary 1985); and roots (Santantonio and others 1977). Total N levels in the upper 10 cm of soil were from Thran and Everett (this proceedings). Total N content was determined with a soil volume weight of 1.35 g/cm^3. No values were available for the N content of the 10- to 60-cm depth; this was estimated from the change in N concentration with depth presented by Barth and Klemmedson (1978) for mesquite in southern Arizona. Nitrogen concentration declined by approximately one-half between the surface 15 cm beneath mesquite canopies and the 15 to 60 cm depths.

Approximately 1400 kg/ha or 18 percent of the total ecosystem N is stored in the aboveground biomass components of the pinyon-juniper ecosystem. The potential N loss from biomass depends on the way the stand of trees is managed. Management for fuelwood where only the boles and larger branches are taken would remove less than 2 percent of the total ecosystem N. Using a volatilization loss rate for N of 60 percent (Tiedemann 1981), piling or windrowing after chaining or cabling would cause a loss of only 3 percent of the total system N because the litter layer would not likely be affected by burning. If, however, residues or trees are broadcast burned after fuelwood harvest or chaining, the losses of N could approach 13 percent because of N volatilization. In an ecosystem with apparently inherent marginal levels of soil N, future productivity of the site for pinyon and juniper or for forage production could be adversely affected. Effects may be subtle, such as reduced forage production of residual native species or seeded species. Effects may also be pronounced and may be manifested as shifts to annual species or perennial species tolerant of reduced levels of soil nutrients.

Effects on productivity or plant succession may not be evident the first time trees are removed; however, maintaining the pinyon-juniper ecosystem in grass/forb status will necessitate successive removal of trees, perhaps as often as every 50 yr. As pinyon and juniper trees re-invade the site, they will develop nutrient accumulation patterns similar to those described above. Unless N is replenished, successive removal of trees may eventually reduce N levels to the point that plant growth cannot be supported.

A more realistic determination of relative magnitudes of N loss in response to management among the three ecosystems is provided by comparing them in the same time perspective (100 yr). For these comparisons, all three ecosystems are considered to be grazed to remove 50 percent of the current year's forage production. Grazing losses of N were determined with a model developed by Tiedemann

and others (1986). This nitrogen budget model accounts for N redistribution and loss as a function of forage production and grazing use. The sagebrush/grass ecosystem is also managed by burning twice during the 100 yr time span. The pinyon-juniper ecosystem is considered to be mature (100 yr) and is managed by chaining and broadcast burning. This is a realistic age for a mature pinyon-juniper stand (Meeuwig 1979). Volatilization rates for N of 60 percent of that contained in biomass were used to calculate N loss by burning (Tiedemann 1981).

Grazing management for 100 yr removes approximately 370 kg/ha of N from the low shrub/grass/forb and sagebrush/grass ecosystems (table 1). Burning the sagebrush/grass ecosystem twice during the 100 yr period would result in an additional N loss of 156 kg/ha. Because understory productivity in the pinyon-juniper ecosystem is only 400 kg/ha per yr, grazing related losses of N are smaller than from the other two ecosystems (340 kg/ha). The major losses of N from the pinyon-juniper ecosystem would occur as a result of chaining followed by broadcast burning--approximately 856 kg/ha. These comparisons indicate that when similar time spans of management are considered for the three ecosystems, total losses of N in the pinyon-juniper ecosystem are 2.3 and 3.2 times greater than in low shrub/grass/forb and sagebrush/grass ecosystems, respectively. Natural rates of replenishment of N in these ecosystems are not known. Precipitation adds approximately 1 or 2 kg/ha/yr (Coats and others 1976). At this rate, 428 to 856 yr would be required to restore the N lost by chaining and broadcast burning of the pinyon juniper ecosystem.

CONCLUSIONS AND RECOMMENDATIONS

Trees in the pinyon-juniper ecosystem accumulate nutrients beneath their canopies in a manner similar to other arid and semi-arid trees and shrubs. This apparently occurs by action of lateral roots that extend into open areas between tree canopies. In the pinyon-juniper stands studied by Meeuwig (1979) tree crowns occupied about 50 percent of the surface area. Therefore, nutrient enrichment of about one-half of the area occurs at the expense of the other half.

Comparisons among the three nutrient distribution profiles support the hypothesis that invasion of grass/forb and sagebrush/grass areas by pinyon and juniper is accompanied by a greater nutrient accumulation in aboveground biomass.

Our present management strategy of chaining followed by piling and burning has a high potential for substantial redistribution and loss of nutrients from pinyon-juniper ecosystems. Fuelwood management strategies could also cause large losses of nutrients,

Table 1.--Projected 100 yr nitrogen losses from three ecosystems in response to grazing and vegetation conversion strategies

Ecosystem	Grazing	Burning	Chaining and burning	Total
	kg/ha			
Low shrub/grass/forb	370	0	0	370
Sagebrush/grass	370	156	0	526
Pinyon-juniper	340	0	856	1196

depending on the type of residue treatment. Elimination of all residues and the pinyon-juniper litter by burning could cause a loss of approximately 13 percent of the total system N.

The effect of large nutrient losses on future productivity of these ecosystems is not precisely understood. It is, however, probable that losses of as much as 13 percent of the total system N from an already impoverished system will result in lowered productivity. There may also be successional shifts such as invasion of annual species.

In addition to nutrient losses, concentrations of nutrients resulting from windrowing and piling and burning have the potential to affect site productivity. Consequences of this management strategy should be examined.

There is a need to accelerate our research in these ecosystems to gain a better understanding of nutrient dynamics of the entire ecosystem. It is important to characterize the distribution of total and available nutrients and their rates of cycling among biotic and abiotic portions of the system. Natural rates of nutrient replenishment also need to be characterized.

The next step is to assess the effects of various management strategies on the total site nutrient capital and nutrient fluxes. Site productivity and successional dynamics should be evaluated as part of this assessment.

Considering the greater aboveground accumulations of N in the pinyon-juniper ecosystem relative to the other two ecosystems, and the apparent limited soil capital of N, it seems prudent to suggest caution in the manner these stands are managed. Careful consideration should be given to effects of management on biomass-contained nutrients and future site productivity in developing strategies for vegetation conversion and fuelwood harvest. These strategies will almost certainly impact the nutrients contained in biomass. There is enough basic information about effects of various management strategies on nutrients in biomass to make some educated guesses about effects on future site productivity.

If we err on the conservative side, nothing is lost. On the other hand, if pinyon-juniper stands are not managed with a strategy for conserving nutrients, their productivity could be impaired for a long time to come.

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MYCORRHIZAE, MICROBES AND NUTRIENT CYCLING PROCESSES IN PINYON-JUNIPER SYSTEMS

Carole Coe Klopatek and Jeffrey M. Klopatek

ABSTRACT: Two pinyon-juniper communities, one remnant and one grazed, were examined as to their microbial processing and mycorrhizal status. Nitrifying bacteria were in greater numbers in the interspaces than their corresponding canopies. The interspace of the undisturbed site had the highest concentration of bacteria (213,000 bacteria/g soil) followed by the interspace of the grazed site (96,000 bacteria/g soil), the disturbed canopy soil (48,000 bacteria/g soil) and the undisturbed canopy having the lowest number of bacteria (35,000 bacteria/g soil). All soils exhibited ammonification and nitrification. Mineralization coefficients of total nitrogen corresponded with the numbers of nitrifiers. Soils were also assessed for the presence of vesicular-arbuscular endomycorrhizae spores. There were greater spore numbers under the canopies than in interspaces at both sites.

INTRODUCTION

Klopatek and others (1979) estimated that the pinyon-juniper vegetation type is the third most vast in the U.S. Considering the expansiveness of this woodland, there has been very little, if any, research regarding the associated below-ground microbiological processes. These woodlands are located between arid and mesic ecosystems. On the lower end of the transitional scale, the juniper trees occur with many of the desert shrubs, while on the upper scale pinyon trees have been shown to occur with ponderosa pine species, therefore demonstrating a wide range of adaptability. As to how these trees can exist together in this transition zone yet separately at the environmental extremes presents an interesting question. One hypothesis is that the below-ground components contribute to their adaptability. For example, juniper trees are endomycorrhizal, as are most arid land plants, (Linsey 1984), while pinyon is ectomycorrhizal as are all pines (Marks and Kozlowki 1973).

Previous studies have documented the nutrient cycling patterns in such systems as grassland (Stewart and others 1983) and forests (Vitousek and others 1982). Preliminary data show the pinyon-juniper systems to have nutrient enriched "islands" under the canopy as compared to the interspaces (Klopatek 1986 this volume). This island effect, in combination with the unique environmental positioning and spatial variability, make the pinyon-juniper below-ground ecosystem distinctly different from other ecosystems that have been previously described.

The data presented herein are a result of two ongoing research projects. The first project had three objectives: (1) estimate the number of nitrifying bacteria; (2) determine the nitrification potential at each site; and, (3) compare the actual rate of nitrification with the number of organisms found. The second study involves the quantification and identification of indigenous mycorrhizal populations at each site. Previous studies have documented the benefits that mycorrhizae have on plant growth (Klopatek and Klopatek 1984, 1985; Mosse 1973). These studies showed that without the fungi, plants demonstrate a decreased growth rate or fail to survive. Since there has been little mycorrhizal work performed in these areas, we wanted to obtain background data on mycorrhizal populations. With this accomplished, our future goal is to link the nitrogen cycling with the nitrogen uptake by the mycorrhizal fungi.

STUDY SITES

This research was conducted in north-central Arizona in the pinyon-juniper woodland. Pinus edulis Engelm. is the pinyon species in this area and the codominant juniper is Juniperus osteosperma (Torr.) Little. Site 1 is an undistrubed "pristine" community located on an isolated mesa in the Grand Canyon National Park (GCNP). This site, Shiva Temple, is totally inaccessible to domestic livestock. It has an elevation of 2300 m. The dominant understory grass species is mutton grass (Poa fendleriana (Steud.) Vasey). Since there has been virtually no microbial ecology-oriented research done in pinyon-juniper, Shiva Temple will serve as a bench mark for our pinyon-juniper ecosystems. Site 2 called the Dillman Site, is located just outside the GCNP in the Kaibab National Forest. It is approximately 30 km SSE of Shiva Temple. This distance was required in order to maintain similar site characteristics. It is a moderately grazed mature pinyon-juniper community

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Carole Coe Klopatek is a Research Assistant and Jeffrey M. Klopatek is an Assistant Professor, Department of Botany and Microbiology, Arizona State University, Tempe, AZ 85287.

at an elevation of 2030 m. The dominant understory species is blue grama (Bouteloua gracilis (H.B.K.) Lab. ex Steud.).

Climatic data were obtained from a weather monitoring station midway between the two sites. Precipitation averages 350 mm/yr, is bimodial, and occurs in late summer in convectional thunderstorms and during winter from frontal systems. Mean monthly temperatures range from -1.4 to 21.1 °C, with a mean annual temperature of 9.2 °C.

Soil physical and chemical characteristics of the Shiva Temple and Dillman sites are as described by Klopatek (1986, this volume). The analyses showed that there were no statistical differences in soil characteristics between each of the two sites. This provided an excellent opportunity to compare microbial processing of nutrients in grazed and ungrazed systems. Analysis of variance did show that there were statistical differences between the aspects of canopy and interspace. Total nitrogen was found to be four times greater (.248 percent) under canopy as compared to interspace (.065 percent).

MATERIALS AND METHODS

Five canopy and five interspace soil samples (of five subsamples each) were collected in polyethelyene bags in early September of 1985. Soils were refrigerated immediately upon collection. Once in the laboratory, soils were sieved (aseptically) through a 2-mm sieve and microbial analysis begun. Nitrification is a two-step biological transformation of ammonia to nitrate, carried out by several genera of chemoautotrophic bacteria, the predominate of which are Nitrosomonas ($NH_4 \longrightarrow NO_2$) and Nitrobacter ($NO_2 \longrightarrow NO_3$). The enumeration of these bacteria cannot be completed using direct microbiological techniques (plate counts) since these bacteria are readily outcompeted by other bacteria (Alexander 1977). Therefore, the most probable number (MPN) technique, an indirect count, was performed (Belser 1977; Soniano 1968).

Three of the five samples from each site and aspect were randomly chosen for the mineralization experiments. Each replicate consisted of field-moist soil, equivalent to 1100 g dry wt, placed in a 500-ml polyethylene container, brought to 60 percent field capacity with double distilled water, and capped with a lid having a 5-mm hole in its center. The containers were incubated in the dark, under high humidity at 20 °C (± 0.5°). Water contents of the soils were kept constant by checking their weight daily and adding any water lost with a syringe. At 0, 15, 30 and 60 d from the start of incubation 10-g subsamples were taken and extracted with 100 ml of 2 mol/L KCl adjusted. The solution was adjusted to a pH of 2.5 to which 0.5 mg/L of phenylmercuric acetate was added to inhibit microbial growth. Extracts were kept frozen until analysis. Nitrate and ammonium were measured colorimetrically with a Technicon autoanalyzer at the University of Arizona Soil and Plant Testing Laboratory.

Analysis of variance was used to evaluate incubation data. Between-site and aspect data were analyzed using Tukey's honest significant difference measure within the SAS statistical software (SAS 1982). The incubation data were also analyzed for differences in production values of the N concentration on the sampling date minus the initial N concentration. Upon analyzing these data with Tukey's measure there appeared few significant differences between sites. However, there did appear to be aspect-time interactions. Because of this factor, the incubation data were subjected to repeated measures analysis using the SPSS-X MANOVA program (Alster 1984) and subsequently ANOVA on the individual time measures. Simple linear regressions were employed to correlate final N prodution data with initial total N contents of the soils.

Enumeration of mycorrhizal spores was peformed using a modified version of Allen and Allen (1984). Endomycorrhizal infection in juniper were examined by clearing and staining fine roots using a modified version of Phillips and Hayman (1970). The quantification of infection in juniper closely followed that of Goivanetti and Mosse (1980). Staining procedures for ectomycorrhizae consisted of clearing roots overnight in 30 percent hydrogen peroxide, washing with distilled water, staining in boiling .05 percent trypan blue in lactophenol for 3 to 5 minutes and destaining in clear lactopenol (Klopatek, unpublished).

RESULTS

Nitrifying Bacteria

The number of nitrifying bacteria are reported in table 1. There were greater numbers of ammonia oxidizing bacteria (Nitrosomonas spp.) in the interspaces than under the canopies at each site. Shiva Temple interspace (STI) had a higher number of Nitrosomonas spp. (213,000 bacteria/g dry soil) than did the Dillman interspace (DI)

Table 1.--Number of nitrifying bacteria (MPN) (cells/g dry wt soil) in two pinyon-juniper communities in north-central Arizona. Values are unweighted means of five subsites; 95 percent confidence limits appear in parentheses

Site	Aspect	MPN X 1000/ g soil NH4-oxidizing	NO3-oxidizing
Shiva Temple	Canopy	35.6 (11.0-117)	1.4 (.42-4.6)
	Interspace	213.0 (64.5-702)	1.7 (.56-5.6)
Dillman	Canopy	48.3 (15.0-159)	3.9 (1.1-12.8)
	Interspace	96.0 (29.0-316)	2.3 (.70-7.5)

(96,000 bacteria/g dry soil). Nitrosomonas spp. were found in greater numbers under the Dillman canopies (DC) (48,000 bacteria/g dry soil) as compared to Shiva Temple canopy (STC) (35,000 bacteria/g dry soil). Initially, there appeared to be a greater number of nitrite oxidizing bacteria, Nitrobacter, under canopy than in the interspaces, but this difference was not significantly different.

Nitrogen Mineralization

Soils from each site and aspect exhibited ammonification and nitrification over the duration of the incubations (table 2). Both STC and DC produced more total mineral nitrogen accumulation than did their respective interspaces, with DC having the highest ammonification and nitrification rates. In fact, DC and DI showed the only statistical differences at 30 and 60 d. However, when all data were pooled (due to time-aspect interactions) there were significant differences between aspects at all dates (table 2). The results of an ANOVA demonstrated that there was a linear increase of total mineral nitrogen accumulation over time ($p > .01$). Nitrate production was correlated with ammonia production at both sites. Nitrate production had not leveled off at the end of 60 d indicating that nitrification had not completed. In some cases, total nitrate production was greater than total mineralized nitrogen indicating a more rapid conversion of ammonia than that produced.

Rates of mineralization (ammonification plus nitrification) were linearly correlated with percent total nitrogen. For each site and aspect there was a significant positive correlation ($r^2 = 0.7$, F value = 27.45, $p > F = 0.0002$). However, for individual sites and aspects DC had the highest correlation ($r^2 = 0.996$, F value = 249.0, $p > F = 0.04$) and STC had the lowest (non-significant) value ($r_2 = 0.02$, F value 0.025, $p > F = 0.90$). With STC data removed, a correlation of $r^2 = 0.91$ was found.

Mineralization coefficients [mineralized N produced (ug/g-1) x 100/total N present before incubation (ug/g-1)] (Charley and West 1977) were calculated for each site. Mineralization coefficient values were found to be higher in the interspaces than under the canopies at both Shiva Temple and Dillman even though there was over four times as much total nitrogen under canopy than interspace. It follows that the higher the mineralization coefficient, then, the greater the amount of nitrogen was mineralized per total amount of nitrogen present before incubation. Shiva Temple interspace had a higher mineralization coefficient value (6.1) than did DI (4.8) with DC having a higher value (2.2) than STC (1.4). We then took the mineralization coefficients and plotted them against the numbers of ammonia-oxidizing bacteria for each site and aspect (fig. 1). We found that the greater the mineralization coefficient, the greater the bacterial numbers and vice versa. On the upper end of the scale, STI had the highest bacteria

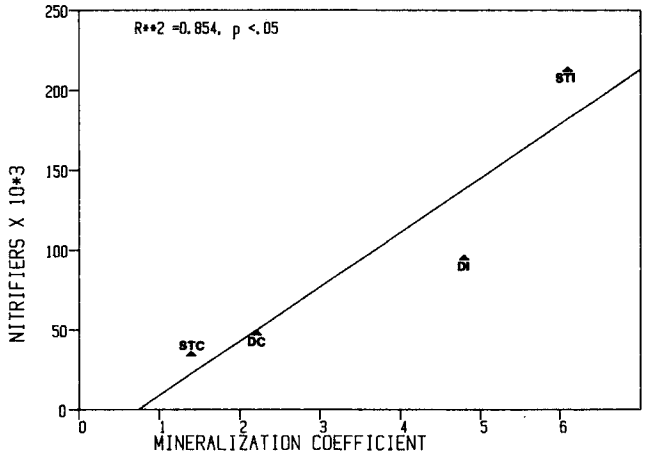


Figure 1.--Comparison of ammonia-oxidizing bacteria to the mineralization coefficients. STI = Shiva Temple interspace, DI = Dillman interspace, DC = Dillman canopy, STC = Shiva Temple canopy.

Table 2.--Net nitrate and total mineral nitrogen (ammonium plus nitrate) production (ugN per g dry soil) in incubated mineral soils from under canopy and interspaces from Shiva Temple and Dillman sites. Values are the means (± SE). C = canopy, I = interspace

Site	Aspect	NO_3-N production ($ug\text{-}g^{-1}$)			Mineral-N production ($ug\text{-}g^{-1}$)		
		15-d	30-d	60-d	15-d	30-d	60-d
Shiva Temple	C	15.1(3.64)	35.4(4.86)	52.7(9.44)	18.0(5.65)	34.8(4.55)	53.1(9.04)
	I	9.80(1.90)	26.7(3.47)	40.4(5.82)	9.17(1.58)	26.2(3.09)	39.8(5.49)
Dillman Mature	C	30.0(10.6)	50.1(10.8)	78.4(17.3)	24.3(6.28)	39.7(6.67)	68.2(13.2)
	I	14.0(1.45)	28.9(4.08)	37.1(10.9)	12.9(1.30)	28.5(3.98)	36.9(10.8)

numbers (231,000 bacteria/g soil) with the highest mineralization coefficient (6.1). While STC had the lowest mineralization coefficient (1.4) and the lowest bacterial numbers (36,000 bacteria/g soil).

Mycorrhizal Populations

As mentioned earlier, Pinus edulis is ectomycorrhizal and Juniperus osteosperma is infected with endomycorrhizae, more specifically vesicular-arbuscular endomycorrhizae (VAM). This was true for juniper at our study sites with VAM infections ranging from 66 to 100 percent. However we also found juniper to be infected with ectomycorrhizae. We determined juniper as being ectomycorrhizal by microscopically examining stained root sections and confirming the presence of a Hartig net.

Since the majority of the plant species at our sites are infected with VAM (Klopatek and Klopatek, unpublished), we quantified the VAM spore populations. At each study site, there were a greater number of spores under canopies of both pinyon and juniper than their corresponding interspaces. At Shiva Temple, VAM spores were in greater concentrations under juniper (580 spores/100g soil) than pinyon trees (300 spores/100g soil) with STI having only 92 spores/100g soil. In fact, STC had a higher number of VAM spores than any other area. At the Dillman site, spore nubers were not significantly different between pinyon (420 spores/100g soil) and juniper (450 spores/100g soil) even though only juniper is endomycorrhizal. DI had the lowest VAM spores numbers with 53 spores/100g soil.

DISCUSSION

As indicated in table 1 there were a greater number of nitrifying bacteria in the interspaces than the canopies at each study site. This was not anticipated since there was more substrate (organic nitrogen) for the bacteria to utilize under canopies than in the interspaces. A possible explanation for this may be alleopathic substances produced by the pinyon and juniper trees on these bacteria (Richard Everett, pers. comm.)

The soils of each site and aspect clearly exhibited both ammonifiation and nitrification. This strongly suggests that nitrification does occur in mature pinyon-juniper systems. This differs from neighboring ecosystems such as mature ponderosa pine forests that have been shown by Vitousek and others (1982) to exhibit low rates of nitrification. It should be emphasized that the nitrification data presented represent potential nitrification under a controlled environment and not actual in situ rates. It appears that in the grazed system there was a higher mineralization coefficient than at our ungrazed site. This may be a result of the disturbance as suggested by Vitousek and others (1982) and Vitousek (1983).

Figure 1 demonstrates that the greater the mineralization coefficient, meaning the greater the rate of mineralized nitrogen over the total amount of nitrogen present before incubation, the higher the amount of nitrifing bacteria. Even though there was over four times as much total nitrogen present under the canopies than in the interspaces, the data suggest that there was a greater efficiency of nitrogen utilization in the interspaces than under the canopies as represented by their high mineralization coefficient. The lower mineralization rate under the canopy may again be due to alleopathic substances produced by the pinyon and juniper trees on the nitrifing bacteria.

A greater number of VAM spores were found under the canopies than in the interspaces. This is presumably due to water and wind dissemination in which spores accumulated under the protected canopies. Most of the spores resembled those of Glomus spp. STC, followed by STI, had the greatest accumulation of spores. This may be attributed to the undisturbed nature of the community. As mentioned earlier, juniper was found to be both endo- and ectomycorrhizal at our study sites. This is an indication of the below-ground complexities of the pinyon-juniper woodland despite its apparent above-ground structural simplicity.

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SOIL FAUNA AS REGULATORS OF DECOMPOSITION AND NITROGEN CYCLING IN PINYON-JUNIPER ECOSYSTEMS

Walter G. Whitford

ABSTRACT: There was no correlation between decomposition rate of buried barley straw and population of soil fauna. There was net immobilization of nitrogen in decomposing straw during the first 100 days followed by net mineralization. Net nitrogen mineralization was correlated with high population numbers of fungus feeding tarsonemid mites.

INTRODUCTION

There is increasing evidence that nitrogen may be as important or even more important than water as a factor affecting productivity of arid and semi-arid ecosystems (Ettershank and others 1978; Penning de Vries and Djiteye 1982). In such ecosystems the most important source of available nitrogen is that mineralized from decomposing dead plant materials (West and Skujins 1978). Therefore if we are to understand processes affecting primary productivity of such ecosystems with a view to development of optimal management schemes, we must understand the key processes of decomposition and mineralization. Over most of their range of distribution, pinyon-juniper woodlands may be classified as semi-arid systems that intergrade with grasslands or desert ecosystems. Pinyon-juniper woodlands are similar to desert shrublands with respect to soil nutrient distributions with high soil organic matter and high nutrient levels under tree canopies where litter accumulates and low organic matter and nutrient levels in soils in intercanopy spaces. Since these woodlands share soil organic matter distribution characteristics with deserts, it may be instructive to compare the limited data on decomposition and nitrogen immobilization and mineralization and the soil fauna involved in these processes in pinyon-juniper woodlands with the more extensive data available from desert ecosystems. It must be emphasized that these data are preliminary data, hence only suggestive of relationships in pinyon-juniper systems. In this paper I will make such comparisons and suggest questions for future research efforts in pinyon-juniper woodlands.

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Walter G. Whitford is Professor of Biology, New Mexico State University, Las Cruces, NM.

STUDY SITES AND METHODS

Studies of decomposition and nitrogen immobilization-mineralization were conducted in a pinyon-juniper woodland 30 km northwest of Gallup, New Mexico. These processes were studied by burying fiberglass mesh bags containing barley straw in soils at the edge of tree canopies. The soils at approximately 2100 m elevation were shallow, sandy clay loams. Soil microarthropods were extracted from litter and/or soil cores in modified Tullgren funnels (Santos and Whitford 1981).

Nematodes were extracted from the litter by a combination of the Cobb sieving and Oostenbrinch cotton-wool filter methods (Nicholas 1975). Protozoans were estimated by the most probable number methods (Elliot and Coleman 1976). Bacteria were estimated by direct counts using the flourscein isothiocyanate method . Fungal lengths were measured using an ocular grid (Olsen 1950). Total nitrogen was measured by the micro Kjeldahl method (Bremner and Mulvaney 1982).

Additional samples of soil and litter microarthropods were collected in a *Pinus cembroides-Juniperus deppeana* woodland 5 km south of Paradise, Cochise Co. Arizona, elevation ca. 2000 m., and in a *Pinus edulis-Juniperus monosperma* woodland 5 km east of Los Alamos, New Mexico, elevation ca. 2400 m.

RESULTS

There was a net 17% loss of barley straw in four months from the end of June through mid-October yielding a rate of 0.14 percent . day^{-1}. Mass loss was nearly linear over that period (fig. 1). Populations of small fungus feeding mites, Tarsonemidae, in the barley straw increased from 10 individuals per litter bag after one month to 2300 in July and more than 9000 per litter bag in October.

Bacterial numbers and fungal lengths increased only slightly during the study period but protozoan and nematode populations increased markedly in the decomposing straw. Protozoans increased from 5×10^4 to 1×10^8 individuals . bag^{-1}. There was a net immobilization of nitrogen through early September (day 1 through day 100) followed by net mineralization for the duration of the study (fig. 2).

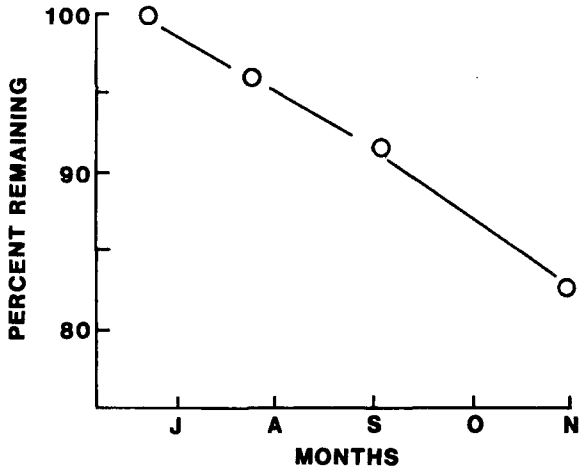


Figure 1. The mass loss of barley straw buried in soil at the edge of tree canopies in a pinyon-juniper area in northwestern New Mexico.

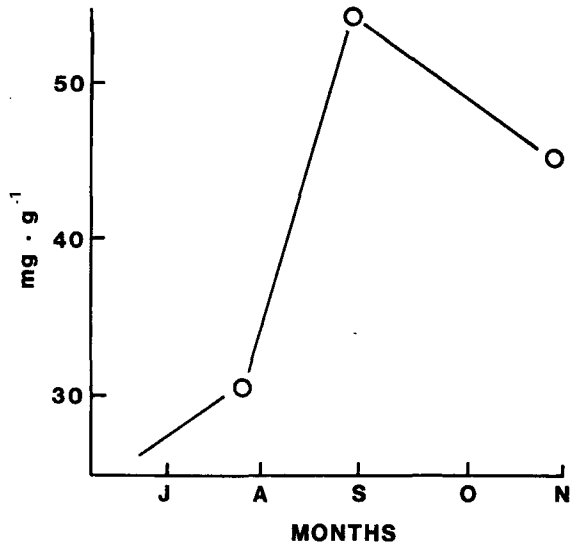


Figure 2. Changes in concentration of nitrogen in decomposing barley straw buried in a pinyon-juniper area in northwestern New Mexico.

In pinyon-juniper systems sampled in this study most of the microarthropods were found in the litter layers under canopies of the trees. The soil of interspaces had fewer species and lower numbers of microarthropods even in soil cores that included the root mat of bunch grasses (table 1). Densities of microarthropods were higher in pinyon litter than in juniper litter and at the Portal, Arizona site than at the Los Alamos site (table 1). In juniper litter the ratio of cryptostigmatids to prostigmatids was nearly 1.0 while in pinyon litter that ratio was 1.4 to 2.1. The most abundant prostigmatids were algivorous Nanorchestes spp. and fungivorous mites: Tarsonemus sp.;Tydeus spp.; the remainder are primarily predatory.

DISCUSSION

This limited set of data on decomposition and nitrogen dynamics in a pinyon-juniper ecosystem can best be understood by comparison with a more intensive study of decomposition in a desert ecosystem. The rates of decomposition of buried barley straw in pinyon-juniper systems are considerably lower than those reported for an annual with a similar C:N ratio, Lepidium lasiocarpum in a hot desert ecosystem (Parker and others 1984). However, there was a similar pattern of nitrogen immobilization and mineralization in L. lasiocarpum. In L. lasiocarpum there was considerably greater nitrogen immobilization and reduced mineralization with the exclusion of microarthropods (Parker and others 1984).

Parker and others (1984) concluded that microarthropod grazing on fungi reduced the quantity of nitrogen immobilized in the microbial biomass growing in and on the decomposing plant tissues. Parker and others (1984) found that after 96 days decomposing Lepidium lasiocarpum roots had 132% of the original nitrogen content with microarthropods present but where microarthropods were eliminated the decomposing roots had 270% of the original nitrogen content. In this study nitrogen immobilization produced 204% of the original nitrogen content in September which was reduced to 169% by November. In this study of decomposing straw in a pinyon-juniper ecosystem, nitrogen immobilization peaked while microarthropod populations were low and net mineralization of nitrogen occurred when populations of fungal grazing tarsonemid mites peaked. The direct relationship between population densities of the tarsonemid mites and mineralizatio is consistent with the data reported in Parker and others (1984). Other populations of microbial grazers (nematodes and protozoans) also peaked at the end of the study and undoubtedly also contributed to the increase in mineralization.

The microarthropod population size and diversity is low in the intercanopy spaces in comparison to those parameters in the litter layer and soil under canopies of the trees. The predominance of cryptostigmatid = oribatid mites in the litter layers suggest that in this portion of the system the fauna is a forest fauna. Oribatid mites in forests have been shown to feed on litter and fungi, transport fungal spores, and prey on nematodes (Wallwork 1983). These activities of oribatids should accelerate the rate of decomposition. The dense litter layers and thick canopies that characterize pinyon-juniper woodlands should provide both substrate and micro-climate suitable for stimulating high rates

Table 1.--Estimated densities of soil microarthropods (no. m^{-2}) in litter under tree canopies and in soil without a litter-layer in two pinyon-juniper ecosystems

	Pinyon		Juniper		Open	
	Los Alamos	Portal	Los Alamos	Portal	Los Alamos	Portal
Prostigmata	4,653	9,051	4,599	5,813	2,667	2,540
Tydeus sp.	1,427	1,368	1,524	1,482	508	254
Nanorchestes sp.	914	0	178	0	889	762
Eupodes sp.	1,067	1,550	102	68	0	0
Cunaxa sp.	1,067	1,140	0	91	762	0
Spinibdella sp.	0	1,072	1,372	0	508	0
Tarsonemus sp.	0	3,921	686	0	0	1,524
Erythraeidae	178	0	737	2,531	0	0
Mesostigmata	2,972	0	1,550	1,003	0	0
Laelapsis sp.	940	0	1,245	1,003	0	0
Uropodidae	2,032	0	305	0	0	0
Cryptostigmata	9,777	12,499	4,617	4,584	0	0
Cosmochthonius spp.	0	935	737	570	0	635
Sphaerochthonius sp.	76	0	1,219	0	0	0
Joshuella spp.	2,261	2,120	178	456	0	381
Damaeus sp.	914	1,345	0	0	0	0
Galumna sp.	25	1,299	406	2,280	0	0
Eremaeus sp.	279	0	127	0	0	0
Banksinoma sp.	4,826	1,904	660	1,049	0	0
Tacrocepheus sp.	431	0	991	0	0	0
Parapilops sp.	965	0	299	1,414	0	0
Passalozetes spp.	0	4,284	0	456	0	508
Aphelacarus sp.	0	612	0	0	0	0
Σ=	17,402	21,550	10,766	11,400	2,667	4,064

of activity of these organisms. If high population densities of oribatids are active in the litter accumulations, then they will be involved in comminution of the litter and effectively uncouple decomposition from abiotic constraints such as rainfall (Wallwork 1983; Santos and Whitford 1981) and reduce nitrogen immobilization in the decomposing litter.

The data on microarthropod assemblages can be compared with data for desert and ponderosa pine woodlands. Wallwork (1972) sampled juniper litter at Joshua Tree National Monument. There he found that the cryptostigmatid:prostigmatid ratio was 3.5:1 and the common genera were *Joshuella* spp., *Haplochthonius* and *Eremaeus*. Average density of all microarthropods on a Chihuahuan desert watershed range from 25,000 . m^{-2} in areas of litter accumulation to 3,500 . m^{-2} in mineral soil (Wallwork and others 1985; J. Cepeda unpublished data). In Chihuahuan desert shrublands and grasslands, prostigmatids are more abundant than cryptostigmatids. In ponderosa pine forests, densities of microarthropods were reported to be an order of magnitude larger than I found in pinyon-juniper sites i.e. 220, 739 . m^{-2} (Price 1973). Price reported large numbers of collembolans and pauropods that were not found in pinyon-juniper litter. However, we have recovered large numbers of these animals in late summer from litter and soil in dense mesquite thickets (Wallwork and others 1985; J. Cepeda unpublished data).

Except for *Joshuella* spp. and *Passalozetes* spp. the remaining cryptostigmatids are characteristic of woodland rather than desert or arid ecosystems. The prostigmatids are a mixture of predators and fungivores that have been found to be important in nitrogen mineralization of dead roots (Parker and others 1984). These data suggest that microarthropods will be important in decomposition of leaf litter and in nitrogen mineralization in litter and soil in pinyon-juniper ecosystems. The densities found in this study are consistent with the idea that pinyon-juniper ecosystems will be intermediate between forests and semi-arid to arid grasslands and shrublands.

The data presented here provide only an indication of the kinds of data needed to evaluate factors affecting nitrogen turnover and availability in pinyon-juniper ecosystems. Pinyon-juniper woodlands in northern Arizona and in New Mexico have significant populations of subterranean termites. These animals have been found to affect soil fertility (Parker and others 1982), organic matter turnover (Schaefer and Whitford 1981; Whitford and others 1982), nitrogen cycling (Schaefer and Whitford 1981) and water

infiltration and storage (Elkins and others 1986). Termites could be of equal or greater importance in pinyon-juniper ecosystems. Other species of larger soil arthropods affect nutrient cycling and need to be considered (Krivolutzky and Pokarzhevsky 1977).

In conclusion, the limited data presented here on decomposition, nitrogen cycle processes and soil-litter microarthropods demonstrate some interesting similarities and differences with both deserts and forests. Obviously additional studies will be needed to ascertain the degree of difference and similarity and to provide sound basis for management decisions.

ACKNOWLEDGMENTS

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NITROGEN FIXATION IN CRYPTOGAMIC SOIL CRUSTS AS AFFECTED BY DISTURBANCE

Richard E. Terry and Steven J. Burns

ABSTRACT: Cryptogamic soil crusts are major constituents of the desert ecosystem, effectively stabilizing the soil surface against wind and water erosion. Significant amounts of nitrogen are also fixed by the blue-green algal component. The objective of this study was to determine the effects of grazing and burning disturbances on nitrogen fixation by crust organisms. Research sites were located at Camp Floyd State Park and at Rush Valley in central Utah. In April and May of 1981, at the Camp Floyd site, nitrogen fixation in the ungrazed portion was greater than in either the burned or grazed sites. However, there were no significant differences in nitrogen fixation rates in annual spring samples collected from the disturbed and undisturbed Camp Floyd sites between 1982 and 1984. In April 1985 nitrogen fixation rates were significantly higher at the two disturbed Camp Floyd sites. A partial explanation for this reversal is related to the fact that the cryptogamic crusts of the grazed and burned Camp Floyd sites had recovered significantly due to the higher than average precipitation from 1981 through 1984. There were also significant differences in nitrogen fixation rates between the undisturbed, grazed, and tilled areas at the Rush Valley site. The rates were generally higher in the undisturbed area. Nitrogen fixation in crusted soils increased significantly with increasing soil moisture. Nitrogen fixation also decreased with increasing time following wetting of the crusts.

INTRODUCTION

Cryptogamic soil crusts (a combination of lichens, mosses, and algae) form an important and abundant ground cover on some desert rangelands (Anderson and Rushforth 1977). Cryptogamic crusts are frequently found on sites with low vascular plant cover and thus contribute significantly to the protection of such soils against wind and water erosion (Anderson and others 1982).

Greater amounts of nitrogen, potassium, phosphorus, and organic matter have also been found in crusted soils (Kleiner and Harper 1977; St. Clair and Nebeker 1980). Research has indicated that significant amounts of nitrogen are fixed by cryptogamic soil crust organisms in certain desert ecosystems. MacGregor and Johnson (1971) measured nitrogen fixation rates of approximately 4 g N ha^{-1} hr^{-1} in moistened algal crusts. Snyder and Wullstein (1973) reported that nitrogen fixation in cryptogamic crusts contributed only small quantities of nitrogen to local sites of the desert ecosystem. Rychert and Skujins (1974) studied the effects of moisture, temperature, and light intensity on nitrogen fixation in crusts from the Great Basin Desert. These researchers estimated that algal-lichen crusts fix from 10 to 100 kg N ha^{-1} yr^{-1}. The nitrogen fixed by the cryptogamic crusts may be cycled through soil microorganisms, higher plants, and animals.

Several studies concerning the recovery of cryptogamic soil crusts following both grazing and fire disturbance have been conducted (Anderson and others 1982; Johansen and others 1984). Generally speaking, both intensive spring-summer grazing or fire are quite devastating to crusts. The recovery pattern, following either type of disturbance, tends to be similar, with the algal component rapidly commencing reestablishment followed by weedy moss species and lichens with vegetative diaspores. Other moss species as well as lichen species, which reproduce exclusively by sexual means, tend to require more time. Full recovery may require as many as 15 to 20 years (Anderson and others 1982). Other factors influencing recovery are intensity and duration of disturbance, proximity of disturbed sites to established crust communities, size of the disturbed site, summer moisture, and extent and duration of protection from perturbation.

Due to the fragile nature of soil crusts, they can be severely impacted or destroyed by activities such as grazing, burning, and off-road vehicles. The objective of this study was to determine the effects of grazing and burning disturbances on nitrogen fixation rates by crust organisms.

SITE DESCRIPTION

Two sites were chosen for this study. The first was at Camp Floyd State Park near Fairfield, UT. This 16.2-ha park was created in 1962 and has been protected from grazing since that time. An inactive military cemetery occupies a small

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Richard E. Terry is Associate Professor of Soil Microbiology and Steven J. Burns was Graduate Assistant, Dept. of Agronomy and Horticulture, Brigham Young Univ., Provo, UT 84602.

portion of the park, however the balance of the park remains undeveloped and is dominated by an Sarcobatus vermiculatus (greasewood)--Atriplex confertifolia (shadscale) desert shrub community. In 1979 1.5 ha of the park was destroyed by fire. The area adjacent to the park was heavily grazed by both cattle and sheep until 1975. These areas comprised the undisturbed, burned, and grazed sites of the Camp Floyd study area, respectively.

The second study site is at Rush Valley, which is located approximately 16 km northwest of Camp Floyd. This area consists of a heavily grazed area and two adjacent fenced exclosures. The area (2 ha) within the ungrazed exclosure has been protected for more than 10 years. The tilled exclosure (2 ha) was established in 1982 and consists of tilled rows with shrub plantings.

MATERIALS AND METHODS

The properties of soils used in this study are listed in table 1. Soil texture was determined using the Bouyoucos hydrometer method and pH was determined by glass electrode on a 1:1 soil paste (McLean 1982). Organic carbon was determined by the Walkley-Black method (Nelson and Sommers 1982) and total-N was determined by the microKjeldahl method (Bremner and Mulvaney 1982).

Table 1.--General soil properties of soils at Camp Floyd and Rush Valley sites

Site	pH	Organic C	Total N	Sand	Silt	Clay
		g kg^{-1}				
Camp Floyd	8.1	12.0	0.10	235	390	375
Rush Valley	8.0	14.2	0.12	320	460	220

An acetylene reduction technique was used to estimate the nitrogen fixation rate of surface soil samples. Intact soil cores (0-4 cm in depth) were obtained by inserting 136 mm x 24 mm pyrex glass tubes into the soil and extracting the cores. Sample tubes were constructed from 150 mm x 24 mm pyrex culture tubes with the bottom 14 mm of the tubes removed to allow for insertion into the soil. After extraction of the cores from the site, the bottoms of the tubes were sealed with neoprene stoppers and the tops were sealed with "mininert" septum caps (Precision Sampling Corp., Baton Rouge, LA). A 30 mL headspace volume remained in each tube. The tubes were transported to the laboratory for acetylene reduction assays which were conducted within 24 hr of sampling. Five replicate core samples were randomly selected at each site. Samples collected in 1983 and 1985 were dry at the time of sampling and were moistened in the laboratory to approximately -33 kPa moisture potential prior to acetylene reduction assay.

For the acetylene reduction assays 10 percent of the headspace air was removed by syringe and replaced with commercial C_2H_2 which had been purified by passage through concentrated H_2SO_4 and water traps (Hardy and others 1968). The samples were incubated for approximately 24 hr at 21°C under a light intensity of 36 µE m^{-2} s^{-1}. Ethylene and acetylene in the headspace gases were detected with a Hewlett-Packard 5840-A gas chromatograph with a flame ionization detector. Gases were separated on a Porapak R (80-100 mesh) column (0.003 by 2.5 m). Oven and detector temperatures were 40°C and 250°C respectively. The ratio of ethylene to nitrogen fixed was assumed to be 3:1 (Hardy and others 1968).

Table 2.--Soil moisture content and nitrogen fixation rates of soils collected at Camp Floyd, UT

Date Sampled	Disturbance	Soil moisture	Nitrogen fixation rate
		kg kg^{-1}	g N ha^{-1} hr^{-1}
6 Apr. 81	Ungrazed	0.23	2.02 a[1]
	Burned	0.23	0.73 b
	Scalped	0.23	0.29 b
29 May 81	Ungrazed	0.24	0.58 a
	Grazed	0.24	0.15 b
	Burned	0.24	0.16 b
20 Aug. 81	Ungrazed	0.02	N.D.[2]
	Grazed	0.04	N.D.
	Burned	0.02	N.D.
29 Sep. 81	Ungrazed	0.02	N.D.
	Grazed	0.02	N.D.
	Burned	0.02	N.D.
17 Nov. 81	Ungrazed	0.23	0.37 a
	Grazed	0.15	2.18 a
	Burned	0.15	0.28 a
4 May 82	Ungrazed	0.12	0.56 a
	Grazed	0.06	0.17 a
	Burned	0.06	N.D.
30 May 83	Ungrazed	0.23	0.61 a
	Grazed	0.23	1.05 a
	Burned	0.23	0.94 a
20 Mar. 84	Ungrazed	0.10	0.14 a
	Grazed	0.06	0.21 a
	Burned	0.06	0.25 a
9 Apr. 85	Ungrazed	0.24	0.52 b
	Grazed	0.20	8.10 a
	Burned	0.20	7.38 a

[1]Nitrogen fixation rates at the same sampling time followed by the same letter are not significantly different at the 5 percent level (Duncan's new multiple-range test).

[2]N.D.= not detectable

RESULTS AND DISCUSSION

Nitrogen fixation rates in soil cores collected at Camp Floyd State Park from 1981 through 1985 are listed in table 2. In April 1981 cores were taken from the ungrazed and burned areas. In order to determine the location and type of nitrogen fixers in the soil crust, the top 1 to 2 cm of the crust was removed (scalped) from some of the cores collected from the ungrazed area. Nitrogen fixation was approximately seven times greater in intact crust, indicating that the majority of nitrogen fixation was conducted by cyanophytes in the upper surface of the crust. At the beginning of the study in 1981 the cryptogamic crusts were much better developed in the ungrazed area than in the disturbed areas (Johansen and others 1984). In May of 1981 nitrogen fixation was significantly greater in cores from the ungrazed area than in samples from the burned or grazed sites. Samples collected in August and September of 1981 were dry when collected and N fixation was below the levels of detectability. In November 1981, crust samples were moist at the time of collection, however, no significant differences in N fixation rates were noted between the various treatments.

Samples were collected from the disturbed and undisturbed sites at Camp Floyd each spring from 1982 through 1985. There were no significant differences in nitrogen fixation rates between disturbed and undisturbed sites in 1982, 1983, or 1984. Samples collected in April 1985 were moistened in the laboratory prior to the acetylene reduction assay. Nitrogen fixation rates were significantly higher in the cores from the grazed and burned areas than from the ungrazed area. Johansen and others (1984) have described the recovery of the Camp Floyd sites during the period 1980 to 1982. They reported that the algal community in the burned area had substantially recovered by 1982 so that there were no significant differences in the algae of the burned and unburned sites. Their study also indicated that the algae were the first crust organisms to invade the burned area. Johansen (1984) further reported that even though the algal community had fully recovered in the burned and grazed sites, the lichen and moss communities were still in the process of recovery. The recovery of the algal communities in the two disturbed sites was further verified by the substantial increase in nitrogen fixation rates documented in this study. The recovery of algal species and nitrogen fixation rates during this study was more rapid than anticipated. A major factor in this rapid recovery was the above normal annual precipitation during the study. It appears that the nitrogen fixing cyanophyte component of the crusts in the ungrazed area had declined somewhat by 1985 due to increased competition from bryophytes and vascular plants during the wet years (Johansen and St.Clair 1984). This may explain the significantly lower nitrogen fixation rates of the ungrazed samples in April 1985.

Nitrogen fixation rates in protected and disturbed crusted soils of Rush Valley are listed in table 3. Samples were collected in November 1982 from the undisturbed area and adjacent grazed and tilled areas. The tilled site was part of an experimental shrub planting. There were significant differences in nitrogen fixation rates at each of these sites, indicating that mechanical disturbance due to tilling and grazing greatly decreases nitrogen fixation capabilities of the cryptogamic crusts. There were no significant differences in nitrogen fixation rates of samples collected from the various sites in May 1983. However in April 1985 nitrogen fixation rates were significantly higher in the ungrazed area than in either the grazed or tilled areas. For comparison, cores were collected from a disked firebreak which surrounded the tilled site. The firebreak was established in the fall of 1984. Though N fixation in the grazed, tilled, and disked areas were not significantly different, the N fixation rate of the disked samples was below the levels of detectability. These results further illustrate that mechanical damage to soil crusts significantly reduces nitrogen fixation. The experimental evidence also indicates that if disturbed sites are protected from perturbation long enough, nitrogen fixing organisms will eventually become reestablished.

Cores collected from the grazed area at Camp Floyd in April 1985 were used to determine the effects of soil moisture on nitrogen fixation in soil crusts. The soil moisture content at the time of sampling was 0.06 kg kg^{-1}. Samples were irrigated to soil moisture contents of 0.23, 0.17 and 0.12 kg kg^{-1} (approximately -33, -100, and -1,500 kPa moisture potential, respectively) and preincubated under lights for 24 hours prior to the acetylene reduction

Table 3.--Soil moisture content and nitrogen fixation rates of soils collected in Rush Valley, UT

Date Sampled	Disturbance	Soil moisture (kg kg^{-1})	Nitrogen fixation rate (g N ha^{-1} hr^{-1})
18 Nov. 82	Ungrazed	0.18	1.03 a[1]
	Grazed	0.18	0.16 b
	Tilled	0.18	0.01 c
30 May 83	Ungrazed	0.18	2.33 a
	Grazed	0.18	3.15 a
	Tilled	0.18	0.71 a
9 Apr. 85	Ungrazed	0.18	2.54 a
	Grazed	0.18	0.15 b
	Tilled	0.18	0.16 b
	Disked	0.18	N.D.[2]

[1]Nitrogen fixation rates at the same sampling time followed by the same letter are not significantly different at the 5 percent level (Duncan's new multiple-range test).

[2]N.D.= not detectable

assay. The preincubation was designed to allow moisture to effectively penetrate the entire core. The effect of soil moisture content on nitrogen fixation rates is shown in figure 1. Nitrogen fixation proceeded at significantly higher rates with increasing soil moisture. Additional samples were irrigated to a soil moisture content of 0.23 kg kg^{-1} and immediately exposed to C_2H_2 to determine the effect of initial soil wetting on N fixation. The nitrogen fixation rates decreased with increasing incubation interval following irrigation of the crusts (fig. 2). The nitrogen fixation rate was five times greater during the first 12-hr incubation interval than during the interval from 36 to 48 hr. The nitrogen fixation rate during the second 24 hr of incubation was similar to that of the 0.23 kg kg^{-1} moisture treatment shown in figure 1. These results indicate that the nitrogen fixers in cryptogamic crusts are capable of rapid initiation of nitrogen fixation at the commencement of a precipitation event. The importance of rapid initiation of nitrogen fixation by soil crust cyanophytes in conjunction with the availability of moisture in desert systems is two fold: (1) infrequent precipitation and (2) severe day time temperatures. Thus, nitrogen fixers capable of tolerating severe dessication as well as rapid exploitation of available moisture have been selected for. In both cases heterocystous cyanophytes fill the bill adequately.

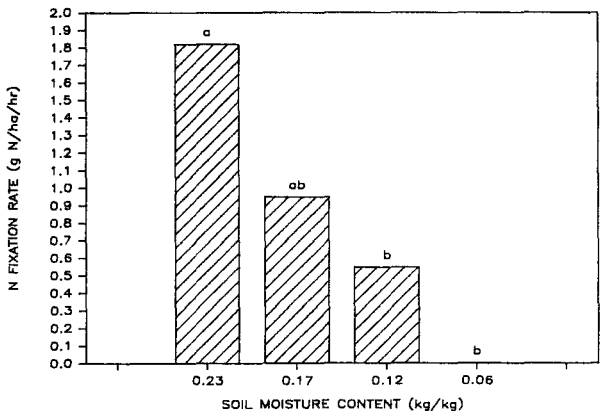


Figure 1.--The effect of soil moisture on nitrogen fixation rates by cryptogamic soil crusts.

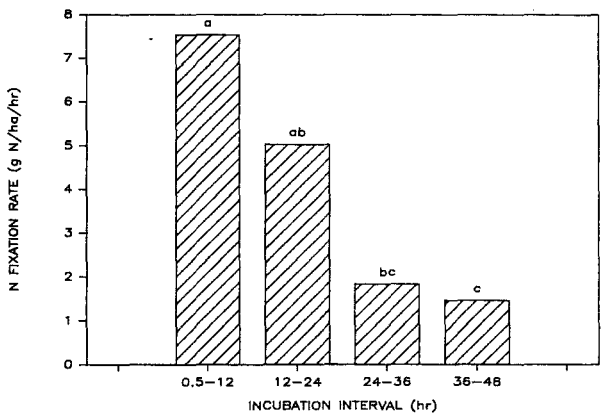


Figure 2.--The effect of incubation interval on nitrogen fixation by cryptogamic soil crusts.

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STEM FLOW ON WESTERN JUNIPER (JUNIPERUS OCCIDENTALIS) TREES

James A. Young and Raymond A. Evans

ABSTRACT: Stem flow is the water from precipitation that is intercepted by plant canopies and conveyed down the outside of the stems to wet the soil at the base of the plant. For western juniper (Juniperus occidentalis Hook.) trees, stem flow was only a small fraction of the precipitation intercepted by the canopy. However, this moisture may be important in the nutrient flux of the trees. The first stem flow in the fall after the summer drought was enriched in nitrate-nitrogen although the quantity of nitrogen per unit area was small. The enrichment of the stem flow may not be as important as the precise placement of the moisture at the base of the tree. The combination of favorable moisture and temperature conditions at the base of the tree leads to litter decay and nitrification. The root system of the trees had many fine roots in the trunk base area.

INTRODUCTION

Stem flow is the water from precipitation that collects on the foliage and branches of trees and is channeled by the limbs to flow down the outside of the tree trunk. The existence and volume of this flow have been documented for several different species of coniferous and broadleaf trees (Eaton and others 1973; Gersper and Holowaychuk 1970, 1970b, 1971; Kittredge 1948; Zinke 1962). Most of the scientific interest in stem flow has been by soil scientists who have investigated this process as the cause of differential soil development under trees as compared to interspaces. The differential soil development is caused by: (a) increased moisture near the trunk, (b) enriched nutrients from the stem flow, and (c) an interaction of stem flow and litter decay beneath the tree canopy. Review and synthesis of the available literature is provided by Birkeland (1974) and Tiedemann and others 1980.

An accompanying phenomenon of canopy interception and stem flow is the precipitation that passes through the tree canopy. This precipitation is termed "throughfall" (Eaton and others 1973; Hart and others 1974). Throughfall and stem flow are usually enriched with nutrients, both from atmospheric inputs and material washed, or possibly leached, from foliage (Helvey and Patric 1965; Henderson and others 1977; Reiners 1972; Tiedemann and others 1980).

The objectives of this research were to ascertain the existence of stem flow, quantify it for western juniper trees, and investigate the role of this phenomenon in the ecology of this tree species.

METHODS AND MATERIALS

Field studies were located in a western juniper woodland in western Lassen County, California (41°N, 121°W). This woodland consists of trees of relatively even age that became established between 1890 and 1910. Detailed demographic studies of this woodland have shown that the site probably supported a Wyoming big sagebrush (Artemisia tridentata Nutt. spp. wyomingensis Beetle and Young), bitterbrush [Purshia tridentata (Pursh DC.)], bluebunch wheatgrass [Agropyron spicatum (Pursh) Scribn. and Sm.] plant community before the establishment of the juniper trees (Young and Evans 1981). The woodland consists of approximately 150 trees/ha with an average height of 10 m and trunk diameter of 50 cm at the soil surface. The trees are not randomly distributed but tend to be roughly grouped around irregular openings in the woodland. Although the trees were mainly established around 1900 (±10 years), there is considerable variability in height and crown diameter, apparently because of intraspecific competition, with larger trees having become dominant and smaller trees being suppressed.

The tree canopies do not touch in the woodland, and projected cover of the canopies averages 40 percent. However, the trees preempt the available environmental potential, largely suppressing the understory of shrubs and herbaceous species except in the larger openings (Young and Evans 1981).

Annual precipitation averages 30 cm, falling mainly as snow during the winter. The summer months are usually dry.

Stem flow.--For stem flow measurements, 10 trees were selected in 1977. The trees ranged from 18-cm trunk diameter and 5 m tall to 75-cm trunk diameter and 10.8 m tall. The trunks of the trees were circled with soft aluminum sheeting in a spiral pattern. The metal was sealed to the

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James A. Young and Raymond A. Evans are Range Scientists, Agricultural Research Service, U.S. Department of Agriculture,

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contours on the trunk with a waterproof adhesive. The outer lip of the sheeting was bent up to form a collection trough. The lower end of the spiral was formed into a tube that discharged into a covered collection reservoir. The contents of the reservoir were measured at intervals corresponding to the fall, winter, spring, and summer precipitation periods. Occasionally, stem flow from individual storms was measured. The trees that were fitted with collection collars for stem flow had normal canopy geometry and branchlet morphology. The trees had stiff branches that curved up and out from the trunk. The branchlets were stiff and arranged nearly vertically.

Canopy interaction.--To measure the interception of precipitation by the canopies of western juniper trees, 20-cm-diameter rain gauges were placed in natural openings in the woodlands, at the edge of the tree canopies where the canopy dripline was estimated to occur, halfway between the canopy edge and the trunk, and next to the trunk. Four replications were established by using similar trees approximately 9 m tall with 10-m diameter canopies. The gauges were arranged in lines from the north side of the tree trunk. A layer of oil was put in each gauge to retard evaporation, and during the winter antifreeze was added to melt snow and protect the gauges from the effects of freezing water.

The water collected in the gauges was measured at irregular intervals, but often enough that precipitation could be accumulated in seasonal periods. Additional gauges were located in the center of 0.1- and 4.0-ha openings in the woodland where the juniper trees had been removed. There were four replications of the 0.1-ha openings with gauges, and four gauges were dispersed in the 14.0-ha opening.

Nutrient content of stem flow and throughfall.--To obtain an estimate of the relative nutrient content of stem flow and throughfall versus precipitation falling in openings, we used a network of stainless steel rain gauges. These gauges were cleaned, rinsed in distilled water, and sealed in plastic bags. When weather reports indicated a storm was imminent we placed the gauges in the woodland in the same pattern as the canopy interception gauges. The stainless steel cans were used for stem-flow collectors on specific trees, paired with the 10 stem flow trees to obtain samples for analysis of the nutrient content of the stem flow.

Precipitation, stem flow, and throughfall water from individual storms were analyzed. The samples were refrigerated when collected and analyzed promptly. All samples were analyzed for: (a) nitrate-nitrogen by cadmium reduction; (b) total phosphorus by persulfate digestion followed by determination by mixed reagent ascorbic acid method as modified by Tiedemann and others (1980); and (c) Ca, K, and S determined by atomic absorption spectroscopy (Robinson 1966). The pH of samples was determined by glass electrode, and conductivity by a conductivity meter (Golterman and Clymo 1969).

Quantity and location of litter.--To determine the quantity and location of litter under western juniper trees in the study area, we collected 0.1-m^2 samples located at the trunk, 0.5 and 1 m from the trunk, and at the canopy edge. The same 10 trees on which stem flow was measured were used for litter sampling. The samples were taken in transects in the four cardinal directions from each tree. We defined litter as organic material lying on the soil surface that would not pass through a 1-mm screen. The samples were oven dried and separated into herbaceous and woody litter. The woody litter was further subdivided into coarse material that would not pass through a 1-cm screen and finer material.

Nitrate level in subcanopy soils.--The nitrate level in the surface soil was determined under each tree canopy with the same sampling design and sequence as for litter samples. These samples were taken annually in May at the peak herbaceous production and in October after the first autumn rain. The soils were analyzed by the permanganate-reduced iron modification of the Kjeldahl method (Bremer and Mulvaney 1982).

Rooting characteristics.--To relate the rooting characteristics of western juniper trees to stem flow, we excavated trenches to bedrock from the base of the trees to 6 m north and south. The depth of the soil averaged 1 m. Columns 0.1-m squared were sampled by 0.1-m increments from the side of the trenches. The columns were located at the tree base and at 1-m intervals along the trench walls. Roots with a diameter greater than 0.5 cm were removed as the columns were excavated. Smaller roots were removed by washing the samples in the laboratory. The total weight of the roots in the samples was determined after oven drying the recovered material.

Soil moisture.--Gypsum soil moisture blocks were used to obtain an estimate of moisture depletion in the soil profile at the base of western juniper trees, at one-half the distance of the canopy radius, at the edge of the canopy, and in 0.01-ha openings in the woodland. The blocks were buried at 7.5-, 30-, and 60-cm depths in the soil profile. Readings were taken periodically during the spring growing season of each year.

RESULTS

Stem flow.--Relatively large amounts of water flowed down the outside of western juniper trunks in response to precipitation (table 1). The amount of stem flow in relation to the precipitation varied among the seasons. During the four winter periods of the study, the trees averaged 0.53 L of stem flow/cm of precipitation received as measured by precipitation gauges located in 10-ha openings in the woodland (table 1).

Table 1.--Stem flow collected per tree by season in relation to precipitation recorded in 0.01- and 0.1-ha openings in the woodland and 10.0-ha cleared areas [1]

Year and season	Precipitation gauge located in woodland: Sunspot, 0.01-ha	Circular clearing, 0.1-ha	Large clearing, 10.0-ha	Stem flow per tree	Stem flow vs. precipitation[2]
	(cm)			(L)	(L/cm)
1978					
Winter	23.5	24.0	24.5	13.1 b	0.54
Spring	10.6	11.0	11.6	2.9 cd	0.24
Summer	1.8	2.0	2.1	4.8 c	2.29
Fall	1.0	1.4	1.4	0.2 e	0.14
1979					
Winter	29.2	30.7	31.2	13.8 ab	0.44
Spring	28.9	30.2	31.3	15.0 ab	0.48
Summer	2.4	2.6	2.7	1.1 de	0.41
Fall	5.9	6.1	6.2	3.1 cd	0.50
1980					
Winter	29.2	29.3	30.3	15.9 a	0.52
Spring	24.4	25.2	26.4	15.2 ab	0.58
Summer	4.1	4.3	4.5	1.2 de	0.27
Fall	1.7	2.0	2.1	1.0 de	0.48
1981					
Winter	1.7	2.0	2.1	1.3 de	0.62
Spring	20.1	21.5	22.6	14.1 ab	0.62

[1]Means followed by the same letter are not significantly different at the 0.01 level of probability as determined by Duncan's multiple range test.

[2]Based on precipitation received in 10.0-ha cleared area.

The average canopy diameter of the trees on which stem flow was collected was 4.44 m, while the orifice of the standard rain gauge was 20 cm in diameter. When we compared the collection of precipitation by the gauges and stem flow by the trees, we found that the trees were 9 percent as efficient as the gauges in precipitation collection. The trees were most efficient as collectors during the summer and least efficient during the winter. During winter, precipitation largely occurred as snow, which apparently increased losses from evaporation or sublimation compared with high-intensity showers that infrequently occurred during the summer.

The amount of precipitation recorded in gauges located in small (0.01-ha) natural openings in the woodland, which we term "sunspots," was always smaller than that recorded in 0.1-ha or 10.0-ha openings in the woodlands (table 1). This difference in recorded precipitation was apparently due to lateral interception by trees of wind-driven rain and snow. The closest agreement between precipitation measured in sunspots and the 10.0-ha opening occurred during the winter periods (difference of 16 percent). The precipitation measured in the 10.0-ha openings was used to calculate the ratio of stem flow (L) versus total precipitation (cm). Because of horizontal interception of wind-driven precipitation, the trees are probably less efficient as precipitation collectors than our figures indicate. Despite variation due to lateral interception, about 95 percent of the variability in stem flow was accounted for by variability in precipitation in either the 0.01-, 0.1-or 10.0-ha clearings in the woodland (coefficients of determination averaged 0.95).

Stem flow and tree size.--Both tree height and canopy diameter were related to the amount of stem flow but as individual parameters they were not markedly correlated with stem flow because of a high degree of variability in the data (table 2). For specific collection periods, variation in tree height accounted for a high of 92 percent and a low of 2 percent of the variability in stem flow. A similar range existed for canopy diameter. When a collection period produced at least 8 L of stem flow per tree, the coefficients of determination for the relation between stem flow and canopy diameter (r^2 = 0.60 vs. 0.35) or tree height (r^2 = 0.87 vs. 0.29) were higher than for collection periods with less than 8 L per tree.

Table 2.--Coefficients of determination for the correlation between stem flow and either tree canopy diameter or height[1]

Season	Year	Storm	Stem flow	Coefficient of determination	
				Canopy diameter	Tree height
			(L)	(r^2)	
Winter	1978	...	13.1	0.58	0.89**
	1979	...	13.8	0.51	0.83**
	1980	...	15.9	0.66*	0.88**
	1981	...	1.3	0.25	0.08
Spring	1978	...	2.8	0.59	0.89**
	1979	1	8.3	0.63*	0.92**
		2	3.2	0.05	0.03
		3	3.2	0.04	0.16
		4	0.3	0.34	0.04
	1980	1	4.2	0.01	0.07
		2	2.9	0.28	0.71*
		3	8.1	0.68*	0.92**
	1981	1	1.1	0.61	0.27
		2	0.7	0.75*	0.36
		3	9.1	0.54	0.77**
		4	3.2	0.60	0.67*
Summer	1978	...	4.8	0.14	0.35
	1979	...	1.1	0.61	0.28
	1980	...	1.2	0.63	0.29
Fall	1978	...	0.2	0.28	0.02
	1979	...	3.1	0.20	0.41
	1980	...	1.0	0.75*	0.41

[1] *, **, indicate significance at 0.05 and 0.01 levels or probability, respectively.

The most precise estimate of stem flow was obtained by the model: stem flow = function of amount of precipitation, tree height, canopy diameter, trunk diameter, year, season, and interactions between the variables. The form of the calculated complete model is:

$$Y = 14.711 - 836.346X_1 + 0.832X2 - 0.261X_3 + 0.072X_4 - 0.009X_5 + 5755.001X_6 + 825.974X_7 + 2300.286X_8 + 0.424X_1X_5 - 1.024X_1X_6 - 0.197X_1X_7 - 0.526X_1X_8 - 0.068X_2X_3 - 0.014X_2X_4 + 0.013X_3X_4 + 0.559X_3X_6 + 0.131X_3X_7 - 0.097X_3X_8 - 2.906X_5X_6 - 0.417X_5X_7 - 1.162X_5X_8$$

Y = estimated stem flow, X_1 = amount of precipitation,
X_2 = tree height, X_3 = canopy diameter, X_4 = trunk diameter,
X_5 = year, X_6 = 1 if winter, 0 otherwise, X_7 = 1 if spring,
0 otherwise, X_8 = 1 if summer, 0 otherwise.

NOTE: If X_6, X_7, X_8 = 0, then season = fall.

The variable year was included to make the model more complete because it would account for some of the variation due to unmeasured environmental factors such as temperature. The coefficient of determination for this multiple regression equation accounted for 93 percent of the variability observed in the amount of stem flow.

Canopy interception.--Under the edge of western juniper canopies there was about a 20 percent reduction in precipitation received at ground level compared with that measured from gauges located in 0.01-ha openings in the woodland (table 3). At one-half of the distance between the canopy edge and the tree trunk canopy, interception increased to about 50 percent of the precipitation received and at the trunk this interception (not including stem flow) increased to two-thirds of the precipitation. There was no dripline where the water accumulation at ground level was greater than that received in openings in the woodland. Despite the predominance of snow in the winter and intense rain showers in the summer there were no differences among seasons in the percentage of precipitation measured under the canopy.

The relationship between canopy interception and stem flow can be visualized diagrammatically by considering the fate of 23.5 cm of precipitation intercepted during a winter period by a western juniper tree with a canopy of 10 m in diameter (fig. 1). A 20-cm diameter rain gauge, located in a 0.01-ha opening in the woodland, received 6.8 L of precipitation during the winter, and on the basis of proportionality the tree would have received 17,000 L of precipitation. The trunk of

Table 3.--Average precipitation by seasons in relation to tree canopy interception. Precipitation means given as percentage of that received in gauges located in 10.0-ha openings in the woodlands [1]

Season	Subcanopy precipitation		
	Edge of canopy	One-half of canopy radius	At trunk
	(%)		
Winter	80 a	50 b	31 c
Spring	79 a	49 b	33 c
Summer	81 a	49 b	32 c
Fall	83 a	49 b	27 c
Mean	81 x	49 y	31 z

[1] Means by seasons (a through c) and total means (x through z) followed by the same letter are not significantly different at the 0.01 level of probability as determined by Duncan's multiple range test.

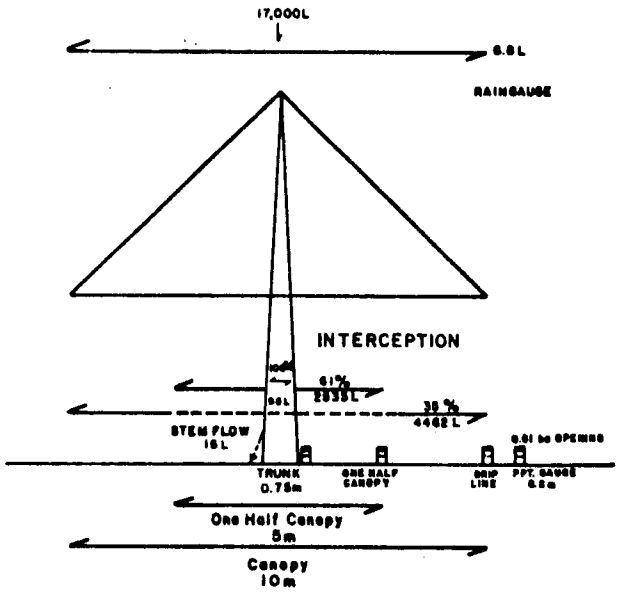


Figure 1.--Diagrammatic western juniper tree depicting canopy interception and stem flow from a winter period when precipitation of 23.5 cm was measured in 0.01-ha openings of the woodland.

the tree, in cross section at the soil surface, constituted 0.56 percent of the subcanopy area and theoretically would intercept 95 L of precipitation. The area from the trunk to one-half of the canopy diameter constituted 24.5 percent of the total. If an interception rate of 61 percent was assumed for this area, based on the average interception at the trunk and halfway to the canopy edge, the area would have intercepted 2500 L of precipitation (table 3). The outer half of the canopy constituted 75 percent of the subcanopy area with an assumed interception rate of 35 percent. The total canopy interception constituted 42 percent of the precipitation received by the canopy area of the tree. Only 16 L of this interception were measured to reach the soil surface as stem flow (fig. 1). Stem flow constituted 0.094 percent of the total precipitation or 0.23 percent of that which was intercepted by the tree and not passed on to the ground as through-fall. The unaccounted-for intercepted precipitation had to be lost by evaporation or sublimation from the foliage and limbs of the tree.

Nutrient content of stem flow.--The nutrient content of the stem flow and throughfall water that passed through or dripped from the canopy of western juniper trees was not markedly different from control precipitation trapped in gauges located in 0.01-ha openings in the woodland, with the exception of the first storm that occurred in the fall and broke the summer drought (table 4). The stem flow water collected from the tree trunks during this first storm in the fall was a dark, brown-colored, foul-smelling liquid enriched in nitrate-nitrogen and bases (table 4). The precipitation samples collected under the tree canopy showed a progressive enrichment for most nutrients as the collection location approached the tree trunk.

Samples collected during the winter and spring were highly variable in nutrient enrichment but never contained more than a fraction of the enrichment detected in the first autumn moisture event samples (data not shown). Samples of summer moisture storms were not obtained because of the unpredictability of local summer storms in this environment. When the gauges are left exposed for too long before the storms they become contaminated with dust, seeds, and bird droppings.

The stem flow water collected during the first storm had a high content of solids compared with samples collected during the winter. These solids included soil particles from dust that settled on the trees, and fragments of lichens. The twigs and branches in the canopies of western junipers often support rich flora of foliar lichens.

Despite the apparent enrichment of the stem flow solution in nitrate-nitrogen compared with the precipitation received in openings in the woodland, the amounts of nitrate-nitrogen received per tree were small. If we assume an average stem flow of 1.4 L during the fall, then the nitrate-nitrogen received per tree would be 12.6 mg/tree or 2 g/ha.

Litter under tree canopies--The taller the trees the greater was the litter accumulation ($r^2 = 0.78$) (fig. 2). A similar but less precise relationship was noted for canopy diameter versus litter accumulation ($r^2 = 0.58$). Tree height and canopy diameter used in a regression equation to predict amount of litter did not improve precision over height alone (data not shown).

Table 4.--Nutrient content of precipitation in open, precipitation under canopy, and stem flow of western juniper trees for first cool season rain or snowfall after summer drought. Means combined for 1978 through 1980 [1]

Nutrient	Location of sampling gauge				
	Control 0.01-ha opening in woodland	Dripline	One-half under canopy	Trunk	Stem flow
	(ppm)				
Nitrate-nitrogen	0.1 c	0.8 c	1.0 c	3.0 b	9.0 a
Phosphorus	0.0 c	0.2 c	0.3 c	1.2 b	2.6 a
Sulfate	0.0 c	0.1 c	0.0 c	5.8 b	8.5 a
Potassium	0.0 b	0.0 b	0.0 b	0.0 b	2.0 a
Calcium	0.1 c	0.0 c	0.0 c	0.8 b	3.0 a

[1]Means of individual nutrients (rows) followed by the same letter are not significantly different at the 0.01 level of probability as determined by Duncan's multiple range test.

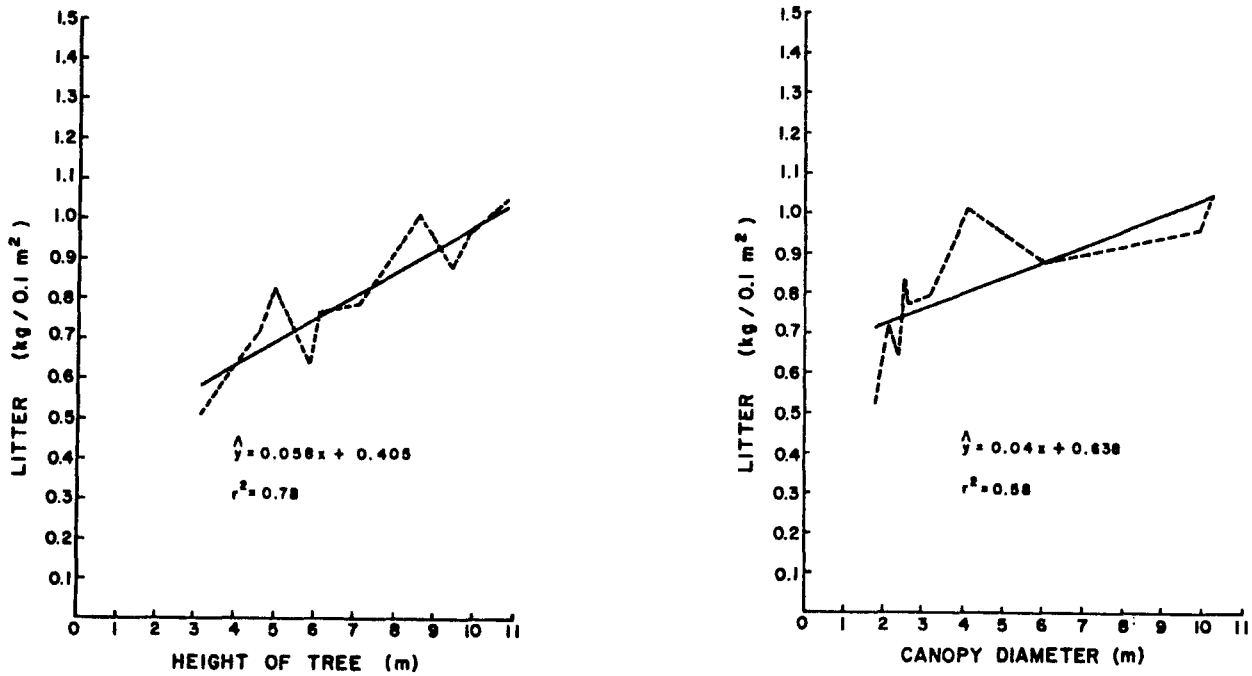


Figure 2.--Cumulative woody litter under western juniper trees in relation to tree height and canopy cover. Regression equations (Y = a+bx), distributions, and coefficients of determination (r^2) shown.

Most of the woody litter was located at the base of the tree trunk (table 5). Underneath the outer portion of the canopy there was very little litter accumulation. This probably accounted for the imprecise relation between canopy diameter and litter weight.

Average woody litter accumulation beneath the tree canopies was similar for the four cardinal directions (data not shown). However, the mean of the plots located along the north transect was higher than in other directions. This probably was a function of the southwesterly winds that accompany winter storms.

Nitrate-nitrogen.--The surface soils under the western juniper trees had the highest nitrate-nitrogen level in the zone located next to the tree trunk (table 6). There is virtually no herbaceous vegetation rooted next to the tree trunk because the accumulation of litter does not provide a suitable seedbed for these plants.

Root distribution.--The distribution of the roots of western juniper trees influences both the ecology of the woodland and control measures (fig. 3). The major roots (>7.5 cm in diameter) curved at an acute angle from the trunk and spread laterally at least 6 m from a 7-m-tall tree. At 6 m from the trunk the subdivisions of the major

Table 5.--Accumulation of woody litter beneath western juniper trees[1]

Location of sample	Woody litter
	(kg/0.1 m^2)
At trunk	1.49 a
0.5 m from trunk	0.85 b
1 m from trunk	0.65 c
At canopy edge	0.33 d

[1]Means followed by the same letter are not significantly different at the 0.01 level of probability as determined by Duncan's multiple range test.

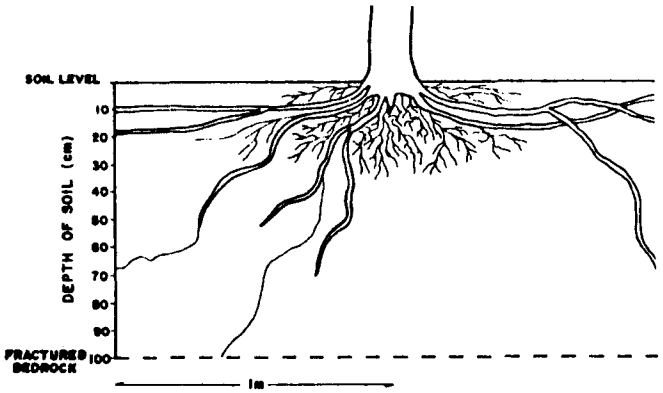


Figure 3.--Diagram of western juniper root system within 1 m of the tree trunk.

roots were so intermixed with similar roots from neighboring trees that they were difficult to separate. There were few roots extending straight down at the base of the tree. There was no tap root. Seedling western junipers have a tap root which apparently ceases development and even decays at about the time the juvenile spiney foliage is replaced with adult scales (unpublished data). The major lateral roots develop at that time. Although the major roots spread laterally, occasional branches grow down forming a column (about 1 m in diameter) and small roots grow into cracks in the bedrock.

At the base of the tree, both above and below the major roots, there was a mass of multibranched very fine roots (<1 mm diameter). At the top of branches of the major roots there were fine rootlets, but not in the concentration found at the tree base. The many fine roots near the tree base combined with the massive spreading roots resulting in the greatest biomass of roots being located close to the trunk (table 7).

Soil moisture depletion.--Soil moisture depletion under the western juniper tree canopies had interesting patterns (table 8). At the base of the tree, soil moisture remained available for plant growth

Table 6.--Nitrate-nitrogen level of surface soil beneath western juniper canopies. Means combined for 1978 and 1979[1]

Location of sample	Season of sampling	
	May	October
	(NO_3, ppm)	
At trunk	4.03 a	6.25 a
0.5 m from trunk	0.88 b	3.38 b
At canopy edge	0.20 c	1.63 c

[1]Means within columns followed by the same letter are not significantly different at the 0.01 level of probability as determined by Duncan's multiple range test.

until midsummer at the very shallow soil depth of 7.5 cm. In contrast, available soil moisture had usually been depleted to -1.5 MPa at the canopy edge by early summer. Halfway under the canopies, surface soils were often relatively dry in early spring.

The depletion of soil moisture beneath the tree canopies was largely a function of the tree and not the very scanty herbaceous vegetation. Only at the margin of the tree canopy was there sufficient herbaceous vegetation to influence soil moisture depletion.

The surface soils at the edge of the canopy and in openings in the woodland were often frozen in early spring, whereas the surface soils near the tree trunk were never frozen.

DISCUSSION

The entire biologic and ecologic system that is involved in stem flow is a quite remarkable adaptation. In terms of precipitation intercepted by the area of the trunk and canopy of the western juniper trees, the amount converted to stem flow is relatively small. This small amount of water could be ecologically significant. This significance lies first in the concentration of fine feeder roots in a mass close around the base of the trunk where watering occurred from stem flow. Secondly, the initial stem flow in the fall after the summer drought was rich in nitrate-nitrogen. Although the amount of nitrogen was small, it might favorably influence microorganisms engaged in recycling litter. Thirdly, the combination of stem flow and litter at the base of the tree could lead to nitrification and the nitrate could be readily absorbed by the network of fine roots at the tree base. The combination of stem flow and nitrification could help balance carbon nitrogen ratios so litter accumulated at the tree base can decay and the sink of nutrients be recycled. This has been demonstrated for other species (Gersper and Holowaychuk 1971). The accumulation of litter at the base of the tree should retard evaporation, and it apparently protects the surface soil from

Table 7.--Dry weight of western juniper roots per dm^3 of soil in relation to depth in the soil and distance from the tree. Means are the average for bisects located north and south from the trunk[1]

Depth	Distance of sample from tree trunk				
	Base	1 m	2 m	3 m	6 m
(cm)	(g/dm^3)				
0 to 25	184 a	74 bc	67 c	65 c	63 c
26 to 50	176 a	66 c	60 c	58 c	56 c
51 to 75	148 ab	37 cd	31 c-e	29 c-f	27 c-f
76 to 100	85 a-c	0 d-f	0 ef	0 f	0 f

[1]Means followed by the same letter are not significantly different at the 0.05 level of probability as determined by the confidence interval technique of multiple regression.

Table 8.--Moisture depletion under western juniper trees during spring and early summer. Average figures for three seasons (1978-1980) presented. Data from 7.5 cm below soil surface. Trees 7- to 9-m tall were used for moisture block location[1]

Sampling period	Sample location			
	Tree base	One-half canopy	Canopy edge	0.01-ha opening
	(-MPa)			
Early spring	0.0 c	0.5 bc	0.0[2] c	0.0 c
Midspring	0.0 c	0.8 b	0.6 bc	0.8 b
Early summer	0.1 bc	1.5 a	1.5 a	1.5 a
Midsummer	0.5 bc	1.5 a	2.0 a	2.0 a

[1]Means followed by the same letter are not significantly different at the 0.01 level of probability as determined by Duncan's multiple range test.

[2]In early spring these shallow depths in the soil profile are often frozen.

frost, which would prolong conditions conducive to nitrification.

The root and stem flow systems of the western juniper interact with mechanical and herbicidal control methods (Young and others 1981). In mechanical control methods, the heavy support roots must be broken in order to uproot the trees. The mass of fine roots at the base of the trunk holds soil particles so that a great deal of soil must be moved with the uprooted trees. This accumulation of soil interferes with burning to dispose of the uprooted trees.

There is no dripline in western junipers because of the geometry of the scales and branches that compose the canopy. Herbicide application to the soil beneath the edge of the canopy is not advantageous as has been shown in previous studies (Young and others 1981). Likewise, it is inefficient to simply distribute the herbicide under the tree canopy because canopy interception keeps the midcanopy areas relatively dry. Broadcasting the herbicides under the canopy does, however, control western junipers (Young and others 1981). The herbicide must be moved to the roots largely by stem flow. An application system that concentrates the herbicide on the stem flow area might be more efficient.

The canopy-interception stem flow system is a very inefficient method of moisture concentration for plant growth because of the large losses to evaporation. These losses need to be considered when evaluating the consequences of western juniper invasion of range plant communities.

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EFFECTS OF FUELWOOD HARVESTING AND SLASH BURNING ON BIOMASS AND NUTRIENT RELATIONSHIPS IN A PINYON-JUNIPER STAND

L. F. DeBano, H. M. Perry, and S. T. Overby

ABSTRACT: Fuelwood made up about 38% of the tree biomass in a stand of Utah juniper, but contained less than 25% of individual nutrients. Fire acted as a rapid mineraling agent. Slash burning and tree removal also affected soil mineralization and nitrification.

INTRODUCTION

The pinyon-juniper association occupies between 17 and 31 million hectares in western North America (Wright and Bailey 1982). Prescribed fire has been used in the pinyon-juniper type primarily to eradicate trees for range improvement. However, considerable interest in pinyon and juniper trees as fuelwood has developed during the past decade. Fuelwood harvesting removes all bole material larger than 7.6 cm in diameter. Tree materials less than 7.6 cm in diameter are left as slash and either are allowed to decompose naturally, or are scattered or piled, and burned. The effect of burning on the nutrients in the slash, litter, and underlying soil may affect the long-term fertility and productivity of these sites. Previous studies of nutrient relationships in pinyon-juniper ecosystems (Barth 1980; Bunderson and others 1985) have not examined fire effects. This paper reports preliminary information on nutrient distributions and the effects of a prescribed slash fire on nutrients in a stand of Utah juniper (Juniperus osteosperma) in central Arizona.

STUDY AREA

The 2-ha study area was occupied by Utah juniper that had been harvested for fuelwood during the fall and winter of 1983. The study site was on House Mountain, in the Coconino National Forest near Sedona, Ariz. The slash, after a fuelwood harvest, was prescribe burned in July 1984.

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DeBano is Supervisory Soil Scientist and Perry and Overby are Soil Scientists, Rocky Mountain Forest and Range Experiment Station, Tempe, in cooperation with Arizona State University. Station's headquarters is in Fort Collins, in cooperation with Colorado State University.

STUDY DESIGN

Information on the distribution of biomass and nutrients in the juniper trees was obtained by harvesting five live trees. The trees were separated into fuelwood and slash which were weighed wet in the field, subsampled, sealed in large plastic bags, and brought to the laboratory for drying, separation into fuel components, and chemical analysis. The slash was separated into leaves and <0.6 cm, 0.6-1-3 cm, and >1.3 cm diameter stems; was oven-dried; weighed; and was used to calculate the total amounts of each slash component in the trees that were harvested.

All woody material was ground in a Wiley mill to pass through a 2-mm sieve prior to analyzing for total nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur. Total nitrogen was determined by Kjeldahl analysis. The remaining elements were determined on a perchloric acid digest (Allen and others 1974).

The effect of prescribed fire on soil nutrients was assessed by sampling the fuels, litter, and soils when slash was burned on: (1) interspace areas (bare) between trees, and (2) areas surrounding stumps (cut trees) where litter had accumulated before harvesting. Slash was piled evenly on 12 study plots at a rate of about 56 x 10^3 kg/ha. The fuels, litter, and soil were sampled for each treatment on six replicate sites immediately before and after slash burning. The slash on each of the 12 sites was sampled by removing two representative branches and separating them into leaf and stem diameter classes. Two litter samples were randomly collected from each site by removing all of the organic material on the soil surface within a 0.1 m^2 frame.

After removing the litter from each 0.1-m^2 plot, three soil cores 3.8 cm deep and 3.8 cm in diameter were removed for determining bulk density and chemical analysis. Sampling was limited to the upper 3.8 cm of the soil because only minor changes were expected below this depth in the mineral soil. Total nitrogen (Kjeldahl); total potassium, calcium, and magnesium; pH on a 1:10 (soil:water), organic matter (Walkley-Black), and cation exchange capacity by ammonium acetate extraction were determined on the soil samples using methods described by Page and others (1982). Total phosphorus was determined on a potassium persulfate-sulfuric acid digest after autoclaving (Johnson 1971).

At the time of the burn, the fuel stick moisture was 11%, the relative humidity 44%, the wind speed was 8 km/hr from the southwest, and the maximum temperature was 36° C. All piles burned briskly and hot over a moist soil that had been saturated by rain 2 days prior to the slash burn.

Ten months after the burn, in May 1985, ammonia- and nitrate-nitrogen and bicarbonate extractable phosphorus in the soil were determined for the 12 burned sites and an additional 18 unburned sites consisting of: 6 bare areas with no slash, 6 cut-tree plots with no slash, and the area under 6 standing trees. Available nutrients were sampled at the 0-to-3 and 3-to-6 cm depths on all sites. Ammonia and nitrate-nitrogen were determined after extraction with a 2M KCL solution (Keeney 1982). Bicarbonate extractable phosphorus was determined according to Olsen and Sommers (1982).

The biomass and nutrient distribution data were expressed in nutrient concentrations (percent) and amounts (kg/ha) present in the different fuelwood components. The variability of the nutrient concentration data was characterized with standard deviations. The differences in nutrients and soil properties between trees and interspaces were tested by individual ANOVAs for each combination of soil property and ecosystem component (e.g., soil, surface litter, biomass). The effect of fire on total and available nutrients was analyzed as a repeated measures design where fire (before and after) and soil depth (0-3, and 3-6 cm) were treated as repeated measures (Milliken and Johnson 1984). Significant differences between means were tested by using least significant difference test using the error form associated with the repeated measurement.

RESULTS AND DISCUSSION

Biomass and Nutrient Distributions in Juniper Trees

Fuelwood made up about 38% of the tree biomass and contained 25% of the nitrogen, 13% of the phosphorus, 10% of the potassium, 25% of the calcium, 12% of the magnesium, and 23% of the sulfur in the above ground tree components (table 1). Although the leaves made up only 22% of the above ground biomass, they contained higher percentages of the N, P, K, Mg, and S than the other plant parts (table 1). The highest concentrations of calcium were found in the twigs, particularly those <0.6 cm which contained 8.6% Ca. This nutrient distribution is important not only from the standpoint of nutrient removal as fuelwood but also because the nutrients in the slash are exposed to heating when the slash is burned.

The removed fuelwood contained (in kg/ha) 8.6 of N, 0.5 of P, 2.3 of K, 69 of Ca, 0.61 of Mg and 0.32 of sulfur (only 11% of the area was covered by tree canopies). Over a 200-year rotation, these amounts of nutrients could easily be replaced by atmospheric deposition. Davis (1984) reported an average input of 4.3 kg/ha annually of nitrate-nitrogen by precipitation on chaparral watersheds in central Arizona, near Lake Roosevelt.

Nutrient Accumulations Under Juniper Trees

The nutrient distributions on the areas occupied by trees as compared to those in interspace areas indicated that trees redistributed the nutrients vertically in the system (among soil, litter, and tree parts) rather than horizontally between interspaces and trees (table 2). All soils

Table 1.--Average biomass and nutrient distribution in Utah juniper (Juniperus osteosperma) trees

		Nutrient											
	Biomass	Nitrogen		Phosphorus		Potassium		Calcium		Magnesium		Sulfur	
Tree component	kg/ha[1]	kg/ha	%[2]	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%
Fuelwood													
(>7.6 cm)	26,250	78	.30(.06)	4.6	.02(.01)	21	.09(.06)	628	2.1(0.53)	5.6	.02(.004)	3.0	.01(.0004)
Slash													
Leaves	15,006	128	.87(.16)	19.8	.13(.004)	147	.95(.08)	440	3.0(0.54)	29.2	.21(.03)	5.7	.04 (.004)
Twigs													
<.64 cm	7,078	30	.40(.06)	3.5	.05(.004)	23	.05(.05)	652	8.6(2.30)	4.0	.06(.008)	1.2	.02 (.007)
.6-1.3 cm	5,050	22	.44(.11)	2.1	.04(.004)	10	.20(.04)	376	6.4(1.86)	2.3	.05(.011)	0.8	.01 (.005)
1.3-7.6 cm	15,667	57	.36(.05)	4.9	.03(.004)	22	.13(.03)	417	2.5(0.66)	5.5	.03(.005)	2.3	.01 (.005)
Total	69,050	316		34.9		224		2,514		46.6		13.0	

[1] The quantities of biomass per unit area are based on the area covered by tree canopies. In the study area there were about 117 trees per hectare and each tree occupied 9.6 m^2 resulting in about 11% of the total soil surface being covered by a tree canopy.

[2] The percent concentration of each nutrient contained in each tree component and standard deviation in parentheses.

Table 2.--Soil chemical and physical properties and nutrients contained in the litter under tree canopies compared to interspace areas

	Ecosystem Component							
	Soil		Surface		Biomass		Totals	
	(0-3.8 cm)		(Litter)		(Plants)		(Ecosystem)	
Nutrient	Interspace	Tree	Interspace	Tree	Interspace	Tree	Interspace	Tree
Nitrogen (kg/ha)	7,117[a1]	8,014[a]	0.53[a]	164[b]	0	316	7,116[a]	8,494[a]
Phosphorus (kg/ha)	2,940[a]	2,512[a]	0.15[a]	44[b]	0	35	2,941[a]	2,590[a]
Potassium (kg/ha)	2,526[a]	2,273[a]	0.23[a]	65[b]	0	224	2,526[a]	2,562[a]
Calcium (kg/ha)	20,008[a]	18,270[a]	2.4[a]	1,003[b]	0	2,514	20,010[a]	21,787[a]
Magnesium (kg/ha)	3,613[a]	2,369[b]	0.17[a]	45[b]	0	47	3,613[a]	2,461[a]
OM (%)	1.28[a]	2.92[b]						
pH	7.79[a]	8.02[b]						
CEC (meq/100 gm)	35.7[a]	36.85[a]						
BD (gm/cm^3)	1.06[a]	0.87[b]						

[1] Values of any interspace versus tree comparison having the same letter are not significantly different at the 0.05 level.

occupied by trees generally had smaller quantities of nutrients, with the exception of nitrogen, than did the soils occupying the interspaces. This is contrary to the findings of other investigators (Virginia and Jarrell 1983; Barth 1980;), who reported higher accumulations of nutrients under tree canopies. However, there were significantly less nutrients in the litter on the soil surface in the interspaces than on the areas occupied by trees. When the total ecosystem was considered, no statistical differences existed between the total amounts of nutrients on areas occupying trees as compared to interspaces. The pH in the soil under the tree canopy was significantly higher and the bulk density significantly less than in the interspace areas.

Fire Effects on Total Nutrients

Fire acted as a rapid mineralizing agent for the nutrients contained in the slash. About 96% of the slash on the cut-tree and bare areas was consumed by the slash burn (table 3). Fragments of charred fuel were deposited on the soil surface, where the organic matter increased from 76 to 3085 kg/ha on the soil surface of the interspace plots during burning (table 3). Significant quantities of total nitrogen, phosphorus, potassium, calcium, and magnesium were released by burning and were deposited on the soil surface leaving more plant nutrients there after the fire than were present before the fire (table 3). No significant differences were found in the amounts of nutrients in the upper soil layer before and after burning.

Fire Effects on Available Nutrients

Ten months after the slash fire, there were significant differences in available nutrients between burned and unburned areas as well as between interspaces and areas occupied by standing trees. For ammonia- and nitrate-nitrogen the treatment, soil depth and soil x depth interactions were statistically significant. There was significantly more ammonia-nitrogen in the 0-3 cm depth as compared to the 3-5 depth only for the unburned cut tree where slash was not piled (table 4). The 0-3 cm layer contained significantly larger concentrations of ammonia-nitrogen under the unburned cut tree receiving no slash. There were significantly higher concentrations of ammonia-nitrogen on all standing and cut tree treatments than on the bare areas. The ammonia nitrogen in the 3-6 cm depth was significantly higher under trees, or cut trees, than in bare areas (table 4). In contrast to ammonia-nitrogen, nitrate-nitrogen was significantly higher in both the 0-3 and 3-6 cm depths on cut tree areas where slash had been burned (table 4). Nitrate-nitrogen in the 0-3 cm depth was also significantly higher under unburned cut trees with no slash than under standing trees and bare

Table 3.--Quantities of plant nutrients (kg/ha) in the slash, litter, and soil before and after a prescribed slash fire

Nutrient	Treatment	Ecosystem Component: Slash Pre	Slash Post	Litter or Ash Pre	Litter or Ash Post	Soil (0-3.8 cm) Pre	Soil (0-3.8 cm) Post
Organic matter	Cut-tree	$58,000^{a,x1}$	$1,516^{a,y}$	$14,376^{a,x}$	$13,446^{a,x}$	$92,577^{a,x}$	$102,585^{a,y}$
	Interspace	$58,000^{a,x}$	$2,423^{a,y}$	$76^{b,x}$	$3,085^{b,x}$	$47,693^{b,x}$	$58,832^{b,y}$
Nitrogen	Cut-tree	$243^{a,x}$	$5.3^{a,y}$	$164^{a,x}$	$271^{a,y}$	$8,014^{a,x}$	$7,829^{a,x}$
	Interspace	$235^{a,x}$	$8.4^{a,y}$	$.53^{b,x}$	$71^{b,y}$	$7,117^{a,x}$	$6,372^{a,x}$
Phosphorus	Cut-tree	$28^{a,x}$	$0.6^{a,y}$	$44^{a,x}$	$72^{a,y}$	$2,512^{a,x}$	$2,581^{a,x}$
	Interspace	$30^{a,x}$	$1.1^{a,y}$	$0.15^{b,x}$	$30^{b,y}$	$2,940^{a,x}$	$2,924^{a,x}$
Potassium	Cut-tree	$163^{a,x}$	$2.6^{a,y}$	$65^{a,x}$	$151^{a,y}$	$2,273^{a,x}$	$2,572^{a,y}$
	Interspace	$172^{a,x}$	$4.1^{a,y}$	$0.23^{b,x}$	$96^{b,y}$	$2,526^{a,x}$	$2,985^{a,y}$
Calcium	Cut-tree	$1,705^{a,x}$	$39^{a,y}$	$1,003^{a,x}$	$2,443^{a,y}$	$18,270^{a,x}$	$18,552^{a,x}$
	Interspace	$1,866^{a,x}$	$71^{a,y}$	$2.4^{b,x}$	$1,294^{b,y}$	$20,008^{a,x}$	$18,739^{a,x}$
Magnesium	Cut-tree	$40^{a,x}$	$0.9^{a,y}$	$40^{a,x}$	$94^{a,y}$	$2,369^{a,x}$	$2,230^{a,x}$
	Interspace	$54^{a,x}$	$1.5^{a,y}$	$0.17^{b,x}$	$43^{b,y}$	$3,613^{b,x}$	$3,434^{b,x}$

[1] When comparing any set of four values (representing combinations of cut tree and interspace versus before and after burning) for any particular nutrient, there is a significant difference at the .05 level between canopy and interspace if the first superscript (a or b) is different and between pre- and post-fire if the second superscript (x or y) is different.

Table 4.--Available nitrogen and phosphorus collected in House Mountain soils collected under different treatments in May 1985

	Nitrogen: Ammonia		Nitrogen: Nitrate		Phosphorus: Bicarbonate Extractable	
Soil Depth (cm)	0-3	3-6	0-3	3-6	0-3	3-6
Treatment	PPM					
Bare, no slash, no fire	$2.77^{a,w1}$	$2.88^{a,w}$	$0.50^{a,w}$	$0.25^{a,w}$	$10.00^{a,w}$	$10.69^{a,w}$
Bare, slash, fire	$4.00^{a,wx}$	$3.20^{a,w}$	$0.80^{a,w}$	$0.36^{a,w}$	$10.62^{a,w}$	$10.50^{a,w}$
Cut-tree, no slash, no fire	$18.45^{a,z}$	$10.36^{b,x}$	$7.50^{a,x}$	$2.09^{b,w}$	$23.68^{a,w}$	$16.74^{a,w}$
Cut-tree, slash, fire	$8.54^{a,xy}$	$7.90^{a,wx}$	$22.07^{a,y}$	$9.88^{b,x}$	$18.17^{a,w}$	$16.65^{a,w}$
Standing tree no slash, no fire	$11.56^{a,y}$	$11.23^{a,x}$	$1.00^{a,w}$	$0.16^{a,w}$	$14.57^{a,w}$	$13.55^{a,w}$

[1] For individual nutrients, means in a row having the same first superscript (a to b) and in columns having the same second superscript (x to z) are not significantly different at the 0.05 level.

areas. These results indicate higher mineralization rates were present under trees or on burned and unburned areas that previously had a tree canopy. The highest mineralization rates in both the 0-3 and 3-6 cm depths occurred when the trees were cut but the slash was not burned on the site. In contrast, nitrification rates (production of nitrate-nitrogen) were highest on areas where slash was burned on cut-tree sites. The interspace areas had lower mineralization and nitrification rates, regardless of whether slash is piled and burned or not. The low levels of nitrate-nitrogen and high levels of ammonia-nitrogen under the standing trees were not expected. These results indicate either nitrification was inhibited under the trees or that if nitrate-nitrogen was produced it was rapidly immobilized either microbially or by plant roots. Nitrification in several ecosystems has been reported to be inhibited by alleopathic substances (Rice and Pancholy 1972).

Although the amounts of bicarbonate extractable phosphorus generally were higher on the cut-tree sites, there were no statistical differences among treatments (table 4).

SUMMARY AND CONCLUSIONS

Although not more than 25% of the nutrients contained in the above-ground biomass was removed as fuelwood, this did not represent a large quantity of nutrients, because most of the nutrients on the site are contained in the soil and litter and are not directly affected by fuelwood harvesting. The nutrients removed from site by fuelwood harvesting could be replaced by atmospheric inputs if this loss occurred over a a 200-year rotation.

This study did not indicate that the trees accumulate large amounts of nutrients in the soil under their canopy. There were generally smaller amounts of total nutrients in the soils under trees than in the bare interspace areas between trees. When the nutrients in the tree parts and the underlying litter layer were accounted for, only minor differences in total nutrients existed between trees and interspaces. Nutrient cycling was primarily a vertical rather than a horizontal process in the juniper stand studied and fire acted as a rapid mineralizing agent, which deposited most of the nutrients contained in the slash on the soil surface.

Slash burning affected both nitrate- and ammonia-nitrogen. Less ammonia-nitrogen was present on cut-tree sites where slash had been piled and burned as compared to cut tree sites where slash had not been burned. In contrast, nitrate production was greater on the cut tree sites where slash was burned. These results indicate that removing the tree canopy is about as effective in increasing available nitrogen and phosphorus as the subsequent burning of the slash. Removal of the tree canopy seems to stimulate the mineralization of both nitrogen and phosphorus.

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IMPACT OF TREE HARVEST ON SOIL NUTRIENTS ACCUMULATED UNDER SINGLELEAF PINYON

D.F. Thran and R.L. Everett

ABSTRACT: This study was undertaken to document the distribution of soil nutrients in undisturbed woodlands and changes in surface mineral soil nutrients following tree harvest. Samples from soil profiles were analyzed to define available nutrient distribution in undisturbed woodlands. Iron, manganese, zinc, copper, nitrogen, and phosphorus are concentrated in the A horizons. Calcium, magnesium, sodium, and nitrogen reached maximum concentrations in the B horizons. Most nutrients decline with distance from under a tree canopy into the interspace. Surface soil was sampled in the area once covered by the canopy and in the former interspace between trees 5 years after tree harvest. Surface soils from under the canopy of harvested plots were significantly ($p=.05$) higher in nitrate, calcium, magnesium, zinc, copper, and potassium than surface soils of control plots. In the former interspace areas, only zinc and manganese increased following tree harvest.

INTRODUCTION

Forest trees accumulate nutrients in the soil under their crowns. Zinke (1962) reported increased nitrogen, potassium, and sodium under tree canopies; exchangeable bases were lower near the tree stems, increasing with distance from the bole to a maximum, and then declining beyond the canopy. Challinor (1968) reported increased concentrations of available calcium, potassium, phosphorus, and nitrogen under the canopies of four species, red pine (Pinus resinosa) Norway spruce (Picea abies), red oak (Quercus rubra), and white pine (Pinus strobus). The increases have been attributed to foliage drip and stem flow. Potassium, magnesium, and calcium are found in high concentration in foliage leachate (Tukey 1970; Tamm 1951; Will 1955; Tiedemann and others 1983) and stem flow (Carlisle and others 1967).

The litter is a source of nutrients that enrich soils over time. Zinke and Crocker (1962) and Charley and West (1975) report nutrients added to soil from litter create localized zones of enrichment under tree and shrub crowns. Soils were enriched adjacent to trees in a 30-year-old plantation (Challinor 1968).

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D. F. Thran is an Assistant Professor of Plant Science, University of Nevada-Reno; R. L. Everett is a Project Leader, Intermountain Research Station, Forest Service, U.S. Department of Agriculture, Reno, NV.

Barth (1980) documented a 5- to 13-fold increase in sodium, calcium, magnesium, and potassium under the canopies of pinyon (Pinus edulis) forests. He reported nitrate and sulfate increased 2- to 16-fold from shrub-dominated areas to tree-dominated areas in a 490-year-old stand. We found increases of smaller magnitude under pinyon-juniper woodlands that were 140 years old. All nutrients were lower in concentration in the interspace between trees.

If the presence of trees influences the nutrient status of the soil, then it is reasonable to assume tree removal will also affect soil nutrient concentrations. The release of nutrients following harvest has been reported in several studies. Matson and Vitousek (1981) found greater soil nitrate in clearcuts than in unharvested plots. Adams and Boyle (1982) found increased potassium 1 year after harvest and increased calcium, magnesium, and phosphorus 4 years after tree harvest.

Forage productivity and soil nutrient content increased following tree harvest on the sites described in this study even though understory grasses did not invade the area of the former tree canopies (Everett 1984). Silkworth and Gigal (1982) suggest that differences in climate and vegetation from site to site will influence nutrient availability following harvest. To this one could add soil differences, both chemical and physical, that would influence the rate of litter decompostion and water percolation.

In this paper we will discuss soil nutrient distribution patterns adjacent to singleleaf pinyon and the long-term changes in surface soil nutrients following tree harvesting. Land managers must evaluate the effects of tree harvesting operations on the soil resource. Documentation of soil nutrient changes following tree harvest could be a valuable tool for those who must predict potential for improvement or decline in productivity of a harvested area.

STUDY SITES AND METHODS

The study site is in the Shoshone Mountains of the central Great Basin; it has an annual precipitation of 320 mm and an elevation of 2,000 m. Plots had a 26 to 61 percent cover of singleleaf pinyon (Pinus monophylla) and Utah juniper (Juniperus osteosperma) and an understory of perennial grasses (Festuca idahoensis, Poa sandbergii). In 1979 we clearcut three, 30-meter square plots of all trees greater than 1-meter height. Trees were handcut and all slash

was removed from the site. Three adjacent, unharvested, control plots were left untouched. The soil at the site was identified by the Soil Conservation Service as a clayey-skeletal, mixed, frigid, Lithic Xerollic Haplargid.

To document soil nutrient distribution by horizon-adjacent singleleaf pinyon trees in undisturbed woodlands, we selected two large trees on each of north, west, and south aspects (mean stump diameter was 44.9 cm and mean crown area was 39 m^2). The trees had an average age of 143 years. To collect the samples and expose the soil profile, a trench was dug to bedrock from the stem into the interspace a distance equal to 4/3 crown radius Soil profiles under the six trees were similar. The needle mat and fermentation layer was 0-to 15-cm thick. The A11 horizon was thin (0-4 cm) and was not present at all points under the canopy. The A12 (3-27 cm) was overlaid with a vesicular crust (Alv) 0-to 9-cm thick at points beyond the crown edge. The A/B transition began 31 to 59 cm below the mineral surface and was 10 to 28 cm thick. The B horizon below it was 28-30+ cm thick. Approximately 200 grams of soil were collected from each horizon, including the O horizon, at the stem, 1/3, 2/3, 3/3, and 4/3 crown radius away from the stem. The 4/3 crown radius sample represents the interspace between trees and was free of tree litter. Exposed soil profiles allowed us to examine the vertical distribution of roots in a 100-mm wide belt at each of the sampling points.

In 1984, 5 years after harvest, surface mineral soils (0 to 10 cm depth) were collected at each of the sites. "Canopy" mineral soil samples were taken 50 cm from the stem under the canopy of eight trees in the three control plots and 50 cm from the stumps of the eight trees in the three harvest plots. Soil 50 cm out from the crown edge was taken to represent the interspace soil.

SOIL ANALYSIS

Soils were analyzed for dilute acid-flouride soluble phosphorus (Olsen and Dean 1965); exchangeable cations (Chapman 1965); DTPA extractable iron, zinc, copper, and manganese (Lindsay and Norvell 1969); Kjeldahl nitrogen (Bremner 1965); and water extractable nitrate.

RESULTS AND DISCUSSION

Root Distribution

Roots were not present in the surface organic litter (O1, O2) or in the surface A11 horizons. Small feeder roots were found to be concentrated in the A12 and A/B horizons and were more dense at the crown edge than near the stem. Only lateral roots that were deeper than 28-31 cm extended beyond the crown of the tree.

Nutrient Enrichment From Litter

We found all nutrients except potassium and magnesium increased from the loose needle layer to the fermentation layer under pinyon-juniper. Table 1 compares nutrient concentrations in the organic horizons, (the O1 horizon or loose needle layer, and the O2 or fermentation layer) with the B1 mineral soil horizon. Downward leaching and/or degree of mineralization is demonstrated by the greater concentration of nutrients in the O2 or fermentation layer than in the O1 litter. The B1 horizon is significantly lower in all nutrients except phosphorus.

Soil Nutrient Patterns

Nutrients were found to be concentrated under the tree crowns. The nutrient concentrations decreased from the crown outward to the interspace. Calcium, magnesium, sodium, and total nitrogen reached a maximum concentration in the subsoil (B horizons) under the canopy, whereas iron, manganese, zinc, copper, nitrogen, and phosphorus were at maximum concentrations in the A horizons (table 2).

Surface Soil Changes Following Tree Harvest

All nutrients except copper and manganese were higher in the soil under the canopy than in the interspace soils before and after harvest. Soil taken from under the canopy 5 years after

Table 1.--Nutrients extracted from organic and mineral horizons in mg/kg

	Horizon		
Nutrient	O1	O2	B1
Nitrogen	212	285	34.3[x]
Calcium	9,571	11,920	3,055[x]
Magnesium	3,295	2,554	566[x]
Sodium	653	795	252[x]
Zinc	35.9	46.9[x]	0.32
Manganese	82.9	92.8[x]	27.8
Iron	31.8	86.7[ax]	13.2
Copper	2.0	1.8[x]	1.1

a Significant (p=.05) difference between O1 and O2 horizons.
x Significant (p=.05) difference between O2 and B1 horizons.

Table 2.--Nutrient elements in mg/kg by horizons at 2/3 crown distance

Nutrient	Horizon A11	A12	B1	B2
Calcium	1,940	1,645	2,451	3,179
Magnesium	399[b]	378[b]	483[b]	655[a]
Sodium	65	54	81	209
Phosphorus	93[ab]	112[a]	51[bc]	22[c]
Nitrogen	109[a]	46[b]	25[bc]	13[c]
Iron	143[a]	27[b]	15[b]	6[b]
Manganese	41[a]	22[b]	17[b]	11[b]
Copper	9[a]	3.8[b]	1.0[b]	1.1[b]
Zinc	9.1[a]	1.4[b]	0.8[b]	0.9[b]

Different superscripts among values in the same row indicate significant (p=.05) differences.

Table 3.--Soil nutrient content means in mg/kg

Nutrient	Under canopy Control	Under canopy Harvest	Interspace Control	Interspace Harvest
Calcium	2,844[b]	3,444[a]	2,490[c]	2,770[c]
Magnesium	445[b]	513[a]	334[c]	391[c]
Nitrogen (NO_3)	30.48[b]	56.19[a]	46.13[ab]	58.4[ab]
Nitrogen (Kel.)	1,460[ab]	1,590[a]	960[cd]	1,080[c]
Zinc	8.81[b]	20.77[a]	1.17[d]	1.46[c]

Different superscripts among values in the same row indicate significant (p=.05) differences.

harvest showed significant (p=.05) increases over control plots in nitrate, calcium, magnesium, zinc, copper, and potassium. Iron and manganese decreased in concentration. In the interspace only zinc and manganese increased in concentration following harvesting activities (table 3).

Management Implications

Soil nutrients that accumulate under the tree canopy are available to the tree. Surface feeder roots should capture nutrients as they are leached from the litter layers. Following harvest, surface soil nutrients remain higher in soils previously under the canopy. Unfortunately, understory species are often absent from the litter-covered area and do not invade this area for several years. Thus we find that even though available nutrients are increased by harvesting, there is no understory of forbs and grasses to take advantage of them. Leaching losses from the areas of soil nutrient accumulation are probable if they are not taken up by understory plants. Disturbance of the needle layers adjacent to the tree stem during tree harvest could be desirable if its allows understory plants to invade former tree canopy areas. In the future, understory species capable of establishing in the needle areas should be evaluated.

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NUTRIENT PATTERNS AND SUCCESSION IN PINYON-JUNIPER ECOSYSTEMS OF NORTHERN ARIZONA

Jeffrey M. Klopatek

ABSTRACT: Soil nutrient patterns were evaluated in interspaces and under canopy of a number of pinyon-juniper woodlands. The interspaces and canopies of the mature ecosystems displayed definite differences in both the physical and chemical properties. Nitrogen and organic carbon were 4 and 5.5 times as great, respectively, under canopy then in the interspaces. Soil pH, texture, and bulk density were also different. The early successional stages following fire showed remarkedly less differences. Differences in total phosphorus concentrations indicate that the trees may be mining the interspaces for nutrients. This is subtantiated by changes in litter C:N ratios over successional time. Analyses of the soil nutrient levels indicate that, following fire, it may take 200+ years for the pinyon-juniper ecosystems to regain their prefire soil nutrient levels.

INTRODUCTION

Recent estimates (West 1984) indicate that pinyon and juniper species dominate nearly 325,000 km^2 in the western United States. These woodlands are unique in that they are transitional between arid and mesic ecosystems and are located on the allogenic axes between deserts, grasslands, coniferous forests, and deciduous forests. It is therefore surprising that, aside from some static measurements of soil and plant elemental concentrations (Charley and West 1975; Barth 1980; Young and others 1984; Bunderson and others 1985), little information exists on nutrient cycling processes in these vast, transitional ecosystems. The environmental position of pinyon-juniper ecosystems is characterized by a seasonal moisture stress that plays a major role in the spatial and temporal nutrient dynamics. The moisture stress results in a definite clumping of trees with significant open or interspaces in the woodland (West 1984). It has been documented by a number of investigators that similar arid and semiarid communities with interspaces have a horizontal patterning of nutrients such that the trees and shrubs exist in relatively nutrient-rich islands (Barth and Klemmedson 1978; Charley and West 1975, 1977; Romney and others 1980; Doescher and others 1984). This pattern has also been reported for isolated conifers (Zinke 1962).

The object of this study was to determine if this nutrient patterning exists in soils of pinyon-juniper woodlands and if this mosaic develops during succession. Most of the pinyon-juniper type in Arizona has been subject to over-grazing with a subsequent loss of understory species. It was hypothesized that if the structure has changed, the functional processes are also different. For example, nitrogen has been shown to be one of, if not the most, limiting nutrient in arid, semiarid and coniferous forest systems (Skujins and West 1978; Marrs and others 1983). Hence, there may be different stategies in the conservation of this nutrient under canopy and in interspaces [mineralization (Charley and West 1977)].

SITE DESCRIPTIONS

The study area is located in north-central Arizona. Two of the sites, Shiva Temple (ST) and Dillman-mature (DM), are dominated by Utah juniper (Juniperus osteosperma (Torr.) Little) and pinyon (Pinus edulis Engelm.). The third site, Dillman-burn (DB), burned approximately 35 years ago, is dominated by shrubs. Grasses dominate the interspaces of all the sites and are often accompanied by large expanses of cryptogamic crusts.

Shiva Temple is located in the heart of Grand Canyon National Park. This site is an isolated 310-ha mesa with an average elevation of 2300 m. Tree ring analysis indicates that many of the mature pinyons are >400 yr old. The dominant understory and interspace species is mutton grass (Poa fendleriana (Steud.) Vasey), while the dominant shrub is cliffrose (Cowania mexicana D. Don.). Shiva Temple, due to its inaccessability, has never been grazed by domestic livestock. This is reflected by the significant occurrence of mutton grass which has largely been eliminated from the surrounding grazed areas on the canyon rim (Jameson and others 1962).

The Dillman-mature site is located 33 km SSE of Shiva Temple in the Kaibab National Forest. This distance was required in order to locate a site

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Jeffrey M. Klopatek is an Assistant Professor, Department of Botany and Microbiology, Arizona State University, Tempe, AZ.

floristically similar to Shiva Temple [with a noted absence of big sagebrush (Artemisia tridentata Nutt.)]. This site is at an elevation of 2130 m with an age since last major disturbance (burning) of >300 yr. The dominant understory and interspace species is blue grama grass (Bouteloua gracilis (H.B.K.) Lag. ex Steud.) and the dominant shrub is cliffrose. The site is moderately grazed by cattle as well as deer, elk, and antelope. The Dillman-burn site is immediately adjacent to the mature site. Tree ring analyses of new trees and fire-scarred trees indicate that this site burned approximately 35 yr ago (Tress and Klopatek 1986, this volume). The site is primarily dominated by rubber rabbitbrush (Chrysothamnus nauseosus (Pall.) Britt.). The dominant grass species is blue grama. The site reflects the greatest disturbance as indicated by its relatively recent burn and grazing status. Abbreviated vegetation data are listed in table 1.

Soils are all Lithic Ustochrepts with loamy sand textures. Kaibab limestone is the parent material. Slope is minimal at all three sites ranging from 0-2 percent. Annual precipitation, 350 mm, is bimodally distributed. Approximately half occurs in intense thunderstorms from July-September with the remainder coming as mild winter rains or snows from December-April. Temperatures are variable, ranging from -27 to +38 °C with an average of 150 d between last and first frost.

A number of other sites were analyzed for litter nutrient contents. These sites are environmentally similar to those above and are described by Tress and Klopatek (1986, this volume).

METHODS

Soils were obtained from each site on the same day in mid-October, 1984. Five composite samples (three subsamples each) were taken from the mineral soil at a depth of 2-10 cm from midway under canopy and in the interspaces. Soils were stored in polyethylene bags, transported to the laboratory in an ice chest, refrigerated, and analyzed within 1 week from time of collection. Litter samples were collected at a different time in the fall using 20 to 30 quadrats (-25 X 25 cm) placed randomly under the canopy of each species and in the interspaces. Soil samples from each site were evaluated for their moisture equivalency at field capacity (-0.03 MPa) and wilting point (-1.52 MPa) using a pressure-plate apparatus (Richards 1965).) Soils were analyzed for texture (hydrometer method), pH (1:1 slurry with distilled water), percent organic carbon (Walkley-Black method), and bicarbonate-extractable P (on field moist soils) in the laboratory. The above chemical methods are referenced in Page and others (1982). Total phosphorus was analyzed using the persulfate digestion method (USEPA 1979).

Table 1.--Vegetative characteristics of three pinyon-juniper study sites located in north-central Arizona

Site	Shiva Temple	Dillman Mature	Dillman Burn
Community Age	>400 y	>300 y	35 y
Tree Density	591/ha	421/ha	70/ha
Tree Ratio (P:J)	3.2:1	1.1:1	1:3.1
Tree Cover (%)	52.1	36.8	1.4
Grass Cover (%)	19.1	8.9	13.3
Total Vegetative Cover (%)	77.9	47.2	30.9

Total nitrogen, nitrate, and ammonium were determined colorimetrically with a Technicon autoanalyzer at the University of Arizona Soil and Plant Testing Laboratory. Nitrate and ammonium were extracted using approximately 10 g soil and 100 ml of 2-mol/L KCl adjusted to pH 2.5 and containing 0.5-mg/L phenylmercuric acetate to inhibit microbial growth.

Analysis of variance was used to evaluate the site characteristics. Between-site and aspect data were analyzed using Tukey's honest significant difference measure within the SAS statistical software (SAS 1985).

RESULTS

Physical Differences

The analyses of the physical properties of the soils indicate no significant differences between the grazed (DM) and ungrazed mature sites (ST)(table 2). However, analysis of variance showed statistical differences between the canopies (C) and the interspaces (I) (table 2). Bulk density varied between 0.87 (DMC) and 1.54 (DBI). Textural analysis showed significantly more sand underneath the canopies than in the interspaces. This is presumably a result of aeolian deposition of sand as reported earlier by Miller (1953) and Barth (1980). Water holding capacity is approximately twice that under canopy than in the interspaces. Highest values for field capacity were obtained for STC and DMC of 39.0 and 35.7 percent, respectively. This is presumably due to the greater organic matter content of the canopy soils (table 3), despite the interspaces having twice the amount of silt and clay. On the burn site (DB) the soil under canopy had field capacity values which were between those of the canopy and interspace at the mature sites. The soil moisture holding capacity at -1.52 MPa of the burn site interspaces had the lowest value of 9.2 percent.

Table 2.--Physical characteristics of soils from three different pinyon-juniper sites in north-central Arizona. Values are the means of samples taken from 5 subsites of three composited subsamples each. Common letters in a column indicate no significant difference (P<.05) between sites as determined by analysis of variance

Site	Aspect	Bulk density (g/cm^3)	Water-holding capacity -0.03 MPa	Water-holding capacity -1.52 MPa	Texture %sand	Texture %silt	Texture %clay
			percent				
Shiva Temple	Canopy	0.98a	39.0a	34.7a	86a	12a	2a
	Interspace	1.22b	20.6b	16.6b	74b	21b	5a
Dillman Mature	Canopy	0.87a	35.7a	31.1a	86a	10a	4a
	Interspace	1.54b	19.5b	18.5b	67b	26b	7a
Dillman Burn	Canopy	1.37b	25.4c	21.2b	75b	22b	3a
	Interspace	1.48b	18.8b	9.2c	73b	22b	5a

Chemical Differences

The differences in soil chemical properties (table 3) between the canopy and interspaces can be interpreted to show that the pinyon-juniper ecosystems develop nutrient islands similar to those reported by Romney and others (1981) and Charley and West (1975, 1977) for semiarid shrubs and by Tiedemann and Klemmedson (1973) and Klemmedson and Barth (1979) for arid-land trees. Canopy and interspace soil pH values were significantly different at both mature sites. The relatively low pH value (6.5) for STI presents an anomaly when compared to the other sites. The differences between the two mature site canopies and the other sites are also apparent with respect to carbon and nitrogen (table 3).

Table 3.--Chemical characteristics of the three pinyon-juniper study sites located in north-central Arizona. Values are the means of samples taken from 5 subsites of three composited subsamples each. Common letters in a column indicate no significant difference (P<.05) between sites as determined by analysis of variance

Site	Aspect	pH	PO_4-P (ug/g^{-1})	NO_3-N (ug/g^{-1})	NH_4-N (ug/g^{-1})	Total N (%)	Organic Carbon (%)	C/N
Shiva Temple	Canopy	7.4a	19.5a	0.73a	10.0a	.284a	6.54a	26.7a
	Interspace	6.5b	6.1b	0.07b	9.96a	.063b	1.78b	33.6a
Dillman Mature	Canopy	7.2a	38.0c	4.36c	20.08b	.284b	7.01a	31.6a
	Interspace	8.1c	6.2b	1.13a	9.37a	.066b	1.27b	23.4a
Dillman Burn	Canopy	8.3c	23.4a	0.50a	12.10a	.108ab	2.20b	21.3a
	Interspace	8.4c	10.1b	0.70a	8.90a	.046b	1.00b	30.4a

Organic C content of the soil under canopies was statistically greater for the mature sites compared to the burn site and the respective interspaces. Shiva Temple had the highest amount of organic C among the interspaces and reflects its greater cover by herbaceous vegetation. The values reported here for the two mature sites are considerably higher than those listed for nearby ponderosa pine soils (Klemmedson 1975) and for cold-desert soils (Charley and West 1975). Percent total N under canopy at the mature sites was approximately four times that found in the interspaces compared to only twice that at the burn site. This indicates that it takes the pinyon-juniper ecosystem a long period to recover its N reserves, perhaps as long as the 200+ years needed to reach its mature state (Tress and Klopatek 1986, this volume).

Carbon:nitrogen ratios were all fairly consistent ranging from a high of 33.6 for STI to 21.3 for DBC with interspaces all greater than canopy.

Bicarbonate-extractable P displayed a different pattern under canopy than the other chemical properties. The Dillman mature site was highest followed by the burn site and Shiva Temple, respectively. The burn site had the highest amount among interspaces, but this was not statistically significant. It appears that more than just the organic fraction is responsible for P availability [suggested by Fuller and McGeorge (1951) for Arizona soils], when comparing both P and soil organic matter contents.

Total phosphorus concentrations of the soils were used to evaluate if mining of the interspaces does occur. Total soil P was used because of its being relatively uninfluenced by organic or extractable P concentrations. Thus, we can use the ratio of total P in the interspaces to that under canopy. If mining does not occur the ratio should be 1:1; if it does, it should be less. Figure 1 depicts the ratios from five sites near Grand Canyon. Four of the five show mining to occur ($p < 0.05$). The site that does not exhibit mining, Fishtail Mesa, was the only site where extractable P was higher in the interspaces than under canopy. It also exhibited a definite lack of herbaceous vegetation in the interspaces in comparison to the other sites.

The successional change in the C:N ratio of litter should also indicate whether or not mining may be occurring. Figure 2 shows that while the C:N ratio of both pinyon and juniper canopy litter decrease over time, it increases in the interspace litter. Soil samples for three of the sites (35, 90, 250+) showed constant ratios. Thus, the canopies increase their resource base, in terms of total nutrient availability, while decreasing that of the interspaces. Total litter

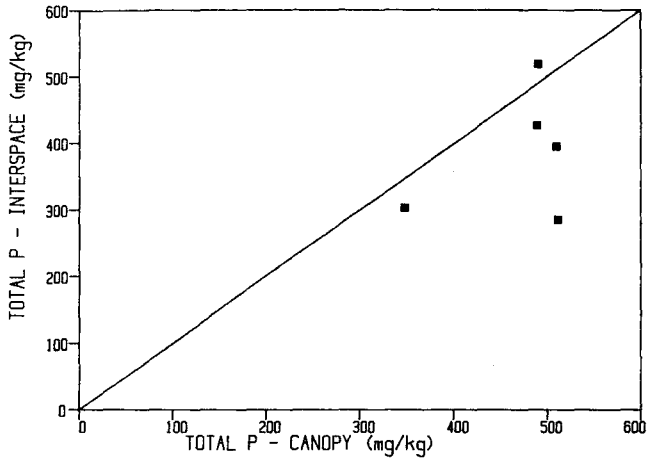


Figure 1.--Comparison of the total phosphorus concentration in the interspace and canopy covered soils of five sites near Grand Canyon, AZ.

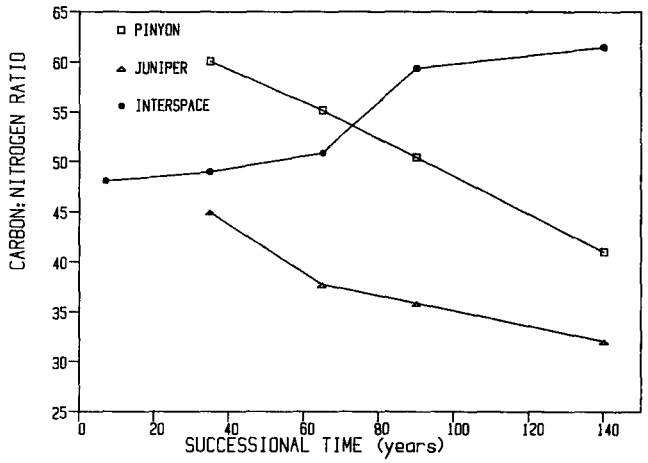


Figure 2.--Change in the carbon:nitrogen ratio of litter underneath pinyon-juniper and in the interspaces over a successional sequence.

accumulation of C, N, and P show increasing trends in both aspects, but an order of magnitude greater under canopy (fig. 3).

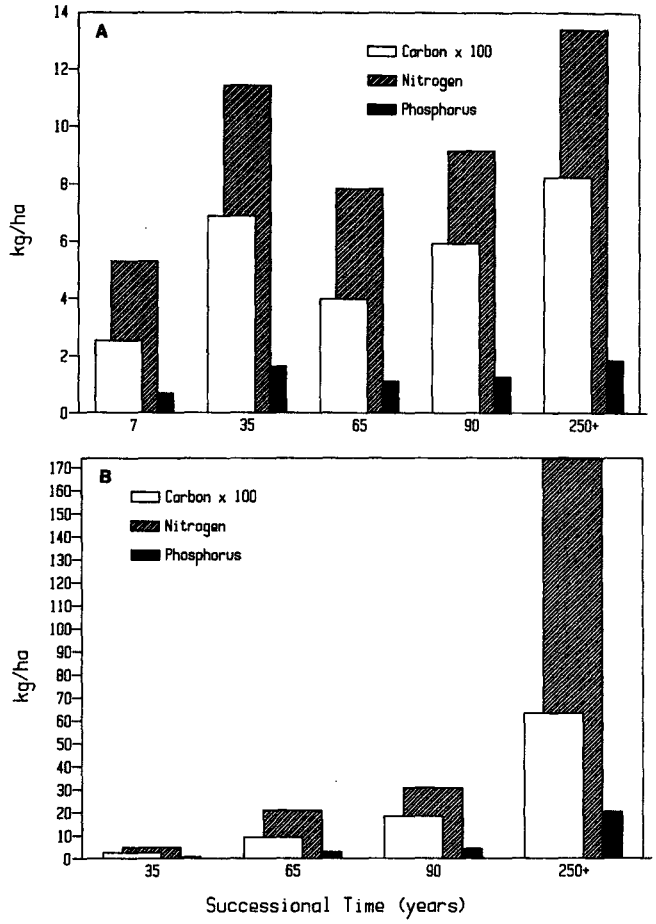


Figure 3.--Accumulation of carbon, nitrogen, and phosphorus in the interspaces (A) and under canopy (B) along a successional sequence of a pinyon-juniper woodland.

DISCUSSION.

The horizontal patterning found in the pinyon-juniper sites dictates that two mineral cycling strategies exist within these communites. Soils at the 2-10 cm depth under canopy are characterized by coarse texture but better water retention and higher total and available nutrients than those in the interspaces. The interspace soils, although being characterized by more silt and clay have less water retention at -1.52 MPa. Both available and total nutrients are significantly less in the interspaces than under the canopy. The high pH and finer texture of the interspace soils of the two Dillman sites can lead to a loss of nitrogen through denitrification and ammonia volatilization. This is especially true under the cryptogamic crusts (Skujins 1983). These processes need further study.

Junipers have been shown to adapt to these intersite differences by having a mass of fine roots at the base of the tree and again at the end of the lateral roots that extend throughout and across the interspaces. These differences may have significant effects on tree regeneration as well as the establishment of other vegetation types. Preliminary analysis indicates that the below-ground microbial community differs between the canopy and interspaces. They differ not only

in numbers but also in types of bacteria, endo- and ectomycorrhizae (Klopatek and Klopatek 1986, this volume). This biological and nutrient patterning indicates that earlier work on pinyon-juniper systems with soil sampling restricted to areas adjacent to the canopy (Charley and West 1977; Bunderson and others 1985) be re-evaluated. Although only soil from three sites was studied, the results allow some inferences to be made. First, it appears that without drastic disturbances (such as tree removal at the Dillman burn site) there are little differences in the soil nutrient contents between sites. The pinyons and junipers, given an adequate amount of time (>200 yr), are able to accumulate similar pools of macronutrients and influence the physical and chemical composition of the underlying soils. The effects of grazing, besides changing the species composition and reducing the amount of cover in the interspaces, may also reduce the organic C pool. Carbon has been indicated as a limiting element to nutrient retention in semiarid and arid ecosystems (Reichle 1975). This can influence the processing rates of limiting nutrients such as nitrogen. Fire seems to have a long-term effect on nutrient storage in the pinyon-juniper ecosystem. After 35 yr, organic C of DBC is only one-third that of the mature site (DMC) and total N is less than half. The cause for this difference in nutrients is difficult to ascertain without knowing the fire history prior to the last burn. Based on previous work on fire effects on soils (DeBano and Conrad 1978; Wells and others 1979), the loss of soil nutrients at these depths may not be a direct result of the fire (volatilization), but may have been erosional or even the result of microbial processing (denitrification, respiration, etc.).

In summary, the preliminary evidence supports Tiedemann's (1986, this volume) hypothesis that both the pinyon and the juniper trees mine the interspaces for nutrients. This may affect the regeneration of grass species in the interspaces, especially if the organic carbon concentrations are reduced due to grazing pressures. The trees build up their nutrient bases through litter deposition with an apparent decline in their nutrient use efficiency during succession. This is evidenced by the decrease in C:N ratios while the interspaces exhibit an increasing trend. Other factors influence the nutrient availability including inhibition of microbial competition. In preliminary work we have found that there is considerably less microbial phosphorus and phosphatase activity and total nitrogen mineralization under canopy than in the interspaces. This may be the result of alleochemical inhibition which is known to occur under some species of pinyon (R. Everett, pers. comm.). The pinyon-juniper ecosystem thus presents a series of complexities that require additional research to determine their role in nutrient cycling.

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Plant-Water Relations

Chaired by:

Lee E. Eddleman, Associate Professor, Department of Rangeland Resources, Oregon State University, Corvallis

ECOPHYSIOLOGY AND WATER RELATIONS RESEARCH IN THE PINYON-JUNIPER VEGETATION TYPE

Ray W. Brown

ABSTRACT: An accelerated program in basic plant water relations research promises to contribute toward refined management of pinyon-juniper woodlands. Focus is required on recent technological advances in research methods together with investigations of the morphological and physiological adaptations that influence drought tolerance of plants.

INTRODUCTION

The availability of water is the most important limiting environmental factor affecting survival and growth of plants in arid regions. Because they are so prevalent, water deficits are responsible for more plant mortality and reduced growth and development in arid regions than any other factor (Kramer 1933). Frequent drought conditions in arid and semiarid regions dramatically impact decisions made by land managers, user groups, and ultimately, researchers. Hence, knowledge of plant water relations characteristics is being recognized as vital to an improved understanding of ecosystems in semiarid and arid regions of the world.

The most extensive arid region in the United States is in the Great Basin and surrounding deserts of the West. The pinyon-juniper woodland is a common vegetation type throughout this vast area (Tueller and others 1979), the importance of which is accentuated by a rapidly accelerating demand for numerous products and uses. Pinyon-juniper woodlands are important for wildlife, watershed, range, recreation, and mineral development. As these values are recognized and uses intensify, greater effort is needed to understand the ecophysiology of this ecosystem (Tueller and others 1979). A major concern of some managers of pinyon-juniper woodlands is the control and reduction of the dominant species (particularly juniper) in order to increase forage production for grazing (Leckenby and Towell 1983; Rippel and others 1983; Young and others 1982). Replacement of the dominants with desirable native or introduced forage species by revegetation has been a major focus of numerous research and administrative studies, for example, Hull and Doran 1950; Springfield 1965; Plummer and others (1968). Research has shown that juniper control results in increases in available soil moisture (Gifford 1975, 1982), presumably improving water availability for more desirable forage species (Everett and Sharrow 1985). In recent years, revegetation of mined lands in the pinyon-juniper type has also become a major concern (Redente and Cook 1981; Ferguson and Frischknecht 1985).

A better understanding of the basic ecophysiology and water relations of the various floristic components of the pinyon-juniper ecosystem can be instrumental in refining management techniques. Investigations of plant water relations provide a means of identifying the adaptations and suitability of species, which helps in making prudent management decisions. Intensive water relations research identifies how plants respond to water deficits, what species and ecotypes are suited to particular environmental conditions, what physiological or morphological adaptations are employed to moderate the effects of drought, and what ranges of adaptability occur. Although this approach, and that of "matching species with environments," may both appear somewhat simplistic and perhaps naive, they provide valuable general guides toward understanding how plants and environments interact. At least three advantages should result from such research: (1) a more complete understanding of the biology of the organisms involved, (2) more successful selections of species for specific applications such as revegetation, and (3) an ability to make more informed land management decisions.

TECHNICAL CONSIDERATIONS

Plant water relations has been studied for decades, but most effort has been devoted to agricultural crops and other plants considered to have high economic value. Relatively few native range plant species have been thoroughly studied.

Recent technological advances in field instrumentation greatly improved our ability to measure various physiological characteristics of plants. As a result, greater numbers of field studies are being conducted. Technology also has provided a broad spectrum of electronic procedures that permit easy access to large data sets and methods of data reduction. Field studies are easier to conduct with these instruments because of their relative ease of operation, and because many studies can be

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Ray W. Brown is Plant Physiologist, Intermountain Research Station, Forest Service, U.S. Department of Agriculture, Logan, UT 84321.

monitored frequently with automatic data scanning, storage, and retrieval systems. It is no longer rare for a study to be installed and the data collected, retrieved, and analyzed all by computer techniques. Less field time is required per unit of information collected than ever before.

Although the ability to make field observations is often deemed beneficial, it has some potential pitfalls. One of the most obvious is the collection of data simply because it is feasible to do so. Unfortunately, in the rush to be first at making quantitative observations of physiological phenomena in field plants, there may be a tendency to overlook the relationship between the observed phenomena and other physiological processes and their integrated contribution to survival in that environment. Numerous recent publications merely document the track of water potentials in species that have not been studied before, but devote little or no consideration to interpreting the data, the dynamics of internal water potential components, or other physiological processes. Given the previous absence of such data, it certainly is of some benefit to document these phenomena under field conditions, but alone the data contribute little to our understanding of ecophysiological processes on both the species and ecosystem levels. Such efforts should probably not be the primary focus of our water relations research.

With the high level of technology and information now so readily accessible to scientists, more comprehensive knowledge should be sought that can be used by land managers. Numerous exemplary publications on plant ecophysiology and water relations have appeared recently that serve as models for the kinds of research needed in the pinyon-juniper woodlands (Ackerson and Hebert 1981; Bowman and Roberts 1985; Caldwell and others 1977, 1981, 1983; MacMahon and Schimpf 1981; Nilsen and others 1983; Turner and others 1978; Wilson and others 1980). These examples are not an exhaustive list, and do not necessarily deal with pinyon-juniper woodlands, but they all have elements of relevancy to needed research. From a personal point of view, and as a scientist concerned about plant water relations and its utility to land managers, some of the more important elements in water relations research that contribute the most essential information include:

1. The interactions of plant water potential and its components with other physiological processes such as photosynthesis or transpiration.
2. The effect of water deficits on physiological processes and the identification of critical levels of water status.
3. Identification of adaptation features that influence plant responses to water deficits, and their interaction with physiological processes.
4. Assessment and interpretation of how new knowledge impacts management decisions.

BASIC PRINCIPLES: ADAPTATIONS TO WATER STRESS

One of the primary objectives in studying the water relations of plants is to identify those morphological structures and physiological functions that enhance survival and reproduction under conditions of water stress. In this paper, heritable modifications in structure or function that increase the probability of survival under stress are termed "adaptations" (terminology follows Kramer 1980, 1983). These adaptations are central to understanding how plants cope with drought and other stresses in severe environments, and certainly will influence how management decisions are made about them. Water relations research in the pinyon-juniper ecosystem should not only identify adaptations to plant water stress, but also determine how they interact to influence the growth, development, and survival of plants on an individual and community level.

In a general sense, plant adaptations to water deficits can be classed as morphological-anatomical or physiological. Drought tolerance has been variously defined by researchers (Levitt 1972; MacMahon and Schimpf 1981; Kramer 1983), but most broadly refers to the ability of plants to survive under conditions of water stress by means of various morphological and physiological adaptations. This discussion of adaptations is intended only to illustrate and emphasize their significance, not to be all-inclusive.

Morphological-Anatomical Adaptations

Numerous morphological-anatomical adaptations, mostly associated with roots or leaves, have been identified that contribute to plant drought tolerance (Oppenheimer 1960; Kramer 1983; Turner and Kramer 1980). Examples of such morphological adaptations include: deep or widespread root systems, sunken or small stomata, small leaf size, reduced leaf numbers, epidermal cutinization, an abundance of water storage tissues, and leaf-folding or leaf-rolling in response to water stress. Anatomical adaptations include reduced cell size, thickening of cell walls (Cutler and others 1977), and increased mesophyll surface area per unit of leaf area (Nobel 1980).

These adaptations are not mutually exclusive. A plant may possess one or more of them, and it is often difficult to determine which are most important in specific habitats. However, their collective importance to survival during drought is well documented and should be identified wherever possible. In big sagebrush (Artemisia tridentata), for example, two distinct leaf types are produced during the year. Large primary leaves produced early in the growing season are shed in early summer in response to water stress; smaller overwintering leaves persist through dry periods (Caldwell 1979). Although morphological and anatomical adaptations to drought tolerance of few pinyon-juniper ecosystem species have been documented, some predictions about them could

perhaps be made based on known features of life-form and growth characteristics.

Generally, morphological adaptations are the most important means by which most mesophytic species influence their survival during drought (Begg 1980). One of the first effects of water deficits is a reduction in growth, manifested primarily in reduced leaf area. In addition, stress may induce an accelerated rate of leaf senescence and may simultaneously stimulate root growth (Begg 1980; MacMahon and Schimpf 1981). In fully expanded leaves, water stress often results in changes in leaf angle, folding, or rolling (O'Toole and Cruz 1980; Farris 1984), which not only reduces intake of incident solar radiation but also decreases leaf area and protects stomata from more advanced vapor pressure deficits. Also, responses to water stress often result in significant reductions in cell volume, increases in cell wall thickness, and increased lignification of cells (Pitman and others 1983; Cutler and others 1977).

The adaptive advantages of extensive plant root systems are well documented (Kummerow 1980; Caldwell 1976; Nilsen and others 1983). Although root systems apparently have fewer adaptive features than leaves, root systems generally are considered of importance as drought tolerance mechanisms if they are: (1) wide-spreading or deep, (2) succulent for water storage, or (3) have thick, hardened surfaces to retard water loss in dry soil (Kummerow 1980). Rooting distributions and water relations of various Great Basin and surrounding desert species have been studied (Branson and others 1976; Caldwell 1976; Everett and others 1977; Fernandez and Caldwell 1975). Although roots of arid-land plants have extensive vertical and lateral penetration into the soil, they also apparently have phased activity of growth and water absorption. These phased activities have been observed in such shrubs as big sagebrush, shadscale (Atriplex confertifolia), and winterfat (Ceratoides lanata), where extension occurred in only a fraction of the total roots at any one time (Fernandez and Caldwell 1975). In these species, deep exploration and absorption appear to continue well into the driest months of the growing season while the shallower roots remain inactive.

Physiological Adaptations

Of all the adaptations plants may possess for drought tolerance, those based on physiological mechanisms are by far the most significant. Identification and characterization of these adaptations is essential if water relations characteristics of the pinyon-juniper flora are to be understood and more effectively used to make management decisions.

Physiological adaptations for drought tolerance include such characteristics as stomatal control of water loss during periods of stress, alternative photosynthetic pathways, the accumulation of various organic constituents such as organic acids or hormones, turgor maintenance by osmotic adjustment, and the protoplasmic tolerance of water deficits. This last adaptation is usually described as "desiccation tolerance" of protoplasm, and has been observed in relatively few higher plants (Gaff 1980), being most common in ferns, mosses, lichens, and algae (Bewley 1979). Since few, if any, of the familiar higher plants in the pinyon-juniper type are truly desiccation tolerant, this adaptation will not be discussed further.

Stomatal control.--The adaptive significance of stomatal responses to drought has probably been studied more than any other physiological mechanism (Jarvis 1980; Kramer 1983; Ludlow 1980). To photosynthesize, plants must open their stomata to relatively dry air. One consequence is water loss due to transpiration, which in arid environments can be extremely water-costly to plants. Hence, stomata play a pivotal role in regulating the conflicting processes of assimilation and transpiration.

Stomata are sensitive to leaf water potentials below critical thresholds, responding by partial closure as the leaf dries and imposing increasingly larger resistances to water loss (Ludlow 1980). The water potential range between partial and total closure (when turgor falls to zero) indicates the efficacy of stomatal response as a positive feedback mechanism that allows water potential to recover in plant leaves. This range of water potential appears to be flexible and can be manipulated by exposure to progressively greater stresses in many species (see the concept of acclimation vs. stability of adaptations discussed by Kramer 1980).

Stomata of certain species are also responsive to changes in air humidity (for example, the vapor pressure gradient between the substomatal cavity and bulk air). The ability of some species to maintain open stomata in dry air appears to be partially linked with osmotic adjustment and alternative photosynthesis pathways, whereby photosynthesis continues at lower water potentials allocating newly fixed carbon to augment root development (Caldwell and others 1977; Ludlow 1980).

Alternative photosynthetic pathways.--One of the most important implications of water deficits in plants is a reduction in growth due to the slowing or complete shut-down of photosynthesis. However, some species demonstrate unique adaptations that ameliorate these consequences. One example is crassulacean acid metabolism (CAM) which occurs primarily in the family Crassulaceae and other succulents, but has been noted in other species as well. These plants close their stomata during the day when transpiration demands are greatest, and open them at night for CO_2 accumulation when vapor pressure deficits are lower. Carbon is fixed as malic acid during the night and is decarboxylated and refixed in carbohydrates by photosynthesis during the day.

Also, the C_4 photosynthetic pathway is thought to confer some drought-tolerance capabilities over that of the C_3 (Calvin cycle) pathway (Osmond and others 1980; Kriedemann and Downton 1981). The C_4 pathway is a CO_2 concentrating mechanism that fixes carbon in mesophyll cells, then concentrates it at high levels within bundle sheath cells for later fixing into carbohydrates. This concentrating mechanism indirectly imparts drought tolerance to C_4 plants by allowing CO_2 to accumulate in the bundle sheaths so that if drought occurs and stomata close, photosynthesis may continue for a time. The C_4 pathway apparently evolved in plants from hot, dry environments and is particularly common among native western range plants. However, contrary to expectations, Caldwell and others (1977) found that the C_4 pathway in shadscale does not convey any substantial advantage to water use efficiency over the C_3 species, winterfat, in the northern Great Basin.

Accumulation of organic constituents.--Many plant species have been shown to accumulate various biochemical constituents in response to water stress. Abscisic acid (ABA) and proline are examples that have been studied extensively (Aspinall 1980; Bokhari and Trent 1985; Kramer 1983). It appears that accumulation of these and other organic acids and hormones is triggered by the onset of water stress. ABA appears to be implicated in the control of stomatal opening and closure. Aspinall (1980) suggested that the initial decline in water potential during stress periods may release ABA from mesophyll chloroplasts, causing the stomata to close. Indeed, he proposes that the major factor limiting damage to virtually all mesophytic plants from water deficits is the drought-induced control that variable endogenous concentrations of ABA and intercellular CO_2 have on regulating stomatal aperture.

Unfortunately, the physiological role of accumulated organic constituents during drought is poorly understood and will require additional research before definitive interpretations can be made (Aspinall 1980; Kramer 1983). Bokhari and Trent (1985) express confidence that some definitive role must be served by proline accumulations in both warm- and cool-season grasses because its concentration markedly decreased when water stress was relieved.

Osmotic adjustment.--Research on the role of osmotic adjustment as a drought-tolerance mechanism has captured the attention of many researchers in the last decade (for example, Turner and Jones 1980; Turner and others 1978; Ackerson and Hebert 1981; Nilsen and other 1983). Osmotic adjustment in higher plants is the lowering of protoplasmic osmotic potential resulting from a net accumulation of solutes in response to water deficits (Turner and Jones 1980). Positive turgor is maintained to lower water potentials than would be possible if osmotic adjustment did not occur. Osmotic adjustment results in either partial or full turgor maintenance, which favors continued growth, stomatal opening and photosynthesis, and possibly continued root exploration and water absorption during stress periods (Turner and Jones 1980). Turgor is the main controlling component of water status in plants, and changes in turgor are more likely to affect changes in metabolism than any other water potential component. The maintenance of turgor would therefore aid the survival of plants during periods of severe water stress.

Turgor maintenance within cells occurs as the result of a net gain in total solutes, thus decreasing osmotic potential as water potential declines during stress. Equally proportional decreases in both osmotic and total water potentials would result in maintenance of full turgor, but this is rare. Osmotic adjustment usually results in a more gradual decline in turgor during water stress than would occur with no solute accumulation. The complete loss of turgor is thus shifted in adjusting plants to a lower water potential (about -0.3 to -1.5 MPa) than occurs in nonadjusting plants (Turner and Jones 1980).

The solutes responsible for osmotic adjustment appear to include organic acids, carbohydrates, and such inorganic ions as Na, K, and Cl (Morgan 1984). As plant water stress progresses, solutes accumulate in the vacuoles and cytoplasm of mesophyll tissues from photosynthesis, reserves in storage tissues, or absorption directly from the soil.

The turgor potential component of leaves is controlled by the osmotic potential and elasticity of the tissue. Osmotic potential and elasticity are determined by such factors as solute concentration, cell size, cell wall thickness, and osmotic volume of the protoplast. A plant's ability to maintain positive turgor under water stress conditions is strongly influenced by a lowering of the osmotic potential, highly elastic cells, small cell size, and thick cell walls (Turner and Jones 1980).

Osmotic adjustment apparently occurs slowly and is enhanced by successive cycles of water stress (Turner and others 1978; Morgan 1984). Although a sudden intense water deficit may initially be very detrimental (when only morphological features or other more immediate physiological adaptations can mitigate stress), with increased time or additional exposure to drought osmotic adjustment can come into play as an additional buffer against severe damage. Plants adjust osmotically more efficiently in large rooting volumes, presumably in deeper soils rather than shallow or confined locations.

Osmotic adjustment has been recognized as a significant adaptation to water stress in numerous plant species, including many crop species and some native and introduced range plants (Turner and Jones 1980; Wilson and others 1980). Such familiar range species as bluebunch

wheatgrass (Agropyron spicatum), crested wheatgrass (A. desertorum), western wheatgrass (A. smithii), blue grama (Bouteloua gracilis), and numerous desert halophytes are believed to adjust osmotically in response to water stress, but neither the ranges of adjustment nor details of their functional responses are yet well defined or completely understood.

DISCUSSION AND CONCLUSIONS

Expanding our knowledge about the water relations characteristics of plant species and ecotypes should be beneficial to land managers in making decisions about the pinyon-juniper ecosystem. Such land management activities as range and wildlife improvements, revegetation and surface mine reclamation, watershed protection, and vegetation conversions are impacted to some degree by the manager's knowledge of plant species adaptability. If we understand the complexities of how plants are adapted to arid climates, perhaps more clearly refined management decisions and options could be made about such activities as species selection and revegetation.

Species adapted to water stress conditions are important inclusions in any revegetation effort. They provide watershed protection and forage for wildlife and livestock during periods of drought when other less-adapted species might be severely damaged. Although many questions remain, a surprising amount of new knowledge is being accumulated about the water relations of western range plants, and particularly species in arid regions such as the Great Basin. Notable among such efforts is the work reported by Caldwell and others (1977, 1981, 1985), DePuit and Caldwell (1975), Everett and others (1977), Fernandez and Caldwell (1975), Johnson (1980), Love and West (1972), Monson and Smith (1982), Nilson and others (1983), Nobel (1976), Nowak and Caldwell (1984), Oechel and others (1972), Romo and Eddleman (1985), Roundy (1985), and Young and Evans (1981).

Recently improved techniques available for field water relations research such as use of thermocouple psychrometers and peripheral equipment, pressure chambers, steady-state gas exchange systems, and new methods of root system study (Richards 1984) promise greater flexibility in observing, measuring, and interpreting natural phenomena. This, combined with insight and understanding of the basic principles of ecophysiology and water relations will further refine our knowledge about species adaptability. Presumably, as more quantitative information becomes available about the physiological requirements of species, both individually and as components of more complex communities, we can be more precise in prescribing improved management options.

As an example, a species known to adjust osmotically in response to water deficits may have some distinct advantages for revegetation in arid regions over those that rely solely on morphological adaptations. However, because optimum osmotic adjustment occurs only gradually and is enhanced over repeated exposures to stress, revegetation techniques may need to be altered to accommodate this generally desirable water relations characteristic. Successful use of such species may be significantly improved by reducing early competition for soil water by reducing seeding and planting rates so that water stress, when it does occur, develops more slowly with fewer catastrophic effects. By understanding drought-tolerance adaptations, selections of species for use in revegetation mixtures could be made that minimize the occurrence of competition between similar features such as rooting habits (Caldwell and others 1981; Richards 1984), or other morphological and physiological characteristics. Also, innovative breeding techniques for improvements in plant performance on arid rangelands offer substantial promise for the future (Johnson 1980).

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WATER RELATIONS AND PRODUCTIVITY IN PINYON-JUNIPER HABITAT TYPES

Fairley J. Barnes and G. L. Cunningham

ABSTRACT: Pinyon pine (Pinus edulis) and one-seed juniper (Juniperus monosperma) co-occur in northern New Mexico. Relative dominance of the two species varies with elevation along a complex environmental gradient. To determine the ecophysiological parameters contributing to this dominance pattern we have investigated photosynthetic responses to important variables along this gradient. As soil dries, photosynthesis of juniper decreases to zero at a predawn leaf water potential of -4.6 MPa, while in pinyon the rate decreases to zero at -1.8 MPa. Results indicate that the pattern of species dominance is correlated with the pattern of relative seasonal carbon gain in these species. Wetter sites where pinyon is more dominant support greater carbon gain by that species.

INTRODUCTION

Any particular pinyon-juniper woodland is usually dominated by one of three pinyon species and one of six juniper species. The ranges of these nine dominant species have been well documented (West and others 1975; Lanner 1975) but the characterization of many of the communities is incomplete and little is known of the autecology of the dominant species or their associate understory species (Tueller and Clark 1975; West and others 1975). It has frequently been noted that across one continous local elevational gradient, the dominant juniper species has greater amplitude in distribution than the co-occurring pinyon species, usually by extension of the juniper into a lower elevation drier savannah (Cottom and Stewart 1940; Woodin and Lindsay 1954). This leads us to ask whether the change in species dominance along an elevational gradient in the woodland results from differences in fundamental niche dimensions between the species, or from competitive interactions that lead to restricted realized niches.

Elevation produces a complex environmental gradient along which moisture and temperature are usually important factors controlling species' distributions. Several studies have suggested that moisture may well be the factor controlling the distribution of pinyons and junipers, but it is not known whether the species differ in their ability to survive drought conditions. This study was designed to study seasonal carbon gain of pinyon pine (Pinus edulis Engelm.) and one-seed juniper (Juniperus monosperma (Engelm.) Sarg.) as affected by water stress, over a habitat gradient in which tree dominance varies in accordance with a moisture gradient. Our aim was to determine whether photosynthetic responses to water stress would explain the differences observed in the distributions of the two species.

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Fairley J. Barnes is a graduate student in the Biology Dept, and G. L. Cunningham is Professor of Biology, New Mexico Sate University, Las Cruces, NM.

METHODS

Study Area

The study area was primarily in the Los Alamos National Environmental Research Park (LA/NERP) in Los Alamos County, New Mexico, with some study plots on adjacent US Forest Service and National Park Service lands. The area is largely on the Pajarito Plateau on the eastern flank of the Jemez Mountains in northern New Mexico. The Plateau has been much eroded over time, resulting in a series of mesas and deep canyons, and thus slopes have a very wide range from almost level mesas to steep canyon walls. The range of the pinyon-juniper woodland in the LA/NERP extends from 1640 m (at the Rio Grande) to the ecotone with ponderosa pine forest, which varies with exposure and slope from 2130 m to 2225 m. The LA/NERP lands have been closed to disruptive management and public access for over 30 years, and a variety of range conditions can be found, from apparently pristine areas to those in various stages of recovery after grazing or logging.

North-central New Mexico has a semi-arid continental climate. There are two precipitation periods annually, with over 60% of the yearly rainfall occurring from May through October. Winter precipitation falls primarily as snow, averaging 127 cm at upper elevations in the woodland. Total annual precipitation ranges from 450 mm at 2259 m elevation down to 240 mm at the Espanola weather station (Nyhan and others 1978) which approximates the climate of the lower elevation woodland at the Rio Grande. Lower elevation maximum temperatures (1944m) are higher in the summer by 2 to 3°C and lower in the winter by up to 1°C, compared to measurements at 2259m elevation (Los Alamos National Laboratory weather station data). Mean minimum temperatures show a similar trend. The frost free growing season in 1982 was 199 days at the higher elevation and 197 days at the lower elevation. The length of the season with the mean maximum temperature above 20°C was 25 days longer at lower elevations. Total 1982 precipitation was 550 mm in 1982 compared to the 30 year average of 452 mm, however the excess precipitation occurred primarily in February, November and December, dur-

Table 1.--Characteristics of intensive study sites used to study field water relations of pinyon and one-seed juniper across a habitat gradient in which the tree dominance ranged from juniper (site 1) to pinyon (site 6)

Habitat Type	Site	Elevation (m)	Slope (%)	Aspect (deg)	% Cover			% Relative Cover	
					Pinyon	Juniper	Understory	Pinyon	Juniper
JUMO/BOCU	1	1700	15	140	0.3	48.0	13.7	0.5	77.4
	2	1950	19	120	9.3	23.0	8.5	22.5	56.4
PIED-JUMO/BOGR	3	1950	7	192	8.2	11.0	5.0	33.9	45.5
	4	2011	5	190	49.0	14.0	7.5	69.5	19.7
PIED-JUMO/MUMO	5	2164	13	148	25.0	4.3	20.0	50.7	8.7
	6	2072	27	30	79.0	16.0	15.0	71.8	14.5

ing the period when plant metabolic activity is likely to be low due to low temperatures. The warmer months of 1982 were about average in both temperature and precipitation, with the exception that June was considerably drier than usual.

Three habitat types (HT) were distinguished on the basis of the presence or absence of mature and juvenile tree species, and understory grass species (Barnes 1986). The three HT were associated with elevational and slope/aspect criteria. Juniper dominated sites in the Juniperus monosperma/Bouteloua gracilis HT (JUMO/BOCU HT) were at lower elevations and on steep south-facing slopes. Mid-elevations and gentle slopes were the usual sites for the Pinus edulis-Juniperus monosperma/Bouteloua gracilis HT (PIED-JUMO/BOGR HT), in which both tree species were codominant. At higher elevations, and on north-facing slopes, sites were dominated by pinyon, with very high regeneration of both tree species, forming the Pinus edulis-Juniperus monosperma/Muhlenbergia montana HT (PIED-JUMO/MUMO HT). After the completion of the HT analysis, two stands were chosen from each HT for continued study in 1982 of seasonal water relations of the dominant species in each stand. The primary consideration in choosing the stands was that the tree population structure exhibited a reversed J-shaped diameter distribution and thus was likely to be in a steady state that is neither senescent (Goff and West 1975) nor has been subjected to prior disturbance (Peet 1981; Jackson and Faller 1973; Johnson and Ball 1975). Within each HT, the two stands were chosen to represent high and low overall productivity as suggested by total tree density. The six stands chosen as intensive study sites (table 1) exhibited a steep gradient in per cent relative cover of pinyon and juniper. Site 5 was noticably lower in tree standing crop than sites 4 or 6, but was typical of south facing slopes in the PIED-JUMO/MUMO HT. Site 1 had a high standing crop and was strongly dominated by juniper.

Field water relations

Predawn leaf-water potentials (LWP) were measured on the dominant trees, shrubs (if present) and grasses (one each of a C_3 and C_4 species) of each site approximately every two weeks from April to October, 1982. Ten individuals of each species were sampled from each stand. Samples were placed in plastic bags and kept on ice in dark insulated containers until measured. Xylem pressure potentials of the samples were determined using a Scholander type pressure chamber (PMS model 1000). Tests showed that when samples were collected before sunrise, there was no significant change in LWP between the collection time and the time of measurement.

Controlled Environment Studies

Juvenile individuals of both tree species were collected from field sites at both ends of the HT gradient. Plants were maintained with frequent watering and monthly additions of a commercial fertilizer for 6 to 12 months before gas exchange measurements began. One month prior to physiological measurements, plants were moved to an environment chamber where they were maintained with 14/10 h d/n photoperiods and thermoperiods (25/11°C d/n) with a growth photon flux density of 800 μmol m^{-2} s^{-1} (400-700 nm, measured with a LI-COR LI-185 quantum sensor). One week prior to measurements of gas exchange rates, 2 or 3 twigs on each plant were trimmed to fit the cuvette, minimizing self-shading of the photosynthetic surfaces.

The gas exchange measurements were made using an open flow-through system similar to that of Kemp and Cunningham (1981), and fully described in Barnes (1986). Using a temperature controlled horizontal plexiglass cuvette for junipers, or a vertical cylindrical cuvette for pinyons, CO_2 and H_2O exchange of attached twigs were monitored under controlled temperature and light conditions. Ambient CO_2 concentration averaged 350 μmol mol^{-1} over the course of the experiments. Air and leaf temperatures in the cuvette were measured with fine-wire thermocouples. Photon flux density (400-700 nm) was measured with a LI-COR LI-185 sensor positioned inside the cuvette. Vapor density in the cuvette was not controlled.

Using the same set of individuals for each experiment, several gas exchange experiments were performed with 3 to 5 replications for each of the 4 species-habitat combinations: pinyon/xeric, pinyon/mesic, juniper/xeric, juniper/mesic. Photosynthetic responses to light and temperature are reported in Barnes (1986). The effect of water

stress on CO_2 fixation rate was determined on individual plants as they dried gradually over 1 to 3 weeks. Using a pressure chamber as described above, LWP was measured at the end of the dark period every second day. Using the same twig as for the previous experiments, dark respiration at 25°C was determined. The cuvette was then illuminated (1300 μmol m^{-2} s^{-1}) and net CO_2 and H_2O exchange rates determined at 25°C after the illuminated rate had stabilized (0.5 to 1.5 h). At the conclusion of the drying cycle, when net CO_2 uptake had become very low or negative, the twig was harvested and the plant rewatered. Pinyon twigs were separated into individual needles and woody stems. Juniper twigs were separated into green, linear segments and woody (non-green) segments. Projected areas of green segments and needles were determined using a leaf-area meter (LI-COR Model 3050). The material was then dried at 75°C for 48 h and weighed. Specific leaf mass for each individual was calculated for all twig samples. Net photosynthetic rates (P_n) and dark respiration (R_d) rates were calculated using the methods of Catsky, Janac and Jarvis (1971). Water vapor partial pressures were calculated according to Campbell (1977) and stomatal conductances calculated according to Cowan (1977). Continuous response data from each experiment were analysed using an analysis of covariance with a repeated measures design, testing the effects of species and habitat on the model parameters against the individual mean square as the error term (Freund and Littell 1985). If significant effects or interactions were noted, the data for each species were analysed separately.

RESULTS AND DISCUSSION

Field Water Relations

Predawn xylem-pressure potentials (LWP) of the tree species showed a similar response to apparent soil moisture availability, with lowest values during the midsummer drought period, and higher values in the spring, after soil moisture recharge from winter precipitation, and after summer rains began in July. Interesting and consistant differences between the species were noted (table 2). As the soil dried on sites where both species occurred, much lower LWP were attained by juniper than by pinyon. Conversely, when soil moisture was presumably higher due to spring snow melt (in April) or summer rains (September), juniper had much higher LWP than pinyon. These differences between species in LWP at the extremes of soil moisture availability, were significant in all cases except for September values at Site 2 (in the JUMO/BOCU HT). Pinyon seasonal minima ranged from -2.26 MPa to -1.85 MPa compared to a range of -3.57 MPa to -2.29 MPa for juniper. The seasonal coefficient of variation (CV) for LWP of juniper was generally over twice that of pinyon, reflecting the wide seasonal shifts observed in LWP of juniper. The vegetative gradient of the study sites was not closely correlated with a moisture gradient as estimated by LWP. Neither maximum, mean nor minimum values of LWP of either species were exactly correlated with the presumed productivity gradient. Attempts to devise a site moisture index based on mean values of LWP for trees, shrubs and grasses (data on shrubs and grasses not presented) were not successful. However, the mean minimum LWP of pinyon and the time-weighted average LWP (April through October) of juniper correlated well with the site gradient. Since the pinyon minimum LWP are all close in value, the most promising direct moisture index for pinyon-juniper woodland is the time-weighted average LWP of juniper, except on sites with very high vegetative cover such as site 6. This site, with the highest stand leaf area index (LAI) values, actually had the lowest LWP for juniper measured at any site, and the highest CV. There is potentially strong competition for soil water at this site because the high vegetative cover would result in high soil water utilization. Similar results, in which apparently mesic sites or north facing slopes had both high vegetative cover and low soil moisture availability in comparison to more xeric sites, have been reported by Zobel (1974) and Ng and Miller (1980) in other plant communities.

Table 2.--Predawn leaf water potentials (MPa) pf pinyon pine and one-seed juniper on six study sites during the 1982 growing season (April through October). Maxima and minima are extremes measured during the season (mean of 10 sampled trees). Mean values are time-weighted averages. Coefficients of variation (CV) are seasonal values

Site	Maximum	Mean	Minimum	CV
A. Pinyon leaf water potential (MPa)				
1	---	---	---	---
2	-1.10	-1.67	-2.26	22.1
3	-1.29	-1.67	-1.93	17.2
4	-1.26	-1.67	-1.91	13.1
5	-1.03	-1.50	-1.85	20.8
6	-1.03	-1.53	-2.03	21.9
B. Juniper leaf water potential (MPa)				
1	-1.00	-1.94	-3.35	40.4
2	-1.06	-1.61	-3.37	47.2
3	-0.98	-1.60	-3.49	47.9
4	-0.93	-1.44	-2.32	34.9
5	-0.76	-1.18	-2.29	38.4
6	-0.75	-1.58	-3.57	62.3

Stomatal responses to water status

With increasing water stress, net photosynthetic rates decreased linearly to zero at -4.6 MPa in juniper, and at -1.8 MPa in pinyon (table 3, part A). Pinyon responses showed that there were significant differences ($P < 0.05$) between habitat groups, with the individuals from the mesic habitat having higher intrinsic photosynthetic capacity than those from the xeric habitat. In juniper, there was no significant effect due to habitat origin. Dark respiration rates decreased linearly as water stress increased (table 3, part B).

Pinyon had significantly lower R_d than juniper ($P < 0.0005$), but the rate of decrease was not significantly different between the species. The positive carbon gain of juniper at very low water potentials partly explains its dominance on lower elevational xeric sites.

Productivity gradients

Foliage biomass per unit ground area at each intensive study site was estimated using the frequency distributions of the diameter at base (DAB) size classes as input to the regression equations of Miller and others (1981) expressing the relationship between DAB and foliage biomass of singleleaf pinyon (P. monophylla) and Utah juniper (J. osteosperma), two species very similar in form to P. edulis and J. monosperma respectively. Leaf area indices were then estimated using specific leaf mass values for each species. Estimates were similarly made for the mean size class frequency distributions for each HT (table 4). There was a strong association (positive for pinyon, negative for juniper) between mean LAI of each species and the HT gradient. However, the JUMO/BOCU HT and the PIED-JUMO/BOGR HT supported about the same total LAI. The intensive study sites, which were were chosen to represent high and low productivity within each HT, had LAI values which bracketed the mean for each HT. Using either total LAI or species LAI for individual stands did not correctly rank stands with respect to species dominance. However there was a strong correlation between juniper LAI and average juniper LWP (r^2=0.91, $P < 0.01$), such that juniper LAI was highest on the driest sites where LWP was lowest (fig.1). The relationships between pinyon LAI and juniper average LWP or pinyon minimum LWP were not significant. The significant relationship between juniper LAI (or standing biomass) and predawn leaf water status will prove useful since juniper LAI could be used as a site moisture index in modeling stand productivity across sites with varying stand density and species dominance.

An estimate of growing season leaf carbon balance on a dry mass basis was calculated for both species on each site used in the field water relations study. Several simplifying assumptions were made. Light and temperature effects on net photosynthesis were considered to be secondary to the effect of water stress across the habitat gradient and were not used in the calculations. The effect of water stress on P_n and R_n was calculated from

Table 3.--Net carbon gain per unit leaf mass of pinyon pine and one-seed juniper (mg g^{-1} h^{-1}) as a function of predawn leaf water potential or leaf temperature. Regression parameters (B_0 B_1), correlation coefficient (r^2) and number of observations (n) are given for the linear model, net carbon gain = $B_0 + B_1(X)$, where X and the measurement conditions are as follows: A. X = predawn leaf water potential (MPa); 1300 μmol m^{-2} s^{-1} photon flux, 25°C leaf temperature. B. X = predawn leaf water potential (MPa); dark conditions, 25°C leaf temperature. C. X = leaf temperature (°C); dark conditions, well watered plants

	B_0	B_1	r^2	n
A. Predawn leaf water potential (light)				
pinyon	3.62^{a*}	1.65^{bb}	0.30	118
/mesic	5.31^{a}	2.59	0.61	57
/xeric	2.48^{a}	1.17_{bb}	0.34	61
juniper	2.97	0.65^{bb}	0.83	75
B. Predawn leaf water potential (dark)				
pinyon	-0.476^{c}	-0.112	0.06	110
juniper	-0.595^{c}	-0.079	0.38	74
C. Leaf temperature (dark)				
pinyon	0.199^{dd}	-0.027	0.70	58
juniper	0.429^{dd}	-0.044	0.57	51

*Parameters superscripted by similar single letters are significantly different at $P < 0.05$, by double letters at $P < 0.01$.

Table 4.-- Estimated leaf area indices (m^2 m^{-2}) for each intensive study site (1-6), and mean values for each habitat type in the study area

Site	Pinyon	Juniper	Total
1	0.02	2.70	2.72
2	0.41	1.31	1.72
3	0.35	1.11	1.46
4	1.92	0.76	2.68
5	0.85	0.19	1.04
6	3.07	0.70	3.77
JUMO/BOCU	0.26	2.20	2.46
PIED-JUMO/BOGR	1.47	0.96	2.43
PIED-JUMO/MUMO	2.55	0.74	3.29

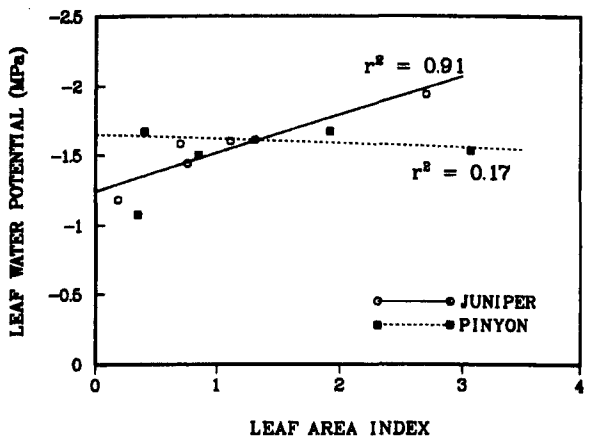


Figure 1.--Relationship between time-weighted average predawn leaf water potential and estimated leaf area indices of pinyon pine and one-seed juniper.

the regression relationships (table 3). Dark respiration rates were assumed to be constant during the dark period, and were calculated using the mean monthly minimum temperatures and then adjusted for the decrease resulting from water stress. Each date of field measurement of LWP was taken as the midpoint of a time period of constant LWP for that species at that site. Daylength was calculated for each date and total diurnal carbon gain per unit leaf mass was estimated using the sine function factor of Jackson and others (1984), assuming that maximum carbon gain occurred at solar noon.

Over the growing season, total photosynthetic carbon gain less respiratory loss per unit leaf dry mass (mg CO_2 g^{-1}) was estimated as:

Site	Pinyon	Juniper
1	---	2609
2	734	2868
3	1247	2879
4	1225	3067
5	2252	3334
6	2365	2947

These results show that there was a strong gradient in potential success of pinyon resulting from considering the effects of water stress across the habitat gradient. The gradient of productivity for pinyon showed a consistant increase from the JUMO/BOCU HT site 2 to a high level in the PIED-JUMO/MUMO HT sites 5 and 6. This was in marked contrast to juniper which generally had high carbon gain per unit leaf mass at the leaf level at all sites.

It is not anticipated that including light or temperature effects would change the ranking of sites along the carbon gain gradient. However, temperature effects may considerably alter the absolute carbon gain rates, since the degree or rate of acclimation to changing growth temperatures or the interaction between temperature and water stress may differ between the species. These estimates are thus considered to be relative, not absolute, indications of productivity. The actual performance of the species from year-to-year will depend on the frequency with which certain climatic conditions, which may be either stressful or favorable, actually occur (Weins 1977; Fuchs and others 1977).

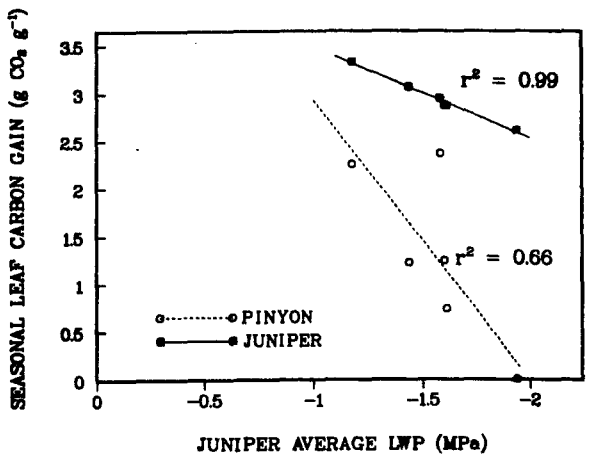


Figure 2.--Relationship between estimated seasonal leaf carbon gain (g CO_2 g^{-1}) and seasonal time-weighted average of juniper predawn leaf water potential (Mpa).

Estimated juniper carbon gain was highly correlated with juniper average LWP (r^2=0.99) across the habitat gradient. Pinyon carbon gain did not have a significant relationship to pinyon minimum LWP (r^2=0.28), but did have a significant relationship to juniper average LWP (r^2=0.66, $P < 0.05$), with a steep increase with increasing soil moisture. This indicates that pinyon is more responsive to increasing soil moisture than juniper by a factor of 3 (fig. 2). The lower elevational limit of pinyon coincides with its physiological tolerance of water stress as estimated by seasonal leaf carbon gain. Thus pinyon is increasingly dominant as soil moisture increases, and, based on leaf carbon gain, there is an increasing competitive advantage for pinyon along the gradient. This presumed competitive advantage for pinyon as reflected in the carbon gain gradient suggests that junipers are more subject to competitive stress than pinyons. This is substantiated by the observation that junipers have lower LWP and lower leaf carbon gain under the conditions of high stand productivity at site 6. Other authors have also concluded that juniper species are more subject to competitive stress than pinyon species (Schott 1984; Meeuwig 1979) and that juniper tree density has a significant relationship to leaf water potential (Wambolt 1973).

It can be concluded that pinyon distribution is limited by its physiological tolerance for water stress at the lower elevational, more xeric habitats by its lack of water stress tolerance. Pinyons successfully survive extended periods of low but available water, but there is a very strong gradient in seasonal carbon gain at the leaf level across the habitat gradient. Thus pinyon is severely disadvantaged on the hotter, drier sites by the environmental conditions encountered. At higher elevations, pinyon distribution may be limited by competition with ponderosa pine, or by low temperatures in winter (Daubenmire 1943). Juniper is more drought resistant than pinyon, photosynthesizing at much lower LWP, exhibiting lower LWP in the field, and maintaining high leaf carbon gain at the xeric end of the habitat gradient. The interaction between the physiological limitations of each species due to abiotic factors (soil moisture, temperature and humidity) and biotic factors (competition for soil moisture) remains to be studied under natural field conditions.

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PLANT WATER RELATIONS IN ECOTONAL AREAS OF PINYON-JUNIPER AND SEMI-ARID SHRUB ECOSYSTEMS

Scott D. Wilkins and Jeffrey M. Klopatek

ABSTRACT: Plant-soil water potential parameters for pinyon (Pinus edulis), juniper (Juniperus osteosperma), and several associated Great Basin shrub species were measured on Black Mesa in northeastern Arizona. Internal water potential components from pressure-volume curves were correlated with whole plant water potential, soil moisture, and atmospheric vapor-pressure deficit to compare and rank species according to their drought-resistance capabilities on undisturbed coal mine sites. Statistical analyses showed both intra- and intercommunity differences. Mean site water potentials were significantly more negative in the shrub-steppe community than in the pinyon-juniper woodland.

INTRODUCTION

One of the most extensive vegetation types in the southwestern U.S. is the cold-adapted, xeric Great Basin conifer woodland (Brown 1982). Although many studies have attempted to explain the sharply defined spatial distributions of the different shrub and woodland communities, neither depth of water table, depth of soil horizons, soil salinity, soil texture, total soil moisture, nor maximum osmotic stress tolerance alone account for this mosaic pattern. Adjacent monotypic shrub communities may show very little differences in climatic, edaphic, or topographic characteristics.

In this study we measured soil edaphic characteristics and moisture content in both a pinyon-juniper woodland and a shrub-steppe community. Total plant water potentials and internal water potential parameters were compared between species on both sites to see if plant water stress could be correlated with site edaphic characteristics.

STUDY SITES

Two study sites were located on coal-mine lease areas of the Peabody Coal Company at Black Mesa on the Hopi and Navajo Indian Reservations in northeastern Arizona. Black Mesa is a large (850,000 ha) heavily dissected highland ranging in elevation between 1900 and 2300 meters. The vegetation of Black Mesa is characterized as Great Basin conifer woodland, interspersed with a mosaic of Great Basin desert scrub communities (Brown 1982). Soils are generally extensively eroded, poorly developed, and very low in organic matter (Verma and Thames 1975). Annual precipitation is unpredictable, both spatially and seasonally, averaging approximately 25 to 30 cm. The precipitation pattern is bimodal, characterized by intense late summer convectional thunderstorms and less frequent winter frontal systems. The temperature ranges from -27° to 38 °C annually.

Site 1 is in a pinyon-juniper woodland (Pinus edulis Engelm.--Juniperus osteosperma [Torr.] Little) with little understory vegetation. Major shrub components of the community include rubber rabbitbrush (Chrysothamnus nauseosus [Pall.] Britton), cliffrose (Cowania mexicana D. Don.), broom snakeweed (Gutierrezia sarothrae [Pursh.] Britt. & Rusby), gambel oak (Quercus gambelii Nutt.), and squaw bush (Rhus trilobata Nutt.). Site 2 is a grama-galleta (Bouteloua gracilis [H.B.K.] Lag.--Hilaria jamesii [Torr.] Benth.) steppe with significant incursions of broom snakeweed and rabbitbrush (Chrysothamnus spp.). Other community members are Indian rice grass (Oryzopsis hymenoides [R. & S.] Ricker), bottlebrush squirreltail (Sitanion hystrix [Nutt.] J.G. Sm.), big sagebrush (Artemisia tridentata Nutt.), fourwing saltbush (Atriplex canescens [Pursh.] Nutt.), shadscale (Atriplex confertifolia [Torr. & Frem.] Wats.), and winterfat (Ceratoides lanata [Pursh.] Moq.).

MATERIALS AND METHODS

The dominant woody species were sampled at each site on September 18, 1983 and October 6, 1984. Soil moisture was measured with combination moisture and temperature probes and atmospheric vapor-pressure deficit using a sling psychrometer.

Plant water potential measurements were taken in the field with a Scholander-type portable pressure chamber using nitrogen gas (Scholander and others 1965; Waring and Cleary 1967; Tyree and Hammel 1972). Pinyon pine, Utah juniper, rabbitbrush, cliffrose, snakeweed, gambel oak,

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Scott D. Wilkins is a Graduate Student and Jeffrey M. Klopatek is an Assistant Professor, Department of Botany and Microbiology, Arizona State University, Tempe, AZ.

and squaw bush were sampled in the pinyon-juniper woodland. Big sagebrush, fourwing saltbush, shadscale, winterfat, Greene rabbitbrush, sticky-leaved rabbitbrush, and broom snakeweed were sampled in the shrub-steppe community. Measurements were taken immediately preceding dawn to compare plants following the period of greatest soil moisture recharge when moisture stress was least (Halvorson and Patten 1974; Branson and Shown 1975) and during midday when plant water potential was at its most negative.

Internal water potential components were calculated using pressure-volume curves (Scholander 1966; Hinckley and others 1980; Wilkins and Klopatek 1984). Excised stems were immediately placed under water, recut, and allowed to reach full saturation. Using the method outlined by Monson and Smith (1982), four samples were measured simultaneously in a modified pressure chamber. Liquid expressed (V_e) at each pressure increment was measured to within 0.1 mg, then added to the total sample fresh mass immediately following analysis to obtain the original sample fresh mass (FM). Dry mass (DM) was determined after ovendrying for 48 hours at 105 °C. Relative water content (RWC) was calculated from:

$$RWC = (FM - DM) - V_e / (FM - DM).$$

The internal water potential components were determined by extrapolation from pressure-volume curves using the equation (Tyree and Richter 1981):

$$1/P = (V_o - V_e) / [RTN_s - F(V)],$$

where P = equilibrium balance point;
V_o = symplastic water volume at full hydration;
V_e = volume of liquid expressed at that pressure;
R = universal gas constant;
T = Kelvin temperature;
N_s = total solute concentration in all cells;
$F(V)$ = relation of turgor pressure to the volume of liquid remaining in all cells.

As V_e increases, 1/P decreases curvilinearly to the point of plasmolysis, due to decreases in turgor pressure. Beyond plasmolysis (TLP = turgor loss point), turgor pressure drops to 0 and the relationship between 1/P and (V_o - V_e) (the symplastic water volume) becomes linear, dependent only on changes in the osmotic potential. Extrapolation of this linear relationship back to the ordinate by least-squares regression gives an estimate of the initial osmotic potential of the plant at full turgor. Other water potential components can be estimated from this curve by determining the slope of this line (Clayton-Greene 1983; Jane and Green 1983; Wilkins and Klopatek 1984).

RESULTS AND DISCUSSION

Soils

There exists little difference between the woodland and shrub-steppe soils (table 1). Organic matter (OM) is significantly higher ($p < .01$) in the upper horizon of the pinyon-juniper soils. Percent relative water content at field capacity (1/3 bar; .03 MPa) and at the 15-bar "wilting point" (1.5 MPa) were remarkably similar considering the textural differences between soils. Soils at all depths from the shrub-steppe community had between 76 percent and 80 percent sand. Pinyon-juniper soils varied from 71 percent sand in the upper 30 cm to 48 percent at 50 cm. Clay content increased with depth to a maximum of 28 percent at 50 cm.

Annual precipitation averaged 28.44 cm at the woodland site and 24.74 cm at the shrub-steppe site during the 3-year study. It should be noted

Table 1.--Selected soil parameters for the pinyon-juniper woodland and shrub-steppe communities

Site	Depth	Sand	Silt	Clay	pH	EC[1]	OM[2]	Sat[3]	RWC[4] at Fld. Cap.	RWC at Wilting Pt.
	cm	%	%	%		mmhos	%	%	%	%
Woodland	5	71.0	19.0	10.0	7.70	0.54	3.88	36.8	28.1	20.1
	20	69.0	16.0	15.0	7.80	0.61	2.46	36.9	29.6	25.3
	50	48.0	24.0	28.0	8.00	0.97	2.28	53.9	26.2	19.1
Shrub-steppe	5	77.0	20.0	3.0	7.60	0.43	1.50	34.1	28.0	21.3
	20	76.0	20.0	4.0	7.80	0.44	2.29	37.1	29.8	23.0
	50	80.2	17.0	2.8	8.00	1.50	2.00	46.1	27.8	19.7

[1] Electrical conductivity
[2] Organic matter
[3] Saturation percentage = wt. water/soil dry wt.
[4] Relative water content

that 1982 and 1983 were years of above average precipitation for the region. Mean pan evaporation rates at both sites averaged 150-200 cm annually, and above 25 cm monthly, May through August, for the study period.

Percent relative water content (RWC) of soils at both study sites are compared in table 2. The upper soil horizon in the woodland community held significantly more water on all dates except early October 1984. However, the shrub-steepe soils held significantly greater moisture at 50 cm on all dates (except Spring 1984), and tended to contain more water at 20 cm.

Site precipitation and edaphic data alone are insufficient to explain the measured differences in soil RWC. The higher RWC in the upper soil horizon (5 cm) of the woodland site probably is due to the greater organic matter and higher clay content.

Plant Water Potentials

Total plant water potential can be used as an estimate of the realistic soil moisture potential that the plant is experiencing in the rhizosphere and the accompanying internal water stress of the plant (Waring and Cleary 1967). Typically, internal water stress peaks at midday, stabilizes by midnight, and reaches a low before sunrise (Love and West 1972), allowing the plant to substantially relieve its water deficit overnight. Thus, plant water potential can provide information concerning the relationship of the species to the site and interrelationships between various species (Everett and others 1977).

The data in table 3 allow a comparison of major shrub and tree species on each study site and of site means. Site means were more negative in the shrub-steppe community during both predawn (1.94 to 1.51 MPa) and midday measurements (3.83 to 2.86 MPa) throughout the season, except following precipitation events. This occurred despite the higher atmospheric vapor-pressure deficit and lower soil moisture (table 2) at the woodland site. The range of water potential values was significantly smaller for species in the woodland community during all sampling events, within and between individuals, and between midday minima and predawn maxima.

In comparing species on both sites (table 3 and table 4), broom snakeweed was the most drought tolerant species tested in the pinyon-juniper woodland but the least drought resistant tested in the shrub-steppe. During the period of maximum stress (midday), snakeweed, the only species common to both sites, reached a minimum water potential value of 3.16 MPa at the woodland site, compared to 2.98 MPa at the shrub-steppe. Snakeweed also recovered more slowly overnight in the woodland community, reaching a maximum water potential of 1.71 MPa before dawn. The greater stress experienced in the woodland may be caused by competition with the larger, more extensively rooted tree and shrub species.

On the woodland site, snakeweed was the most drought-resistant species. Values ranged from 1.71 to 3.16 MPa. Rubber rabbitbrush ranked

Table 2.--Comparison of relative water contents of woodland and shrub-steppe soils at three depths. Test for significance using Duncans's New Multiple Range Test (means followed by same letter are not significantly different at p > .05 level)

Date	Depth cm	Woodland RWC (%)	Shrub-steppe RWC (%)
12/19/82	5	21.0 a	14.9 b
	20	23.7 ac	26.5 c
	50	8.1 d	15.5 b
01/07/83	5	15.5 a	8.6 b
	20	6.5 b	7.9 d
	50	8.1 b	14.3 a
03/16/83	5	28.5 a	24.4 a
	20	26.2 ba	28.9 a
	50	32.2 a	20.1 c
05/29/83	5	19.5 a	9.7 b
	20	16.8 a	10.4 b
	50	25.8 c	16.1 a
06/18/83	5	20.6 a	6.9 b
	20	7.2 b	7.9 bc
	50	10.6 cd	13.0 d
07/04/83	5	20.9 a	9.7 b
	20	5.9 c	8.2 bd
	50	7.0 cd	12.8 e
09/12/83	5	22.1 a	11.8 b
	20	6.3 c	9.3 d
	50	6.6 c	13.3 b
09/17/83	5	14.4 a	7.2 b
	20	5.2 b	7.2 b
	50	6.7 b	11.3 c
10/05/84	5	18.3 a	16.8 a
	20	5.7 b	12.0 c
	50	6.7 b	12.8 c

Table 3.--Simultaneous plant moisture potentials (-MPa) for shrub and tree species on woodland and shrub-steppe sites during October 1984. Means followed by same letter are not significantly different (P>.05, Tukey's studentized range test

Site	Water Potential (-MPa) Species	Predawn	Midday
Woodland	Quercus gambelii	1.31 E	3.38 BC
	Juniperus osteosperma	1.43 DE	2.82 DE
	Rhus trilobata	1.43 DE	2.28 F
	Cowania mexicana	1.48 DE	2.90 CDE
	Pinus edulis	1.60 CDE	2.55 EF
	Chrysothamnus nauseosus	1.64 CDE	2.93 DE
	Gutierrezia sarothrae	1.71 CD	3.16 CD
	Mean	1.51	2.86
	VPD (-MPa)	61.8	250.4
Shrub-steppe	Gutierrezia sarothrae	1.44 DE	2.98 C
	Atriplex canescens	1.74 CD	4.29 AB
	Artemisia tridentata	1.75 CD	3.11 C
	Ceratoides lanata	1.78 CD	4.44 A
	Chrysothamnus greenei	1.90 BC	3.94 B
	Chrysothamnus viscidiflorus	2.21 B	3.65 BC
	Atriplex confertifolia	2.75 A	4.42 A
	Mean	1.94	3.83
	VPD (-MPa)	38.9	182.4

Table 4.--Mean plant moisture potential (-MPa) comparisons for shrub and tree species on woodland and shrub-steppe sites during Sept. 18, 1983. Means followed by same letter are not significantly different (P>.05, Tukey's studentized range test

Site	Species	Water Pot.		S.E.
Woodland	Pinus edulis	1.62	A	.16
0900 hours	Chrysothamnus nauseosus	2.39	B	.10
	Juniperus osteosperma	2.43	B	.18
	Rhus trilobata	2.47	B	.08
	Cowania mexicana	2.61	B	.16
	Quercus gambelli	3.29	C	.15
	Mean	2.47		
	VPD (-MPa)	57.6		
Shrub-steppe	Artemisia tridentata	2.73	A	.36
1400 hours	Cerstoides lanata	3.23	A	.28
	Gutierrezia sarothrae	3.52	AB	.56
	Atriplex canescens	4.21	BC	.34
	Chrysothamnus greenii	4.38	C	.36
	Chrysothamnus viscidiflorus	4.58	C	.29
	Atriplex confertifolia	4.86	C	.40
	Mean	3.93		
	VPD (-MPa)	122.4		

VPD = Atmospheric vapor-pressure deficit

second in drought tolerance with values ranging from 1.64 to 2.93 MPa. Juniper maintained consistent values throughout all measurements (1.43 to 2.82 MPa). Pinyon maintained slightly higher predawn values during periods of increased stress. However, during periods of adequate soil moisture, pinyon had less negative minima and maxima. Pinyon appeared to be stressed more and earlier than juniper, being slightly less drought tolerant. Cliffrose and squawbush had moderate readings. Gambel oak had the most interesting results. It had extremely negative midday values (3.38 MPa) and high predawn values (1.31 MPa). The oaks were located in small depressions and drainages with deeper soil horizons. Both the high variation between predawn and midday water potential values and the extreme midday water stress may indicate that the oak is operating at the edge of its ecological range. Woodland species ranked in order of decreasing drought tolerance are: snakeweed < rubber rabbitbrush < juniper < pinyon < cliffrose < squawbush < gambel oak.

Shadscale maintained the most negative water potential values, midday and predawn, of all shrub-steppe species sampled. Mean values ranged from 2.75 to 4.62 MPa. Winterfat also had a very low maximum measurement (4.62 MPa), but was extremely variable in its response. Its response following precipitation together with high predawn water potential values and large range of variation within individual plant measurements indicates that winterfat was often under extreme stress. The two rabbitbrush species sampled (Chrysothamnus viscidiflorus--C. greenei) were also very drought resistant (2.21-4.58 mPa; 1.90-4.38 MPa), with very low predawn maxima and moderate midday minima. Fourwing saltbush and big sagebrush had similar predawn values, but saltbush had significantly more negative midday values. Ranked in order of decreasing drought resistance potential based on whole-plant water potential measurements: shadscale < winterfat < rabbitbrush < saltbush < sagebrush < snakeweed.

Internal Water Potential Components

Site means for various water potential components were derived from the pressure-volume curves (Table 5). The water potential-water content parameters must be evaluated together for each species since different water use strategies emphasize different components throughout the growing season. Researchers (Hinckley and others 1980; Jane and Green 1983) have held that variations in osmotic potentials at the turgor

Table 5.--Internal water potential parameters from presure-volume curves for woodland and shrub-steppe species (for definitions of headings see text)

Community	Date	Species	SAT (-MPa)	TLP (-MPa)	RWC_{TLP} (%)	Bound Water (SAT-TLP)		Content (%)
Shrub-steppe	Aug 15	CHVI	1.98	2.84	85.8	0.86	51.8	
		ATCA	2.07	3.19	91.2	1.12	76.7	
		ARTR	1.52	2.76	76.3	1.24	45.4	
Shrub-steppe	Aug 22	ATCO	1.43	3.30	82.2	1.87	65.0	
		ATCA	1.62	3.19	85.1	1.57	65.3	
		ARTR	0.91	2.49	56.3	1.58	32.0	
Woodland	Sept 7	JUOS	2.19	4.13	76.0	1.94	45.1	
		PIED	1.90	3.53	77.2	1.63	46.8	
		COME	1.63	2.50	73.9	0.87	39.6	
Woodland	July 25	JUOS	2.37	4.03	76.3	1.66	47.2	
		PIED	2.56	3.85	75.2	1.29	27.5	

loss point can be used to rank species in order of drought adaptability. High RWC_{tlp} indicates more rigid cell walls (Hinckley and others 1980) and a subsequent higher ability to resist dessication. Both $\Psi_{\pi\ tlp}$ and RWC_{tlp} appear to be closely related to the point of stomatal closure (Jane and Greene 1983; Hinckley and others 1980).

Pinyon-Juniper Woodland

Using the $\Psi_{\pi\ tlp}$ to rank plants in order of decreasing drought resistance, we find that Utah juniper has the most negative value at -4.13 MPa (table 5). Pinyon is next at -3.85 MPa. Juniper shows the greatest variation in osmotic potential between full saturation and turgor loss point. Both tree species demonstrate more variation than cliffrose. The θ_{wall} is highest in juniper, again higher in the two tree species than in cliffrose.

Cliffrose's shallower rooting pattern makes more use of soil water (Halvorson and Patten 1974; Love and West 1972) in the 10- to 40-cm depths than either juniper or pinyon. Additional soil water available during the 12/19/82 readings (table 2) may have contributed to cliffrose's large decrease (more negative) in the $\Psi_{\pi\ tlp}$. It also showed a very large increase in bound water content (θ_{wall}) from 39.6 percent to 71.5 percent. This may be an example of the drought hardening that commonly occurs in some cold desert shrub species as winter progresses.

Ranking of all three species by predawn Ψ, $\Psi_{\pi\ sat}$, and $\Psi_{\pi\ tlp}$ indicates that juniper is the most drought resistant, followed by pinyon and then cliffrose. Cliffrose shows the greatest ability to change its internal water potential responses in regard to drought hardening or osmoregulation. With less variable and more constant water availability the deeper rooting trees have less need to change osmotic responses throughout the season.

Shrub-Steppe Community

Shadscale has the most negative (-3.30 MPa) $\Psi_{\pi tlp}$ of the four shrub species measured (table 5), followed by fourwing saltbush. This allows them to maintain positive turgor at the lowest osmotic potential and still adequately carry out turgor-mediated metabolic responses as water availability declines (Clayton-Greene 1983; Roberts and others 1980). Both shadscale and saltbush maintain relatively high RWC_{tlp} and θ_{wall} (the osmotic water fraction). This is the effective volume of water available for exchange across membranes. This bound water is important in buffering the effect of cell dessication, conferring greater drought resistance (Clayton-Greene 1983). The lower θ_{wall} availability indicates substantially less drought resistance capability in rabbitbrush and sagebrush.

Shadscale, saltbush, and rabbitbrush all have significantly lower (more negative) osmotic potentials at full turgor than sagebrush. Both saltbush and sagebrush appear to have the ability to change their initial saturated osmotic potential in response to stress by changing their solute concentration. This adaptive feature steepens the plant-soil water potential gradient as water availability becomes limited (Roberts and others 1980), allowing access to a greater volume of soil water (Monson and Smith 1982). Sagebrush apears to have the greatest ability to osmoregulate in this manner. Sagebrush also shows a slight ability to vary its osmotic potential at the turgor loss point.

Saltbush and sagebrush show similar patterns in the difference in osmotic potential between full saturation and the turgor loss point. Sagebrush shows the least negative $\Psi_{\pi sat}$ and $\Psi_{\pi tlp}$, but the greatest variation in both components, giving evidence of the high degree of osmoregulation capacity. Sagebrush also maintains the lowest RWC_{tlp}, allowing much greater water loss before turgor loss occurs while maintaining moderate osmotic potentials. θ_{wall} was lowest in sagebrush and rabbitbrush, indicating that this is apparently not one of the components used in drought resistance by these species.

Comparing all internal water potential components derived from pressure-volume curves, shrubs listed in order of decreasing drought-resistant capabilities are as follows: shadscale < fourwing saltbush < green rabbitbrush < big sagebrush.

CONCLUSIONS

Very few abiotic differences were found between the two study sites. Precipitation amount and frequency, annual evapotranspiration rates, and most soil edaphic characteristics were similar. However, soil moisture differed significantly by depth. The pinyon-juniper soils held more water in the upper 5 cm, while the shrub-steppe soils held more at the 50 cm depth. Additionally, the organic matter content was significantly higher in the upper horizon of the pinyon-juniper soils. If no edaphic differences are detected between these sharply defined vegetation communities, then (a) environmental parameters other than the edaphic features measured are responsible for the mosaic pattern or (b) the perpetuity of the current species pattern is not a result of present environmental influences (Mitchell and others 1966). The pinyon-juniper and shrub-steppe communities do differ in elevation (1925 m vs 2075 m) and vertical structure, which may lead to decreased wind velocity and evapotranspiration, and may influence environmental factors and vegetation patterns over the long term. The differences in vegetation may also lead to differing rates of water loss among the soil horizons, which is reflected in the observed patterns of moisture stress.

ACKNOWLEDGMENTS

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WATER USE BY WESTERN JUNIPER

Richard F. Miller, Raymond F. Angell and Lee E. Eddleman

ABSTRACT: A preliminary water use model for western juniper (Juniperus occidentalis) is proposed based on the equation: total water use = leaf conductance x vapor pressure deficit x leaf area x time. Outputs from the model are compared to actual field data.

INTRODUCTION

Western juniper (Juniperus occidentalis) is rapidly increasing in density and has approximately doubled its range during the last 100 years throughout Oregon, Washington, Idaho, Nevada and California. As juniper woodlands increase, water resources may deteriorate through an increase in sediments (Buckhouse and Mattison 1980), a decrease in subsurface flow (Gifford 1973; Baker 1984), an increase in interception of precipitation (Gifford 1975; Eddleman 1983; Young and others 1984) and a reduction of soil water reserves through transpiration (Jeppsen 1978; Miller 1984). Forage production may also decline. Where juniper has been removed, forage production has increased from 50 to 300 percent (Bedell and Bunch 1978). One of the primary limiting factors of forage production is the allocation of water resources to western juniper. The overall goal of this paper is to discuss the possibility of predicting water use by a western juniper woodland through developing a preliminary juniper water use model.

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Richard F. Miller is a Range Scientist with Oregon State University, Eastern Oregon Agricultural Research Center, Burns, OR. Raymond F. Angell is a Range Scientist with USDA, Agricultural Research Service, Eastern Oregon Agricultural Research Center, Burns, OR. Lee E. Eddleman is an Associate Professor with the Department of Rangeland Resources, Oregon State University, Corvallis, OR. The Eastern Oregon Agricultural Research Center, including the Squaw Butte and Union Stations, is jointly operated by Oregon Agricultural Experiment Station and U.S. Department of Agriculture, Agricultural Research Service.

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THE STUDY AREA

Most of the water relations data used to develop the model were collected on the Squaw Butte Experimental Range located on the northern fringe of the Great Basin in southeastern Oregon (Miller and Shultz 1985). The 40-year mean precipitation for this area is 300 mm. The study site is an Artemisia tridentata ssp vaseyana/Festuca idahoensis habitat type at 1360 m elevation. Soils on the study site are in the Gradon Series, approximately 112 cm to columnar basalt bedrock. Soil textures range from loam near the soil surface to gravelly loam at the lower depths.

In September 1984, seven other sites were selected in the Bend, Horse Ridge and Prineville areas of central Oregon to compare results obtained at Squaw Butte (EOARC file data). These areas ranged from hot dry sites on south aspects at 900 m to cooler more mesic sites on north slopes at 1575 m.

METHODS

To predict total transpiration for a juniper woodland (J') our assumption is:

$$J' = gl \times VPD \times \text{Leaf Area} \qquad (1)$$

where gl is leaf conductance and VPD is vapor pressure deficit. To solve this equation we must adequately predict gl (a measure of how freely water passes through the leaf) and vapor pressure deficit (VPD = the evaporative demand of the air) for a defined time period and total leaf area for the juniper woodland.

Leaf Conductance

Western juniper gl is a dynamic variable influenced by weather conditions and ranges between 0.02 and 0.13 cm sec^{-1} with mean maximum values varying between 0.08 and 0.13 cm sec^{-1}.

Relationships between gl and environmental conditions are based on more than 1,000 gl measurements recorded over three years (Miller and Shultz 1985, EOARC file data). Plant and climatic measurements were recorded from September 1982 through September 1984 on the Squaw Butte Experimental Range and seven additional sites during September 1984 through September 1985. Measurements included gl, stem xylem water potential (Ψ1), soil water, air and soil temperatures, relative humidity and photosynthetically active radiation (PAR). Miller and Shultz (1985, EOARC file data) reported no single environmental variable controls

gl in western juniper. The primary variables controlling gl levels are air and soil temperatures, VPD, soil water and Ψl. In summary, reductions in gl are caused by environmental conditions which decrease the amount of water transported through the tree (i.e., soil or air temperatures near freezing, and low soil water levels), or conditions which could cause large amounts of water loss through the plant (high temperatures and low humidity). When xylem water potential decreases to -2.0 MPa stomates close. Similar results have been reported in other conifers where stomates closed between -1.8 and -2.0 MPa (Hinckley and others 1978) and, -1.4 and -2.5 MPa (Jarvis 1980).

Vapor Pressure Deficit

Vapor pressure deficit is the difference between how much water the air can potentially hold at saturation for a defined temperature and the actual amount of water being held in the air (relative humidity). For example VPD at 25°C and 20 percent relative humidity is 18.4 g m^{-3} while at 10°C and 20 percent relative humidity it is 7.5 g m^{-3}. In equation (1) we are assuming western juniper leaf temperatures are near ambient and vapor pressure of water at the evaporating surface in the leaves is at saturation. Thus the driving force moving water vapor out of the plant is the vapor pressure gradient between the leaf evaporative surface and air surrounding the leaf. As the gradient or vapor pressure deficit increases, thus increasing the driving force, so does the potential for water loss.

Leaf Area

To be able to estimate total transpiration for individual trees or land units total leaf area must be known. The relationship between sapwood area and basal circumference with leaf area for western juniper has been worked out by Miller and others (1985, EOARC file data). This relationship is based on the correlation between leaf area and conducting tissue, a function of the physiological balance between water demand by the crown and the ability of the stem to conduct water (Kaufmann and Troendle 1981). Both sapwood areas measured at the tree base and basal circumference were good estimators of projected leaf area on vigorous western juniper trees (fig. 1). Provided tree density and mean basal circumference are known for a management unit, total leaf surface area can be estimated.

Preliminary Water Use Model

The flow diagram in figure 2 describes a preliminary water use model for western juniper. The model runs on an hourly time step. Data inputs for climate are daily maximum and minimum air temperatures. The beginning and ending dates, defining the time period the model will run, are given in Julian Days. Julian Day is also used to estimate daylength (Ld) using the equation:

$$Ld = [3.5 (\sin (X - 79.01721)) + 12] \times 3600 \quad (2)$$

where X is Julian Day. The diurnal temperature

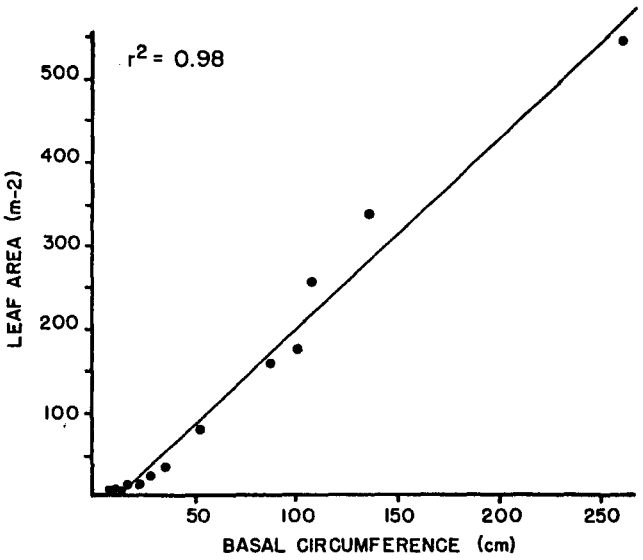


Figure 1.--Regression line and data points for basal circumference and total projected leaf area for western juniper (Miller and others, in press).

flux is estimated on a daily basis with an adaptation of Parton and Logan's (1981) model using maximum and minimum temperatures. Vapor pressure deficit is then estimated from diurnal temperature flux. The model estimates VPD since few weather stations report relative humidity. The next step sets gl. Leaf conductance is set hourly depending on air temperature, VPD and soil water. If air temperatures are $\leq$ 0°C gl is set at zero. If VPD is high the model will reduce gl. Miller and Shultz (1985, EOARC file data) showed as VPD increased the upper limit of gl decreased. The third factor which can potentially limit gl is soil water availability. Soil water may be estimated using the Ekalaka Rangeland Hydrology and Yield Model (Wight and Neff 1983). Another factor that may be used in place of soil water is xylem potential. This portion of the model still needs to be worked out. As soil water levels decrease and evaporative demands increase, xylem potentials decline. Xylem potentials and gl are not closely correlated under good soil water conditions, but as xylem potentials approach -2.0 MPa the relationship changes and gl approaches zero. Once the gl has been set, total water loss through transpiration is estimated for the hour. The hourly loop is run for a 24 hour period, and total daily transpiration per unit leaf area is calculated. Total water loss for the day per unit leaf area is then multiplied by the total leaf area of the juniper woodland to estimate water use on the site. The daily loop will repeat for the defined time period.

DISCUSSION

Two examples of daily output (on a per unit leaf area basis) are shown in figure 3. Hourly estimates of gl, air temperature, VPD and J (ug cm^{-2} h^{-1}) can be displayed, and J accumulated for daily and seasonal summaries of water use. For example a tree with a basal diameter of 30.5 cm would have a projected leaf area of 188 m^2. Total water use

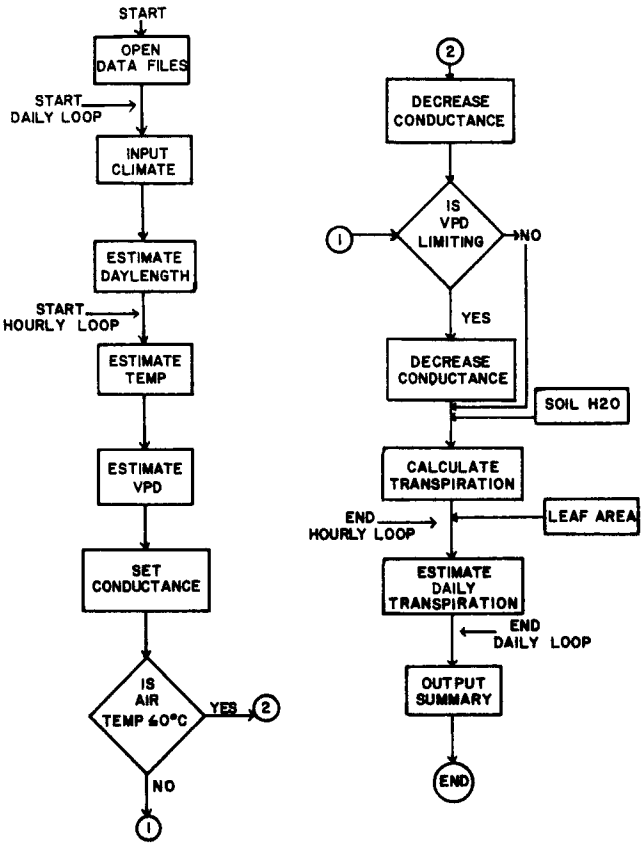


Figure 2.--Flow diagram for calculating water use (transpiration loss) in western juniper woodland canopies.

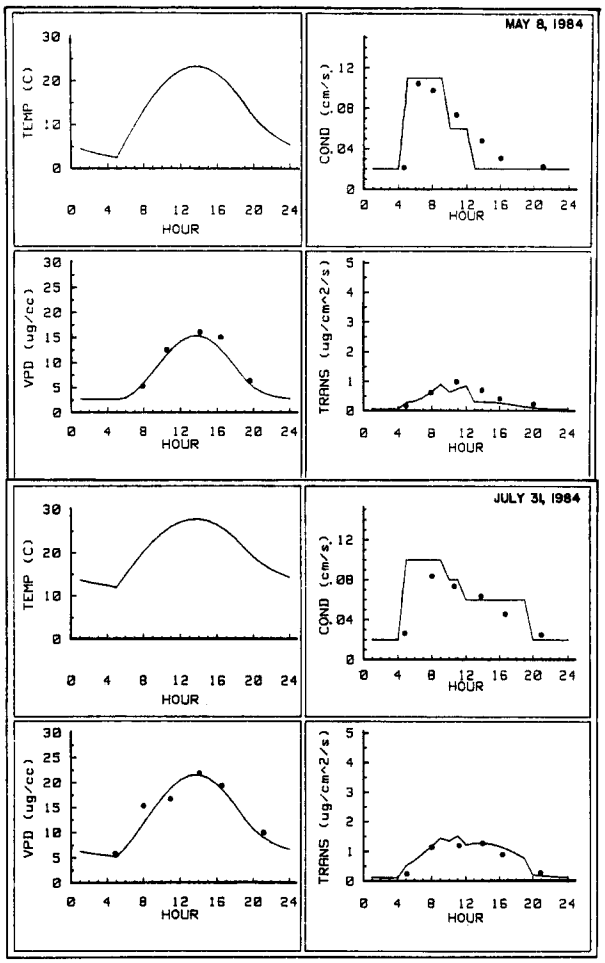


Figure 3.--Juniper water use model estimates of temperature, vapor pressure deficit, leaf conductance and transpiration. Points denote actual field readings.

would be 53 liters d^{-1} and 121 liters d^{-1} on May 8 and July 31, 1984, respectively. Water use on July 31, 1984, is probably higher than normal due to above average soil water in the lower soil profile. Potential water use by western juniper is high even though gl is relatively low compared to other conifer species. Maximum gl reported for other conifers range from 0.12 to 0.40 cm sec^{-1} (Dykstra 1974; Fetcher 1976; Running 1976, 1980; Murphy and Ferrell 1982; Yoder 1982). Since juniper grows in warm dry climates, VPD levels are high compared to climates characterizing most other conifer woodlands. Also, western juniper leaf area is large on an individual tree basis. Seasonal variation for daily J (per unit leaf area) is projected by the model in figure 4. Climatic variables used were based on 1984 climatic data from Squaw Butte. In drier years, transpiration levels beginning around Julian Day 200 would probably be much lower. However, in 1984 deep soil water remained near field capacity allowing western juniper to maintain Ψl above -2.0 MPa during most of this late summer period.

The predictive capability of the juniper water use model is dependent upon: 1) the ability to predict gl under varying environmental conditions; 2) the

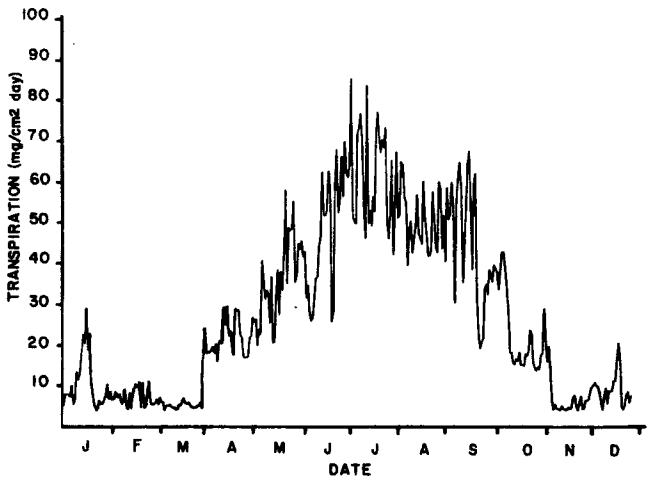


Figure 4.--Estimated seasonal variation for daily transpiration, on a per unit leaf area basis, using 1984 weather data from the Squaw Butte Experimental Range.

ability to predict leaf area and; 3) the environmental data that drives the model. Our first assumption is we can adequately predict gl by using VPD, air temperature and Ψl (or soil water). At this time, the model appears to do a good job predicting changes in gl as it relates to these variables. Our second assumption is we can adequately estimate leaf area using equations developed by Miller and others (1985, EOARC file data). Our final assumption is J' = gl x VPD x Leaf Area. To calculate this equation we must know VPD, which is a function of air temperature and relative humidity. Maximum and minimum air temperatures are readily available from weather stations located throughout the Great Basin, but relative humidity is not. Currently the model uses maximum and minimum air temperatures to predict VPD. Although VPD values are reasonable, VPD was over estimated on overcast days at the Squaw Butte location. The relationship between air temperature and VPD also varies with location and possibly years. If relative humidity data were available, accuracy of the model would be increased. Vapor pressure deficit is especially important since it is used in the equation to compute J', and when VPD values are high, to set gl. The relationships between gl, leaf area and VPD with J' are direct. A 10 percent error in one of these variables will mean a 10 percent error in J'.

The increase in area, density, and dominance of western juniper on rangeland systems is a slow but insidious process resulting in a gradual decline of forage resources. There is a point in the development of juniper woodlands where significant impacts on the forage resource and possibly instream flow will occur because of amount of water transpired. Once the model is fully developed we hope it will be useful to land managers, enabling them to predict outcomes of juniper manipulation practices. The model should help to identify watersheds, portions of watersheds, and even size classes of juniper trees for treatment, which are critically impacting forage supplies and instream flow in lower portions of the watershed. The information will help provide for more efficient selection of treatment areas by better evaluating both the ecologic and economic responses. We hope it will also prove to be a useful tool for researchers in evaluating the role of western juniper on the hydrologic cycle.

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XYLEM WATER POTENTIALS OF SINGLELEAF PINYON SEEDLINGS AND SAGEBRUSH NURSE PLANTS

Evan P. Drivas and Richard L. Everett

ABSTRACT: Encroachment of singleleaf pinyon (Pinus monophylla) into adjacent shrub communities may be related to the trees' ability to maintain a more seasonally stable xylem water potential than associated shrub nurse plants. This study compared xylem water potential of singleleaf pinyon seedlings and shrub nurse plants in low sagebrush (Artemisia arbuscula) and basin big sagebrush (A. tridentata ssp. tridentata) woodland ecotones. Predawn shrub xylem water potentials (-0.95 MPa) were less negative than tree seedling xylem water potentials (-1.1 MPa) in early spring. Sagebrush xylem water potentials became more negative than seedling values in June and remained so for the majority of the 1985 growing season. Predawn water potentials of shrubs declined to the range of -2.1 to -3.9 MPa during summer drought. Seedling xylem water potentials at this time were -1.6 to -1.8 MPa. Tree seedlings appear to have a threshold xylem water potential value of -2.0 to -2.5 MPa that causes stomatal closure and stablizes xylem water potential the remainder of the day. A threshold value of -5.0 MPa created the same response in low sagebrush. Pinyon seedlings maintained daily and seasonal xylem water potentials over a narrower range than sagebrush nurse plants.

INTRODUCTION

The most critical stage in the life cycle of a plant is establishment of the seedling. Pinyon (Pinus edulis) seedlings require a nurse plant to survive (Phillips 1909). Loss of the nurse plant causes mortality of singleleaf pinyon (P. monophylla) seedlings (Everett and others 1986). Nurse plants provide shade and ameliorate microclimate stress for conifer seedlings (Youngberg 1965) but also compete with conifer seedlings for water and nutrients (Wright and Mooney 1965). Eissenstat and Mitchell (1983) found predawn and midday water potentials of Douglas-fir (Pseudotsuga menziesii) seedlings were significantly decreased through grass competition.

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Evan P. Drivas is Hydrologist and Richard L. Everett is Project Leader, Intermountain Research Station, Forest Service, U.S. Department of Agriculture, Reno, NV.

Xylem water potentials of some species are highly responsive to changes in external moisture conditions while others are not (Halvorson and Patten 1974). Prior work on sagebrush and conifer species suggests xylem water potentials of singleleaf pinyon should be less responsive than those of sagebrush to seasonal changes in moisture conditions. Running (1976) found threshold water potentials of -1.8 to -2.4 MPa at which stomatal closure occurred in Douglas-fir. Sagebrush xylem water potentials have been shown to steadily decline over a growing season (DePuit and Caldwell 1973; Branson and others 1976; Everett and others 1977). Stomatal closure must occur over a wide range of xylem water potentials for sagebrush.

Both tree seedlings and shubs should have reduced transpiration and CO_2 fixation as xylem water potentials drop. Brix (1979) and Lopushinsky and Klock (1978) reported seedlings of conifer species have decreased rates of photosynthesis when plant water potentials decline to -1.0 MPa. Transpiration and photosynthesis of sagebrush rapidly decline by 20 percent when soil water potentials reach -.5 to -1.0 Mpa and CO_2 fixation declines by 75 percent at soil stress of -3.0 Mpa (Clark and others 1980).

Pinyon replacement of sagebrush and other species in woodland succession causes a decline in forage production for livestock and wildlife. Tree encroachment and dominance may be in part due to the trees' greater competitive advantage for soil moisture in early spring as suggested for western juniper (Juniperus occidentalis) (Jeppesen 1978). If pinyon maintains lower internal water stress than its competitors, this may partially account for the trees' dominance as suggested for bristlecone pine (Pinus aristata var. longaeva) (Beasley and Klemmedson 1976). By understanding tree-shrub water relations we may be able to develop management prescriptions that enhance or hinder tree regeneration to meet land management objectives.

Our objective in this study was to determine the xylem water potentials of singleleaf pinyon seedlings and associated basin big sagebrush (Artemisia tridentata ssp. tridentata) or low sagebrush (A. arbuscula) nurse plants over a growing season. Supplementary information on transpiration was gathered to explain observed daily patterns in xylem water potentials.

METHODS

Six singleleaf pinyon-shrub ecotone areas were selected as study sites in the Virginia Range of western Nevada. Basin big sagebrush was the nurse plant on three sites and low sagebrush the nurse plant on the remaining sites. Sites were located between 1 520 and 2 080 m elevation. Basin big sagebrush ecotones were found in drainage bottoms and low sagebrush ecotones on side slopes of south (high-elevation) and east (low-elevation) aspects. Sixteen singleleaf pinyon seedlings and associated shrub pairs were chosen at each location. Singleleaf pinyon seedlings varied from 10 cm to 2 m in height.

Xylem water potentials of big sagebrush, low sagebrush, and pinyon seedlings were measured with a pressure bomb. Preliminary measurements showed basin big sagebrush, low sagebrush, and singleleaf pinyon had least negative water potentials at predawn and the most rapid decrease in xylem water potential during midmorning. This information was used to establish predawn and midmorning sampling periods. Six seedlings and shrub nurse plants (two at each site) were randomly selected for sampling from April to September 1985. The sample size was increased to 16 shrub and seedling pairs at each site for spring minimum and summer maximum water stress periods.

Transpiration of three seedlings and associated shrubs in both low sagebrush and basin big sagebrush ecotones was estimated with a LI-COR 1600 steady state porometer. Transpiration and vapor pressure deficit measurements were taken from predawn to early afternoon in September on two occasions. This information was used to explain observed changes in xylem water potential and the approximate time of stomatal closure.

Xylem water potential differences between pinyon seedlings and associated nurse plants were compared in analysis of variance tests (Snedecor 1956). We used 48 (16 plants X three plots) replicates to test for differences among tree seedlings and shrub nurse plants in each sagebrush ecotone type for spring minimum and summer maximum water stress periods. Twenty sampling dates (six replicates each) were used to test seasonal variation in xylem water potentials between tree seedlings and shrubs.

RESULTS AND DISCUSSION

In this discussion xylem water potential is denoted as $-Y_x$. Lower water potentials represent values that are more negative.

Potentials of Seedlings and Nurse Plants

Singleleaf pinyon seedlings had lower predawn and midmorning $-Y_x$ than basin big sagebrush or low sagebrush nurse plants early (May 14-16) in the growing season (table 1). The diurnal pattern during this period was similar for both shrubs and trees with sagebrush maintaining a less negative $-Y_x$ throughout most of the day (fig. 1a,c). $-Y_x$ rapidly declined, or became more negative, in midmorning and increased in late afternoon.

Low and basin big sagebrush predawn $-Y_x$ became more negative than singleleaf pinyon seedling values in June (fig. 2a,b) and were significantly lower by midsummer (July 22-24)(table 1). Pinyon seedlings had less negative $-Y_x$ than sagebrush nurse plants during midsummer days (fig. 1b,d). Following an early morning decrease in $-Y_x$, singleleaf pinyon maintained a relatively stable (-2.0 to -2.5 MPa) $-Y_x$. Low sagebrush $-Y_x$

Table 1.--Xylem water potentials (-MPa) for singleleaf pinyon seedlings (PIMO) and associated basin big sagebrush (ARTR) and low sagebrush (ARAR) nurse plants in spring and summer

	ARTR	PIMO	ARAR	PIMO
		Spring		
Predawn	.95[b]	1.10[a]	.96[b]	1.10[a]
Midmorning	1.55[c]	1.89[a]	1.49[b]	1.93[a]
		Summer		
Predawn	2.10[b]	1.56[d]	3.85[a]	1.79[c]
Midmorning	2.99[b]	2.02[d]	4.74[a]	2.40[c]

Values in each row with dissimilar superscripts are significantly (p=0.05) different.

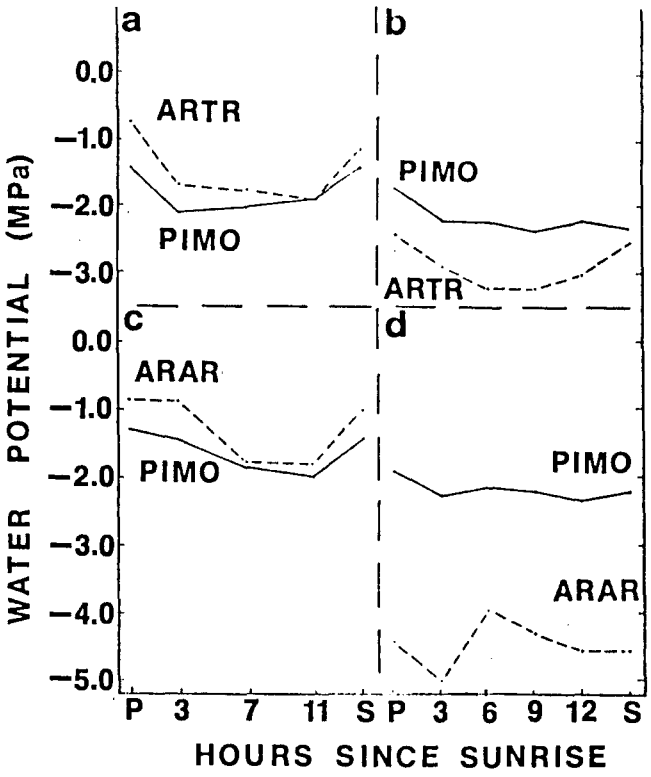


Figure 1.-- Daily xylem water potential patterns for basin big sagebrush (ARTR), low sagebrush (ARAR), and singleleaf pinyon seedlings (PIMO) in spring (April 24) (a and c) and summer (August 8 and 10) (b and d). (P) and (S) denote predawn and sunset.

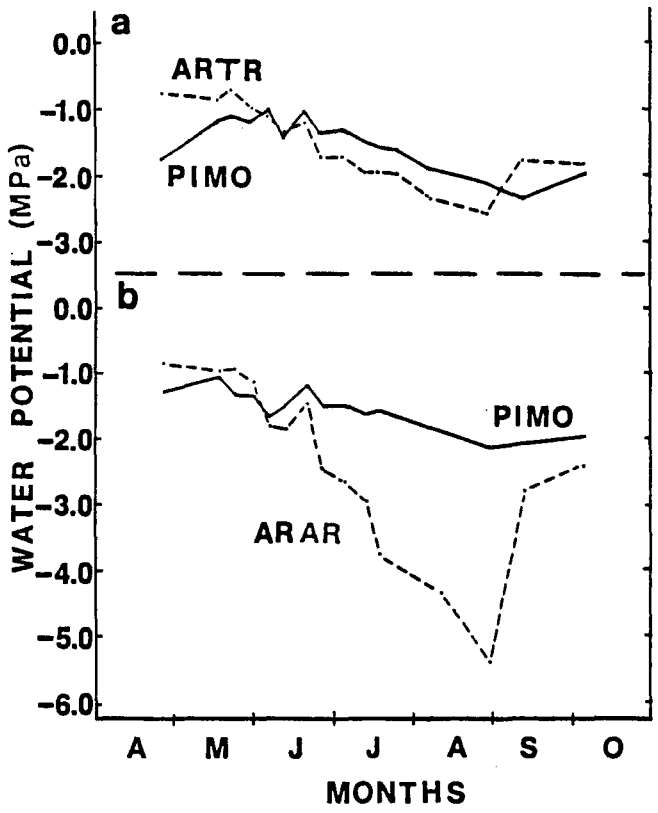


Figure 2.-- Predawn xylem water potentials for (a) basin big sagebrush (ARTR) and (b) low sagebrush (ARAR) and singleleaf pinyon seedlings (PIMO) for the 1985 growing season.

declined to - 5.0 MPa in early morning and then increased, or became less negative, until noon. Big sagebrush $-Y_x$ continued to become more negative until midday and then increased in the afternoon. Similar patterns for each species were also observed on July 16. There appears to be a threshold $-Y_x$ of approximately -2.0 to -2.5 MPa in pinyon seedlings at which $-Y_x$ stabilizes for the rest of the day. A threshold $-Y_x$ of -4.5 to -5.0 MPa in low sagebrush was followed by a rapid increase in $-Y_x$. Probable causes for these changes in $-Y_x$ are explained later by transpiration results. No threshold $-Y_x$ was evident for big sagebrush.

Table 2.--Seasonal mean xylem water potentials (-MPa) for singleleaf pinyon seedlings (PIMO) and associated basin big sagebrush (ARTR) and low sagebrush (ARAR) nurse plants

ARTR	PIMO	ARAR	PIMO
	Predawn		
1.55^{c}	1.46^{c}	2.46^{a}	1.57^{bc}
	Midmorning		
2.20^{b}	2.05^{b}	2.99^{a}	2.18^{bc}

Values in each row with dissimilar superscripts are significantly (p=0.05) different.

In September, xylem water potential of basin big sagebrush, low sagebrush, and pinyon seedlings became less negative (fig. 2a,b). Low sagebrush $-Y_x$ showed the most dramatic change during this time. Despite the September increase, $-Y_x$ never returned to early spring levels for any of the species. We could not distinguish a significant difference between $-Y_x$ of pinyon seedlings and basin big sagebrush over the growing season because of the large seasonal variations in $-Y_x$ of basin big sagebrush (table 2). Low sagebrush had a lower mean $-Y_x$ than singleleaf pinyon seedlings during the 1985 growing season.

$-Y_x$ of sagebrush nurse plants responded to summer drought much more than in singleleaf pinyon as predicted in the literature. Predawn $-Y_x$ of big sagebrush and low sagebrush was more variable (as measured in standard deviations from the mean [SD]) over the season (SD= 0.56 and 1.33 MPa) than for singleleaf pinyon (SD= 0.38 to 0.35 MPa). The seasonal variation in midmorning $-Y_x$ for singleleaf pinyon (SD= 0.25 to 0.30 MPa) was half that of basin big sagebrush (SD= 0.54 Mpa) and one-fourth that of low sagebrush (SD= 1.28 MPa).

Potentials of Pinyon in Sagebrush Ecotones

Singleleaf pinyon seedlings had no differences in predawn and midmorning $-Y_x$ between basin big sagebrush and low sagebrush ecotones in early spring (table 1). $-Y_x$ changed rapidly between predawn and midmorning for seedlings in basin big sagebrush communities, but there was a noticeable delay in low sagebrush communities (fig. 1a,c). Rapid increases in $-Y_x$ were seen in late afternoon.

By midsummer, singleleaf pinyon seedlings in low sagebrush communities had more negative $-Y_x$ than those in big sagebrush communities (table 1). The daily $-Y_x$ pattern was similar between seedlings in the two shrub ecotones. Following a decrease in $-Y_x$ during early morning hours, values remained at the -2.0 to -2.5 Mpa level. Seedling $-Y_x$ did not return to predawn levels at the end of the day as it had in early spring (fig. 1b,d).

The seasonal progression of seedling predawn $-Y_x$ was similar between shrub communities (fig. 2a,b). The standard deviation in the seasonal mean predawn $-Y_x$ was 0.38 MPa for seedlings in big sagebrush and 0.35 MPa in low sagebrush communities.

Transpiration of Seedlings and Nurse Plants

Porometer data collected in September indicated transpiration occurred in singleleaf pinyon seedlings for only a short period in the morning and stomates did not reopen by late afternoon (fig 3a). Transpiration increased in response to increasing vapor pressure deficit (VPD) until approximately 9 a.m. After this time, stomates began to close and there was a rapid decline in

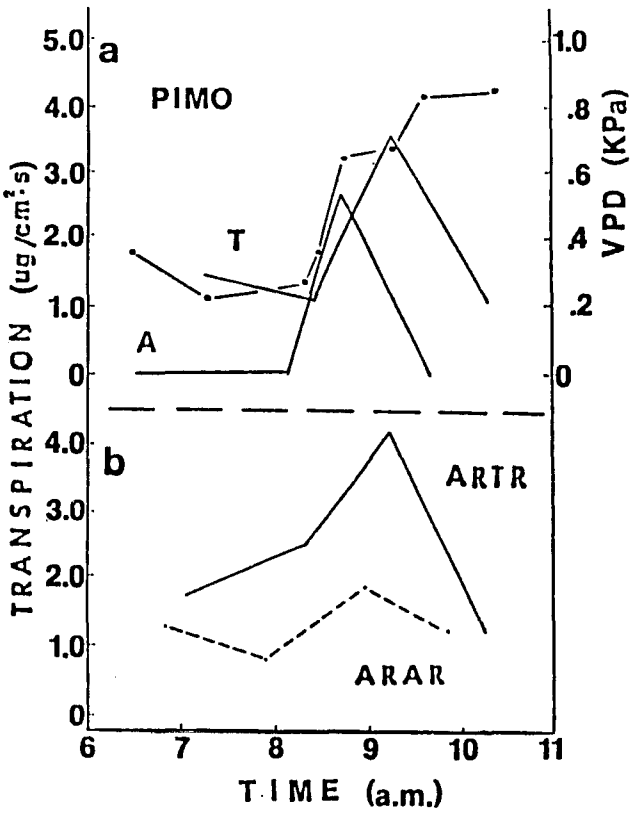


Figure 3.-- a, transpiration for singleleaf pinyon seedlings (PIMO) in basin big sagebrush (T) and low sagebrush (A) ecotones on September 19, 1984; b, transpiration of basin big sagebrush (ARTR) and low sagebrush (ARAR) on September 19. Vapor pressure deficit (VPD) for September 19 (-- ∘ --).

transpiration. These data support the daily pattern of $-Y_x$ seen during summer drought. $-Y_x$ became more negative during early morning hours when seedlings were actively transpiring and then stablilized after midmorning (fig. 1b,d). Based on this information, pinyon seedlings appear to control $-Y_x$ by closing stomates when the threshold $-Y_x$ is reached.

Low and basin big sagebrush had transpiration patterns similiar to pinyon by late summer (fig. 3b). Midsummer low sagebrush $-Y_x$ data showed that an early morning decline in $-Y_x$ was followed by a rapid increase in values (fig. 1d). Data from late summer indicate there was a decline in transpiration at midmorning, with $-Y_x$ changing from -2.5 to -3.5 MPa. Thus, it seems likely that low sagebrush closes stomates in response to threshold $-Y_x$. However, this

species is not able to control $-Y_x$ as efficiently as pinyon seedlings as seen in the progressive decline in $-Y_x$ over the season.

Big sagebrush transpiration also dropped off after about 9 a.m. Midsummer $-Y_x$ changes followed vapor pressure deficit changes and did not reflect a decrease in transpiration if it occurred. Mooney and others (1966) reported maximum transpiration of basin big sagebrush in midsummer and then a rapid decline by late summer. Our late summer transpiration measurements probably do not reflect midsummer transpiration rates and cannot be used to explain changes in midsummer xylem water potential values.

CONCLUSIONS

Results must be viewed as tentative since data were derived from only one growing season. Reliabilty of the information was improved because three sagebrush-singleleaf pinyon sites of each ecotone type were sampled. Sites were separated geographically but showed similar results. Predawn shrub $-Y_x$ (-0.95 MPa) was less negative than tree seedling $-Y_x$ (-1.1 MPa) in early spring. But predawn shrub $-Y_x$ reached -2.1 to -3.9 MPa during summer drought while seedling $-Y_x$ was -1.6 to - 1.8 MPa. For the majority of the growing season, sagebrush $-Y_x$ was more negative than tree seedling $-Y_x$.

Mechanisms for utilization of site soil moisture may vary between shrub and tree species. Singleleaf pinyon maintained more moderate changes in $-Y_x$ than shrub nurse plants during the growing season. Pinyon appears to maintain transpiration and open stomates until threshold Y_x values (-2.0 to -2.5 MPa) are reached, then rapidly closes stomata. This mechanism provides a means for maintaining a more seasonally constant $-Y_x$.

Sagebrush apparently maintains transpiration over a seasonally wide range of $-Y_x$. Low sagebrush appeared to have a threshold $-Y_x$ (-4.5 to -5.0 MPa) which resulted in reduced transpiration. In this respect, low sagebrush and pinyon seedlings use similar mechanisms to control water loss during summer drought.

On midsummer days, basin big sagebrush $-Y_x$ continued to become more negative after $-Y_x$ of pinyon seedlings and low sagebrush had stabilized or increased. A threshold xylem water potential that caused stomatal closure early in the morning was not found for basin big sagebrush. There may be a threshold value but we did not encounter it under existing conditions. The rapid closure of stomates by singleleaf pinyon and low sagebrush may be an adaptive mechanism to conserve soil moisture in shallow soils where these species are often found. Results are in agreement with the widely held concept that plants on moist sites will "use and lose" more water than plants on arid sites (Mooney and others 1965).

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WATER RELATIONSHIPS OF *QUERCUS UNDULATA*, *PINUS EDULIS*, AND *JUNIPERUS MONOSPERMA* IN SERAL PINYON-JUNIPER COMMUNITIES OF SOUTH-CENTRAL NEW MEXICO

M. R. Schott and R. D. Pieper

ABSTRACT: Predawn water potentials of *Quercus undulata*, *Pinus edulis*, and *Juniperus monosperma* were estimated on three areas, each consisting of three different seral communities. Two areas had similar seral communities: one cabled in 1975 for pinyon-juniper control; one cabled in 1954; and an uncabled site. Seral communities of the third area were a 1964 push where the trees were removed by bulldozing, a late-seral community, and a near-climax community. Oak appeared to be a mid-seral species because it exhibited the most negative water potentials on the 1954 cablings and late seral communities. Juniper appeared to be a late seral species because it is the most water stressed in climax communities. Water potential of pinyon was relatively constant over the growing season and among seral communities. Pinyon had different age classes as understory and appeared to be the climax species in these associations. Pinyon does not appear to compete for soil water with other species. However, oak and juniper seem to compete, especially on areas with shallow soils.

INTRODUCTION

Most studies of secondary succession are based on measurements of the entire community, rather than increasing our understanding of the mechanisms of succession. Clements (1916) stated that competition is the driving force of succession. A general concept in successional literature is that interspecific competition increases as the community moves toward climax (Barbour and others 1980; Odum 1983).

Grime (1977) proposed three strategies for plants, and elucidated the role played by each strategy during secondary succession. The three strategies are shown by ruderal or stress-avoiding species, competitive species, and stress-tolerant species. Applying these strategies to succession, competition would be low in the early seral communities when the ruderal species are present. As the competitive species become more established, competition increases until the late seral community where maximum competition occurs. With establishment and dominance of stress-tolerant species at climax, competition declines.

Bazzaz (1976) proposes several features that should characterize early and late successional plants. Early successional plants have high rates of dark respiration, transpiration, and low stomatal and mesophyll resistances. Late successional species are just the opposite. If these features are true, they support Grimes' (1977) defined strategies.

There have been several studies of secondary succession in pinyon-juniper communities. Arnold and others (1964) and Barney and Frischknecht (1974) listed several successional stages expected following wildfire: an annual community, then a perennial grass community, a grass/half shrub stage followed by a shrub stage and, finally, the climax community dominated by trees. Tausch and Tueller (1977) reported a similar successional sequence following pinyon-juniper cabling in Nevada.

This study examined the water relations of *Quercus undulata*, *Pinus edulis*, and *Juniperus monosperma* in several seral communities. The *Quercus undulata* complex involves hybridization of up to seven species of oak, with *Quercus gambelii* being a common contributor to the hybrid complex. Oak on the study area appears to be a hybrid between *Quercus gambelii* and *Quercus muehlenbergii* (Tucker 1961, 1963; Tucker and others 1961).

STUDY AREA

The study areas were in the Lincoln National Forest and the adjacent Fort Stanton Experimental Ranch in south-central New Mexico. The area has cool, dry winters and warm, moist summers with cool nights (Pieper and others 1971). About 65 percent of the annual precipitation (38 cm) falls from July through September.

Two of the study areas, the Bat Cave and Airport areas, were in the *Pinus edulis-Juniperus monosperma/Rhus trilobata/Bouteloua gracilus* habitat type (PIED-JUMO/RHTR/BOGR Ht.). The Jicarilla area was in a *Pinus edulis-Juniperus monosperma/Bouteloua gracilus* habitat type (PIED-JUMO/BOGR Ht.) (Kennedy 1983). The soil of the Bat Cave and Airport areas was a mesic Lithic Haplustoll (Bailey and others 1982). The

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Martin R. Schott is Research Associate, Oregon State University, Corvallis, OR 97331; Rex D. Pieper is Professor of Range Science, New Mexico State University, Las Cruces, NM 88003.

Jicarilla area soil was a mesic Udic Haplustalf (U.S. Forest Service n.d.). Exposure of the Bat Cave and Airport areas was easterly, and the elevation is about 2100 m with slopes of 3-7 percent. The Jicarilla area has a northern exposure with slopes of 3-7 percent, at about 2200 m in elevation.

The Bat Cave and Airport areas each had three sites or treatments: a 1975 two-way cabling; a 1954 two-way cabling; and an uncabled site. All three sites for each area were adjacent. The Jicarilla area had three sites (treatments): an area where the trees had been removed with a bulldozer; a late seral stand; and a near-climax stand. The three treatments were within 400 m of each other.

METHODS

Water potentials of pinyon (Pinus edulis), oneseed juniper (Juniperus monosperma) and wavyleaf oak (Quercus undulata) were estimated at predawn, using a pressure bomb. The water potential of the plants should be in equilibrium with the soil water potentials at predawn conditions (Jones 1983). A pressure bomb was used because it is accurate, rapid, and can be used in the field (Jones 1983). Ten twigs were sampled for each species on each sampling site. Sampling was done at about monthly intervals, starting in April and ending in October. A preliminary study was done the previous year on the Jicarilla area, but only the oaks were sampled in that study.

An analysis of variance (ANOVA) was conducted for each of these dates using site and species as independent variables. Because of a significant interaction between these variables, an ANOVA was run separately for each variable. A protected Fisher's Least Significant Difference (LSD) was used for a multiple comparison of their means (Ott 1977).

RESULTS AND DISCUSSION

Results of the oak data from the preliminary study are shown in table 1. Oak was dormant during the July sampling, and leaves were not formed until mid-August following the first rain of the growing season. In the climax and late seral sites water potentials were not significantly different, but were significantly more negative than the water potential of oak on the bulldozed area. Although the oak was dormant, it was surprising how little mortality there was under these water deficits. There was no significant difference ($P>0.03$) in water potentials between late-seral and climax stands for the July or October samplings (table 2). The late-seral stand was more negative during the September sampling, but the climax stand was more negative during the November sampling. Oak water potentials on the bulldozed area were significantly less negative than those on either the late seral or climax stands for all sampling dates.

Oak data from 1983 show similar results (tables 1, 2). Oak on the Airport and Bat Cave areas exhibited similar water potential patterns (table 2). Generally, oak on the uncabled areas had lower water potentials than oak on the 1954 and 1975 cablings, and oak on the 1954 cablings had lower water potentials than oak on the 1975 cablings. Similar sites for these areas have similar water potentials over time. Water potentials of oak on all three treatment sites for both areas became more negative as the soil dried out, and they all become less negative following rain. Oaks on the 1954 cablings are showing their maximum expression in the association's successional sequence. At this point in the sere, oak plants are starting to receive noticeable competition from the other woody species as well as interspecific competition, which was indicated by the more negative water potentials of these sites.

Table 1.--Plant water potential (bars) for wavyleaf oak, pinyon and oneseed juniper on three treatment sites representing successional stages: push (individual tree control with a bulldozer), a late seral, and climax stands

Stage	Date 4-17	5-29	7-13	8-6	9-10	10-7
	Oneseed juniper					
Climax	10.6AB	8.0B[1]	17.3A	8.3B	7.0B	7.7A
Late Seral	10.1B	9.9A	11.0B	9.2A	8.3A	8.0A
Push	11.7A	6.4C	7.7C	7.2C	5.6C	5.3B
	Oak 1982					
Climax	42.3A	20.4B	15.5A	24.5A		
Late Seral	44.4A	25.0A	16.0A	16.9B		
Push	34.5B	17.5C	13.9B	13.0C		

Stage	Date 4-17	5-29	7-13	8-6	9-10	10-7
	Pinyon 1983					
Climax	12.2A	6.4A	8.2A	5.5A	5.1B	7.0A
Late Seral	10.5B	7.0A	6.0B	5.3A	4.7B	7.8A
Push	8.4C	5.2B	5.2C	5.0A	6.2A	5.4B
	Oak 1983					
Climax	14.9C	9.9B	16.6A	10.1B	12.2A	12.5A
Late Seral	18.1B	12.1A	17.8A	17.4A	13.1A	11.2A
Push	16.8B	8.8C	9.4B	9.2B	13.0A	11.8A

[1]Means followed by different letters are significantly different ($P<0.05$) as determined by LSD multiple mean test.

Table 2.--Plant water potential (bars) for wavyleaf oak, pinyon, and oneseed juniper under two treatments at two locations on six dates

Species	Treatment	4-17	5-29	7-13	8-6	9-10	10-7
			Bat Cave Location				
Wavyleaf oak	Uncabled	17.3A[1]	9.2A	14.4A	26.0A	8.1A	11.5A
	1954 Cable	16.6A	7.6A	14.5A	20.6B	5.9B	9.9B
	1975 Cable	15.2B	7.2A	9.0B	19.9B	4.3C	9.6B
Pinyon	Uncabled	8.7A	4.8A	4.0B	5.6A	7.0A	4.8A
	1954 Cable	7.2B	4.7A	5.7A	5.4A	5.6B	4.5A
	1975 Cable	7.2B	3.5B	4.4B	5.4A	4.7B	3.8A
Oneseed juniper	Uncabled	7.9A	10.8A	11.1A	22.1A	5.9A	7.4A
	1954 Cable	6.4B	7.4B	9.4B	18.1B	6.4A	7.2A
	1975 Cable	7.1B	6.5B	7.4C	17.6B	4.8B	5.9B
			Airport Location				
Wavyleaf oak	Uncabled	15.8A	12.0A	12.6B	21.7A	8.1A	11.9A
	1954 Cable	13.2B	9.7B	14.0A	24.2A	6.3A	10.6B
	1975 Cable	16.2A	9.6B	10.2C	15.8B	7.7A	8.7C
Pinyon	Uncabled	9.4A	4.3A	5.1A	5.0B	5.9B	6.0A
	1954 Cable	9.4A	4.0A	5.1A	6.5A	6.9A	6.5A
	1975 Cable	8.3B	3.6A	4.5A	4.7B	6.2AB	5.5A
Oneseed juniper	Uncabled	11.0A	11.4A	10.6A	20.7A	6.3B	6.8A
	1954 Cable	10.2A	9.4B	11.0A	19.9A	7.6A	7.0A
	1975 Cable	8.6B	9.2B	8.0B	15.0B	6.1B	5.9B

[1]Means followed by different letters are significantly different ($P<0.05$) as determined by LSD multiple mean test.

In contrast, the Jicarilla area showed a different trend. Again, oaks on the bulldozed area had less negative water potentials than oaks on the other sites. However, for the dates where there were differences between the late seral and climax stands, oaks in the late seral stand had more negative water potentials. Oaks in the late seral stand were starting to show signs of stress. These results contrast with the idea that the greatest competition for water occurs at climax (Clements 1916; Odum 1983). However, Barbour and others (1980) stated the environment becomes more mesic during succession because of the canopy's moderating effect on the macroenvironment.

There was not much response by pinyon to the drying or to wetting of the soil on all sites (table 2). Pinyon is the climax species in these associations. Bazzaz (1976) suggested climax species have greater mesophyll and stomatal resistances, and their photosynthetic rates are less sensitive to declining water availability. Cline and Campbell (1976) reported a similar response in Pinus monticola in a northern Idaho study. They believed the stomatal mechanism was the primary water loss control for this species. Another possible explanation for the minimal pinyon response may be that the tree is rooted into strata with more available soil water. Cline and Campbell (1976) and Monson and Smith (1982) mentioned this as a possible explanation.

Juniper water potential had patterns similar to that of oak (tables 1, 2). On both the Bat Cave and Airport areas, oneseed juniper responded similarly on the three sites. Juniper on uncabled sites tended to have more negative water potentials than on either of the other treatment sites, and juniper on the 1954 sites had more negative water potentials than on the 1975 cablings. On some dates, there was no difference between the uncabled site and the 1954 cablings and, on other dates, there was no difference between the 1954 and 1975 cablings. This suggests juniper on 1954 cablings is starting to compete for soil water, but on the uncabled sites it is under greater competition some of the time.

Juniper on the Jicarilla bulldozed site had significantly less negative water potentials than junipers on the other sites. Except for the July sampling, the water potentials of juniper in the late seral community were either equal to or more negative than those of junipers in the climax community. These differences occur at higher water potentials where the junipers are under minimal water stress. In contrast, July readings for juniper in the climax community are significantly more negative than junipers in the late seral community. This indicates that when the soil water potentials become more negative, junipers in the climax community are under greater water stress. Thus, junipers appear to be under the greatest competition in climax communities.

Comparing the three species for the sites of each area, several patterns become apparent (tables 3, 4). Except for the September sampling, pinyon is

Table 3.--Plant water potential (bars) of wavyleaf oak, pinyon, and oneseed juniper on areas cabled at different times and on uncabled control

Species	4-17	5-29	7-13	8-6	9-10	10-7
Bat Cave Location						
			Control			
Wavyleaf oak	17.3A[1]	10.8A	14.4A	26.0A	8.1A	11.5A
Oneseed juniper	8.7B	9.1A	11.1B	22.1B	7.0B	7.4B
Pinyon	7.9C	4.7B	4.0C	5.6C	5.9C	4.8C
			1954 Cable			
Wavyleaf oak	16.6A	7.6A	14.5A	19.9A	5.9A	9.9A
Oneseed juniper	7.1B	7.5A	9.4B	18.1A	6.4A	7.2B
Pinyon	6.4B	4.7B	5.3C	5.4B	5.6A	4.5C
			1975 Cable			
Wavyleaf oak	15.2A	7.2A	9.0A	20.6A	4.3A	9.6A
Oneseed juniper	7.2B	6.5A	7.4B	17.6B	4.8A	5.9B
Pinyon	7.1B	3.5B	4.3C	5.4C	4.7A	3.8C
Airport Location						
			Control			
Wavyleaf oak	15.8A	12.0A	12.6A	21.7A	8.1A	11.9A
Oneseed juniper	11.0B	11.4A	10.6B	20.7A	6.3B	6.9B
Pinyon	9.4B	4.0B	5.0C	5.0B	5.9B	6.0C
			1954 Cable			
Wavyleaf oak	13.2A	9.7A	14.0A	24.2A	6.3A	10.6A
Oneseed juniper	10.2B	9.2A	11.0B	19.9B	7.6A	7.0B
Pinyon	9.4B	4.3B	4.5C	6.5C	6.9A	6.5B
			1975 Cable			
Wavyleaf oak	16.2A	9.6A	10.2A	15.8A	7.7A	8.7A
Oneseed juniper	8.6B	9.4A	8.0B	15.0A	6.6B	5.9B
Pinyon	8.3B	3.6B	5.1C	4.7B	6.1B	5.5B

[1]Means followed by different letters are significantly different ($P<0.05$) as determined by LSD multiple mean test.

Table 4.--Plant water potential (bars) for wavyleaf oak, oneseed juniper and pinyon under three treatments at the Jicarilla site for three successional stages

	Date					
Species	4-17	5-29	7-13	8-6	9-10	10-7
			Climax			
Wavyleaf oak	14.9A[1]	9.9A	16.6A	10.1A	12.2A	12.5A
Pinyon	12.2B	6.4C	8.2B	5.5C	5.1C	7.0B
Oneseed juniper	10.6C	8.1B	17.3A	8.4B	7.0B	7.7B
			Late Seral			
Wavyleaf oak	18.1A	12.1A	17.9A	17.4A	13.1A	11.2A
Pinyon	10.5B	7.0C	6.0C	5.3C	4.7C	7.8B
Oneseed juniper	10.1C	9.9B	11.0B	9.2B	8.3B	8.1B
			Early Seral (Push)			
Wavyleaf oak	16.8A	8.8A	9.5A	9.1A	13.0A	11.8A
Pinyon	8.4C	5.2C	5.2C	5.0C	5.6B	5.3B
Oneseed juniper	11.7B	6.4B	7.7B	7.2B	6.2B	5.4B

[1]Means followed by different letters are significantly different ($P<0.05$) as determined by LSD multiple mean test.

usually less negative than either oak or juniper. The September sampling followed a heavy rain storm, where about an inch of rain fell, and oak and juniper water potentials became less negative while the pinyon failed to change. This lack of response suggests either water failed to reach the roots, or pinyons are unable to respond to the additional water, or they were not under water stress. Regardless of why the pinyon's water potential remains relatively constant, it is obvious there is little observable competition for water between the pinyon and other species. Pinyon appears to be the climax species in these associations; this is supported by both water potential data and field observations.

Juniper appears to be a late seral species. Generally, it has less negative water potentials than oak (tables 3, 4). Also, juniper is a long-lived species and, although it seldom replaces itself in a climax community, it persists in the community. Juniper seeds remain viable for long periods of time and, if conditions become favorable for germination and establishment, a seed source is available (Johnsen 1962).

Wavy leaf oak appears to be a mid-successional species. It has the most negative water potential of the three species, except following rain. It reaches it most negative water potentials in the late seral community.

Oak and juniper have similar responses on the Bat Cave and Airport areas, but juniper has less negative water potentials. This suggests, on these areas, they are rooted in the same general region of the soil and, in the later successional communities, they are in direct competition for soil moisture. The soil of the Jicarillas is deeper than soils of the other areas. Oak and juniper do not have similar water potential patterns on the Jicarilla area (table 4). Because of the deeper soils, there may be a separation in rooting depths of these species. Juniper has less negative water potentials than oak, which suggests that juniper has deeper roots. Thus, juniper is affected less as the upper portion of the soil dries out.

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Range Management

Chaired by:

Rex D. Pieper Professor, Department of Animal and Range Sciences, New Mexico State University, Las Cruces

RANGE MANAGEMENT CONCERNS ON JUNIPER WOODLANDS

Thomas E. Bedell

ABSTRACT: Major concerns are the effects of increasingly larger populations of western juniper on watershed stability, forage production, and diversity and thus values of rangelands for various purposes. An allied but perhaps greater concern is that relatively little is done to satisfactorily control and manage existing stands.

INTRODUCTION

Western juniper (Juniperus occidentalis) occupies large tracts of land in central and eastern Oregon, southwestern Idaho, northeastern California, and northwestern Nevada. Its ecology is just now starting to be understood (Eddleman 1984; Young 1984). Large variations in stand density and cover exist from site to site. Invasion rates largely depend on site conditions. For example, Young (1984) documented juniper density doubling every three years in the early stages of development on a susceptible Wyoming big sagebrush site (Artemisia tridentata ssp. wyomingensis). In a 125 year period, density increased to 150 trees/ha. On an adjacent low sagebrush (Artemisia arbuscula) site the oldest trees are almost 400 years old with only 28/ha currently present. Obviously, the plant is exceedingly well adapted.

The high degree of adaptation to a large variety of site conditions and the aggressive manner by which it exerts its competitive forces should have caused greater concern many years ago. As juniper density increases, effects on the site and its uses may be negative, positive, or even lacking. I believe that there are negative effects and I believe there are valid concerns for the future of rangelands that currently support juniper or are capable of supporting juniper.

Junipers have a long history in this area. Mehringer and Wigand (1984) documented them here 5,000 to 6,000 years ago. Populations no doubt waxed and waned throughout time, but when modern man became part of the picture some 100 to 130 years ago, some additional changes in juniper populations appear to have been set in force (Eddleman 1984; Young 1984). Juniper must be viewed as a management challenge.

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Thomas E. Bedell is Extension Rangeland Resources Specialist, Oregon State University, Corvallis, Oregon 97331.

From a pragmatic standpoint, my range management concerns are from a use perspective. That is, as western juniper has come to occupy a site, how has that affected the water cycle, associated plant competition, forage production, soil erosion, and the overall environment?

A juniper stand to the untrained eye does not appear to change greatly from year to year. It is only with the more dense stands when juniper overtops the herbaceous and/or shrubby layer that managers recognize the potential and real impacts upon forage production, water production and soil erosion, obstructed vision and plant and animal diversity. An inadequate knowledge base, although a fact, is nevertheless not an excuse to ignore the spread of juniper, nor is the excuse that management is too expensive. Because the moving front of juniper can be insidious, the clear recognition of effects on other plants, animals, soils, and water have some time to be dealt with, but ultimately we must come to terms with the situation as it exists.

I have one more or less overriding concern -- western juniper keeps getting more dense -- and whether on private or publically owned land, relatively little effective management action is taken (fig. 1). Many landowners seem, as it were, to stand by and allow their land to be taken over by juniper. Perhaps they're waiting (hoping) for a quick fix or times to get better or some new magical product. So far, none has arrived and I doubt the possibility that one will. All that time the "choke hold" gets tighter.

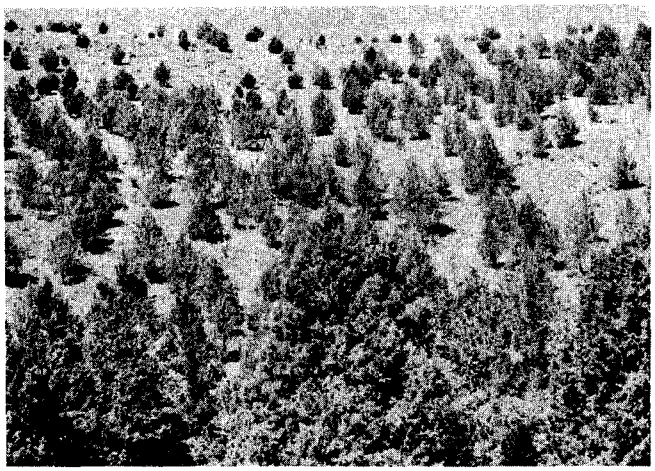


Figure 1.--This stand of western juniper in the Deschutes River basin continues to increase. The area on the right part of the photo has received much heavier levels of use yet juniper density is not apparently different.

Unfortunately, costs for controlling juniper have always been relatively high compared to other kinds of management practices. However, much of the cost situation needs to be examined in the light of other economic alternatives. In the private sector, when expansion was the objective, it was common practice to purchase another ranch. With juniper, the expenditure of resources to manage it may be likened to purchasing new land when the use of the juniper land has been so reduced as to be almost valueless. This is especially true when available ranches also are occupied with dense stands of juniper. In the public sector, one of the main impediments revolves around the value received from increased benefits in computing cost:benefit ratios. Forage does return some money to the treasury, but more water, less erosion and improved wildlife habitat do not, presently.

Beyond the overriding concern and a fairly high apathetic management attitude, I will discuss my concerns from the following perspectives of grazing management, forage production, plant succession and water-soil relations.

GRAZING MANAGEMENT

Since western juniper will not be grazed by either cattle or sheep, these animals cannot be used to directly affect the individual state of juniper plants. A major question revolves around the indirect effects of grazing. In areas without juniper seedlings, it may be possible to manage livestock to create a herbaceous plant cover dense enough to effectively restrict opportunities for juniper seeds to germinate and take hold. Obviously, there would need to be minimum opportunity for movement of juniper seed onto that site. Once established, there does not appear to be evidence that any kind of intensive grazing management will restrict juniper growth.

SUCCESSION

Once juniper gets started, the path toward its ultimate site occupation is open. Current ecological work by Eddleman in Oregon will help explain the susceptibility of a site to juniper invasion. Armed with that information, managers can better predict management consequences over a long period. For example, when some population of juniper is termed desirable, managers can plan for that on a site basis.

For those sites now supporting juniper, the succession situation needs to be made clear. Outside of the use of fire or a herbicide such as Tordon which will control juniper, a site's fate is sealed. Here is where great need for ecological data exists. Through careful examination, it should be possible to determine at what point(s) in plant/animal succession some intervention would be desirable and effective. Examples of intervention could be prescribed fire, selected herbicides, or some mechanical forms of control. With that kind of data, land managers could paint a fairly clear ecological picture through time and across space. It would then be possible to assess the economics of various management practices over that same time and space. This would, indeed, be exciting because then management could better utilize current technology to best advantage. As it is, sites for juniper manipulation often are chosen on the basis of the best hunch and intuition.

Observations suggest that with juniper advancement and larger/older trees both plant and animal species diversity declines. Indeed, dense juniper stands in central Oregon can be found where very few other plant species can now compete (fig. 2). Sites may actually become modified over a period of time. One might go so far as to suggest that juniper succession on some sites should more properly be termed retrogression.



Figure 2.--Western juniper dominates this site so that mainly Sandberg bluegrass (Poa secunda) and Wyoming big sagebrush (Artemisia tridentata ssp. wyomingensis) remain.

FORAGE PRODUCTION

This subject is closely tied to successional changes and site. Impacts may vary rather dramatically from site to site. Conventional wisdom suggests forage production is greatly reduced as juniper density and size increase. No question exists on this point for dense stands. Forage plants are often smaller or weaker, especially in the interspaces between large trees. More from practical observations than from research studies it appears that forage production increases after juniper control. The practical question exists as to which juniper stands to treat and what would be the most appropriate mix of practices to employ to move to greater plant diversity and productivity.

WATERSHED

Buckhouse (1984) measured the amount of sediment produced from 10 different ecosystems in eastern Oregon. He also evaluated water infiltration rates. Juniper dominant ecosystems have the greatest potential for high sediment production and they also tend to have low infiltration rates. Sagebrush ecosystems also had similar although not as severe characteristics. Other ecosystems such as grassland, meadow, and several conifer types had much less sediment production. Since juniper often invade sagebrush ecosystems, it would not be unusual for them to have similar hydrologic characteristics.

Poor hydrologic condition probably results from factors such as tree form, size and competitive ability. Precipitation falling on juniper trees tends to flow down the upstretched limbs to the trunk and comes off as stem flow. In large amounts, rills can form on the soil surface beneath the trees and, in time, gullies will occur (fig. 3).



Figure 3.--This western juniper dominated site is in a deteriorated watershed condition with rill erosion in evidence.

Individual trees can transpire large amounts of water each day (Miller 1984). His experiments suggest that a single tree having a 30 cm average diameter on a cool spring day can use an average of 53 liters. With a temperature of 32° C and 15% relative humidity, the usage would average 122 liters. When placed in the context of several hundred trees per hectare, soil moisture on a site can be depleted rapidly. When limited moisture is available for plant growth anyway, the juniper seems to have a strong competitive advantage over associated shrubs and herbs. As they decline, hydrologic conditions worsen. Only if the goal of land management were to retain the high populations of juniper would the consequences of poor watershed protection and decreased soil stability possibly be acceptable.

CONCLUSIONS

As Bunch (1984) lucidly pointed out, after juniper is controlled follow-up management must be changed from the past or the problem will reoccur. This fact often is not well understood by land managers and owners. Only after cause/effect relationships are recognized and understood can effective management practices develop. Whether an area is seeded or not following juniper removal, the grazing management applied will be critical to ultimate success. As an example, conventional wisdom suggests deferring grazing for a season or two after control to allow plants to regain vigor, or if seeded, for new plants to establish. The converse should be done - that is - graze early in the season for short periods of time so the result is utilization of all herbaceous species.

Both annuals and perennials will be grazed, but if timing is correct, most regrowth will be perennial. Such delayed regrowth of perennials has the potential for producing viable seed. One of the limiting factors to viable seed production is occurrence of late frost. Observations suggest that more viable seed results when growth is delayed. Also, early short duration grazing serves somewhat of a weed control function.

Summing up -- western juniper will continue to have a dominant negative impact on range watersheds until the value of all of the products of progressive management is better recognized and accepted. More scientific information will help greatly. The situation that presently occurs took many years to develop and cannot be changed overnight. Because of the magnitude of juniper population changes, the kinds of sites occupied, and the economics of conversion, western juniper will probably continue to expand its site control for some years to come. What we can work for are positive attitudes and accurately knowing the consequences of various actions.

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HERBAGE PRODUCTION AND LIVESTOCK GRAZING ON PINYON-JUNIPER WOODLANDS

Warren P. Clary

ABSTRACT: In the past 10 years relatively little new information has become available on herbage production and grazing systems for most areas of the pinyon-juniper ecosystem. Although there are some similarities across the woodlands in herbage production and response to tree removal, the great variety of environmental conditions in which pinyon-juniper woodlands exist reduces the applicability of average values. Broad comparisons of published data suggest that grazed plant communities may have substantially less herbage production than ungrazed plant communities. Continuous season-long grazing at proper stocking rates appears to produce the heaviest calf weights in summer rainfall areas, but no information is available from other parts of the woodlands. New grazing systems are currently being tested.

INTRODUCTION

Pinyon and juniper occur mingled as scattered trees and as extensive stands throughout the Southwest and the Nevada and Utah parts of the Great Basin. The species vary with geographic location. For instance, in Nevada and western Utah singleleaf pinyon (Pinus monophylla) and Utah juniper (Juniperus osteosperma) predominate; in eastern Arizona and in New Mexico pinyon (Pinus edulis) and oneseed juniper (Juniperus monosperma) are the major components of the woodlands. Rocky Mountain juniper (Juniperus scopulorum) occurs at higher elevations in northern New Mexico and Colorado, and alligator juniper (Juniperus deppeana) at higher elevations in southern New Mexico and central and eastern Arizona (Lymbery and Pieper 1983). Various other combinations of pinyons and junipers occur where their ranges overlap. Several juniper species may be found in the same area, particularly in the center of the distribution of the pinyon-juniper woodlands. Little overlap normally occurs of the ranges of the pinyon species.

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Warren P. Clary is Supervisory Range Scientist, Intermountain Research Station, Forest Service, U.S. Department of Agriculture, Boise, ID.

Throughout these woodlands average annual precipitation of as little as 8 to as much as 22 inches is distributed in summer-dominant to to winter-dominant patterns. The proportion of an average year's precipitation falling during April to September varies from approximately three-fourths in eastern New Mexico to about one-third in much of Nevada. A pronounced spring drought trend occurs along an east to west gradient (Paulsen 1975). Eastern New Mexico normally has a Great Plains precipitation pattern peaking in May. Farther west this pattern is lost so that western New Mexico and Arizona experience a distinct spring drought. To the north and west of Arizona the Great Basin precipitation pattern extends the winter moisture somewhat later into the spring than the California pattern affecting Arizona (Jameson 1969). Mean annual temperatures range from 40 to 61°F (West and others 1975).

The pinyon-juniper woodlands occur on a great diversity of soils. For instance, in Arizona they occur on a variety of soils developed from a multitude of sandstones, shales, limestones, granites, Tertiary and Quaternary volcanics, and mixed alluvium (Springfield 1976). Soil textures vary from stony, cobbly, and gravelly loams to clay loam and clay, and in depth from shallow to deep. This great diversity of soils and geologic formations supporting the pinyon-juniper woodlands suggests that climate and perhaps other forces such as fire are significant factors controlling the woodland distribution.

The variation in understory vegetation appears to be largely related to climatic patterns (West and others 1975). For example, in the cold winter/dry summer regimes of northern Arizona to Nevada, sagebrush (Artemisia spp.) and several cool-season grasses such as bluegrass, ricegrass, squirreltail, and wheatgrass (Poa spp., Oryzopsis spp., Sitanion spp., and Agropyron spp.) dominate the composition. Farther south and east into central New Mexico where the winters are dry, warm season grasses such as the gramas (Bouteloua spp.) are most noticeable. South of the Mogollon Rim in Arizona, where the winters are cool and moist, chaparral understories often occur [mainly shrubby oaks (Quercus spp.) and manzanita (Arctostaphylos spp.)] (Clary and Jameson 1981; West and others 1975). Herbage production in open pinyon-juniper stands may be as much as 600 lb/acre, although dense tree stands often result

in herbage production levels of less than 100 lb/acre (Wright and Bailey 1982).

Historically, livestock grazing has been the most important use of these southwestern woodlands. Because herbage production often appears to be reduced in the presence of pinyon or juniper trees, a considerable effort has been expended to reduce or eliminate the tree overstory in many locations. The need for such extensive control measures has been disputed. Field data which would help answer this question are scarce in most of the woodland areas (Pieper 1983).

Several earlier studies from Arizona have shown that an increase of tree canopy cover from 0 to 10 percent can reduce herbage production by about 50 percent while additional increases in canopy cover have comparatively modest effects on herbage production (Clary and others 1974; Jameson 1967). Similar results were obtained in western New Mexico (Short and others 1977). In the Great Basin, however, moderate levels in tree canopy may result in greater total reductions in the understory than for the Southwest (Arnold and others 1964; Tausch and others 1981). Thus it is more typical to see a grassy understory occurring within a pinyon-juniper stand in the Southwest than in the Great Basin.

Current information suggests that only partial control of pinyon-juniper stands may result in little response of understory vegetation (Pieper 1983). A trial, in fact, showed no effect from thinning pinyon-juniper trees (Short and others 1977).

A number of studies have shown an increase in herbage production following tree control, and this response is often related to climate, and in some cases to soil type. The mechanism of tree control over herbage production has been assumed to be soil moisture, physical and chemical effects of needle litter, light reduction, or a combination of these factors (Jameson 1966; Pieper 1983; Schott and Pieper 1985). Redistribution of available nutrients from interspaces between trees to enriched locations under the tree crowns has also been proposed as an herbage reduction mechanism (Everett and Sharrow 1983, 1985).

RECENT INFORMATION ON HERBAGE PRODUCTION

No flood of new information is available on herbage production in pinyon-juniper woodlands. A similar problem was found 10 years earlier by Dwyer (1975). New information is certainly available--mostly on plant cover--but not a great deal on herbage production. There are several likely reasons for this. One, assembling herbage production data requires time-consuming measurements and they must be repeated for several years to obtain a reasonable estimate of average yields. Two, there seemed to be a reduced interest in the pinyon-juniper woodlands for most of the past 10 years.

Overstory-Understory Relationships

Only one overstory-understory reference was found that had been published within the past 10 years (Short and others 1977). Here the relationship of herbage production versus number of trees per acre showed trends similar to those of earlier studies (fig. 1). A relatively small number of trees (about 40 per acre) resulted in a one-half reduction in herbage production. Maximum herbage production of about 1,000 lb/acre occurred in the absence of trees and apparently in the absence of shrubs. Current annual growth of several shrubs [hairy mountain-mahogany (Cercocarpus breviflorus), Wright silktassel (Garrya wrightii), and skunkbush sumac (Rhus trilobata)] also decreased as the number of trees increased, but the decrease was at a very modest rate compared with the changes in herbage production. The numbers of small gray oak trees (Quercus grisea) appeared to increase slightly as the numbers of pinyon and juniper trees increased.

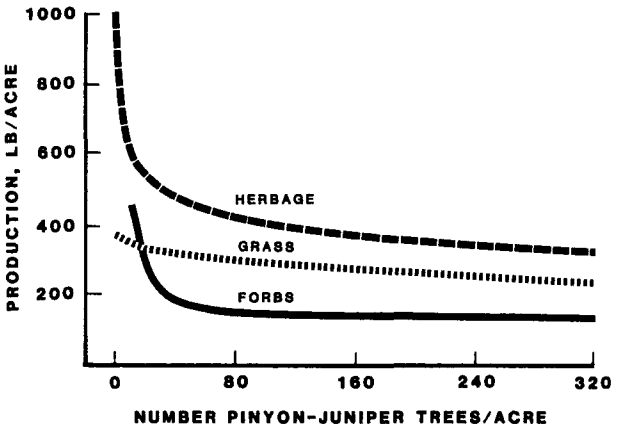


Figure 1.--Grass, forbs, and total herbage production related to pinyon-juniper tree densities (from Short and others 1977).

Herbage Production Increases Following Tree Removal

The land management agencies have a substantial amount of allotment-specific information dealing with forage production and utilization and with range condition and trend, but much of this has not been brought together in a form that is readily accessible. Several sources of information are available from work conducted or supported the Forest Service's Intermountain Region. Phillips (1977) studied 18 chaining project areas and found an average increase in perennial grasses, perennial forbs, and shrubs of 696 lb/acre with 600 lb of the gain being grasses. Forty-six percent of the chained acres had total increases of less than 500 lb/acre, 36 percent gained between 500 and 1,000 lb/acre, and 18 percent gained more than 1,000 lb/acre. The

projects were 2 to 20 years old and the seeding rates ranged from 6 to 12 lb/acre. Plantings were dominated by seed of introduced wheatgrasses with lesser amounts of other grasses, forbs, and shrubs. The total herbage increase measured on these sites would likely have been somewhat higher if annuals had been included in the measurements.

A similar study in southern Utah showed an average of 53 lb/acre in an unchained control area of which 79 percent were native grasses. The average increase in understory plants after chaining and seeding (10 lb of seed mix/acre) was 665 lb/acre of which 93 percent was grasses (Phillips 1979). On 18 National Forest sites in Utah, 4 to 20 years after chaining, the average increase in production of grasses was about 361 lb/acre for a total production of 379 lb/acre (Payne and Busby 1980). Reseeded allotment areas in the Southwest appear to average 600 lb/acre ranging from 350 to 900 lb/acre depending upon the ecological site (Dalen 1985).

Typical data from central Utah showed average herbage production of 694 lb/acre after chaining and seeding compared to 60 lb/acre without treatment (Clary 1983). In the Colorado River Basin herbage production increased significantly on 13 of 14 pinyon-juniper sites after chaining and seeding. Herbage production increases varied from less than one to more than 6 times previous production (Hessary and Gifford 1979).

In an Arizona study of a highly disturbed transmission line corridor, a pinyon-juniper control project, and an undisturbed area, significant differences remained after 25 years. The corridor site produced 995 lb/acre of herbage, the tree control site produced 672, and the undisturbed site produced 400 lb/acre. Cool-season grasses averaged 250 lb/acre on the two tree removal sites; on the undisturbed site they averaged 28 lb/acre. No seeding was done (Kruse and others 1979). Rippel and others (1980) in New Mexico found herbage production to be only marginally better 2 years after two-way cabling of pinyon-juniper stands.

Johnsen and Gomm (1981) studied forage plantings on four Arizona pinyon-juniper climatic subtypes. Average herbage production of plantings of adapted individual species varied from 634 lb/acre to 1,569 lb/acre. All sites but one (a cold-dry site) had average production greater than 1,300 lb/acre. These values are near those produced by native vegetation on other Arizona locations from which the trees and shrubs were removed and where the sites were protected from grazing (Clary and Jameson 1981). Production averaged 1,205 lb/acre on basalt-derived soils and production on other soils averaged 1,365 lb/acre. These values are substantially higher than those reported for grazed areas (tables 1 and 2).

Table 1.--Comparison of herbage production on different sites under grazed conditions

Production	Annual production (lb/acre) reported by various authors						
	Phillips 1977	Phillips 1979	Kruse and others 1979	Payne and Busby 1980	Rippel and others 1980	Clary 1983	Dalen 1985
Production before tree removal							
Grasses	--	42	208	18	427	--	--
Total	--	53	400	--	600	60	--
Production increases after tree removal							
Grasses	[1]600	620	[2]286	[3]361	[2]58	--	--
Total	696	665	434	--	197	634	--
Total production after tree removal							
Grasses	--	662	494	379	485	--	--
Total	--	718	834	--	797	694	600
Range of total when from differing sites	100 to 2,000			202 to 676			350 to 900

[1]Perennials only.
[2]No seeding.
[3]Grasses only.

Several studies have been made of the effect of pinyon and juniper removal on habitat characteristics for deer and elk. In Arizona, tree removal by wildfire resulted in an increase of perennial cool-season grasses and palatable forbs to 373 lb/acre from 96 lb/acre, while in a second location tree removal by cabling caused these same plant groups to increase from 38 lb/acre to 91 lb/acre (McCulloch 1979). In New Mexico, Short and others (1977) studied effects of treatments that include: uprooting all trees, grouping and burning; uprooting all trees and leaving them in place; and uprooting all trees except on northeast slopes greater than 15 percent. Herbage production averaged 712 lb/acre compared 472 lb/acre for the untreated and thinned areas. No mention was made of seeding following tree removal on these wildlife habitat study areas.

Table 2.--Comparison of herbage production on different sites under ungrazed conditions

Production	Annual production (lb/acre) reported by various authors			
	Johnsen and Gomm 1981	Clary and Jameson 1981	Short and others 1977	
Production before tree removal				
Grasses	--	89	368	--
Total	--	193	472	--
Production increases after tree removal				
Grasses	--	[2]849	144	--
Total	--	1,092	240	--
Total production after tree removal				
Grasses	[1]1,242	938	512	[3]370
Total	--	1,285	712	[3]1,000
Range of totals when from differing sites	634 to 1,569	638 to 3,303		

[1]Adapted seeded species.
[2]No seeding.
[3]From overstory-understory graph-apparently from areas without shrubs.

Prediction methods that would describe site production potential for a wide range of environmental conditions would be a useful guide to where vegetation management would be worthwhile. In one example, herbage production after tree removal was found to be predictable from average precipitation, pretreatment tree canopy cover, pretreatment nitrate-nitrogen, and presence or absence of limestone soil. The herbage production means varied from 638 lb/acre to 3,303 lb/acre across the study sites (Clary and Jameson 1981). The same data were examined in more detail and the theoretical aspects were explored (Clary and Jensen 1981). A hypothetical predictive model was developed graphically and described in FORTRAN.

Unfortunately, little environmental information is available for study sites from which most herbage production data have been obtained. The most detailed information is from studies in northern Arizona (Clary and Jameson 1981; Johnsen and Gomm 1981). Data are particularly lacking relating herbage production to environmental conditions in the western summer-dry areas of the pinyon-juniper woodlands. A far more complete understanding of grazing history, plant composition including seeded species, site factors, and climatic factors in relation to herbage yields is necessary to make accurate predictions of response to tree removal. Currently, in many cases, experience in the local area appears to be the only guide.

In addition to the herbaceous plants described here, chained or cabled areas often sustained substantial numbers of shrubs and small pinyon-juniper trees which either survived the treatment or became established afterward. Phillips (1977) reported an average of 154 pinyon and juniper trees and 764 sagebrush plants per acre following chaining on a number of sites. He later (Phillips 1979) reported 429 pinyon and juniper trees and 309 sagebrush plants per acre after chaining in southern Utah, which represented decreases of 35 percent and 22 percent, respectively, compared to the control. On sites studied by Payne and Busby (1980), there were 115 and 153 trees per acre for chained and unchained conditions, respectively; there were 251 sagebrush plants per acre on chained sites compared to only 80 per acre on unchained sites. In New Mexico, Rippel and others (1980) recorded 233 trees per acre before cabling and 105 after cabling. Short and others (1977) reported 107 shrubs per acre in bulldozed stands compared to 278 shrubs in untreated or thinned stands of pinyon-juniper.

RECENT INFORMATION ON LIVESTOCK GRAZING

Most of the southwestern pinyon-juniper ranges are grazed year-long, especially those in private ownership, because of the mild climate of the woodland type. About one-half of the National Forest allotments are grazed year-long, but other allotments may be restricted to one or more of the major seasons of the year. Lower elevation southern locations are most likely to be grazed year-long, while grazing at higher elevation northern locations is most likely to be limited to summer. Intermediate locations are often grazed at various seasons (Springfield 1976).

In 1972, the permitted livestock use on woodland ranges in the National Forests of Arizona and New Mexico was 630,000 animal unit months (AUM) for cattle and 140,000 AUM for sheep. The sheep numbers had declined drastically since World War II. Carrying capacities of these woodland ranges were estimated to be 3.9 acres/AUM on good-condition ranges down to 28.2 acres/AUM on very poor condition ranges (Springfield 1976). Some preliminary estimates of livestock carrying capacity on a few Nevada sites, where trees had been removed but no seeding had been done, fell below the range of those previously described for the Southwest (Everett and Sharrow 1984).

Springfield (1976) suggested that continuous and often heavy grazing, with little or no concern

for the needs of the plants, has been the prevailing system on many southwestern pinyon-juniper woodlands for several centuries. Only in fairly recent times have various rotation or deferred systems been adopted. Through the efforts of conservation-minded agencies, increasingly larger acreages of private and public lands are being brought under more intensive management. As an example, more than one-half of the National Forest woodland ranges are now under some form of rest-rotation or deferred-rotation system.

In the Intermountain area on federally managed land, the typical grazing pattern is continuous use each year during the spring period as an intermediate grazing zone between winter and summer range. The location of woodlands along slopes of desert mountain ranges in the Great Basin probably makes improved management somewhat more difficult to achieve there than in many areas of the Southwest. However, if the more productive sites have been chained and seeded, more intensive grazing systems, which include some rest, are often applied there.

Currently, grazing procedures similar to those advocated by Allan Savory are being applied to private and public lands, particularly in New Mexico (Allison and others 1982). Several of the Savory Grazing Method cells have been installed on National Forest allotments in Arizona. At present, a limited survey of range managers associated with these administrative trials shows, as might be expected, some differences in opinion as to the benefits of such a grazing system or grazing method. In several cases the allotments converted to a Savory type of system were rather large, which resulted in the pastures of a grazing cell being several miles long. This sometimes caused animal distribution or handling problems, particularly where young calves were involved. All managers agreed that a major commitment is required for success of such a system, and that different kinds of sites will not likely respond similarly (Allison and others 1982).

A short-duration grazing study is being conducted in the Great Basin pinyon-juniper in Tintic Valley on crested wheatgrass seedings (Malechek and others 1985). Initial results show no clear distinction between short-duration grazing and continuous season-long grazing in livestock biting rate, forage ingestion rate, forage digestibility, and animal weight gain.

Published results of grazing studies in the pinyon-juniper woodlands are very difficult to find. In New Mexico at the Fort Stanton Experimental Ranch, calf weights were greater under continuous grazing than under a four-pasture, one-herd system, although grass production and total production were greater under the rotation system (Pieper and others 1978). Considerable variability was present in studies of dietary digestibility between these two systems. Although the cattle in the continuous system appeared to have an opportunity to select a more digestible diet, the authors did not believe that this fully explained the weight gain difference (Pfister and others 1984). At the same location, initial results comparing a moderately continuously grazed pasture and a short-duration cell showed a higher proportion of grasses, mainly blue grama (Bouteloua gracilis), in the cattle diets on the continuously grazed pasture (Long and others 1982). Apparently the diets in the short-duration cell had greater amounts of forbs or shrubs at various times, but this result was not consistent.

SUMMARY AND CONCLUSIONS

1. There is no wealth of new published information on herbage production and livestock grazing in the pinyon-juniper woodlands.

2. The great variety of environmental conditions in the pinyon-juniper woodlands reduces the usefulness of average values. Direct comparisons of data from specific, but different, situations appear to have limited value because there is typically little documentation of weather, soils, grazing history, seeding success, and sometimes even of plant composition.

3. Total herbage production under grazed dense to open woodland stands varied from 60 to 400 lb/acre. The residual understory production in untreated woodlands appeared to be greater in Arizona and New Mexico than in the Great Basin States. This is probably why less forage plant seeding was done on southwestern tree control projects.

4. Increases in total herbage production on grazed areas following tree removal averaged about 500 lb/acre but a great deal of variation occurred. The portion of the increase in perennial grasses was highly affected by initial plant composition, method of tree removal, success of seeding if done, and the ecological site. Total production after treatment averaged 700 to 800 lb/acre, but varied from about 300 to over 3,000 lb/acre.

5. In the Southwest, production of native and introduced herbaceous species often exceeds 1,200 lb/acre when protected from grazing. This suggests a greater suppression of herbage yields by grazing than is generally assumed, because herbage yields in grazed areas are usually under 900 lb/acre. Several possible reasons include direct effects on plant physiology, soils impacts, and competition of shrubs that tend to increase more rapidly under grazing.

6. In the Southwest, herbage production after tree removal and protection from grazing was predictable from precipitation, pretreatment tree canopy, pretreatment nitrate-nitrogen, and presence or absence of limestone soils.

7. An average of 200 small trees per acre remained after chaining or cabling pinyon-juniper stands, and in sagebrush areas over 400 sagebrush plants per acre remained.

8. Much of the pinyon-juniper woodland is grazed under low-intensity, season-long or year-long management at often heavy levels of use, although increased acreages have been brought under some form of improved management.

9. Several trial grazing systems similar to that advocated by Savory have been installed in southwestern pinyon-juniper areas. Most of these installations are too recent to provide a sound basis for evaluation as yet. In the Great Basin, a short-duration grazing system is being tested with crested wheatgrass stands. Initial results show no clear distinction in effects of short-duration and continuous, season-long grazing when stocking is at the same rate.

10. At present, only limited published information is available on the good or bad points of any grazing system in the pinyon-juniper woodlands, except that season-long grazing in the summer-wet parts of the type may be best for animal weight gains when animal stocking rates are proper. In any event, results for the eastern or summer-wet part of the woodlands will not likely fit the western or summer-dry portion. Major efforts in grazing management evaluation should proceed in several areas of these extensive woodlands.

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SELECTIVE CONTROL OF PINYON-JUNIPER WITH HERBICIDES

Kirk C. McDaniel and Linda WhiteTrifaro

ABSTRACT: Various rates of tebuthiuron and picloram pellets were applied on pinyon-juniper woodlands in New Mexico to determine effects on the trees and associated shrubs. Pinyon (Pinus edulis) were generally controlled with 1.0 lb active ingredient (a.i.)/ac of tebuthiuron, and 0.8 lb a.i./ac of picloram. About 0.8 lb a.i./ac of tebuthiuron pellets controlled one-seed juniper (Juniperus monosperma) growing on sand or loamy sand, whereas 1.5 lb a.i./ac was needed to control the trees on loamy or clay loam soils. Picloram controlled one-seed juniper at a 2.0 lb a.i./ac rate on sandy and loam soils, but did not satisfactorily kill the trees on clay loam soils. Wavyleaf oak (Quercus undulata), sand sagebrush (Artemesia filifolia), skunkbush (Rhus trilobata) and algerita (Berberis spp.) were controlled by tebuthiuron at 0.8 lb a.i./ac, but were not generally controlled by picloram. Higher rates of tebuthiuron and picloram are needed to control trees and shrubs on deep, fine textured soils than on shallow, coarse textured soils. Trees less than 10 feet tall were usually more readily controlled than larger trees.

INTRODUCTION

Brush management in pinyon-juniper (P-J) woodlands can essentially be broken into three distinct phases since 1950. From 1950 to 1965 over one million acres throughout the western United States were treated with the objective of converting P-J woodlands to grasslands. Mechanical methods were the primary technology employed during this era. During the mid 1960s to early 1980s, the emphasis on land conversion began to diminish because of public concerns and questions about the ecological value of such practices. Further, the resource value of the trees came of age and the optimization of a single return product, such as increasing forage for livestock, could not be justified by benefit-cost analysis. From 1965 to 1980 little new technology was developed or applied for brush management in the P-J type.

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Kirk C. McDaniel is Associate Professor, and Linda WhiteTrifaro is a graduate assistant, Department of Animal and Range Sciences, New Mexico State University, Las Cruces, NM.

Presently, management of P-J woodlands is characterized by a comprehensive approach towards yielding benefits from the total resource base. The value of the trees is equal to or exceeds that of forage and, therefore, is taking precedence in management decisions. The primary goals for manipulating P-J woodlands prior to the 1980s were (a) to increase forage production for livestock, (b) to improve watershed characteristics, (c) to improve wildlife habitat, and (d) to facilitate livestock handling (Evans and others 1975). Manipulating these woodlands for the benefit of tree growth was usually not a primary consideration.

In recent years interest in the use of herbicides has increased, both for the reasons listed above by Evans and others (1975) but also as a silvicultural tool for improving a tree stand. Herbicides for use in P-J have been examined since the 1960s (e.g. early tests with such chemicals as monuron, karbutilate, and bromacil, among others) but until recently have not been used commercially on a wide scale basis. Herbicides were considered to be useful on an individual plant basis but were not considered for aerial broadcast until tebuthiuron and picloram were registered for this use in the early 1980s.

In New Mexico, aerial field trials using picloram and tebuthiuron have been applied (since 1981) by various agencies, chemical companies and ranchers in addition to New Mexico State University test plots. In summer 1985 we collected results of treatments from all known aerial herbicide trials in New Mexico. Many of the herbicide trials reported were not established for research purposes, but do provide a valuable comparison of different herbicide rates and formulations. Data describing site conditions, species treated, size of trees, associated vegetation, and soil type were included in order to develop treatment recommendations and to identify areas where further research may be required.

PINYON-JUNIPER CONTROL WITH PICLORAM AND TEBUTHIURON

In a paper by Evans and others (1975) given at the previous pinyon-juniper conference, research on various herbicides for control of these trees was described. However, at that time no chemical compounds were specifically registered or commercially available for control of pinyon-juniper. Evans and others (1975) reported at some length the potential use of picloram (4-amino-3,5,6-trichloropicolinic acid) and karbutilate

(test-butylcarbonic acid) ester with 3-(m-hydroxphenyl)-1, 1-dimethylurea) when applied on an individual plant or broadcast basis. Picloram is currently registered with the Environmental Protection Agency and has been used commercially in New Mexico since 1981. Karbutilate has been applied on an experimental basis, but to our knowledge, never on a commercial basis in New Mexico.

Picloram is formulated as a liquid for primarily foliage activity or as a 10% a.i. pellet for soil activity. Picloram has a low level of toxicity to mammals and is relatively selective in not killing grasses. Pelleted picloram applied by hand or aircraft at 2 to 4 lbs/ac has effectively controlled mature redberry juniper (Juniperus pinchotti) in the Rolling Plains and Edward Plateau regions of Texas (Schuster 1976; Scifres 1972). Ueckert and Whisenart (1982) reported redberry juniper seedlings to be more easily controlled by foliar sprays (0.5% a.i.) of picloram than equivalent rates of pelleted or granular formulations. Young and others (1982) reported a lower investment in time and cost when applying picloram by hand compared to mechanical clearing of western juniper (Juniperus occidentalis). Johnson and Dalen (1984) applied pelleted picloram to juniper trees and found Utah juniper (Juniperus osteosperma) most sensitive to the herbicide, one-seed juniper least sensitive, and alligator juniper (Juniperus deppeana) intermediate. Applications of 3.6 gms a.i. of picloram per meter of tree height controlled all species, but only Utah and alligator juniper were consistently controlled with 1.8 gms a.i. or less per 3 feet of height.

Tebuthiuron [N-(5[1,1-dimethylethyl]-1,3,4-thiadiazol-2-yl)-N,N'-dimethylurea] was not discussed by Evans and others (1975) but was registered for commercial rangeland use in Texas and Oklahoma in 1980, and in New Mexico in 1981 for control of a variety of woody plants including pinyon and some juniper species. In western Oregon, Britton and Sneva (1981) reported only 1 and 22 percent of western juniper trees killed when pelleted tebuthiuron was applied by aircraft at rates of 2 and 4 lbs/ac, respectively. However, results from individual plant applications indicated that smaller western juniper trees could easily be killed by the herbicide (Britton and Sneva 1981). Tebuthiuron applied at rates of 2 and 4 lbs/ac to eastern red cedar (Juniperus virginiana) did not provide satisfactory control where trees occurred as a scattered component in an area dominated by post oak (Quercus stellata) and blackjack oak (Quercus marilandica) (Scifres and others 1981). Clary and Goodrich (1983) applied pelleted tebuthiuron aerially on several sites in the Fish Lake National Forest in Utah and reported crown kills of Utah juniper at 78, 97 and 98 percent at rates of 1.0, 2.0 and 2.5 lb/ac, respectively. They found trees under one and one-half feet to be less susceptible to the herbicide and percent crown kill of trees to be higher on ridges and side slopes compared to bottomlands.

Tebuthiuron and picloram are classified as a non-selective, soil applied sterilants, although selectivity is accomplished by dosage (Masters and Scifres 1984). The herbicides when formulated as clay pellets require rainfall to dissolve and transport the chemical into the root zone where it is normally concentrated in the surface 6 inches of soil (Bovey and others 1978). As a general rule, the optimum time of application is just prior to seasonal rainfall which dissolves the pellet and often stimulates rapid vegetative growth (Elanco 1983). Once in the root zone, the chemicals are absorbed by the roots of woody species and move by transpiration in the xylem to plant stems and leaves.

Picloram is only transported by the xylem if the chemical is applied as a dry formulation, but it can also be foliar applied as a liquid and transported in the phloem. The most active mechanism for picloram to enter usually differs for a particular species. Picloram affects a multitude of vital processes, so it is difficult to attribute its biological activity to disruption of any given process (Bovey and Scifres 1971). Low levels of picloram promote the growth of some species and inhibit that of others depending on species, stage of growth, herbicide concentration, and the specific tissue to which it is applied (Scifres 1980). Nucleic acid metabolism and various enzymes in stems are disrupted by picloram. In general, broad leaf species are most susceptible to picloram, grasses are least susceptible, and shrubs and trees are intermediate. Pinyon and juniper species are probably most susceptible to soil applied formulations of picloram with the exception of seedlings which have a small root system and are less likely to absorb the chemical in the soil (Ueckert and Whisenart 1982).

The primary control mechanism of tebuthiuron within a plant is the inhibition of photosynthesis (Bauer and Bovey 1975). Specifically, electron transport at the reducing side of photosystem II is inhibited along with the ability to produce food, thus non-structural carbohydrates are reduced (Hatzois and others 1980). The response of most woody plants to tebuthiuron is slow, with repeated defoliations, until carbohydrate reserves are depleted and death occurs. The cycles of defoliation-refoliation caused by tebuthiuron are dictated by rainfall patterns (Sosebee and others 1978; Scifres and others 1979). The first defoliation after application typically occurs between 30 to 90 days after rainfall (Scifres and Welch 1982).

Tebuthiuron, then, acts more slowly than other soil applied herbicides such as picloram (Meyer and Bovey 1979) and control of woody species may take as long as 3 years especially in arid and semi-arid rangelands (Elanco 1983). The persistence of tebuthiuron or picloram in the soil is a beneficial characteristic in that they may effectively control some woody plants for five or more years (Sosebee and others 1979; Jacoby and Meadors 1982; Britton and Sneva 1983).

Within the soil, tebuthiuron or picloram are absorbed to organic matter and clay particles (Chang and Stritzke 1977). Organic matter could be more significant than clay in regulating herbicide availability, however, the organic matter in most rangeland soils is so low that its net influence is less than that of clay (Elanco 1983).

Both tebuthiuron and picloram are metabolized by soil microorganisms, mainly via demethylation. The rate of degradation is dependent upon growing vegetation, temperature, precipitation, soil type, and other edaphic variables. In Arizona, it has been calculated that tebuthiuron would degrade to a non-detectable level between 3 to 7 years (Emmerich 1985), and because only one application is necessary, accumulation does not occur. Accumulation in animal tissue is usually low or does not occur when plants treated are ingested because mammals, birds and fish rapidly transform and excrete these chemicals. Additionally, where tested, amounts of residues found in vegetation are usually well below tolerances (Elanco 1983).

Duncan and Scifres (1982) have listed three principles regarding the bioactivity of soil herbicides. First, the single most important variable in regulating response of susceptible species is rate of application. Secondly, given a specific application rate, the most important variable in regulating response of a susceptible species is soil clay content. This becomes especially important where the rate to be applied is marginal relative to susceptibility of the target species. This second principle is demonstrated in a study by Fischer and Stritzke (1978) in Oklahoma where 2 lb/ac tebuthiuron killed 98% of the oak on soils with 12.5% clay but no trees were killed on soils with 60% clay. Lastly, organic matter of soils can affect availability and thus phytotoxicity of the herbicides. But, again, due to the low organic matter content of most rangeland soils, this is usually the least significant of the three principles.

INDIVIDUAL PLANT TRIALS

Prior to our evaluations of aerial broadcast trials, we examined the results from about 85 demonstration trials established primarily for control of one-seed juniper using soil active herbicides applied on an individual plant basis. The trials were conducted by the New Mexico State University Cooperative Extension Service beginning in 1968. These trials were rarely replicated except by locations, and were not designed for statistical analysis. However, they have provided useful information on the degree of control which might be anticipated using a particular herbicide (table 1). Many of the trials were repeated at the same location for 5 or more years.

From these trials and from similar trials reported from nearby states, we have developed guidelines related to the control of juniper species on an individual plant basis in New Mexico (Duncan and McDaniel 1985). When a soil active herbicide is applied on an individual tree basis, we have found control to be related to tree species, tree height or canopy diameter, soil texture, method of application, herbicide, formulation and rate. General points or guidelines developed for New Mexico include:

1. Of the common juniper species which occur in the state, one-seed juniper and Rocky Mountain juniper (Juniperus scopulorum) are most difficult to control, Utah juniper is least difficult, and alligator juniper is intermediate. One-seed and Rocky Mountain juniper are the dominant species in the state.

2. Treating stands of young junipers is recommended since, generally, trees less than 9 feet in height are more effectively controlled than larger trees. Areas previously cabled, chained or cleared, or areas where juniper appears to be invading are stands usually selected for control.

3. Because of herbicide and application costs, tree densities of less than 150 plants per acre are recommended for control.

Table 1.--Recommended application rate for control of juniper species using soil active herbicides on an individual plant basis

		Minimum rate per 3 ft. canopy diam.	
		Soil texture	
Herbicide	A.I.	Light	Heavy
	%	tbs.	tbs.
Lithium salt of bromacil	22P[1]	2	4
Karbutilate	10G	2½	3½
Prometone	5P	No effective rate determined	
Fenuron	25P	1	2
Dicamba	5G	No effective rate determined	
Picloram	10P	1	2
Tebuthiuron	25B	3	Not recommended
Hexazione	25L	2 ml	4 ml

[1]L - liquid, G - granule, P - pellet, B - bullet.

4. Soil active herbicides are most effective when clay content is less than 15%, organic matter is less than 1% and the cation exchange capacity is less than 25 meq/100g. An exact relationship between a herbicide rate and clay content has not yet been developed, but it is known that with the chemicals available today, rate must be increased as soil clay content increases.

5. Liquid or pelleted soil applied herbicides should be distributed uniformly around the tree and outside of the canopy drip zone. High organic matter content and reduced rainfall penetration under the canopy reduces herbicide activity.

6. Forage response usually occurs after control and is highly dependent upon species present before treatment. However, a primary goal for controlling trees on an individual plant basis is usually to maintain existing forage yields in a treated area.

7. Soil applied herbicides can be used to selectively control unwanted trees which can enhance the growth of desirable trees. However, from a practical standpoint, it is usually not possible to control dense stands of associated unwanted shrubs if present. Composition of understory species must be considered in the control program.

8. Pinyon is rarely a target species for control and should be maintained. Mature pinyon is highly prized by man and wildlife because of its nut production. In New Mexico, pinyon is protected as the state tree.

BROADCAST TRIALS

While a great amount of research has been conducted on the control of juniper on an individual tree basis, relatively little work has been done examining control with broadcast applications of soil active herbicides. Tebuthiuron and picloram were first broadcast on pinyon-juniper woodlands in New Mexico in 1981. About 600 acres across 10 different locations have been treated in various research-demonstration trials. In summer 1985, we evaluated all of these trials.

It was not the original intent when these broadcast trials were established to be able to compare results in a comprehensive manner. Several of the sites were established by either Elanco Products Co. (Division of Eli Lilly and Company) or Dow Chemical Co. U.S.A. in cooperation with New Mexico State University, a rancher or an agency. The primary purpose for the trials was to establish an optimum rate for either tebuthiuron or picloram at a particular location. Results from these trials have been used as a guide for later commercial applications. Approximately 17,000 acres of P-J woodlands have been commercially treated by aerial broadcast with these two chemicals from 1981 to 1985 in New Mexico.

Our primary purpose for evaluating the sites was to determine efficacy of herbicides by species of juniper, pinyon and associated woody plants, and to determine effects on different size classes of trees. To evaluate sites, four belt transects were taken in each treated plot with the length varying depending on the size of area. Height for each tree was estimated to be in one of four size classes (less than 3, 4-6, 7-9 and 10+ feet) and herbicide damage was noted. Damage rating categories were no effect (alive), no green growth (dead), and partial defoliation. This last category was further detailed by percent of plant defoliated: 1-25%, 26-50%, 51-75% or 76-99%. If less than 25 plants were observed in a plot for a particular height class then data were not included in summary tables. Untreated woodlands adjacent to herbicide plots were used as a control, unless these areas were included in the original study design. Soil cores to 6 inch depth were obtained from areas between trees and were analyzed for soil pH, cation exchange capacity, percent organic matter and particle size.

Picloram (10% a.i.) was aerially applied at four sites in 1983 with a Pieper Pawnee "C" equipped with a Transland spreader and spreader gate. The equipment was calibrated and rates determined for each plot by taking beginning and ending weights of the herbicide. Plot size was about 20 acres (336 x 5280 ft.) with a 200 foot buffer between plots. Table 2 shows the soil texture, annual rainfall, and kill of pinyon at each of these sites. Picloram killed 88% or more of the pinyon, except for the application of 0.8 lb/ac at the Guadalupe site. Observations on pinyon not killed showed trees to be highly defoliated (usually greater than 75%). By comparison, the range in kill on one-seed juniper varied greatly by soil texture and tree size (table 3). In general, as soil texture became finer or tree size increased, control of one-seed juniper by picloram decreased. One-seed juniper not killed in plots with low picloram rates were usually only slightly defoliated (less than 25%), whereas higher rates did increase the amount of defoliation. It was our impression that one-seed juniper trees which were highly defoliated but alive after two years would continue to survive. Observations on shrubs showed skunkbush, wavyleaf oak and mountain mahogany (Cercocarpus mountanus) to be partially defoliated but rarely killed by picloram. Shrubs which were not affected by picloram included algerita (Berberis trifoliotata) and sand sagebrush.

Tebuthiuron (40% a.i.) was applied by hand broadcasting pellets in one-quarter acre plots near Gran Quivara and Corona, New Mexico in September 1981. Aerial trials were established in 1983 near the hand broadcast treatments at Gran Quivara and at new locations at Ft. Stanton and in the Guadalupe Mountains, New Mexico. Aerial treatments were applied with a Cessna Ag. Husky, equipped with an Elanco meterate and a Transland spreader. The plane flew at a height of 100 feet and swath width was about 40 feet. Plots were from one-half to one mile in length and 336 feet wide with 150 to 200 foot buffer strips between

Table 2.--Pinyon control following aerial broadcast of picloram at four locations in New Mexico[1]

Site	Soil type	Annual rainfall (inches)	Rate (lb ai/ac)	Mortality of pinyon (% Dead)
Gran Quivara	Sand	15	0.8	100
			1.2	98
			1.5	100
			2.0	100
Montoya	Loam	14	0.8	88
			1.2	89
			1.5	99
			2.0	100
Wagon Mound	Cobbly Clay loam	17	0.8	94
			1.2	99
			1.5	89
Guadalupe Mts.	Shallow Clay loam	16	0.8	58
			1.1	94
			1.5	99
			2.0	99

[1]Applied in February 1983 at Gran Quivara, Montoya and Wagon Mound; and August 1983 in the Guadalupe Mountains, NM.

Table 3.--One-seed juniper control following aerial broadcast of picloram at four locations in New Mexico[1]

Site (Soil texture)	Rate	Mortality of one-seed juniper following application of picloram by tree height				
		< 3 ft	4-6 ft	7-9 ft	10+ ft	$\bar{x}$
	(lb ai/ac)	(% Dead)				
Gran Quivara (sand)	0.8	41	59	42	29	37
	1.2	55	69	70	51	58
	1.5	57	80	67	69	70
	2.0	94	85	75	76	77
Montoya (loam)	0.8	38	19	9	6	9
	1.2	18	10	3	3	8
	1.5	77	60	65	46	58
	2.0	86	75	75	63	70
Wagon Mound (clay cobbly loam)	0.8	10	17	7	12	11
	1.2	30	16	22	20	21
	1.5	29	21	18	22	21
Guadalupe Mts. (clay shallow loam)	0.8	4	5	0	0	3
	1.1	17	2	3	4	5
	1.5	9	4	4	7	6
	2.0	58	22	24	13	31

[1]Applied in February 1983 at Gran Quivara, Montoya and Wagon Mound; and August 1983 in the Guadalupe Mountains, NM.

treatments. Table 4 shows the kill of one-seed juniper at each of these sites except for the Guadalupe Mountain site. At this site one-seed juniper were partially defoliated but none of the trees were dead. Our evaluations were made 16 months (February 1984) after treatment on the Guadalupe Mountain site which we believe is not enough time to determine the eventual effects of tebuthiuron on one-seed juniper. Elsewhere tebuthiuron proved to be highly effective for control of one-seed juniper on sandy textured soils. Higher rates of tebuthiuron were needed to control the trees on deep, finer textured soils than in shallow, coarse textured soils.

Pinyon kill at the Corona site was 79, 73 and 60% for the 1.0, 1.5 and 2.0 lb/ac rates of tebuthiuron, respectively (data not shown). Pinyon kill at Ft. Stanton was 32, 37 and 60% for rates of 0.8, 1.25 and 1.5 lb/ac, respectively. Pinyon was not present on the Gran Quivara sites. Associated shrubs on sandy textured soils which were usually killed (at least 75% mortality) by all rates of tebuthiuron included sand sagebrush and skunkbush. Tebuthiuron had little effect on cactus. On loam or clay loam soils tebuthiuron at 1.0 lb/ac proved most effective for control of algerita and wavyleaf oak (approximately 50% or higher mortality) but was less effective for control of skunkbush (less than 50%).

Tebuthiuron (40% a.i.) and picloram (10% a.i.) were applied side-by-side for control of Rocky Mountain juniper and pinyon at one location near Maxwell, New Mexico in October 1981. The herbicides were aerially applied with a Pieper Pawnee "C" aircraft on plots 336 x 1640 feet. Soil on the site is a sandy loam and annual rainfall is 17 inches. Neither tebuthiuron or picloram killed Rocky Mountain juniper at the 0.8 lb/ac rate (table 5). About 34% of the Rocky Mountain juniper were killed with a 1.25 lb/ac rate of tebuthiuron, but few of the trees were killed at the same rate by picloram. Control of Rocky Mountain juniper and pinyon with tebuthiuron generally decreased as the trees became larger. Picloram was more effective than tebuthiuron in killing pinyon and a few ponderosa pine (Pinus ponderosa) that occurred mainly in drainage bottoms at this site. Most of the pinyon trees were mature, reaching heights of 30 feet or higher. These trees are prized for their nut production and killing the trees was not considered to be beneficial.

From these data in New Mexico several important points were learned which we believe provide direction for future research needs in the aerial application of herbicides in the P-J ecosystem. These are:

1. A better understanding of the relationship between soil texture and herbicide activity is needed. Unquestionably, soil type is an important factor affecting herbicide activity.

2. At comparable rates, tebuthiuron is more effective than picloram for control of a wider range of tree and shrub species. Tebuthiuron

Table 4.--One-seed juniper control following broadcast of tebuthiuron at four locations in New Mexico[1]

Site (Soil texture)	Rate	Mortality of one-seed juniper following application of tebuthiuron by tree height				
		< 3 ft	4-6 ft	7-9 ft	10+ ft	$\bar{x}$
	(lb ai/ac)	(% Dead)				
Gran Quivara[1] (sand and shallow sand)[2]	1.0	100	100	100	100	100
	1.5	100	100	100	100	100
	2.0	100	100	100	100	100
Corona[1] (shallow clay loam)	1.0	50	67	58	27	49
	1.5	50	86	76	76	75
	2.0	100	80	100	67	89
Gran Quivara[2] (deep sand)	0.8	100	77	84	67	76
	1.0	90	78	75	75	77
	1.25	98	97	93	89	92
	1.6	92	99	97	88	94
Ft. Stanton[2] (deep loam)	0.8	17	0	0	0	0
	1.25	40	0	22	9	13
	1.5	67	36	43	37	40

[1]Applied by hand scatter in September 1981 at Gran Quivara and Corona.

[2]Applied by aircraft at Gran Quivara in March 1983 and at Ft. Stanton in August 1983.

Table 5.--Mortality of trees and shrubs with broadcast aerial applications of pelleted tebuthiuron and picloram near Maxwell, NM[1]

Plant species	Plant size	Tebuthiuron rate (lb/ac) 0.8	1.25	1.7	Picloram rate (lb/ac) 0.8	1.25
	Ft	% Dead				
Rocky Mountain juniper	1-3	0	100	40	0	0
	4-6	0	50	39	0	0
	7-9	0	63	30	1	0
	10+	0	16	26	0	4
	$\bar{x}$	0	34	30	0	3
Pinyon	1-3	17	50	-	52	86
	4-6	24	77	73	57	98
	7-9	35	62	51	63	97
	10+	18	54	16	77	73
	$\bar{x}$	22	59	56	66	81

[1]Applied October 21, 1981, evaluated June 14, 1981.

killed or suppressed one-seed juniper, Rocky Mountain juniper, pinyon, sand sagebrush, skunkbush, wavyleaf oak and algerita. Picloram killed pinyon and ponderosa pine but provided less control than tebuthiuron on the other tree and shrub species.

3. A minimum herbicide rate needs to be determined for unwanted understory shrubs when the goal is to maintain an existing tree stand. For example, near Gran Quivara an approach is now being investigated for the control of sand sagebrush and skunkbush in the understory while maintaining a widely scattered tree layer. Low rates (less than 0.5 lb/ac) of tebuthiuron are being applied with the goal of controlling shrubs but killing a minimum number of trees. The herbicide was applied in 1984 and 1985 but results are not yet available.

4. An objective for pinyon-juniper management expressed to us by some agency conservationists working in the P-J type is to be able to kill smaller trees by broadcast applications while maintaining larger trees. While larger trees were usually not killed as often as smaller trees in the trials we examined, the difference was usually not very great at a particular herbicide rate. Further work is needed in this area.

INTEGRATED BRUSH MANAGEMENT IN PINYON-JUNIPER WOODLANDS

Development of Integrated Brush Management Systems (IBMS) has recently become a popular approach to applying control programs in rangeland ecosystems (Scifres 1980; Scifres and others 1983; Young and others 1983). This approach which recognizes the potential value of woody plants may be particularly appropriate in pinyon-juniper woodlands. The IBMS approach uses a favorable economic result from brush control or any other alternative management practice as a primary consideration for management.

The first step in IBMS according to Scifres and others (1983) is to develop clearly stated objectives for the long term use of land. Management goals are then set and a sequence of treatments and practices is devised at the outset to reach these objectives (Scifres 1981). However, as we have seen from the history of use of pinyon-juniper woodlands, management goals change over time. This change may result from new technologies, new uses demanded by the public or a changing political or economic environment.

Herbicides can be applied as a method of initial control or as a low-cost secondary treatment to maintain and extend the effective life of a previous brush control project. However, applying a herbicide as a single brush management method in pinyon-juniper woodlands may not provide a return on the investment. In the IBMS context there would be a need to subject the initial treatment and follow up treatments to an economic analysis as if they were a single entity. Alternative brush management methods would need to be compared as to their applicability, availability and projected potential return to benefit all other major resource products (trees, wildlife, forage, etc.).

While the economic viability of a program is a primary consideration in the IBMS approach, it is not the only criteria. The relative degree of emphasis on each resource product when planning an IBMS varies with the current or projected land use goals. Thus, no two programs developed for practical application would likely be identical.

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COMPOSITION AND PRODUCTIVITY OF A WESTERN JUNIPER UNDERSTORY AND ITS RESPONSE TO CANOPY REMOVAL

Milda R. Vaitkus and Lee E. Eddleman

ABSTRACT: Understory production was sampled in 1983 and 1984 by clipping small plots on a per tree basis. Areas with intact juniper canopies and areas from which juniper had been removed in 1982 served as treatment comparisons. Canopy removal resulted in species-specific productivity increases. Production increases were greatest beneath the canopy and least in the interspaces. Poa sandbergii did not respond to canopy removal, while other perennial grasses provided small, but variable production increases. Annual grasses and annual forbs contributed most to elevated productivity following juniper removal.

INTRODUCTION

Western juniper (Juniperus occidentalis Hook., subsp. occidentalis) is indigenous to southeast Washington, southwest Idaho, central and eastern Oregon, northwest Nevada, and northeast California. Stands are most heavily developed and highly concentrated in central and south-central Oregon (Dealy and others 1978). Evidence suggests a dramatic increase in establishment in the late 1800's and early 1900's (Burkhardt and Tisdale 1969; Adams 1975; Young and Evans 1981). Expansion into mountain big sagebrush (Artemisia tridentata ssp. vaseyana) - perennial bunchgrass communities has been especially prevalent (Burkhardt and Tisdale 1976).

Historically, wildfires were a major factor limiting distribution of this species (Driscoll 1964) and old, climax juniper stands were confined to rocky ridges, where understory vegetation was sparse (Burkhardt and Tisdale 1969, 1976). Fire suppression and overuse of rangelands by livestock have been postulated as significant factors contributing to the increase of juniper (Burkhardt and Tisdale 1976; Dealy and others 1978).

Although few studies have examined understory/overstory relationships in western juniper communities, effects of increasing tree distribution and density have been documented for the pinyon-juniper type (Dwyer 1975). In general, invasion and growth of trees reduced the quantity and quality of available forage. Arnold and others (1964) found associated herbage production decreased from 673 kg/ha (600 lb/Ac) with no tree overstory to less than 112 kg/ha (100 lb/Ac) with a 60% canopy. Stands with 80% or greater canopy produced less than 56 kg/ha (50 lb/Ac).

Canopy removal in the pinyon-juniper type has resulted in significant increases in understory production (Barney and Frischknecht 1974). Production has been shown to increase more than 10-fold for grasses and 6-fold for total herbage (Clary and Jameson 1981). Kruse and others (1979) found enhanced forage production even 25 years following juniper removal. Everett and Ward (1984), however, although they did not evaluate production, found postburn understory plant cover had reached only two-thirds that of preburn conditions five years after treatment.

In the pinyon-juniper woodlands of Arizona (Arnold and others 1964) and west-central Utah (Barney and Frischknecht 1974), annuals initially increased after clearing, peaked during the second or third growing season, and were displaced by perennials in the fourth or fifth year. In California, however, annual species still dominated sites of western juniper removal 7 years after treatment (Evans and Young 1985).

Although thousands of acres of western juniper-covered lands in Oregon have been controlled by a variety of methods, no forage response research preceded or accompanied these efforts (Bedell and Bunch 1978). To obtain information on western juniper understory relationships for management purposes, we decided to examine (1) the relationship between western juniper canopies and their understory herbage composition and production, and (2) the response of understory herbage composition and production to western juniper canopy removal.

STUDY AREA AND METHODS

The study area was located 8.8km (5.5 miles) southeast of Prineville in central Oregon on a gentle north, northwest-facing slope at an elevation of approximately 1220m (4000 ft). Soils were Frigid Pachic Argixerolls, relatively shallow (63.5cm /25in/) stony loams, derived from basaltic parent materials. Long-term precipitation from the nearest recording station at Prineville, elevation 868m (2850ft), averages 25.4cm (10 in) annually, 89% of which occurs from October to June. The study area falls into the "Juniper Zone" described

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Milda R. Vaitkus is a Graduate Research Assistant, Department of Rangeland Resources, Oregon State University, Corvallis, OR; Lee E. Eddleman is Associate Professor of Range Ecology, Oregon State University, Corvallis, OR.

by Driscoll (1964). It is characterized by the dominance of western juniper and associated shrubby vegetation, most commonly two subspecies of big sagebrush--Wyoming and mountain (Artemisia tridentata ssp. wyomingensis and ssp. vaseyana) and scattered low sagebrush (Artemisia arbuscula). Native perennial grasses include Idaho fescue (Festuca idahoensis), squirreltail (Sitanion hystrix), bluebunch wheatgrass (Agropyron spicatum), and native bluegrass (Poa sandbergii). Cheatgrass (Bromus tectorum) and a number of annual and perennial forbs comprise the rest of the herbaceous component. In recent years this area has been used for winter and early spring grazing under moderate stocking rates.

Mixed tree size classes (Burkhardt and Tisdale 1969), continuing recruitment of western juniper trees, the presence of locally isolated areas of vigorous bunchgrasses, and on-site soil characteristics indicate the site is at a mid-seral successional phase.

We delineated 2000m^2 paired plots of approximately 40% juniper canopy cover, containing trees of similar size and density. In these plots, trees were separated into three canopy diameter size classes, small (3m /9.8ft/), intermediate (3-5m /9.8-16ft/), and large (5m /16ft/). In the fall of 1982, we hand-cut trees from one of the two paired plots and measured herbage production on both during the summers of 1983 and 1984. We determined herbage production on an individual tree basis from five trees within each size class by clipping, oven-drying, and weighing vegetation. Herbage production was measured along transects established within four 90-degree quadrants radiating from the bole of each individual sample tree extending at least 1/2 meter beyond the edge of the canopy. Samples were designated into two zones, based on location relative to the bole. The beneath-canopy zone extended from the base of the tree to the edge of the canopy, while the interspace zone consisted of the area between tree canopies.

A split-split plot analysis of variance was conducted on composite data of all trees sampled from the three size classes. Means were separated using Tukey's w-procedure at $P \leq 0.05$ (Steel and Torrie 1980). Productivity comparisons were made on a grams per square meter basis.

RESULTS

For the two years of the study, potentially effective growing season precipitation (October to June), measured on-site with rain gages, was 45.42cm (17.88in) in 1983 and 49.44cm (19.47in) in 1984. These values were nearly double the Prineville 30-year average of 23.50cm (9.25in).

Canopy Intact

In areas where the juniper canopy remained intact, total production, based on 40% canopy cover and 60% interspace, was 49.65 g/m^2 (442 lb/Ac) in 1983 and 42.20 g/m^2 (376 lb/Ac) in 1984. Production of most species did not differ between years (table 1). Only Idaho fescue and native bluegrass beneath-canopy production was greater in 1983 than 1984.

Total beneath-canopy production did not differ from total interspace production with an intact canopy in either year (table 1). Production of certain species, however, was variable and dependent upon location. Idaho fescue beneath-canopy production exceeded that of the interspace in 1983, while cheatgrass showed a similar response in 1984. Perennial forb beneath-canopy production was greater than interspace production both years. Native bluegrass production, on the other hand, was greater in the interspaces than beneath the canopy both years. Sagebrush production was higher in the interspace areas only in 1983. Perennial grass production averaged 26.4 and 26.5 g/m^2 (222 and 237 lb/Ac) in 1983, and 15.2 and 12.9 g/m^2 (136 and 114 lb/Ac) in 1984, beneath the canopy and in the interspace respectively.

Table 1.--Mean herbage production with canopy intact

Species		Production in g/m^2	
		Beneath Canopy	Interspace
Idaho fescue	1983	[1]13.31a1	8.09b
	1984	8.05 2	4.55
Native bluegrass	1983	8.23a1	14.99b1
	1984	3.62a2	6.87b2
Squirreltail	1983	3.88	1.97
	1984	2.61	0.73
Bluebunch wheatgrass	1983	0.97	1.62
	1984	0.97	0.73
Cheatgrass	1983	4.48	1.95
	1984	6.32a	0.94b
Annual grasses	1983	0.46	0.65
	1984	0.55	2.35
Perennial forbs	1983	13.32a	6.20b
	1984	15.36a	5.66b
Annual forbs	1983	3.37	5.14
	1984	4.88	10.88
Sagebrush	1983	2.67a	7.86b
	1984	3.90	6.28
Miscellaneous	1983	0.44	0.20
	1984	0.17	0.07
Total	1983	51.13	48.67
	1984	46.42	39.38

[1]Different numbers denote significant (α=0.05) differences between years for production values of individual species within the understory and the interspace, using Tukey's w-procedure (Steel and Torrie 1980). Different letters denote significant (α=0.05) differences between understory and interspace production values within years, using Tukey's w-procedure.

Canopy Removed

Total production in the canopy-removed area was greater in 1984 than in 1983. Production, based on a 40% to 60% beneath-canopy to interspace ratio, was estimated at 75.01 g/m^2 (668 lb/Ac) the first year following canopy removal and 99.45 g/m^2 (885 lb/Ac) the second year.

Species production response was variable between years (table 2). Idaho fescue and bluebunch wheatgrass production did not differ between years, regardless of location. Similar to the intact canopy areas, native bluegrass beneath-canopy and interspace production were greater in 1983 than 1984. Squirreltail beneath-canopy production was also greater in 1983 than 1984. In contrast to production with an intact canopy, cheatgrass, annual grass, perennial forb, and annual forb production beneath the canopy were greater in 1984 than 1983.

Table 2.--Mean herbage production with canopy removed

Species		Production in g/m^2	
		Beneath Canopy	Interspace
Idaho fescue	1983	[1] 9.08a	3.82b
	1984	10.90a	2.60b
Native bluegrass	1983	12.08a1	17.29b1
	1984	5.83 2	8.98 2
Squirreltail	1983	11.92a1	2.21b
	1984	8.94a2	1.06b
Bluebunch wheatgrass	1983	2.89	0.75
	1984	1.87	1.49
Cheatgrass	1983	8.46a1	0.20b
	1984	13.03a2	0.07b
Annual grasses	1983	1.55 1	1.57
	1984	4.51 2	5.48
Perennial forbs	1983	13.84a1	3.19b
	1984	20.92a2	6.49b
Annual forbs	1983	21.50a1	33.76b1
	1984	46.80a2	60.67b2
Sagebrush	1983	0.83	4.83
	1984	0.68	1.85
Miscellaneous	1983	1.76	0.35
	1984	2.02a	0.06b
Total	1983	85.56a1	67.97b1
	1984	115.51a2	88.75b2

[1]Different numbers denote significant (=0.5) differences between years for production values of individual species within the understory and the interspace, using Tukey's w-procedure (Steel and Torrie 1980). Different letters denote significant (=0.05) differences between understory and interspace production values within years, using Tukey's w-procedure.

Annual forb production was greater in 1984 than 1983 in both the beneath-canopy and interspace zones. In general, perennial grasses, if present, showed a negative production response to years for 1984, while the response of annual grasses and forbs, if present, was positive for 1984.

In the canopy-removed area, total beneath-canopy production was greater than total interspace production for both years (table 2). Individual species production, however, was variable. Beneath-canopy production of Idaho fescue, cheatgrass, squirreltail, and perennial forbs was greater than interspace production both years. Native bluegrass production was greater in the interspace than beneath the canopy in 1983 but not in 1984. Annual forb production, which did not differ with an intact canopy (table 1), was greater in the interspace zone, as contrasted with the beneath-canopy zone, both years. Perennial grass production averaged 36.0 and 24.1 g/m^2 (321 and 215 lb/Ac) in 1983, and 27.5 and 14.1 g/m^2 (246 and 216 lb/Ac) in 1984 for the beneath-canopy and interspace zones, respectively.

Canopy Intact Versus Canopy Removed

Total beneath-canopy and interspace herbage production in the canopy-removed areas was 67% and 40% greater, respectively, in 1983, and over 100% greater for both locations in 1984, in comparison to production in the intact canopy areas. Responses were species-specific and dependent upon location (figures 1 and 2). Beneath-canopy squirreltail production with canopy removed was approximately 155% greater both years, while native bluegrass production was greater both beneath the canopy and in the interspace only the first year (1983). Production by annual forbs, primarily fireweed (Epilobium paniculatum), was over 500% greater in both the beneath-canopy and interspace zones the first year, as compared to canopy-intact areas. The second year, annual forb beneath-canopy production was 858% greater and interspace production was 457% greater than comparable canopy-intact areas.

Canopy-removed perennial forb production beneath the canopy was not different from production with canopy intact the first year following canopy removal, but was significantly greater the second year. Annual grasses also showed greater beneath-canopy and interspace production the second year in comparison to the canopy-intact areas.

Composition differences, based on biomass production, were also evident. The beneath-canopy zone with canopy intact was dominated by perennial grasses (Idaho fescue, squirreltail) and perennial forbs (Astragalus spp. and Lupinus spp.), while native bluegrass and sagebrush were prevalent in the interspace. On canopy-removed areas, annual forbs comprised up to 41% of beneath-canopy and 68% of interspace production, compared to an average of 8.5% beneath-canopy and 20% interspace production on canopy-intact areas. Other species consequently composed lesser percentages of the relative production.

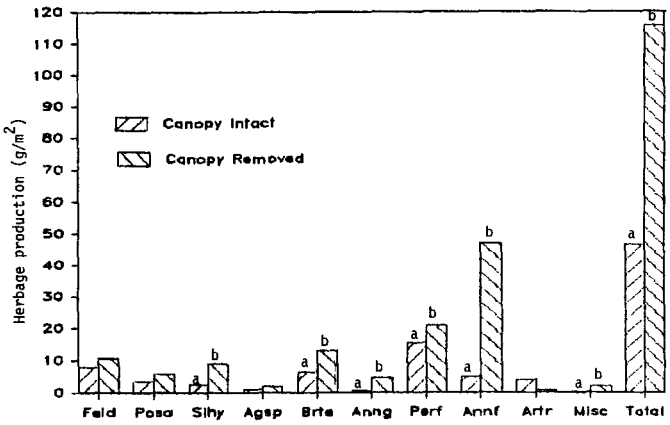


Figure 1.--1984 beneath-canopy production with canopy removed (Feid - Festuca idahoensis; Posa - Poa sandbergii; Sihy - Sitanion hystrix; Agsp - Agropyron spicatum; Brte - Bromus tectorum; Anng - Annual grasses; Perf - Perennial forbs; Annf - Annual forbs; Artr - Artemisia tridentata; Misc - Miscellaneous). Different letters denote significant (α=0.05) differences between canopy-intact and canopy-removed production values within species, using Tukey's w-procedure (Steel and Torrie 1980).

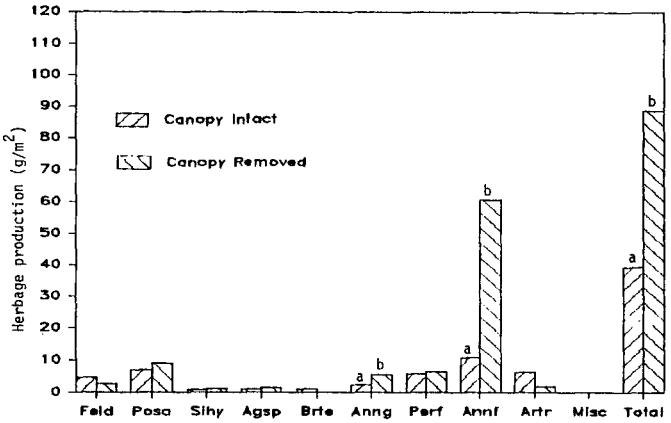


Figure 2.--1984 interspace production with canopy removed (Feid - Festuca idahoensis; Posa - Poa sandbergii; Sihy - Sitanion hystrix; Agsp - Agropyron spicatum; Brte - Bromus tectorum; Anng - Annual grasses; Perf - Perennial forbs; Annf - Annual forbs; Artr - Artemisia tridentata; Misc - Miscellaneous). Different letters denote significan (α=0.05) differences between canopy-intact and canopy-removed production values within species, using Tukey's w-procedure (Steel and Torrie 1980).

DISCUSSION AND CONCLUSIONS

Year-to-year variation in production with western juniper canopy present, as found in this study, may be partially explained by differences in precipitation during critical growth periods over the two years. May 1984 precipitation was approximately 22% that of May 1983 precipitation (1.42cm /0.56in/ vs. 6.34cm /2.53in/, respectively). Native bluegrass and, possibly, Idaho fescue production are likely sensitive to this late spring precipitation.

Precipitation patterns during the growing season apparently had little effect on production in the canopy-removed area. Release from competition with juniper for moisture seemed to compensate for changes in growing season precipitation for most species, except native bluegrass and squirreltail.

Herbage production associated with western juniper trees tended to occur in species-specific patterns. Due to microclimatic differences between the environment beneath the canopy and in the interspaces, some species occurred with greater frequency in particular zones. The more mesic conditions and, possibly, greater nutrient concentrations under the canopy favored production of some species, such as Idaho fescue, squirreltail, cheatgrass, and perennial forbs; while native bluegrass, annual forbs, and sagebrush were more abundant in the drier and warmer interspaces.

The release from competition with juniper for moisture (Jeppeson 1978) and a possible release of nutrients (Evans and Young 1985) resulted in significantly greater total production of the site. With canopy removal, type and magnitude of biomass production response were closely tied to location. Squirreltail, cheatgrass, annual grass, and perennial forb production was greater with canopy removed than canopy intact primarily in areas beneath the canopy. Annual forb production was also greater with canopy removed, but the response was not location-dependent.

Elevated productivity, however, can be deceiving. Although desirable species, such as Idaho fescue and squirreltail increased in production to a limited extent, the greatest contribution to total production came from annual forbs. This initial flush of productivity dominated by annuals is expected (Barney and Frischknecht 1974). However, since there has been so little work done with western juniper in the Pacific Northwest, future trends cannot be predicted. Western juniper is not the only factor determining production and composition differences. Cattle grazing has also played a significant role in present interspace and understory composition.

If removal of western juniper trees does not accomplish the desired goal, e.g. an increase in carrying capacity, then other improvement practices, such as reseedings and better grazing management, must also be implemented. As shown by this study, an increase in herbage production after tree removal does not necessarily result in an improvement in range condition. More information is needed before prescribing improvements to achieve specific goals in juniper woodlands of the Pacific Northwest.

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OVERSTORY-UNDERSTORY INTERACTIONS IN SOUTHWESTERN PINYON-JUNIPER VEGETATION

Martin R. Schott and Rex D. Pieper

ABSTRACT: Pinyon-juniper overstory has pronounced influence on understory vegetation. This influence is reflected in reduced understory biomass and shifts in species composition. The overstory may restrict understory production by limitations in soil water, influence of pinyon-juniper litter, light reduction, or a combination of factors. Considerable efforts have been expended in the Southwest to control pinyon and juniper trees to increase herbaceous production for livestock. Studies in Arizona and New Mexico revealed distinct zonation patterns around individual juniper trees. In most cases there is a gradient from relatively high herbaceous cover near the edge of the canopy to low values near the trunk. Some species such as Piptochaetum fimbriatum and Muhlenbergia pauciflora appear to be adapted to conditions under juniper canopies.

INTRODUCTION

Pinyon-juniper vegetation forms a mosaic pattern with the small trees and their zone of influence and open areas between the trees. The pattern varies with the density of trees. In extremely dense stands, the influence of the trees is expanded with the open areas reduced. The age of the trees also influences the degree of influence.

Pinyon-juniper trees influence other plants (especially herbaceous species) in several repects: shading, deposition of litter beneath the tree, interception of precipitation and development of a root system beneath the canopy and in the open spaces. In this sense, pinyon and juniper trees could be viewed as independent variables and other species influenced by the trees as dependent variables (Jenny 1958). The trees could be viewed as centers of spheres of influence with gradations of the influence lessening into the interspace.

Studies of the influence of individual shrubs or trees on soil properties have shown considerable influence, especially on soil chemical properties (Follet 1969; Garcia-Moya and McKell 1970; Tiedeman and Klemmedson 1973; Zinke 1962). Barth (1980) studied soil properties in Pinus edulis and Artemisia tridentata stands in northwest Colorado. Although similar influences have been evident in pinyon-juniper communities, they have not been studied extensively. Such influences on vegetational characteristics are important from a management standpoint, especially those involving manipulation of tree density for specific purposes.

This paper will consider mainly those studies involving relationship of canopy cover or tree density to understory production and those involving studies of vegetational patterns around individual trees.

OVERSTORY-UNDERSTORY RELATIONS

Several studies have shown a direct relationship between canopy cover and understory herbage production: as tree canopy increases, herbage production decreases (Clary and others 1974; Clary 1975; Arnold and others 1964; James 1967, 1971; Pieper 1983; Tausch and Tueller 1977). In general all the curves presented by these authors are similar. At relatively low canopy cover levels, herbage production is relatively high. As canopy closure increases there is a sharp decline in herbage production until the curve levels off and is relatively level until full canopy cover is reached. In western New Mexico production of total herbage, grasses, and forbs declined sharply as tree densities increased from 0 to 80 trees per acre. Little decline in herbage production occurred at tree densities higher than 80 per acre (Short and others 1977). Herbage production also declined as density of shrubs increased.

However, this general similarity among curves does not mean that one general relationship can be developed and used for all cases. On the Beaver Creek watershed in northern Arizona, Clary (Clary and others 1974; Clary 1971, 1975) found that herbage production was depressed to a much greater degree under Utah juniper (Juniperus osteosperma) than under alligator juniper (Juniperus deppeana). In addition he developed separate curves for areas with different amounts of summer precipitation. The degree of suppression was much less for each increment of basal area under 9 inches (22.9 cm) of summer precipitation than under 3 inches (7.6 cm). Studies on springerville soils on the Beaverhead Watershed showed that total understory production decreased linearly with increases in overstory crown cover (Clary 1971). Perennial grass decrease was slightly curvilinear. In Nevada Tausch and Tueller (1977) found that the rate of understory decline appeared to be inversely related to the rate of reoccupancy by conifers

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Martin R. Schott is Research Associate, Oregon State University, Corvallis, OR 97331; Rex D. Pieper is Professor of Range Science, New Mexico State University, Las Cruces, NM 88003.

(pinyon and junipers) on sites where the trees have been controlled. They developed slightly different curves for three different areas.

PATTERNS AROUND INDIVIDUAL TREES

Arnold (1964) first described vegetational zonation around oneseed juniper trees. He recognized four zones: (1) near base of tree; (2) canopy zone; (3) juniper root zone; and (4) open area beyond juniper roots. Herbage standing crop was highest in zone 4, intermediate in zone 3 and lowest in zone 2 with no herbaceous plants in zone 1 next to the tree bole. Clary (1973) also found pronounced zonation patterns associated with large alligator juniper (Juniperus deppeana) trees in northern Arizona. Perennial cool season grasses such as mutton bluegrass (Poa fendleriana), bottlebrush squirreltail (Sitanion hystrix), and prairie junegrass (Koeleria cristata) were much more productive under alligator juniper crowns than in the root zone or open areas between trees (table 1).

Total grass basal cover increased away from the oneseed juniper trees in the Sacramento mountain foothills of south-central New Mexico (Schott and Pieper 1985). Direction from the base of the tree did not influence basal cover of perennial grasses at the edge or the center of the canopy, but cover was higher on the north side of the tree bole than on the south side (table 2). Some perennial grasses such as blue grama, wolftail (Lycurus phleoides), and creeping muhly (Muhlenbergia repens) followed a similar pattern. Pinyon ricegrass (Piptochaetium frimbriatum) showed the opposite reaction with greatest basal area on the north side of the tree in the center and middle positions (table 2). Apparently most of the perennial grass species are restricted by shading under the canopy or by a heavier litter deposition under the canopy compared to the edge (table 3). Reduced light intensity can be inferred from the reduced canopy height and higher canopy closure of positions under the canopy than for those positions near the edge of the canopy. These observations agree with earlier studies (Johnsen 1962; Jameson 1966, 1970) which indicated the detrimental effects of juniper litter on blue grama. Pinyon ricegrass apparently is adapted to conditions under juniper canopy where it is not subject to severe competition from other perennial grasses.

Table 1.--Early-spring total herbage and grass production (lb/acre) and forage consumption (lb/acre) by sampling zones (from Clary 1973)

Production and consumption	Crown zone	Root zone	Open zone
Total herbage production	377.1**[1]	120.5	147.6
Grass production	350.2**	73.0	78.3
Forage consumed	87.6**	2.0	0.5

[1] **Significantly greater ($P \leq 0.01$).

Limited work has been done on vegetational patterns around the pinyons (Pinus edulis and P. monophylla). In central Nevada Everett and other (1983) found a peak in understory cover near the outer boundary of singleleaf pinyon litter, and a decline in both directions--toward the tree bole and into the open. Total herbaceous cover decreased from north (6.7 percent) to west (3.7 percent) to south (1.9 percent) aspects. There were also differences in understory patterns up, down, and cross slope. Individual species such as Idaho fescue (Festuca idahoensis) showed a progression of depletion, high vigor and exclusion phases from the interspace area, the litter boundary area, and the plant canopy zones, a pattern relatively consistent among tree size classes and slope directions (Everett and others 1983).

These patterns are likely related to microsite differences among environmental variables already discussed. Although Everett and others (1983) discounted possible allelopathic effects, other studies have shown that soil chemical characteristics are influenced by pinyon (Pinus edulis) canopy (Barth 1980).

MANAGEMENT IMPLICATIONS

Studies reviewed in this paper have relevance to management decisions for pinyon-juniper reductions. Large increases in herbage production are unlikely unless tree basal area can be reduced below 10 sq. ft. per acre and canopy cover less than 20 percent (Clary 1975; Jameson 1967).

Although some studies indicate a rapid response in herbaceous vegetation to stand reduction (Rippel and others 1980; Everett and Sharrow 1985), apparently peak production does not occur for some time following the control program. Arnold and others (1964) showed maximum herbage response occurred 9-12 years after control in northern Arizona. Everett and Sharrow (1984) reported more than a 200 percent increase in carrying capacity in Nevada following control.

Careful planning and evaluation are important in anticipated control projects. Lanner (1977) has questioned the need for large-scale control projects in the Intermountain Region. He believes that adequate documentation for invasion of pinyon-juniper stands is often lacking.

Table 2.--Average basal areas (percent) of total grass, blue grama, wolftail, pinyon ricegrass, and creeping muhly for the six locations under oneseed juniper canopy (from Schott and Pieper 1985)

Location	Basal area				
	Total grass* (percent)	Blue grama* (percent)	Wolftail*** (percent)	Pinyon ricegrass*** (percent)	Creeping muhly* (percent)
S. Edge	35.18 A[1]	23.06 A	2.36 A	0.00 C	7.68 A
N. Edge	31.32 A	23.84 A	2.24 A	0.00 C	4.30 AB
N. Middle	22.72 B	16.72 B	0.18 B	3.96 A	1.26 BC
S. Middle	13.68 C	9.56 C	0.44 AB	0.32 BC	2.34 BC
N. Center	5.32 D	1.42 D	0.00 B	2.30 AB	0.94 BC
S. Center	2.58 D	1.40 D	0.00 B	1.34 BC	0.00 C

[1]Means followed by different letters are significantly different (*P $\leq$ .0001, ** $\leq$ .0018, ***P $\leq$ .0242).

Table 3.--Average canopy closure, litter depth, and height to canopy at six locations around oneseed juniper plants in the Sacramento Mountains, New Mexico (from Schott and Pieper 1985)

Location	Percent Canopy closure	Litter depth (cm)	Height of canopy (cm)
South center	91 A[1]	4.3 A	32.3 C
North center	89 AB	4.0 AB	34.4 C
South middle	86 B	3.5 B	49.1 BC
North middle	81 C	2.4 C	69.3 AB
South edge	39 D	0.5 D	83.4 A
North edge	33 E	0.3 D	81.1 A

[1]Means with same capital letters are not significantly different (P $\geq$ 0.01 among positions under the canopy.

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SEEDING PINYON-JUNIPER SITES IN THE SOUTHWEST

Thomas N. Johnsen, Jr.

ABSTRACT: Past efforts to reseed southwestern pinyon-juniper sites are briefly reviewed, specific problems unique to this area are discussed, and research needs suggested. Twenty-six species adapted to one or more of nine suggested southwestern pinyon-juniper climatic subtypes are tabulated.

INTRODUCTION

Many southwestern pinyon-juniper ranges need understory vegetation restoration or improvement to increase plant cover, protect soils, increase forage, improve forage balance, or extend the green feed period. Range revegetation may be done naturally or artificially (Forsling and Dayton 1931). Natural revegetation depends on increasing plant remnants by management; however, without a seed source bare ground may remain unproductive indefinitely. Artificial revegetation, or reseeding, depends on planting adapted native or introduced plants. Reseeding southwestern pinyon-juniper rangelands is difficult, expensive, and success is unpredictable. Reseeding should be tried only if natural revegetation will not work in a reasonable time and proper reseeding procedures and follow-up management will be done.

Reseeding has been used on southwestern pinyon-juniper rangelands to increase plant cover in openings within juniper stands and to establish forage plants following juniper control. Responses have been variable. A review of 370 reseeding projects on Arizona and New Mexico pinyon-juniper ranges showed at least two-thirds failed within two years (Johnsen unpublished data). Most of these failures seem to be due to improper planting times, methods, species, and competition. These failures indicate a need for more reliable information and an exchange of this information between researchers and land managers.

Past research and reseeding efforts in the pinyon-juniper of the southwest have been summarized by Fosling and Dayton (1931), Parker and McGinnies (1940), Gomm and Lavin (1968), and Springfield (1976). This paper briefly reviews past works, elaborates on specific problems of reseeding southwestern pinyon-juniper ranges, and suggests research needs. Such information is useful in Arizona, New Mexico, and parts of Colorado, Utah, and Nevada.

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Thomas N. Johnsen, Jr. is Research Agronomist, U.S. Department of Agriculture, Agricultural Research Service, 2000 East Allen Road, Tucson, AZ 85719.

BACKGROUND

Efforts to reseed southwestern ranges began just before the turn of the century. Although little of this early work was done on pinyon-juniper ranges, much of what was learned had general application, such as the need for site preparation, use of adapted species, proper planting methods, and season of planting. Forsling and Dayton (1931), summarizing the results of reseeding ranges on western National Forests, conclude that reseeding should be limited to the moister sites. Wilson (1931), in New Mexico, stressed the need for seedbed preparation, weed control, rabbit control, and planting shrubs in the fall or winter to avoid the spring and summer dry periods. Parker and McGinnies (1940) summarized the results of Forest Service reseeding in the southwest, recognizing the different growth requirements of individual species. Bridges (1942) emphasized the need to remove junipers for successful seeding or to plant only natural clearings larger than one acre, cover broadcast seeds, and plant in July or August. Lavin (1948) suggested species for reseeding of Arizona pinyon-juniper, stressed early summer planting, seedbed preparation, proper planting depth, and protection from grazing. Gomm and Lavin (1968) summarized reseeding efforts in the southwestern pinyon-juniper, emphasizing a need for interseeding into blue grama sod for a better forage balance. Springfield (1976) listed species adapted to climatic and soil subtypes of the Arizona-New Mexico pinyon-juniper. Jordan (1981) summarized Arizona reseeding problems, species to use and how to manage them. Work on reseeding pinyon-juniper in other areas has been reported for Colorado by Hull and others (1958) and McGinnies and others (1963), and for Utah by Plummer and others (1968).

CLIMATIC CONSIDERATIONS

One unique feature of the southwest is the seasonal distribution of rainfall (Sellers and Hill 1974; Tuan and Everard 1965). Briefly, Arizona has a rainfall pattern with wet summers and winters and dry springs and falls. This bimodal pattern extends northward into southern Utah and Nevada where winter precipitation

becomes more dominant. The summer rainfall peak disappears and winter rain dominates just west of Arizona in southern California. Winter rainfall loses its importance and summer rains predominate eastward from eastern Arizona into New Mexico. Short dry spells occur every year, but there can be occasional extended dry periods of a year or more.

Summer rains fall in July to mid-September, often as high-intensity, local thunderstorms with limited moisture penetration into the soil. Summer storms vary widely in spatial distribution. Winter storms occur in November through March, usually as low-intensity, generalized storms, often wetting the entire soil profile. Snow may fall but melts quickly at the lower elevations. Winter storms, although widespread, are more erratic than summer storms, occurring unevenly throughout the winter.

Higher elevations generally are cooler and wetter than lower elevations. New Mexico's rough terrain causes rapid mixing of cold and warm air which results in New Mexico sites being warmer than similar sites at the same elevation in Arizona.

PINYON-JUNIPER CLIMATIC SUBTYPES

Using a combination of temperature, rainfall, and elevation, Lavin (1954) classified Arizona pinyon-juniper study sites to facilitate application of study results. This system has been modified to include more sites and parameters (Springfield 1976; Lavin and Johnsen 1977a, 1977b) and has been useful for identifying potential planting sites. These classifications are based on comparing short-term weather observations at study sites with nearby weather stations to estimate climatic conditions on the site. The temperature classifications for the southwestern pinyon-juniper are as follows:

	Mean Temperatures - °F	
Subtype	Annual	January
Cold	49 or less	31 or less
Cool	50 - 53	32 - 35
Warm	54 - 58	36 - 39
Hot	59 or more	40 or more

Sites with an average of 15 inches or less rainfall annually are classed as dry; 16 inches or more as moist. A site with a dry winter or summer receives less than half of the annual rainfall and averages less than 6 inches for that season. Winter is defined as November through April, and summer as May through October.

Reliable data are needed to help identify planting sites and to determine site potentials. Researchers should describe the vegetation and soils of study locations, and make daily records of rainfall, temperatures, humidity, and wind. Also, some measure of plant production should be made, even in the earliest trials. Such records will help characterize the site and aid in comparisons between sites and years of planting.

JUNIPER EFFECTS ON RESEEDING

Junipers affect reseeding by: 1) competing for soil moisture, 2) providing barriers to planting, 3) reducing soil wetting, 4) forming water-repellent soils under burned juniper slash, and 5) providing mulch which might aid some species and inhibit others.

Junipers are evergreen, using water throughout the year. Plantings in juniper stands often fail because of the seedlings' inability to compete for moisture with the widespread root system of junipers (Hull and others 1958). Johnsen (1962) reported one-seed juniper lateral root lengths were more than twice the height of the tree. Thus, a 10-foot-tall tree would affect plants growing within 20 feet; 34 such trees could affect all plants on an acre of land. Juniper removal is generally recommended before reseeding. Furthermore, standing trees, stumps, or slash are barriers to equipment movement through the stands. Removal of such barriers may be necessary before an area can be reseeded with ground equipment.

Juniper litter reduces the surface soil wettability under the tree, markedly retarding infiltration (Scholl 1971). Skau (1964) showed Utah junipers intercepted from 3 to 34 percent of the rainfall. Johnsen (1962) showed soils under one-seed junipers did not wet as deeply as soils between trees or under the tree base. This reduced wetting could delay or prevent the establishment of some plants under the tree crown. However, weeds and perennial grasses grow under herbicide-killed trees within a year of treatment, indicating detrimental effects do not last very long after rainfall interception and fresh litterfall are reduced. However, some species, such as muttongrass, do grow under junipers (Clary and Morrison 1973).

In Arizona, burning juniper slash sometimes leaves the soil under the burned slash bare for several years. Increased runoff from the bare spot causes an increase in grass growth on the edges of the bare spot (Arnold and others 1964). These fire-related bare spots seem more pronounced on sandy soils and may be the result of the movement into soils of organic materials vaporized by the fire (Savage 1974), especially when the burn is on dry, coarse-textured soils (DeBano and others 1976). The effects of litter or fire-induced water repellency appear to be localized and may not affect overall planting success except for small-scale experimental plots. Plowing or disking should do away with the detrimental effects by destroying the layer resistant to wetting.

Laboratory studies have shown extracts from juniper foliage and litter are phytotoxic to the seedlings of several grasses (Jameson 1970). Utah juniper foliage extracts repressed some grasses, such as blue grama, side oats grama, and crested wheatgrass, had little effect on pubescent wheatgrass and weeping lovegrass and increased fourwing saltbush growth (Lavin and others 1968). This indicates that juniper

foliage and litter used as a mulch might harm some plants but help others. This, combined with the water repellency of soils under juniper litter, might explain the difficulty of establishing some plants by reseeding. However, juniper slash mulch has been successfully used in reseeding (Judd 1948; Judd 1966; Lavin and others 1981). In Arizona, juniper slash mulch increased survival, extended the green growth period, and protected the plantings from rabbits but did attract rodents (Lavin and others 1981). Excessive shading from fresh branches was initially detrimental to pubescent wheatgrass and fourwing saltbush, but this effect disappeared when the foliage fell from the branches (Lavin and others 1981). Weeds invaded under the juniper slash when established forage plants were absent. Scattering juniper branches as a mulch following juniper fuelwood harvesting is recommended to improve desirable plant remnants and aid broadcast seeds in the southwest (Lavin and others 1981). Dead, standing trees killed by herbicides aided understory recovery (Clary and others 1974) and water yield (Baker 1984).

ADAPTED SPECIES

Successful reseeding depends on establishing and properly managing species adapted to the area planted. During the past 50 years several hundred species have been planted to determine survival and growth at one or more locations in the southwestern pinyon-juniper. The 26 species listed in table 1 have established fair or better stands of vigorous plants in multiple-year plantings at one or more of 20 locations listed in table 2: 16 in Arizona and four in New Mexico (Springfield 1965; Lavin and Johnsen 1975, 1977a, 1977b; Johnsen and Gomm 1981). The plantings used were all seeded and evaluated in the same way. The results of other species adaptation trials in the southwestern pinyon-juniper have been reported by Judd (1966), and Judd and Judd (1976) for Arizona; and Merkel and Herbel (1973) and Springfield (1976) for New Mexico.

The 20 locations were divided into the climatic subtypes described earlier to help identify potential planting sites and to facilitate wider application of the results (table 2). In multiple-site subtype plantings adapted species established stands at each location planted. Subtypes represented by single

Table 1.--Reseeded forage species adapted to Arizona-New Mexico pinyon-juniper range subtypes described in text. (X = adapted, 0 = not adapted, - = not adequately tested)

	Cold			Cool		Warm		Hot	
	Moist	Dry	Dry	Moist	Dry	Moist	Dry	Dry	Moist
Species		Winter	Summer		Winter		Winter		
Grasses, C-3:									
Brome, Smooth	X	0	-	0	0	0	0	-	0
Fescue, Hard	0	-	-	X	0	-	0	-	-
Squirreltail, Bottlebrush	X	X	-	-	-	0	-	X	-
Wheatgrass									
Crested	0	0	X	0	0	0	0	0	0
Intermediate	0	0	X	X	0	X	0	0	0
Pubescent	X	X	-	X	0	X	0	0	0
Siberian	0	0	-	X	0	0	0	0	0
Tall	0	0	-	X	0	0	0	0	-
Western	X	X	-	X	X	X	X	X	0
Wildrye, Russian	X	X	X	X	0	0	0	0	0
Grasses, C-4:									
Bluestem, Yellow	0	X	-	X	0	0	0	0	X
Dropseed, Sand	0	0	-	0	0	0	X	0	0
Grama									
Blue	0	0	-	0	X	X	X	X	0
Sideoats	0	0	-	0	0	X	0	X	0
Lovegrass									
Boer	0	0	0	-	0	0	0	0	X
Wilman	0	0	-	-	-	0	-	0	X
Muhly, Spike	X	X	-	X	X	0	X	0	0
Sacaton									
Big	0	0	-	0	0	0	X	0	-
Alkali	0	0	-	0	0	0	X	X	0
Tridens, Rough	0	0	-	X	0	0	0	0	0
Forbs:									
Alfalfa, Yellow	0	0	-	X	0	0	0	-	-
Sweetclover, Yellow	0	0	X	0	0	X	0	0	-
Shrubs:									
Kochia, Forage	X	X	-	-	-	0	-	X	-
Saltbush, Fourwing	X	X	-	X	X	X	X	X	-
Twinberry, Rough	0	0	-	0	-	X	0	0	0
Winterfat	0	X	-	0	-	0	-	X	0

Table 2.--Subtypes, locations, rainfall, soils, and dominant woody plants on Arizona-New Mexico pinyon-juniper range reseeding sites. See text for details of subtype characteristics

Subtype	Location	Rainfall			Soil	Dominant Species[1]	Source[2]
		Annual	Summer	Winter	Texture		
Cold:							
Moist	Cosnino	18	9	9	loam	Juos, Pied, Jumo, Pipo	5
	Indian Flat	17	9	8	clay	Jumo, Pied, Pipo	3, 5
	Mortiz Lake	16	9	7	silt loam	Jumo, Juos, Pied	4, 5
	Peterson Flat	17	10	7	loam	Jude, Jumo, Pied	4, 5
Winter Dry	Dog Knobs	12	8	4	clay loam	Jumo, Pied	4, 5
	Red Mountain	12	8	4	clay	Jumo, Pied	3, 5
	Hart Ranch	13	8	4	loam	Juos, Pied	5
Summer Dry	Hualapai	14	6	8	loam	Juos, Pied, Artr	1
Cool:							
Moist	Mud Tank	18	9	9	clay	Jude	4
Winter Dry	Glorieta Mesa	15	10	5	sandy loam	Jumo, Pied	2
Warm:							
Moist	Blue Grade	16	8	8	clay	Juos, Pied, Qutu	3, 5
	Buckhead Mesa	20	10	10	clay	Jude, Jumo	4, 5
	Pine Creek	20	10	10	loam	Jude, Jumo	4, 5
	Pleasant Valley	19	10	9	loam	Jude, Jumo	4, 5
Winter Dry	Corona	15	10	5	clay loam	Jumo, Pied	2
	Ft. Bayard	14	9	5	clay loam	Jumo, Pied	2
	Monica	14	9	4	loam	Jumo, Pied	2
Dry	Drake	13	7	6	loam	Juos	4, 5
	Perkinsville	13	7	6	loam	Juos	4
Hot:							
Moist	Sierra Ancha	17	8	9	loam	Jude, Jumo, Qutu	4

[1]Jude = alligator juniper; Jumo = one-seed juniper; Juos = Utah juniper; Pied = pinyon; Pipo = ponderosa pine; Artr = big sagebush; Qutu = shrub live oak.
[2]1 = Schaus 1964 and field notes; 2 = Springfield 1965; 3 = Lavin and Johnsen 1975; 4 = Lavin and Johnsen 1977b; 5 = Johnsen and Gomm 1981.

locations may produce different results with more locations.

Of the 26 species (table 1), 13 are native and 13 are introduced. The three most widely adapted species, western wheatgrass, spike muhly, and fourwing saltbush, are native species. Twelve species are adapted to only one subtype, four to two subtypes, four to three subtypes, three to four subtypes, one to five subtypes, and two to seven subtypes. All species were not planted at all locations or subtypes, only three species, crested wheatgrass, intermediate wheatgrass, and Russian wildrye were planted in all nine subtypes, and 12 species were planted in eight of nine subtypes.

Some species, such as fourwing saltbush, are adapted to several subtypes but a single seed source may grow better in some subtypes than others. Other species, such as luna pubescent wheatgrass, may grow equally well in several subtypes (Johnsen and Gomm 1981). This indicates that seed source or cultivars are important for some species but not others. Some species adapted to a subtype may do better on one soil than another, which should be considered when planting specific sites. Immigrant forage kochia, a new species for the southwestern pinyon-juniper, is spreading rapidly on some sites and deserves further investigation.

Generally, C-3 grasses seem better suited to the cooler, moister locations and subtypes, while C-4 grasses seem better suited to the warmer, drier subtypes (table 1). This agrees with the reported distributions of species with these carbon pathways (Hattersely 1983). Descriptions of the characteristics of most of the species listed may be found elsewhere and will not be dealt with here (Merkel and Herbel 1973; Jordan 1981). However, little is known about the successional patterns of most planted species, especially the introduced ones.

Species failure is not, by itself, proof that a plant is not adapted. Some species may require special seed treatment or planting methods; others might survive in larger plantings with less severe animal depredations. Species needs for establishment, survival, and reproduction and how to meet those needs should be determined. Species adaptation is dependent first on seedling emergence and then its growth and survival. Transplanting has been used in limited studies to bypass emergence problems (Springfield 1970; Lavin and Johnsen 1975). The results of these limited tests indicate transplanting can be a useful tool in species adaptation trials which should be used more often.

SEEDBED PREPARATION

Seedbed preparation is usually considered essential for successful range seeding (Gomm and Lavin 1968; Jordan 1981). Numerous adaptations of mechanical and chemical seedbed preparation methods have been used for seeding southwestern

pinyon-juniper; each has its advantages and limitations. Generally, plowing is the best method for preparing seedbeds. Moldboard plows are best for deep bottomland soils, but disk plows are preferred for rough, rocky sites. Plowing combined with disking, harrowing, and cultipacking produces a fine, firm, smooth, friable seedbed free of competition and effective for retaining soil moisture (Lavin and others 1973). However, plowed seedbeds are often invaded by weeds during the growing season after preparation. More gophers and mice may be found on plowed seedbeds, perhaps attracted by the weeds. Some plowed soils form a vesicular crust after the initial rains, making broadcast seeding and seedling emergence difficult. In Arizona, seedling emergence and survival were highest on plowed seedbeds, decreasing progressively on undercut sod, strip-undercut sod, herbicide-sprayed before planting, herbicide-sprayed at planting, and unplowed seedbeds (Lavin and others 1973).

On untilled seedbeds practices such as pitting, furrowing, interrupted furrows, and ripping have been tried with inconsistent results and, except for furrowing, are seldom used. Deep, wide furrows, which remove much of the competing vegetation, and concentrate rainwater, have been the best of the non-tilled seedbed preparation methods (Lavin and others 1981). In furrows, seed zone moisture was high throughout the growing season in Arizona but excessive soil sloughing was detrimental to seedling emergence (Lavin and others 1973, 1981). Species such as the wheatgrasses do well with deep furrowing (Lavin and others 1973, 1981), but species such as fourwing saltbush do best without furrows (Springfield 1970; Lavin and others 1981). Mulching increases furrowing effectiveness by reducing soil sloughing (Lavin and others 1981). Furrows and pits help seedling establishment in the southwestern pinyon-juniper during dry years but not in wet years or periods of extended drought. Plowing and furrowing are difficult to do on juniper control areas without first removing the debris.

Generally, prolonged spring and fall dry periods and the limited rainfall of the southwestern pinyon-juniper do not favor fallowing plowed seedbeds. However, fallowing has resulted in improved establishment and survival in Arizona (Lavin and others 1981). Pubescent wheatgrass and fourwing saltbush had better stands with fallowing than with nonfallowing on a cold, moist site, but not on dry sites. Fourwing saltbush was also helped by fallowing combined with juniper mulching on both cold and warm dry sites. Side oats grama and spike muhly had improved stands when fallowing was combined with juniper mulching of deep furrows on a warm, dry site. Weeds invade fallowed areas and may reduce the amount of stored soil water.

In Arizona, soils at or deeper than 12 inches did not become dry for at least 7 years after the junipers were killed by herbicides and left standing, while soils in adjacent areas with live trees dried to bedrock each spring (Johnsen 1980). Leaving the dead standing trees in place increased water yields (Baker 1984) and may help forage plant establishment. Removal of trees after the seeded plants are established would reduce the visual impact of a stand of dead trees but result in a drier site (Baker 1984). However, dead-tree removal should not affect the survival of established adapted species.

PLANTING METHODS

Many planting methods have been tried on southwestern pinyon-juniper ranges but, if seeds are properly covered, planting method seems less important than seedbed preparation. Overall, drilling is the best planting method, but, except for the rangeland drill, is often limited to relatively smooth, rock-and debris-free areas. Drilling may not be successful without seedbed preparation unless there is little plant competition. Because fine seeds may be difficult to drill, rice hulls or bran are sometimes used as a filler to make seeding small seeds easier (Lavin and Gomm 1968). Seeding depth is critical, especially with small seeds which are apt to be seeded too deeply and fail to emerge.

Seeds broadcast onto rough, rocky or debris-laden areas do best on loose soils with little plant competition. Seeds may be scattered and covered by soil disturbance during juniper clearing by bulldozing or chaining. Usually, however, the debris is burned and as soon after burning as possible, seeds are broadcast into the fresh ashes and newly disturbed soils before rain-induced crusts form. Small seeds may need no further treatment, but large seeds may need to be covered by raking, harrowing, cultipacking, or chaining. Seeds are sometimes hand-broadcast into disturbed soils and holes left by uprooting the trees without removing debris. On fuelwood harvest areas, seeds are hand-broadcast into the juniper slash and the areas under the cut trees with no other treatment. Responses to these planting methods have been variable, but the best responses are on areas with little plant competition.

Natural mulching materials improved seeding results in early southwestern pinyon-juniper seeding trials (Judd 1948, 1966) but the practice was felt to be too expensive and was not developed further. Since then, many different materials such as straw, litter, cinders, gravel, asphalt, and plastic films have been tried (Springfield 1972; Lavin and others 1981). Mulching improved seedling emergence but survival depended on additional rainfall during the growing season. Long-term survival and stand development have been similar with all mulches tried in Arizona (Lavin and others 1981). In Arizona, grasses remained green several weeks longer under juniper slash than under cinder or plastic film mulches (Lavin and others 1981). Areas mulched with juniper slash without established planted species became very weedy; native species then became established while adjacent unmulched areas remained weedy (Lavin

and others 1981). Plastic film and juniper slash attracted rodents that damage plantings.

SEASON OF PLANTING

Early summer plantings are generally recommended in the southwest because this is when soil moisture and temperatures are most favorable for rapid germination and growth. However, fall plantings are considered for cool season plants such as the wheatgrasses. Seeding studies and large-scale plantings done between 1945 and 1966 in Arizona and New Mexico all indicated the best responses are from plantings which are followed closely by adequate rainfall for extended periods. Frequent rains which keep the seedling root zone moist are more important than planting into moist soil. For example, plantings made when the subsoils were wet and remained wet through the growing season failed if the surface 2 inches of soil dried between rainstorms (Lavin and others 1973; Johnsen and Gomm 1981).

Good stands have sometimes been established from plantings made at other times of the year. However, winter and spring plantings succeed only if rain is delayed until summer; otherwise the seeds germinate but seedlings die during the dry spring. Fall plantings succeed during wet, warm falls which allow the seedlings to grow rapidly and become large enough to survive the following dry spring; the seedlings may still fail if the summer is dry or the rains arrive late. Springfield (1956) concluded that fall planting success in northern New Mexico depended on snows which protect the seedlings from frost heaving and provide early spring moisture for early growth. Summer plantings fail if the rains are late or the fall dry period is early or lengthy. Late summer plantings may not survive the fall dry period. Delayed germination and emergence following planting, especially in the fall and spring, may cause failures due to a build up of a thick crust on the surface of some soils which can prevent seedling emergence. Some species, such as fourwing saltbush, have been successfully planted at a variety of times (Bridges 1942; Springfield 1970; Lavin and others 1973). This may be due as much to population variability of this species as to yearly weather variations. Some planting reports are from abnormally wet years and may be misleading for more typical years, thus planting trials should be done over a period of several years. Damping off during cold wet periods can also kill seedlings (Lavin and others 1973). Frost heaving can kill seedlings during winters with little snow. Regardless of season of planting, stand development depends on plants surviving the initial dry spring following planting. Thus, initial growing season success may not indicate successful stand establishment.

GRAZING SEEDED AREAS

Reseeding may not succeed even when planted properly under good growing conditions (Hessing and Johnson 1982). Generally, reseeded areas are protected from livestock for two or more growing seasons after planting. However, the area may receive concentrated use by wildlife and the seedlings may be lost. If the area is part of a larger pasture, it may receive concentrated, selective use by both wildlife and livestock, resulting in overuse. Reseeded areas must be protected from overuse. This has been attempted by expensive fencing which controls large animal access, and by planting large areas. Plummer and others (1968) recommend seeding pinyon-juniper areas in Utah larger than 500 acres to reduce the impact of animal concentrations. Little is known about how patterned placement of reseeded areas might avoid overuse or how reseeded areas would respond to the various grazing methods. It is not certain how long or to what degree plantings should be protected. Some species might benefit from light grazing near the end of the first growing season by reducing plant water needs and causing additional tillering or stooling. The effects of fertilizers have only been briefly examined on southwest ranges. Little is also known about how reseeded species fit into successional patterns and the longevity of planted stands under optimal management.

SUMMARY

Many species and planting methods have been tried in attempts to seed southwestern ranges. In an attempt to facilitate the use of information from plantings and to identify potential planting sites, a system of climatic subtypes based mainly on temperature and rainfall is being developed for southwestern pinyon-juniper areas. Information is needed from more plantings to increase the usefulness of such classification systems. Junipers make seeding success difficult through competition for soil moisture, formation of water repellent soil layers, and production of materials which inhibit growth of some plants.

Southwestern pinyon-juniper forage planting success depends on: 1) planting adapted species, 2) preparing seedbeds to remove competition and enhance infiltration, 3) covering the seeds, 4) planting at the proper time, and 5) protecting plantings from overuse. Of 26 species listed as adapted to one or more of nine climatic subtypes, three species are adapted to more than half of the subtypes: western wheatgrass, spike muhly, and fourwing saltbush. Plowing is the best seedbed preparation method; whereas, low tillage methods such as ripping, pitting, furrowing, and interrupted furrows have given inconsistent results. Small seeds broadcast onto soft, loose soils may need no further treatment, but larger seeds need to be covered by drilling, harrowing, cultipacking, or chaining. The use of juniper slash as a mulch helps establish some species but not others. Fallowing has aided some species on some sites. Early summer plantings have had the most consistent success in the southwestern

pinyon-juniper. Many successfully established plantings have failed because of overuse by livestock and wildlife. The plantings must be managed to prevent overuse from grazing animals concentrating on planted areas after stands are established.

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Woodland Hydrology

Chaired by:

Fred Gifford, Head, Range, Wildlife, and Forestry Department, University of Nevada—Reno

PRESENT AND FUTURE THEMES IN PINYON-JUNIPER HYDROLOGY

Larry J. Schmidt

ABSTRACT: A diverse range of vegetative species, climatic factors, and soil parent materials govern the hydrology of pinyon-juniper ecosystems. Pinyon-juniper covers an estimated 64 million acres (25 million hectares) in the western states. In spite of this, a disproportionally small amount of hydrologic related research has been accomplished. Currently, a gap exists between the available scientific knowledge base and application by land managers. Part of this problem stems from a past tendency to accept hydrologic information supporting eradication of pinyon-juniper and disregard findings that questioned the watershed benefit of these practices. This selective body of accepted facts and folklore inhibits support for further research to flesh out concepts and resolve conflicting findings. The failure to synthesize current research facts into a workable strategy for managers also inhibits application. Changes in public demands have resulted in a reassessment of management goals for pinyon-juniper. However, managers lack adequate knowledge on inventory methods, silvicultural systems, and productivity in relation to runoff processes. An indicated need exists for a soil-vegetation classification to enable transport of hydrologic knowledge gained from research or practice. Further long-term small-watershed studies are needed to fill knowledge gaps and provide a framework for plot studies.

INTRODUCTION

The 64 million acres of pinyon-juniper exercise considerable hydrologic influence on runoff generated from higher elevation ecosystems. Because of its topographic position, it is often the last ecosystem that water passes through prior to being diverted for use.

Other than for the water yield studies at Corduroy Creek (Collings and Myrick 1966) and at Beaver Creek (Clary and others 1974) in Arizona most of the remaining work has been conducted as small plot studies in Utah and Nevada (Gifford 1976). These plot studies utilized various methods for simulating rainfall and evaluating effects on a plot basis.

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Larry J. Schmidt, Hydrologist, USDA Forest Service, Southwestern Region, 517 Gold Ave., SW, Albuquerque, NM 87102.

Expanding resource demands and public use of pinyon-juniper throughout the Great Basin and Southwest will place more stress on these sensitive hydrologic systems. Without an expanded program of research to develop understanding of processes and appropriate management technology, significant risk of increased flood peaks and soil loss exists. Potentially serious problems may go undetected until an infrequent severe precipitation event permanently alters the hydrologic function of the site. Anticipating and avoiding damage requires sufficient knowledge of factors controlling these processes.

ACQUIRING THE KNOWLEDGE

The best description of our current level of knowledge regarding the hydrology of pinyon-juniper lies in paraphrasing Mark Twain's view of science in general: "There is something fascinating about studies of [pinyon-juniper hydrology]. One gets such wholesale returns of conjecture out of such a trifling investment of fact."

This relates more to how the limited body of knowledge has been misapplied, rather than the quality of the studies per se. The previous studies of pinyon-juniper might also be described as tantalizing, but inconclusive. In general, studies have failed to produce a comprehensive body of knowledge applicable in day-to-day management. The few glimmers of insight have lead to selective interpretations and self-serving speculations used by some individuals to justify desired type conversion projects. Even as the body of knowledge grows, the folklore dies hard, as witnessed by the discussion comments offered in response to the paper by Gifford (1975) on the "Impacts of Pinyon-Juniper Manipulation on Watershed Values."

Acquiring understanding of the pinyon-juniper ecosystem challenges our current research technology. The highly variable site conditions, limited number of events that produce runoff, and time references all combine to create a complex study environment.

Of these factors, the time-scale has been the most difficult to realistically accommodate. As Houghton (1969) points out, it may take 30 years or more just to determine average annual precipitation in the Great Basin. This certainly

exceeds the life expectancy, if not the attention span, of most research efforts. With few exceptions, research has been conducted over a few years period, coinciding with graduate student availability. Scientists and managers also encounter difficulties at the other time-scale extreme because many of the infrequent but significant storm events occur in less than 30 minutes. Understanding precipitation-driven processes requires knowledge of storm volumes for time periods of 5 minutes or less.

These factors clearly indicate a need for widely dispersed long-term small-watershed studies in pinyon-juniper to provide a frame of reference for shorter term plot studies.

WHAT WE KNOW ABOUT THE HYDROLOGIC PROCESS

Our current knowledge reflects the management concerns of the 1960's and 1970's regarding pinyon-juniper ecosystems. Hydrologically, these concerns centered on potentials for increasing water yield and effects of various type conversion strategies. In this era, pinyon-juniper was viewed as undesirable and merely represented a barrier to increasing grassland cover.

Scientific studies by numerous investigators indicate current themes and have been summarized comprehensively by Branson and others (1981). This information plus the energy crisis and environmental movement of the 1970's combine to curtail major type-conversion efforts underway in the 1960's.

Economic concerns continue to limit conversion efforts. Also, maturing view points recognize the need to manage pinyon-juniper ecosystems as a resource to produce a variety of products. Current concerns include a recognition of the need for improving watershed conditions.

Some brief reflection on highlights of our current knowledge provides a basis for considering future needs.

Climate

Few studies of the climate of pinyon-juniper exist. Most of these have dealt with defining the silvicultural environment, rather than factors commonly associated with hydrology (Fowells 1965). For example, a study of temperature versus elevation, done in the Virginia Range of western Nevada, found that the pinyon-juniper seemed confined to a thermal belt above the valley inversions and below the colder upslope elevations (Billings 1954).

Precipitation

Houghton (1969) has described some of the precipitation geography of the Great Basin showing seasonal sources of moisture.

However, knowledge of the storm characteristics that dominate the hydrologic process in pinyon-juniper is lacking. Available monthly and annual precipitation data fail to adequately portray the driving mechanism involved. Event-based precipitation data taken on a 5-minute increment are necessary to understand the runoff producing storms and erosional processes (Hershfield and Engman 1978). Studies at Walnut Gulch and other locations in the Southwest, while not in pinyon-juniper ecosystems, indicate the importance of short-duration, high-intensity rainfall (Osborn and Renard 1969). Studies at four Safford, Arizona, watersheds indicate 5-minute intensities approaching 8 inches per hour (Osborn and Reynolds 1963). A study of maximum 2-minute intensities for 41 stations in Idaho, Utah, New Mexico, and Arizona indicates rates ranging from 17 inches per hour at Reynolds Creek, Idaho to 42 inches per hour at Alamogordo Creek, New Mexico. Data from Utah studies also indicate a tendency for greatest intensities in the elevation range between 6,500 feet and 8,000 feet which coincides with the pinyon-juniper ecosystem (Farmer and Fletcher 1971).

Interception

Interception, including stem flow, is generally an insignificant factor in most ecosystems. For a given storm event, pinyon-juniper might function differently, however. Consider, for example, that an interception capacity of 0.2 inch of precipitation would reduce the effective 5-minute intensity by 2.4 inches per hour. Skau (1964) reported values of interception of 0.13 to 0.94 inch for a single high-intensity storm in Utah juniper in Arizona.

Using a 0.5 inch interception capacity, as observed by Collings (1966), would reduce the effective 5-minute intensity by 6 inches per hour. By contrast, using data from Merriam (1961) suggests mixed grama grasslands would retain about 0.15 inch of precipitation, which would reduce the effective 5-minute intensity by only 1.8 inches per hour. No specific studies of pinyon-juniper litter interception were identified. However, it might account for another 0.5 inch to 2.0 inches of reduction in the 5-minute intensity.

The difference in precipitation considered on a storm basis puts the importance of interception and other time-dependent factors in a different light. These factors need further research and consideration in models to evaluate the effect of cultural treatments.

Infiltration

Studies of infiltration in pinyon-juniper have received the greatest amount of attention from watershed scientists. Gifford (1976) provides a concise review of the current status of our knowledge. In general he concluded that:

1. Little difference exists between undisturbed and chained plots.

2. Increased levels of mechanical surface disturbance associated with windrowing will possibly result in reduced infiltration.

3. Grazing impacts are cumulative, detectable for a single season and in one case protection of the site for four years was required to restore maximum infiltration capacity.

4. Burning appears to reduce infiltration rates (Bunkhouse 1975).

5. Researchers have encountered difficulty in identifying a consistent set of easily measurable factors that influence infiltration rates.

6. Average measured infiltration rates range from 1.2 inches per hour to 2.00 inches per hour for soils at field capacity and approximately 2.5 inches per hour for dry conditions (Smith and Leopold 1942; Blackburn and Skau 1974).

7. Cryptogamic soil crusts increase surface roughness, increase infiltration, reduce intrinsic permeability, provide a measure of soil protection, and are slow to recover from disturbance (Loope and Gifford 1972; Bunkhouse 1975).

Surface Detention

Skau (1961) estimated that pits resulting from cabling juniper could retain an average of 0.18 inches potential runoff per storm.

Other properly applied mechanical treatment practices such as pitting, ripping, contour furrowing, and contour trenching used in combination with clearing can provide a range of detention storage from 0.6 to 3.5 inches or more of runoff (Branson and others 1981).

Runoff

Pinyon-juniper generally produces surface runoff only in response to high-intensity, short-duration storms.

These storms typically produce high unit area rates of runoff in small basins. For example, Baker and others (1971) measured rate of flow ranging from 400-700 cubic feet per second per square mile (CFSM) resulting from the September 1970 Labor Day Storm on the Beaver Creek Watersheds in Arizona.

They also showed a 60 percent increase in peak discharge from a cabled watershed. Patterson and Somers (1966) reported rates of 1380 CFSM for the 0.3 square mile Saliz Watershed near Reserve, New Mexico in July 1959. The Saliz Watershed was a heavily grazed watershed that subsequently received watershed improvement treatments. Significant runoff has not been observed since tree removal, contour furrowing and reseeding were completed in 1964.

Currently, information on magnitude and frequency of storm-runoff related to site conditions is inadequate for design of facilities in pinyon-juniper ecosystems.

Water Yield Improvement

At best, the pinyon-juniper ecosystem produces no significant water yield and most attempts to manipulate the type for increased water yield have produced marginal results (Clary and others 1974). Considering the limited precipitation available, few research efforts have pursued this question further. Many managers still cling to the hope that some positive water yield benefits will occur from manipulation, even if unmeasurable and unquantified.

Sediment

The primary water quality concern from pinyon-juniper ecosystems is sediment production. Limited information gathered at Beaver Creek in Arizona indicates average annual sediment rates of 0.07 tons per acre for winter and 0.03 tons per acre for summer seasons from untreated watersheds. In contrast, the cabled watershed produced annual sediment rates ranging from a trace to 1.1 tons per acre. More information is needed to adequately evaluate differences between treated and untreated watersheds (Clary and others 1974).

EMERGING THEMES AND RELATED INFORMATION NEEDS

Predicting future themes is risky because trends often fail to indicate destiny. Describing questions that need answers to meet some emerging needs appears more fruitful than engaging in wild speculation about distant futures. Also, by approaching current hydrologic questions from a process standpoint, we will have a basis for responding to unanticipated future needs.

These questions resulted from discussions with a number of resource professionals and managers involved with the management of pinyon-juniper ecosystems.

Increasing Multiple Use Demands

Current use of pinyon-juniper ecosystems is expanding. New and innovative practices are needed to respond to these demands while maintaining and improving the productive potential. Managers must respond to increasing and often conflicting demands for forage, fuelwood, Christmas trees, fence posts, nuts, off-road vehicle and other dispersed recreation opportunities.

Maintaining on-site productivity and water quality requires development and application of appropriate management practices.

Roads for the most part have developed from old travelways that have serious resource impacts. Many of these roads lie in the bottoms of drainage ways and concentrate diffuse runoff into damaging flows, resulting in serious erosion. Limited dollar returns from pinyon-juniper ecosystems have lead to low priority for investment in better transportation facilities. Wood gathering, hunting, and off-road vehicle recreation continue to expand the travelway network and attendant problems.

Questions regarding livestock use in relation to watershed condition in pinyon-juniper still need more attention. Current management approaches still fail to adequately recognize climatic variability in the management of livestock. Many grazing management strategies are geared to providing for plant health and fail to adequately consider the impacts of use of factors affecting infiltration and flow concentrations.

Little information exists on possible effects of management to improve the accumulation and retention of water on-site to improve production.

Expanded use implies the following hydrometerologic questions:

1. What level and type of road access should be provided in pinyon-juniper ecosytems?

2. What road location and design factors need to be incorporated to control runoff and sediment?

3. What level of constraints or mitigation should apply to off-road vehicle use?

4. What level of livestock production can be sustained without impairing long-term site productivity.

5. What livestock management strategies provide greatest production with least resource impact?

6. What changes in livestock management strategies are needed to respond to highly variable forage production related to climate?

7. What fuelwood and Christmas tree harvest strategies maximize long-term production of forage and fiber?

8. Do size and distribution of woodland openings influence retention of snow and reduction of evaporation, resulting in increased productivity?

9. What soil-vegetation classification framework will best enable managers and researchers to interchange knowledge correctly?

10. What patterns of site characteristics exist that indicate probabilities of success for various management activities?

Improving and Maintaining Watershed Condition

A significant amount of the existing unsatisfactory watershed conditions are associated with the pinyon-juniper ecosystem. In many cases, it produces excessive rates of runoff and sediment as a result of past use. The hydrology of pinyon-juniper is highly sensitive to use.

Many past problems have existed for so long that the public incorrectly views the existing situation as unchangeable. However, combinations of watershed improvement measures applied at Saliz in New Mexico, Murry Canyon in Nevada, Silver City watershed in New Mexico, and Rudd Creek in Arizona have successfully controlled runoff and erosion. These treatments included revegetation and protection from livestock, or improved management.

Relict and protected areas provide indications that some areas can support substantially more ground cover than commonly observed in actively used pinyon-juniper.

Mechanical treatments, while successful, are relatively expensive to apply. Optimum watershed treatment strategies for restoring long-term productivity and reducing flood and sediment risks need to be identified.

Successful watershed condition improvement and maintenance strategies will require resolution of the following questions:

1. What constitutes satisfactory watershed condition and what measurable indicators can be used to assess it?

2. What geomorphic factors indicate dynamic equilibrium with respect to on-site channel stability and sediment transport?

3. Do measurable threshold cover conditions exist that indicate susceptibility to permanent impairment of hydrologic function?

4. What influence does high-intensity short-duration precipitation have on selection of mechanical treatment measures?

5. What roles do plant, litter, rock pavement, and cryptogram cover have in influencing infiltration and soil detachment? Are they equally effective?

6. Do differences in the spatial distribution of cover produce different runoff results? (i.e., is there a difference between 30 percent litter cover concentrated under trees and 30 percent cover of grass and litter uniformly distributed over the same site?). What role does overstory interception play with respect to short-duration storms?

7. What role does intensive frost action have on susceptibility to erosion? What actions reduce its impact?

8. What management or treatment strategies are available to deal with vertisols and vesicular soils?

9. What constitutes a concentrated runoff flow path in determining effective drainage density?

10. What is the current influence of pinyon-juniper on riparian conditions, and what management strategies provide greatest protection for riparian and other downstream values?

CONCLUSIONS

Improving our understanding of the hydrology of pinyon-juniper is a tall order. However, it is vital if we are to overcome misconceptions and folklore that threaten to produce undesirable watershed conditions that are expensive to correct.

As population growth continues in the Great Basin and Southwest, increased demand will focus on the pinyon-juniper ecosystem. Increased distance to fuelwood sources and increases in off-road-vehicle use provide examples of emerging trends. Studies of pinyon-juniper hydrology need more emphasis to provide watershed management technology to keep pace with these increasing user demands.

Use of new solid-state data-acquisition technology coupled with computers offer substantial opportunities for more cost efficient studies. This technology can overcome some of the previous high costs of data management and equipment maintenance that prohibited widespread small-watershed studies and acquisition of storm event data.

For best results it appears that future studies need to:

1. Focus on watersheds as a system and verify plot data at a watershed scale. This is particularly important for cover type and distribution studies.

2. Emphasize process-oriented research leading to models that can detect critical factors, allow managers to test management strategies, enable extrapolation of other research, and focus future research.

3. Define essential factors in determining satisfactory watershed conditions, dynamic equilibrium, and site productivity.

4. Direct research efforts toward understanding the nature of precipitation events and associated runoff, particularly intra-storm characteristics for time intervals of 5-minutes and less.

5. Develop a network of long-term small-watershed studies to define magnitude and frequency of precipitation, runoff, and erosion processes.

6. Define a soil-vegetation-climate classification framework to facilitate technology transfer.

Process-oriented hydrologic studies in pinyon-juniper ecosystems appear to offer the best likelihood of providing the basic facts needed to respond to changing future themes. Restructuring these basic process facts to meet changing needs can provide information to model hydrologic impacts of future alternative use strategies.

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WATER BALANCE CALCULATIONS IN SOUTHWESTERN WOODLANDS

Leonard J. Lane and Fairley J. Barnes

ABSTRACT: Water balance calculations are required to compute individual components of the water budget or balance: precipitation, runoff, evapotranspiration, soil moisture recharge and depletion, and seepage below the root zone. Hydrologic models are used to make these calculations, and soil-water-plant relationships are used to identify gaps in knowledge and, thereby, to suggest methods of improving hydrologic models.

INTRODUCTION

Pinyon-juniper, an important type of southwestern woodland, occupies significant portions of several physiographic provinces (e.g., Hunt 1974). West and others (1975) state that almost three-fourths of the pinyon-juniper ecosystem type are found in the Basin and Range and Colorado Plateau provinces. This means the ecosystem type is especially important in Arizona, New Mexico, Nevada, Utah and Colorado.

The pinyon-juniper type generally occupies an elevation, temperature, and precipitation zone between the more arid desert shrub and chaparral, and more mesic ponderosa pine forests at higher elevations (Dortignac 1960). In discussing water yield, Dortignac (1960) described the pinyon-juniper type as having structure and hydrologic characteristics intermediate between grass lands and forests. Mean annual precipitation for this vegetation type was characterized as usually varying from about 300 to 450 mm. The corresponding approximate elevation zones were described (e.g., Dortignac 1960, p. 19) as follows: Arizona 1370 to 1980 m, New Mexico and Utah 1520 to 2130 m, and Colorado 1830 to 2440 m. Mean annual temperatures vary from about 4°C to over 18°C, depending upon latitude and elevation. West and others (1975) plotted climatic diagrams (using monthly mean precipitation and temperature data) for 15 stations. These diagrams illustrate the relationships between seasonal temperature and precipitation, and suggest periods of soil moisture recharge (when mean monthly temperature is less than mean monthly precipitation) and periods of soil moisture depletion (when mean monthly temperature is greater than mean monthly precipitation). While such diagrams suggest soil moisture recharge and depletion, they are not water balance calculations.

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Leonard J. Lane is a Hydrologist, Agricultural Research Service, U.S. Department of Agriculture, Tucson, AZ; Fairley J. Barnes is a Staff Member, Los Alamos National Laboratory, Los Alamos, NM.

A purpose of this paper is to illustrate the use of hydrologic models to calculate a water balance to quantify the various components: precipitation, evapotranspiration, runoff, percolation below the root zone, and changes in soil moisture storage. These calculations illustrate the water balance on a stand or watershed scale. A second purpose of the paper is to use a simple diffusion model of the woodland canopy to simulate soil-water-plant relationships over smaller spatial scales, and over diurnal cycles. Analyses on these space and time scales are used to illustrate gaps in knowledge limiting the development of more comprehensive water balance calculation methods and improved hydrologic models.

WATER BALANCE CALCULATIONS

As water is often the limiting factor for plant growth and survival in arid and semiarid areas (e.g., Brown 1977) and for growth and productivity in semiarid and subhumid woodlands (e.g., Lieth and Whittaker 1975), water balance calculations are an essential part of soil-water-plant relationship studies in the pinyon-juniper type. Plant water use as the transpiration fraction of the evapotranspiration (ET) component affects the water balance and soil moisture content and, thereby, infiltration and runoff. As discussed below, soil moisture status often limits the rate of ET, so that consideration of a water balance or budget necessarily involves feedback mechanisms (e.g., Veihmeyer and Hendrickson 1955).

With the assumptions of no net subsurface water movement in the horizontal direction, and a limited rooting depth well above the permanent water table, then the discrete form of the water balance equation for a unit area of land surface can be written (e.g., Lane and Stone 1983) as:

$$\frac{\Delta S}{\Delta t} = P-Q-ET-L \qquad (1)$$

where: S = soil water content (mm representing units of volume per unit area),
Δt = time period for the calculations (hr, day, month, etc.),
P = depth of precipitation for the time interval (mm/Δt),
Q = runoff volume (mm/Δt),
ET = combined evaporation and transpiration for the time interval (mm/Δt), and
L = percolation below the root zone for the time interval (mm/Δt).

Positive values of $\Delta S/\Delta t$ represent soil moisture recharge, while negative values represent soil

moisture depletion. If precipitation is considered uncontrolled climatic input to the system, then equation 1 shows that all other components of the water balance are interrelated, and are functions of precipitation.

Runoff occurs as the result of precipitation exceeding the rate of water infiltrating into the soil. The rate of infiltration during a rainfall event depends upon rainfall rate, amount, and time distribution during the storm event. It also depends upon antecedent soil moisture, and thus upon all other terms in equation 1. Soil characteristics, including texture, porosity, water content, hydraulic conductivity, structure, depth, and surface features affect infiltration, as does land use, condition, and management. Vegetation type and conditions affect infiltration, and thus runoff, through a wide variety of complex interactions. Runoff is estimated from precipitation data using a variety of techniques, including indices, regression equations, daily rainfall-runoff equations, and infiltration equations. Key sources describing methods of predicting infiltration and runoff are "Rangeland Hydrology" (Branson and others 1981) and "Hydrologic Modeling of Small Watersheds" (Haan and others 1982).

The rate of ET, in equation 1, depends upon the potential evapotranspiration rate, upon soil texture and surface characteristics, and upon vegetation characteristics (e.g., leaf area index, rooting depth, etc.) when soil moisture is nonlimiting. When water is limiting, it depends upon the same factors as well as soil water content. Hanson (1973) summarized several relationships (e.g., Veihmeyer and Hendrickson 1955; Thornthwaite and Mather 1955) between the ratio of actual evapotranspiration (AET) and potential evapotranspiration (PET) as soil moisture ranges between field capacity and the permanent wilting point. These relationships can be summarized in equation form as

$$AET = \begin{cases} PET & SM \geq SM_1 \\ f(SM, PET) & WP \leq SM \leq SM_1 \\ 0 & SM \leq WP \end{cases} \qquad (2)$$

where SM_1 is a soil water content between field capacity (FC) and wilting point (WP). The function f controls the ratio of AET to PET when soil moisture is between WP and SM_1, and is also a function of the plants' physiological response to water stress. Basic source material on ET processes is given in the references cited earlier, i.e., "Rangeland Hydrology" and "Hydrologic Modeling of Small Watersheds," as well as in "Primary Productivity of the Biosphere" (Lieth and Whittaker 1975).

The rate of percolation or seepage below the root zone, L in equation 1, is determined by many of the same factors determining infiltration rates into the soil. The movement of water in the liquid phase in soil can be described by combining the continuity of mass equation with a flow rate equation called Darcy's equation. With this description, the flow rate of water through the soil is determined by the hydraulic gradient and the hydraulic conductivity. Soil characteristics, such as texture, structure, porosity, and antecedent water content, in large part determine hydraulic gradient and the hydraulic conductivity. Because percolation below the root zone can result in return flow or base flow in intermittent and perennial streams, L, in equation 1, is often included in the runoff term when water balance calculations are made on an annual or monthly basis. Key sources describing percolation include those cited earlier in the discussion of infiltration, and others, such as Hillel (1971), Todd (1959), Brooks and Corey (1964), and Rawls and others (1982).

Examples of the Water Balance on an Annual Basis

The Beaver Creek watersheds are located in the plateau climatic region of Arizona, and are subject to two distinct precipitation seasons (Baker 1982). The winter precipitation season is from October through April, and the summer precipitation season is mainly in July through September, with May and June as dry months. Four intergrading vegetation types found on the Beaver Creek Watershed (Baker 1982) are: semidesert, Utah juniper (Juniperus osteosperma (Torr.) Little), alligator juniper (Juniperus deppeana Steud.), and ponderosa pine (Pinus ponderosa Laws.). Components of the water balance for the three woodlands are given in table 1 (adapted from Baker 1982, and Campbell and Ryan 1982).

The data in table 1 suggest the following approximate values for an annual water balance. Runoff as a percent of precipitation is 6% for the Utah juniper watersheds, 22% for the alligator juniper watersheds, and 22% for the ponderosa pine watersheds. This means that evapotranspiration varied from 94% of annual precipitation on the Utah juniper watershed to 78% on the alligator juniper and ponderosa pine watersheds.

Dortignac (1960) tabulated precipitation and runoff data for 10 years from three experimental watersheds near Santa Fe, NM, for 6 to 20 years of data from 9 watersheds at Mexican Springs, NM, and for 2 years of data from six experimental watersheds at Beaver Creek, AZ. These data suggested that annual runoff amounts to about 2 to 4% of annual precipitation on the New Mexico watersheds and from 5 to 7% on the Beaver Creek juniper watersheds. However, the data in table 1 would suggest that annual runoff amounts to about 6 to 22% of annual precipitation on the juniper watersheds on Beaver Creek. This difference (6 to 22% as opposed to 5 to 7%) illustrates the value of a 23-year record (table 1 1958-1980) over a 2-year record in estimating mean annual values of components of the water balance. Interpretations of the data shown in table 1 also suggest the importance of seasonal distribution of precipitation (winter and summer at Beaver Creek and predominately summer in New Mexico, e.g., see figure 2 on p. 23 of Dortignac 1960), and of soil types and textures (predominately sandy and loamy soils on the New Mexico watersheds and clay soils at Beaver Creek).

Examples of the Water Balance on a Monthly Basis

A simple monthly water balance model based on equation 1 was developed to illustrate monthly

Table 1.--Components of the annual water balance for watersheds in three vegetation types on the Beaver Creek Watershed in Arizona. Data base is 1958-1980

Vegetation Type	Approximate Elevation (m)	Mean Precipitation[1]	Annual Values in mm Runoff[2]	Evapotranspiration[3]
Utah Juniper	1500	441.	27.	414.
Alligator Juniper	1900	553.	121.	432.
Ponderosa Pine	2250	634.	141.	493.

[1]Precipitation data from table 1 of Campbell and Ryan (1982).
[2]Runoff data from table 1 of Baker (1982), and assumed to include L in equation 1.
[3]Calculated as the difference between precipitation and runoff.

water balance calculations. Equation 2 was used for the AET calculation, with PET calculated from mean monthly temperature (e.g., see Bailey 1981), and runoff calculated using a modification of the USDA Soil Conservation Service procedure. This simple model needs prior calibration using measured monthly runoff or output of a more realistic water balance model such as the CREAMS model (Knisel 1980). However, once the monthly water balance model is calibrated, it can be used to predict components of the water balance for various combinations of monthly temperature and precipitation.

Seven sites, selected for illustration of monthly water balance calculations, are listed in table 2. Rock Valley, NV was selected as a climatic extreme for a predominately winter precipitation site, and because water balance calculations have been made there on a daily basis (e.g., Lane and others 1984), Holbrook, AZ was selected as a climatic extreme for a predominately summer precipitation site. Both sites are too arid to support woodland vegetation, but were selected to illustrate differences in seasonal precipitation patterns reflected in the monthly water balance. The Kingman, AZ site was selected as a winter precipitation site, with precipitation just under amounts sufficient to support a pinyon-juniper woodland. The three Beaver Creek, AZ sites represent average climatic and hydrologic conditions from several experimental watersheds (e.g., see Baker 1982). However, it should be noted that the clay-type soils found on the Beaver Creek watersheds have lower infiltration rates, and thus produce relatively more runoff than would occur at the other sites (all other conditions being equal) shown in table 2. The Los Alamos, NM site was selected as a summer precipitation site at the upper limit (with respect to precipitation) of the pinyon-juniper site, and because water balance calculations also have been made there using the CREAMS model (e.g., Lane 1984).

Results of monthly water balance calculations, for the seven sites described in table 2, are summarized in table 3. The calculated ET and runoff values shown in table 3 were made using the simple monthly water balance model described earlier. As such, the values represent approximate monthly means estimated using mean monthly precipitation and temperature. The resulting monthly ET and runoff estimates have less variability than if they were means estimated by summing the results of monthly values estimated using 20 years of monthly precipitation and temperature data.

For example, based on 20-year means for monthly precipitation and temperature, the monthly water balance model predicts no runoff for the months of January-June and November-December at Los Alamos, NM. However, application of the CREAMS model, using daily rainfall amounts (individual values, not means) for the same 20-year period of record and the same soil conditions, suggests that runoff occurred at least once during every month of the year (Lane 1984; table XV, p. 38). The reason for these differences (and a major weakness in using long-term means in calculating a water balance) is illustrated by the variations in April precipitation at Los Alamos over the 20-year period from 1951 -1970. The mean April precipitation was 20.3 mm, with a standard deviation of 19 mm and a range of 0 to 60.5 mm. It is quite likely, for example, as suggested by the CREAMS model, that runoff occurred during the April period, with 60.5 mm of precipitation. In spite of these shortcomings in the monthly water balance model, it did produce much of the information present in the CREAMS model estimates of mean monthly runoff.

The results of monthly water balance model estimates of mean monthly runoff (from table 3) and average measured values for Beaver Creek, AZ were also compared. In each case, the monthly water balance model improved the estimates of mean monthly runoff over those obtained using precipitation alone. Precipitation alone explained from 17 to 30% of the variance in mean monthly runoff, while the monthly water balance model explained from about 33 to 53 %. Therefore, the runoff estimates shown in table 3 should be interpreted as approximate values suggesting generalized seasonal patterns.

Much less observed data are available to judge the validity of the ET estimates shown in table 3. Lane and others (1984) found that the CREAMS daily water balance model explained some 90% of the variance in mean monthly soil moisture for Rock Valley, NV, and for bare soil and vegetated lysimeters at Los

Table 2.--Location and mean annual precipitation and temperature for seven sites in Arizona, Nevada, and New Mexico

Station Name	Location Latitude N Deg - Min	Location Longitude W Deg - Min	Elevation (m)	Mean Annual Precip (mm)	Mean Annual Temp. (C°)	Comments
Rock Valley, NV	36° 40'	116° 05'	1020	161	17	Northern Mojave Desert. Example of climatic extreme for winter precipitation.[1]
Holbrook, AZ	34° 54'	110° 10'	1545	187	13	Summer precipitation site below the pinyon-juniper type.
Kingman, AZ	35° 11'	114° 03'	1024	239	16	Winter precipitation site just below pinyon-juniper type[2].
Beaver Creek, AZ[3]						
Utah Juniper	34° 35'-34° 50'	111° 35'-111° 45'	1500	441	14	Lower pinyon-juniper type.
Alligator Juniper	34° 35'-34° 50'	111° 25'-111° 45'	1900	553	10	Mid pinyon-juniper type.
Ponderosa Pine	34° 40'-34° 55'	111° 20'-111° 45'	2250	634	7	Upper to above pinyon-juniper type for winter precipitation.
Los Alamos, NM	35° 53'	106° 19'	2250	468	9	Upper to above pinyon-juniper type for summer precipitation.

[1]Precipitation distributed over the entire year, but winter season precipitation dominates the water balance. The opposite is true for summer precipitation sites.
[2]"Below pinyon-juniper type" refers to elevation and/or mean annual precipitation below or lower than found at pinyon-juniper sites. The opposite is true for "above pinyon-juniper type."
[3]Approximate range in latitude and longitude, but approximate mean elevation for gaging sites.

Table 3.--Observed monthly precipitation and monthly water balance model[1] estimates of evapotranspiration and runoff for the seven sites shown in table 2

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual[2]
	Precipitation in mm												
Rock Valley, NV	15.5	34.5	22.4	5.8	5.8	5.1	9.9	10.2	13.7	13.0	18.9	16.0	161.
Holbrook AZ	10.7	9.7	11.7	8.9	6.6	6.4	27.4	43.2	21.8	18.5	10.4	11.9	187.
Kingman, AZ	25.9	26.9	26.9	19.6	5.1	3.6	19.8	34.8	17.5	15.7	16.8	25.9	239.
Beaver Creek, AZ													
Utah Juniper	40.4	46.5	52.1	27.7	9.4	4.6	38.1	54.1	47.5	40.6	35.3	44.7	441.
Alligator Juniper	57.2	58.9	65.0	32.5	17.5	8.4	47.2	60.2	52.6	47.0	46.2	60.7	553.
Ponderosa Pine	64.3	68.6	78.0	39.1	19.6	10.2	57.7	64.5	53.3	47.2	61.0	70.4	634.
Los Alamos, NM	18.8	18.5	23.9	20.3	28.2	33.0	85.1	116.3	37.1	41.2	19.3	26.4	468.
	Evapotranspiration in mm												
Rock Valley, NV	13.5	25.1	25.4	16.0	11.2	8.1	9.7	9.9	11.7	10.9	8.6	10.9	161.
Holbrook, AZ	9.4	10.7	12.4	12.2	9.9	8.4	23.4	36.8	23.9	17.5	10.9	9.4	185.
Kingman, AZ	23.4	26.9	27.7	24.1	11.7	6.4	16.8	29.2	19.8	15.5	15.0	20.3	237.
Beaver Creek, AZ													
Utah Juniper	32.3	40.4	48.3	41.1	25.4	13.7	32.3	45.5	42.9	35.3	29.2	31.0	417.
Alligator Juniper	35.1	41.1	47.8	42.7	32.8	20.3	35.8	44.5	41.1	34.5	30.7	33.3	440.
Ponderosa Pine	35.1	42.3	50.3	49.8	45.2	38.1	46.7	47.2	41.1	34.0	31.5	32.5	494.

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Table 3.--(Continued)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual[2]
	Evapotranspiration in mm												
Los Alamos, NM	18.0	20.3	24.6	26.9	32.5	37.8	67.3	90.2	51.6	37.8	23.1	20.1	451.
	Runoff in mm												
Rock Valley, NV	0	0.3	0	0	0	0	0	0	0	0	0	0	0.3
Holbrook, AZ	0	0	0	0	0	0	0.2	1.8	T	0	0	0	2.0
Kingman, AZ	0.2	0.3	0.3	0	0	0	0	0.8	0	0	0	0.2	1.7
Beaver Creek, AZ													
Utah Juniper	2.3	3.5	4.6	0.4	0	0	1.1	3.7	2.6	1.7	1.1	2.8	23.8
Alligator Juniper	14.6	15.6	17.7	5.0	0.8	0	7.3	11.6	9.4	8.1	8.5	14.8	113.3
Ponderosa Pine	16.6	18.8	22.7	7.5	1.4	0	10.6	13.1	9.6	8.0	13.3	17.9	139.5
Los Alamos, NM	0	0	0	0	0	0	5.2	12.0	0.1	0.2	0	0	17.4

[1]Monthly estimates based on long-term mean monthly precipitation and temperature, and a standard 1-m deep soil profile with site-specific estimates of soil water retention properties.
[2]Annual totals may differ from sum of monthly values due to roundoff errors.

Alamos, NM. The monthly water balance model was fitted to monthly ET estimates and estimates from the CREAMS model for vegetated lysimeters at Los Alamos, NM. The monthly water balance model explained about 60% of the variance in monthly ET values. Although these comparisons were based on only 2 years of data from lysimeters, they are probably indicative of the relative precision of ET and runoff estimates--i.e., estimation errors in ET are larger than those in runoff, but proportionally are less, because runoff is a smaller component of the water balance.

A final illustration of the degree to which a simple monthly water balance model can be used to estimate seasonal distribution of water balance components in pinyon-juniper woodlands is shown in figure 1. The data in figure 1 represent averages for both the Utah and alligator juniper sites at Beaver Creek, AZ. The upper portion of figure 1 shows the monthly distribution of measured precipitation and estimated ET. These data suggest soil moisture recharge ($P > ET$) during the months of January - March and July - December, and soil moisture depletion ($P < ET$) during April - June. The resulting profile-average soil moisture estimates are shown in the lower portion of figure 1. Average measured runoff and average estimated runoff are shown in the central portion of figure 1. Although the annual runoff volumes are comparable, the estimated monthly values are low in the winter and spring (February through April), and high during the summer (July through September), and approximately equal to the measured values in January, May, and October through December. However, with the exception of the high runoff estimates in July and August, the seasonal pattern of estimated runoff agrees with the measured seasonal pattern of runoff. This would suggest that the seasonal patterns of ET and soil moisture estimates are approximately correct for the Beaver Creek watersheds. More accurate estimates might result from application of a daily water balance model such as described earlier. The next section describes a more physiologically based approach.

SOIL-WATER-PLANT RELATIONSHIPS

The use of a simple water balance model has shown that there are large variations in yearly ET over a wide geographic range of woodland sites. However, the method used did not differentiate between different vegetation types or between vegetation densities. On a local scale, different vegetation types grown under the same climatic conditions can have wide variation in seasonal ET due to species differences in canopy resistance (a function of leaf area index, LAI, and stomatal resistance, R_s) and phenology (Nulsen 1984; Stewart 1984). As soil moisture, S, decreases, not only is the threshold at which stomata close widely variable, but the dynamics of stomatal closure has been shown to vary among species (Schulze and Hall 1982). This means that the relationships shown in equation 2 are approximate and dynamic through the growing season. Consequently, several authors have emphasized the need to include physiological responses in models designed to simulate ET from native plant communities (Denmead 1984; Kowalik and Eckersten 1984).

A simple diffusion model has been used to simulate ET from forest communities (Tan and others 1978; Sammis and Gay 1979; Running 1984). Based on the Penman-Monteith equation, the model assumes that leaf temperature is not significantly different from air temperature, and that the air in the substomatal spaces is saturated, thus allowing the atmospheric demand to be approximated by the ambient vapor pressure deficit (VPD).

Transpiration (E, in units g cm^{-2} s^{-1}) is calculated as,

$$E = R\ Cp(LAI)(VPD)/(L\ Y\ R_s) \qquad (3)$$

where R is the density of moist air (1.2×10^{-3} g/cm^3); Cp is the specific heat of moist air (1.01 $J^{-1}\ °C^{-1}$); L is the latent heat of vaporization of H_2O(2450J/g); Y is the psychrometric constant (0.066 kPa/°C); LAI is the leaf area index (m^2/m^2); VPD is vapor pressure deficit (kPa); R_s is stomatal resistance to water vapor diffusion (s/cm), and R_s = 1/G where G is stomatal conductance. VPD was calculated according to Campbell (1977).

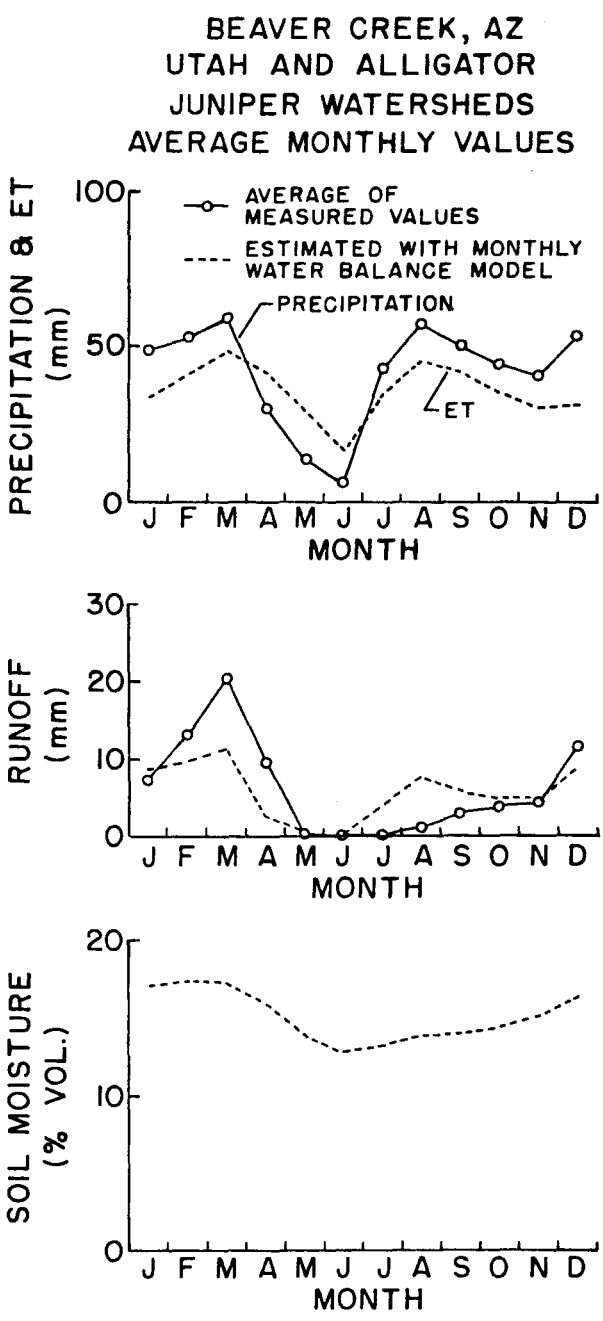


Figure 1.--Illustration of measured and estimated mean monthly water balance components for the Utah and alligator juniper watersheds at Beaver Creek, AZ.

Application of the Canopy Diffusion Model

A study of the physiological ecology of one-seed juniper (Juniperus monosperma) and pinyon (Pinus edulis) in the Los Alamos, NM region (Barnes 1986) has yielded sufficient data to begin to build a model of canopy transpiration rates of pinyon-juniper woodland. Data include measurements (every 2 to 4 weeks from April to October, 1982) of predawn leaf water potentials (LWP) of dominant species across a series of six woodland sites, two in each of three habitat types, as well as laboratory data on the stomatal responses of pinyon and juniper to light, temperature, and water stress. Meteorological data from Los Alamos weather stations (within 12 km of each field site) have also been used. Calculations of daily stand transpiration form the basis for estimating stand transpirational water losses throughout the year. Three of the 6 sites were chosen to illustrate, in tabular form, scenarios typical of the range of pinyon-juniper woodland in the Los Alamos area. The 3 sites differed in physical characteristics, species composition, and seasonal water stress (table 4), and are typical of the range of pinyon-juniper woodland types in the area. Foliage biomass per unit ground area for each site was estimated using the frequency distributions of diameter at base (DAB) size classes of the trees on each study plot. These data were used as input to the regression equations of Miller and others (1981) to express the relationship between DAB and total foliage biomass of singleleaf pinyon (P. monophylla) and Utah juniper (J. osteosperma). Leaf area indices were then estimated using specific leaf mass values for each species (Barnes 1986).

Statistical analysis of the gas exchange measurements on intact juveniles of each species (details in Barnes 1986) showed that stomatal conductance (G) and LWP have a highly significant exponential relationship. There were significant differences ($P < 0.05$) between stomatal responses of the two species. Within the group of junipers studied, there were significant differences ($P < 0.001$) between individuals collected from the xeric (site 2) and mesic (site 6) ends of the habitat continuum. The field LWP data at each site, and the regression relationships (table 5), were used to estimate the depression in monthly maximum G due to water stress of pinyons and junipers on all sites. For the winter and early spring months, when no LWP field data were available (November through April), it was assumed that the LWP was -1.2 MPa for pinyons and -1.0 MPa for junipers.

Daily maximum transpiration was calculated (equation 3) under conditions of maximum daily atmospheric demand using 1982 monthly means of daily maximum temperatures and relative humidity at 1400 h from both the Los Alamos National Laboratory main weather station at elevation 2250 m (LA), and a subsidiary station at elevation 1950 m (WR). The LA data were used to estimate transpiration for sites 5 and 6; the WR data were used for sites 1 and 2, and an average of the two meteorological data sets was used for the intermediate sites 3 and 4 estimates. Daily total stand transpiration (ST) was estimated using a sine function factor calculated for the 15th day of each month, as described by Jackson and others (1983).

The model predicted a reduction in stand transpiration (ST) during June and July at all sites, the reduction being least at site 1, which was the lowest elevation site. This pattern of reduced summer ST was not predicted by the water balance model for

Table 4.--Stand characteristics and seasonal mean minimum predawn leaf water potentials (LWP) of 3 intensive study sites in northern New Mexico

Site	Elevation	Slope	Aspect	Leaf Area Index			Minimum LWP (MPa)	
				pinyon	juniper	total	pinyon	juniper
	(m)	%						
2	1950	19	ESE	0.41	1.31	1.72	-2.26	-3.39
4	2011	5	SSW	1.92	0.76	2.58	-1.91	-2.32
6	2072	27	NNE	3.07	0.70	3.77	-2.03	-3.57

Table 5.--Relationships between stomatal conductance, G(mol m^{-2} s^{-1}), and predawn leaf water potential, LWP(MPa), using the model $\ln G = B_0 + B_1(LWP)$

Species/habitat	B_0	B_1	r^2
pinyon (1-6)*	-2.284	1.644	0.58
juniper (3,4)	-2.136	0.711	0.85
juniper/xeric (1,2)	-1.829	0.808	0.89
juniper/mesic (5,6)	-2.237	0.679	0.84

*Sites for which the parameters were used to calculate stand transpiration.

the Los Alamos area (fig. 2), although this discrepancy is, in large part, the result of mean precipitation data being used for the water balance model and 1982 data for the diffusion model. In 1982, June was particularly dry, followed by large storms in July, which may have generated higher than average amounts of runoff. Yearly stand transpirational water loss was highest at the lowest elevation site 1 (360 mm), lowest at site 5 (69 mm), and intermediate at the remaining sites (site 2, 203 mm; site 3, 165 mm; site 4, 170 mm; site 6, 216 mm) (fig. 2). These values are all considerably below the 451 mm for total ET predicted by the water balance model simulation using the LA weather station data (20 year means). We expected the ST estimates to be below total ET, since ST includes neither interception losses nor soil evaporation. However, yearly ST varied from 15 to 80% of yearly precipitation, a very wide range.

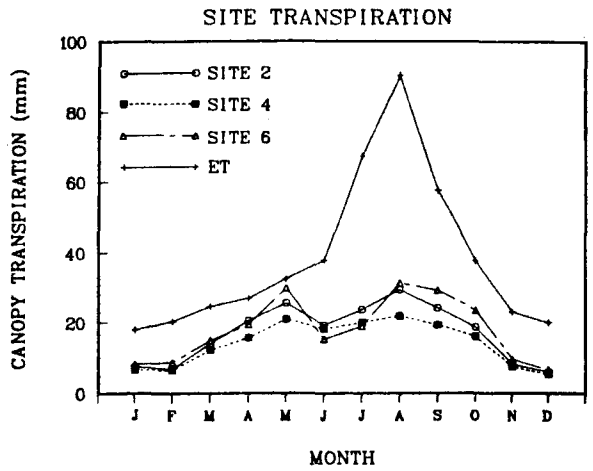


Figure 2.--Monthly stand transpiration estimated using the canopy diffusion model for sites 2, 4 and 6, and monthly ET estimated using the water balance model.

The differences among the 3 sites are probably due to many factors. Given the extremely localized nature of high intensity summer thunderstorms in the Southwest, the actual precipitation at each site may be considerably different from that received at the nearby weather stations. In addition, the slope and aspect of the sites are quite varied, which would have significant effects on runoff and soil evaporation. Finally, cover of vegetation, bed rock, and litter varies among the sites, all of which affect interception, infiltration, and runoff. There are also numerous physiological factors which could account for the wide range of ST predicted. The influence of relative humidity on stomatal conductance of pinyons and junipers has not been studied, and was not included in the diffusion model. Since high VPD can directly affect stomatal closure (Kaufman 1976; Running 1984), the actual stand transpiration rates may be significantly different from those reported here, especially in the drier months, when VPD is high and LWP is low. It is also likely that the two species have uniquely different stomatal responses to decreasing VPD, as noted by Turner and others (1984) and Johnson and Ferrell (1983), for other woody species. The simplification of using monthly means of temperature and RH may have resulted in erroneous estimates of ST if the relationships between stomatal conductance and these factors proved to be nonlinear. Again, this suggests that calculations on a daily basis are required for improvements over monthly calculations described earlier.

Although these results demonstrate the need for additional physiological data on the two species, particularly under field conditions where acclimation to seasonal climatic changes may be quite pronounced, there is strong evidence for the

dependence of stand ET on species composition. The high ST at site 2 (205 mm/yr) is due in part to the higher evaporative demand at lower elevation, but primarily to the fact that the vegetative cover at that site is largely juniper, which has higher conductance than pinyon at high water availability, and greater drought resistance in that the stomata remain open to much lower LWP than in pinyon. At sites 4 and 6, which are dominated by pinyon, junipers contribute as much, or more, to transpirational water losses than the pinyons.

Several authors have noted a correlation between LAI and site water balance (Grier and Running 1977; Gholz 1982), and the water balance models in use generally assume some direct linear relationship between stand LAI and ET. In diffusion model estimates, there was no correlation between total LAI and ST, but very good correlation between LAI of each species and the transpirational losses attributable to the species (fig. 3). The large difference in the slopes of the species plots is the result of the unique physiological characteristics of the two species.

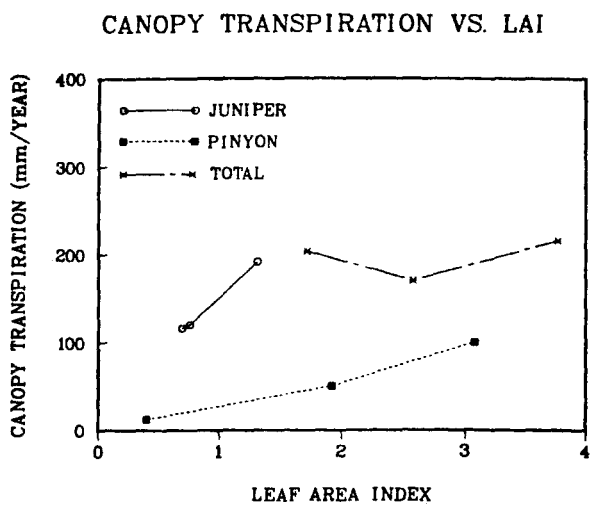


Figure 3.--Relationship between estimated canopy transpiration and leaf area index for each species and for the total stand.

CONCLUSIONS

Monthly water balance models of the type used here require calibration, and reproduce seasonal trends in components of the water balance in only an approximate manner, as shown in figure 1. It is apparent that the diffusion model alone is insufficient to predict site water balance, and must be linked with a hydrologic model capable of modeling runoff, infiltration, and soil water storage over a variety of soils and topographies. Hydrologic models, incorporating a plant physiological component, are rarely used; firstly, because of the limited data on native species, and secondly, because they require a detailed and continuous meteorological data base for each site (Denmead 1984; Running 1984). While current hydrologic models provide us with an assessment of water balance across broad geographic or climatic gradients, a more detailed model, incorporating species composition and specific physiological characteristics, may be needed to describe water balance on a more local scale, and over shorter time periods.

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MULTIPLE-USE MANAGEMENT OF PINYON-JUNIPER FROM A BUREAU OF LAND MANAGEMENT PERSPECTIVE

Edward F. Spang

ABSTRACT: The specific goals and processes to be followed in the implementation of the woodland management program are: (1) develop and maintain an extensive inventory and classification of public woodlands; (2) manage available woodlands under the principle of sustained yield, maintaining an allowable harvest to provide a permanent source of wood products for future generations; (3) receive fair market value from the sale of wood products; (4) manage woodlands to achieve a positive benefit/cost ratio, including development of analysis procedures which ensure that associated values (watershed protection, improved habitat and forage for wildlife and livestock, reduced dependency on fossil fuels for home heating, and other values received from wood product harvest) are considered; and (5) facilitate the management of other resources through wood product sales. Specific examples of the latter include selling pinyon-juniper instead of chaining to improve livestock forage or using commercial woodcutting to make the desirable openings in forest cover to improve wildlife habitat.

INTRODUCTION

In 1973, I gave a talk at a Bureau of Land Management (BLM) forestry workshop in Sacramento entitled, "The Forgotten Woods." In that talk I outlined the lack of recognition of woodlands as a resource in the total resource management program. At that time, I felt we did not recognize pinyon-juniper in the total program. We considered it an invader and limited our thoughts as to its use. I am happy to report that some of the problems identified 13 years ago have been solved, and that pinyon-juniper is being recognized as a valuable resource.

An important event that brought a great deal of attention to the pinyon-juniper woodlands was the energy shortage of the early 1970s. The higher cost for home heating turned many people to heating with wood, and increased the demand to harvest wood. This helped develop an awareness of the woodlands and the sale of other products--such as Christmas trees, fence posts, and pine nuts--also increased. The demand for woodland products in many areas can now be utilized as a tool to manage pinyon-juniper woodlands in combination with other uses and values to obtain the widest range of benefits. The potential to develop manufactured products such as flakeboard, medium-density fiberboard or wood cement board using pinyon and juniper exists. Charcoal can be produced from cordwood or larger residues. Extractive-based chemicals such as resins, oils, and tannins can be produced from pinyon and juniper.

Another important event that led to increased recognition of woodlands management was the passage of the Federal Land Policy and Management Act of 1976, which we refer to as FLPMA. FLPMA requires, unless otherwise specified by law, that public lands be managed under the principle of sustained yield which it defines as:

> The achievement and maintenance in perpetuity of a high-level or regular periodic output of the various renewable resources consistent with multiple use.

FLPMA explicitly establishes the balance inherent in the principle of multiple use by stating that public lands be managed in a manner:

> that will protect the quality of scientific, scenic, historical, ecological, environmental, air and atmospheric, water resource, and archeological values; that, where appropriate, will preserve and protect certain public lands in their natural condition; that will provide food and habitat for fish and wildlife and domestic animals; and that will provide for outdoor recreation and human occupancy and use; and which recognizes the Nation's need for domestic sources in minerals, food, timber and fiber.

In addition to the multiple-use and sustained-yield requirements, FLPMA, along with other laws and executive orders, provides the basis for the following forest management requirements:

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Edward F. Spang is State Director Bureau of Land Management, P. O. Box 1200, Reno, NV 89520

Protect and enhance the productivity of the forest ecosystem and its basic soil, water, and vegetative components.

Minimize erosion, sedimentation, and siltation and ensure soil stability.

Ensure that water and air quality meet Federal and State standards.

Ensure the protection of threatened or endangered plant and animal species and their habitat.

Protect and prevent irreparable damage to important historic, cultural, or scenic values, fish and wildlife resources or other natural systems or processes and public life and safety from natural hazards.

Regulate and manage floodplains and wet-lands to ensure protection of people and property.

The Bureau's Forest Land Policy Statement of 1983 further identifies the actions required in FLMPA and considers woodlands as part of the forest land resource. Previously, only commercial forest lands (CFL) were identified in the forest management concepts. Commercial forest lands are lands that are capable of producing at least 20 cubic feet per acre per year of forest products from coniferous species.

The woodlands really gained their recognition before the Forest Land Policy of 1983. A special Public Domain Forestry Evaluation conducted in 1981-82 points out that the public demand on woodland products is great enough to generate an income which exceeds the cost of management. That report recommends a more positive approach to woodland management through the development of policy and goals at the same level of guidance provided for commercial forestland. Woodlands were defined as lands producing trees that are typically utilized as nonsawtimber products and sold in units other than board feet Woodlands are those forestlands which are not included in the commercial forestland allowable cut base. These lands can include both commercial and noncommercial forestlands.

The Woodlands Management Policy Statement was issued in November 1982. It calls for the program to accomplish the following:

1. Recognize woodlands as distinct ecosystems to be managed and perpetuated for the production of multiple resource values. These values include wood products, livestock forage, wildlife habitat, recreation uses, watershed protection and minerals.

2. Develop and maintain an extensive inventory and classification of public woodlands. This information will be used to determine production capacities and to ensure an orderly harvest of available woodlands.

3. Strive for a woodland program that achieves a positive benefit-cost ratio. The program will apply cost-effective procedures to obtain fair market value for all available woodland products, except those disposed of through a limited free use program.

4. Facilitate the management of other resources and public use through sound management practices.

The woodland policy led to goals to provide for the orderly harvest and management of public woodlands while maintaining and/or enhancing other resource values. Implementation of these goals initiated a positive woodland management program.

GOAL 1. DEVELOP AND MAINTAIN AN EXTENSIVE INVENTORY AND CLASSIFICATION OF PUBLIC WOODLANDS

Woodlands are being inventoried to ascertain their acreage, condition, productivity, and location for wood products. The intensity of inventories and classification of woodlands are determined by resource demands. In woodlands where potential and existing demands for wood products are high or vegetation type conversions are program considerations, tree stands can be further classified by size classes, stocking rates, age, volume, etc. Where extensive inventory is considered adequate, an inventory method such as remote sensing may be used. Individual stand volumes are generally estimated by use of local volume tables. Where accurate volume tables have not been developed, a minimum number of permanent field plots may be necessary to support such estimates.

All woodlands are being classified as "available or nonavailable" for wood product harvesting. Woodlands having the capability of producing wood products will be classified as "available" unless they have been withdrawn from such use. Those woodlands withdrawn for other specific uses will be classified as "nonavailable."

All states are working on this goal to some degree. The Bureau has more than 6,620,000 hectares (16,357,000 acres) in seven states as its share of an estimated 32,460,000 hectares (80,208,660 acres) of woodlands. In Nevada there are an estimated 4,724,000 hectares (11,674,000 acres) of pinyon-juniper woodlands of which the Bureau manages 2,396,000 hectares (5,921,000 acres) which have been inventoried. The inventory identifies the number of growing trees by age and Christmas tree grade, and shows the number of line and corner posts. Measurements necessary to determine volume for both live and deadwood are collected.

GOAL 2. MANAGE AVAILABLE WOODLANDS UNDER THE PRINCIPLE OF SUSTAINED YIELD, MAINTAINING AN ALLOWABLE HARVEST TO PROVIDE A PERMANENT SOURCE OF WOOD PRODUCTS FOR FUTURE GENERATIONS.

A woodland management plan should be developed for areas where the demand for wood products (allowable harvest) is sufficient to justify the cost and where other values/issues are identified that make such a plan desirable. The improvement of watershed condition or the need to increase forage for wildlife or livestock are examples of other values to be considered in the woodland management plan. Energy or mineral development and fire management are values/issues that can affect woodland plan development. The woodland plans will provide for multiple use as well as sustained use. Harvest actions called for in woodland plans will be with multiple-use objectives and designed to benefit all uses, such as wildlife, livestock grazing, recreation values, watershed values, to name but a few. The environmental effects of any actions will be considered.

Areas for which an allowable harvest is developed shall have a sustainable source of wood products to supply regional markets as well as nearby communities. The ideal sustained yield area would be large enough to make it feasible to: provide a regular flow of products, minimize inventory costs, simplify subsequent steps of allowable cut calculations, and provide flexibility in scheduling harvests.

The allowable harvests are normally calculated on a 10-year cycle, however, longer cycles may be acceptable under certain circumstances. The allowable harvest can be adjusted annually, or at longer periods consistent with the principle of sustained yield for the total area.

The allowable harvest shall be calculated only for woodlands available for harvest.

GOAL 3. RECEIVE A FAIR MARKET VALUE FROM THE SALE OF WOOD PRODUCTS

Wood products sold to private individuals and commercial operators must be sold at fair market value (FMV). Negotiated sales of wood products are acceptable when the price agreed upon is equal to or greater than the FMV of the products. Where competition is strong, sales are advertised. Sealed bids, written bids, oral bids, or a combination of bidding methods may be used. The kinds of requests for wood products--including the recreational and social values of gathering wood products, such as firewood and Christmas trees--must also be considered when determining how the material should be sold.

In general, free use disposal is the exception rather than the rule. It may be applied as a limited resource management tool. No permit or fee need be required for individuals collecting limited amounts of downwood for campfires, flowers, berries, nuts, seeds, cones, and leaves for personal use.

Free use is allowed by law for nonprofit organizations; federal, state, or territorial agencies; certain mining claims and certain residents of Alaska. Otherwise, FMV is required.

Emphasis on collecting fair market values for the wood products sold in Nevada the past three years has resulted in a 17 percent increase in receipts. The retail value of the 1984 pine nut crop alone was 2.3 times the total BLM forest management budget for Nevada for Fiscal Year 1984.

The quantity of Christmas trees and fuelwood sold in Nevada decreased slightly the last three years, but the revenue taken in has increased. Some buyer resistance to fair market value probably occurred, but the program did not significantly decline. Bureauwide, the revenue received from the sale of pinyon pine and juniper increased by 3.75 times from 1982 to 1984.

GOAL 4. MANAGE WOODLANDS TO ACHIEVE A POSITIVE BENEFIT/COST RATIO

Develop benefit/cost analysis procedures which (1) ensure that associated values including watershed protection, improved habitat and forage for wildlife and livestock, reduced dependency on fossil fuels for home heating, and other values received from wood product harvests are considered and (2) maintain economic returns from wood products.

Funding priorities go to those areas whose woodland management programs yield a positive benefit/cost ratio.

GOAL 5. FACILITATE THE MANAGEMENT OF OTHER RESOURCES AND PUBLIC USE THROUGH SOUND WOODLAND MANAGEMENT.

Where practical, encourage the public to utilize wood and other forest products that would otherwise be wasted when such action would further resource management objectives. Specific examples include harvesting pinyon-juniper for fuelwood instead of chaining to improve wildlife habitat and livestock forage and harvesting Christmas trees to delay plant succession in old chainings.

We are also using Nevada Department of Forestry crews to create openings by cutting fuelwood in closed pinyon-juniper stands to improve mule deer winter range. Roads developed to facilitate the management of woodlands provide ready access for recreation and fire control and benefit many different users.

To assist in woodland management there is a need for further research or study on how to better manage pinyon-juniper. Site indexes have not been adequately developed for Nevada

and posttreatment of harvest units needs further work. There are other study and research needs but I will not discuss them as others in the symposium have covered such proposals.

SUMMARY

The pinyon-juniper woodland type covers the largest area of all the forest types managed by the Bureau and represents a vast potential forest resource. The commercial products are more in demand than they were 10 years ago. In even greater demand is the recognition of all multiple-use values associated with woodlands. How we manage the pinyon-juniper woodlands affects more than the products produced. Forage production and habitat for livestock, wildlife, and wild horses and burros must be effectively managed to provide the variety needed for food and cover. Watershed conditions need to be maintained in good condition to provide erosion control, prevent soil loss, and enhance water quality and quantity.

Recreational opportunities, esthetic values, and wilderness are important considerations and uses of the pinyon-juniper woodlands that have to be considered in any multiple-use management plan.

Energy and mineral activity must be coordinated with woodland values and uses through appropriate coordinated mining plans. Fire management which includes prescribed burns, presuppression, and suppression activities, must recognize the resource values and uses identified within woodland areas. This is a major role and responsibility in fire management.

The remains of prehistoric cultures are found throughout the pinyon-juniper woodlands. Archeological site protection required by law has attained management considerations intended by that law.

All of the multiple-use values associated with the woodlands have to be considered in managing these resources. The products produced are important and it is mandated by law to practice sustained-yield management that provides a supply of Christmas trees, fuelwood, pine nuts, and other harvestable forest products for future markets. Well-managed woodlands provide a greater variety in meeting these future demands.

The pinyon-juniper woodlands have been the subject of studies and research by a number of agencies and universities. Research is still needed on management techniques and methods of how to provide the greatest multiple-use benefits from pinyon-juniper woodlands.

Good pinyon-juniper management is an integrated mix of all programs--forestry, range, wild horses and burros, watershed, recreation, wilderness, archeology, wildlife, energy and minerals, and fire management. Good management provides for sustained forest resources and values while utilizing to the fullest extent possible the greatest mix of uses.

Multiple-use managers need access to the vast amount of information presented and discussed at this conference. There is an important need to "crosswalk" this knowledge into an effective tool for the decisionmaking process and on-the-ground implementation. Multiple-use demands of pinyon-juniper are upon us today, and any information that can be readily made available for use is welcome. Don't be concerned about questionable conclusions in all cases. Most all information presented this week can be applied in the multiple-use decision and implementation process. Multiple-use managers will welcome the information in the already "high risk" world of multiple-use management.

APPLIED HYDROLOGY IN THE PINYON-JUNIPER TYPE

Richard H. Hawkins

ABSTRACT: The scope of small watershed hydrology in pinyon-juniper areas is described. The limitations imposed by the pinyon-juniper environment are discussed and the need for site-specific data is stressed. Most precipitation goes to soil moisture storage, and ground water recharge is small. Runoff events are rare and usually of small volume, and annual water yields are correspondingly low. Because of this scanty surface water budget and because of inherent climatic and soils factors, on-site erosion and downstream sediment delivery is quite modest. Several operational methodologies are described, and their limitations discussed.

INTRODUCTION

The term "pinyon-juniper" describes a wide array of vegetation and land conditions. Though juniper occupies by far the largest area, various species of pinyon pines and junipers intermingle, and often occur in mixed stands. The label is arboreal, implying a forest, but the concept is so diffuse as to defy precise identification, and in fact most pinyon-juniper lands are used primarily for grazing. At extremes, it is either a dense forest of smallish trees (usually pinyons) or grassland savannas with only occasional trees (usually junipers). The term is used only because of our inclination to lump and classify; as shall be seen, pinyon-juniper lands are not closely linked with specific soils, geology, climate, or botanical associates. Thus, it is not surprising that there is no "pinyon-juniper" hydrology unique to the vegetatively described classification. The observed environmental conditions do provide boundaries which must contain and limit the hydrologic response, however vague.

Climate

The climate of pinyon-juniper lands is notable for being water short. Annual precipitation may vary from as low as 9 inches in Central Utah to well over 20 inches in Arizona and New Mexico. It occurs over mixture of snow and rain fractions, and summer and winter distributions. No clear precipitation pattern marks pinyon-juniper lands. The Great Basin portion of its range contains the lowest return period-duration rainfall intensities in the nation, and thus the lowest rainfall-based erosion characteristics. This property, along with almost continually unused soil moisture storage capacity also leads to only infrequent rainstorm runoff, and essentially no ground water recharge or quickflow. The climate is often windy, sunny and cold, with evaporation opportunity greatly exceeding water supply. The growing season may vary from 100 to 200 days (Ffolliott 1975). In general, the climate is hostile to plant growth, suggesting that resident vegetative cover is by default: very little else will grow there.

Soils

Pinyon-juniper is found at elevations from about 3,000 to 10,000 ft. Soils vary considerably. Within the National Forests of Arizona and New Mexico, soils supporting pinyon-juniper vary in texture from stony, cobbly, and gravelly sandy loams to clay loam and clay, and in depth from shallow to deep. Parent materials likewise vary widely from granite, basalt, limestone and sandstone to mixed alluvium (Springfield 1976). Personal observation suggests that texture is more critical at lower precipitation zones, with pinyon-juniper found more frequently on the gravelly and sandy landforms, and avoiding strongly alkaline soils. The variety of base geology and soils leads to variety of soil infiltration rates, moisture holding capacity, and fertility (Dontignac 1960). Soil characteristics alone do not seem to profoundly limit the presence of pinyon-juniper.

Associated Vegetation

Under the above outlined conditions, it is not surprising that pinyon-juniper occurs with a wide variety of vegetative neighbors. Usually it occupies a zone between the dry deserts, grasslands, and shrublands and the wetter forest lands, often along on elevational gradient. In its range it may be seen as the first forest-like vegetation in a transition or gradient from dry to wet conditions. Pinyon-juniper patches are found adjacent to sagebrush, grasslands, dryland or irrigated crops, Douglas-fir, or ponderosa pine. Often the boundaries are

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Richard H. Hawkins is Professor, Department of Forest Resources, and Professor, Department of Civil and Environmental Engineering, Utah State University, Logan, UT 84322.

diffuse. In a "social" sense, it does not appear highly selective about its vegetative companions.

APPLIED HYDROLOGY

Applied hydrology is that done to meet routine decision making needs in water resource management, engineering design, or land management in planning, design, or environmental impact situations. The focus here is in small drainage areas where the on-land processes may most surely influence runoff, erosion, and the land itself. While there is indeed a subsurface groundwater component, it is of minor interest on pinyon-juniper lands. The surface processes dominate concerns.

In recent years a veritable menagerie of digital process models have been developed to deal with watershed runoff and erosion. They are largely aimed at agricultural lands, and demand information on the land and the input driving variables not always available even in agricultural areas. New models are continuously under development, and improvements and modifications are made on existing models. Some are peculiar to specific agency practice or local application. Thus, there is no generally accepted universal model package widely applied, especially in wildland environments.

There are, however, a series of shorter, pseudo-scientific equations or methods, which are widely used by practitioners. They attempt to "model" fundamental events and processes, and can be used without the aid of computers. Furthermore, some of them are used as components of the computer models. Thus, only these familiar foundation methods will be covered here.

Primary applied hydrology concern usually involves the following questions:

1. Estimation of rainstorm event total flow and peak flow from storm and land characteristics.

2. Estimation of long-term erosion and sediment yield from climatic and land characteristics.

3. Estimation of long-term water yield from climatic and watershed characteristics.

A variation on the above themes calls for the difference in the flow, erosion, yield, etc. with changing land use. With such calculations the hydrologic impact of land use decisions can be estimated. The above, however, seem to be frequent, popular, and treatable questions. They also form methodological building blocks from which more ornate problems such as soil moisture recharge, groundwater budgets, long-term streamflow-sequences can be serviced. Applied hydrology in the pinyon-juniper type reduces to the use of these methods in the conditions broadly typified by the pinyon-juniper environment.

Storm Flow

A common need in applied hydrology is the storm flow from a small watershed from a storm of given depth. The storm depth (inches of rain) is defined by considering a return period and duration, and is usually taken from regional maps of precipitation so described. (For peak flow calculations, the array of intensities within the storm, called the storm distribution, is also specified, although such will not be considered here). For example, the calculation goal may be the runoff depth from a 50-year return period, 12-hour rainstorm of 2.50 inches. The object watershed should also be specified at least as to cover and soils.

By far the most popular attack on this problem is the Curve Number method (USDA 1956). It was originally developed by the USDA Soil Conservation Service for use in conservation planning and engineering design, mostly in traditional rainfed agricultural settings. By default, it is used world-wide in situations well beyond the conditions and assumptions of its original development. Despite its flaws it is currently the most viable candidate for this problem.

The equation used is

$$Q = (P-0.2S)^2/(P+0.8S) \qquad P \geq .2S \qquad [1a]$$

$$Q = 0 \qquad P \leq .2S \qquad [1b]$$

where P is storm rainfall in inches, Q is the storm direct runoff (overland flow, channel interception, and quick flow), and S is a measure of the site storage in inches, defined as 5/6 of the maximum possible difference between gross rainfall and runoff. Conditions of S = 0 imply an impervious surface, and Q = P. At the other extreme, when $S = \infty$, Q = 0 in all cases. The coefficient "Curve Number" (CN) is a transformation of S by the identity

$$CN = 1000/(10+S) \qquad [2]$$

Which is more intuitively pleasing insofar at CN = 0 at $S = \infty$ and Q = 0, and CN = 100 at S = 0 and Q = P. Thus higher CNs mean higher runoff, and lower CNs mean lower runoff.

Tables and charts of CN for a limited variety of soils and vegetative types are given in agency documents. There are none for "pinyon-juniper" directly, but table 1 gives CNs for some associated cover types. It should be realized that such category listings are only estimates based on the intuition, judgment, and data available to the table's creators. They are, like the method itself, statements of policy and/or convention, since few are based on actual field data analysis.

As an example, consider a juniper-grass watershed of 50 percent ground cover in "B" soils. From table 1, a CN of 58 results. Thus

Table 1.--Handbook curve numbers for land types associated with pinyon-juniper

Description	Soil[1] group	Cover density (%)	CN[5]
"Juniper-Grass"[2]	B	0	82
		100	34
	C	0	90
		100	56
"Sage-Grass"[3]	B	0	74
		100	28
	C	0	86
		100	40
"Herbaceous"[4]	B	0	84
		100	58
	C	0	90
		100	71
	D	0	95
		100	83

Source: USDA (1956), NEH-4. Notes: 1. SCS Hydrologic Soil Grouping: Group "A" has the lowest runoff potential, Group "D" the highest. 2. "Juniper or piñon with an understory of grass". 3. "Sage with an understory of grass". 4. "Grass-weed-brush mixtures with brush the minor element". 5. Linear interpolation of CN for 0 < cover density < 100.

$$S = (1000/58) - 10 = 7.24 \text{ inches},$$

and for the example case of P=2.50 inches,

$$Q = (2.50 - .2(7.24))^2 / (2.50 + 8(7.24))$$

$$= 0.133 \text{ inches}.$$

Thus from a 2.50 inch storm on the watershed described, a uniform flow depth of 0.13 inches would result. This is only about 5 percent of the storm rainfall. About 95 percent, or 2.37 inches stays on the land, and becomes soil moisture. Note that the storm duration, return period, and intensity played no role in the calculation.

How good is the method? One measure of goodness is how well the actual or "real" CN may be estimated from the available tables. On this matter, a recent study (Hawkins 1984) showed a discouraging lack of agreement between watershed CNs estimated with soils and vegetation data (from handbook tables) and those determined for the same watershed using rainfall and runoff data and solutions to equations [1] and [2]. As shown in figure 1 and table 2, the CNs were best estimated for agricultural cover, and most poorly for forested watersheds. Thus for pinyon-juniper lands, poor correspondence and high errors can be expected.

Furthermore, the calculation is easily offended by incorrect CN values. Up to a storm rainfall depth of about 10 inches, the runoff calculation is more sensitive to errors in CN than it is to equal errors in input rainfall (Hawkins 1975). A slightly different approach, shown in figure 2, shows that the runoff calculation is especially sensitive to estimates of S (and thus CN) at low P/S situations, that is, with "low" CNs and low rainfalls. The range of pinyon-juniper includes the lowest rainfalls for given return periods and durations in the nation, which exacerbates the situation. Especially on the more porous soils (low CN and high S), the calculation is error prone for pinyon-juniper watersheds.

For at least the two reasons given above--poor a priori estimation of CN, and the calculation sensitivity to CN in the pinyon-juniper environment, the problem of direct runoff estimation is poorly served here. A step towards improvement would be to determine CNs for pinyon-juniper watersheds from local rainfall and runoff data. Unfortunately, there are few appropriate instrumented watersheds in the region, and very little has been done to catalog their response in CN terms.

However, from the only reduced pinyon-juniper data sets known to the author, data-based curve numbers are given in table 3. Of note here is the surprising relative CN consistency between the watersheds. These are specific to the northern Arizona sites where they were experienced.

Table 2.--Summary of predicted and calculated curve numbers

	All		Agr.		Range		Forest	
	Book	Calc	Book	Calc	Book	Calc	Book	Calc
General								
Mean	69.7	74.2	70.9	66.7	74.7	76.2	64.0	76.8
StDev	12.5	13.2	15.1	18.5	9.6	11.6	9.7	10.2
N	110		21		32		51	
"Bias" (CN_{book}-CN_{calc})								
Mean	-4.5		4.2		-1.5		-12.5	
StDev	15.6		9.5		7.4		18.2	
Regression (CN_{calc}=a + b CN_{book})								
a	50.1		-3.9		29.2		66.0	
b	0.346		0.997		0.629		0.169	
r^2(%)	10.7		65.9		26.6		2.6	
SE	12.5		10.8		9.9		10.1	

Notes: SE, a, and means and StDevs in CN.
Source: Hawkins (1984)

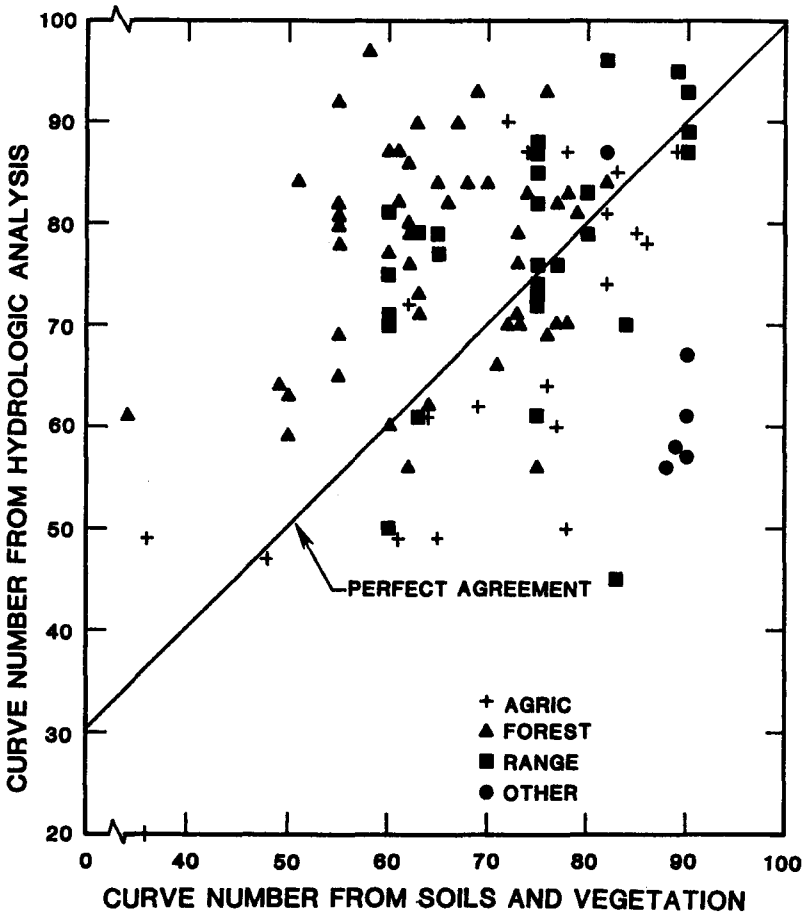


Figure 1.--Plot of hydrologically derived and handbook estimated curve numbers. Points have been rounded to the closest CN. Five points are overplotted, and thus do not show.

Table 3.--Curve number analysis for selected Beaver Creek (AZ) watersheds

Watershed			Storm			CN	
Name	Area (Ac)	Cover 3/	N (#)	P (in)	Q (in)	1/	2/
#1	332	PJ	16	1.38	0.0912	61	58
#2	126	PJ	14	1.53	0.2119	61	63.8
#3	362	PJ	16	1.41	0.2003	64	70.4
#4	346	AJ	20	1.28	0.1292	64	62
#5	66	AJ	25	1.42	0.1947	60	64.4
Avg	246	-	18	1.40	0.1655	62	63.7

1/ CN determines by "P/S" method, as outlined in (Hawkins and others 1985).
2/ Determined as apparent stable value in ordered P:Q data as P increases without limit. See Sneller (1985).
3/ "PJ" = pinyon-juniper, "AJ" = alligator juniper. Data source is U.S. Forest Service, but taken from Anderson (1980).

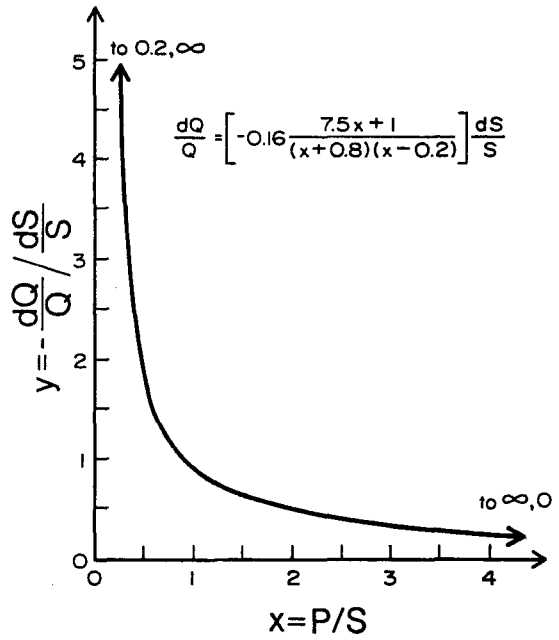


Figure 2.--Curve Number rainfall-runoff sensitivity function. The y-axis is the relative error in calculated runoff Q proportionate to a relative error of S. For example at P/S = 1, y = 0.94 (approx). Thus a 10% error in the estimation of S will give a -9.4 percent error in the calculated Q. Note the high error prospects at low P/S values.

Water Yield

Despite its apparent importance, reliable estimation of long-term water yield from ungaged watersheds is a poorly developed topic, and routine solutions rest on regional studies and/or semi-empirical equations. The problem is difficult because surface streamflow may arise from several sources: rainstorm response, groundwater derived baseflow, and snowmelt. Furthermore, large watersheds or river basins perform differently than small watersheds. Different processes dominate, interactions between lands and processes occur, and the spatial distribution of land and input characteristics confuse analysis. Watershed response does not simply scale linearly with either area or time parameters. Transferability is hazardous.

In the pinyon-juniper range, a variety of climate and geologic structures operate, and no truly fixed pattern of flow sources exists. However, the poverty of the water budget usually eliminates the groundwater component, and most small watersheds provide only rare storm response or occasional snowmelt events. Surface flow is small compared to the precipitation.

Regional Runoff Study

A regional study of note is that of Hawley and McCuen (1982), who statistically related long-term water yield to site and climatic characteristics for real watershed clusters (regions) in the west. Of interest here are the regions "Arizona and New Mexico" (which includes southern California), "Utah and Colorado" (including eastern Nevada), and "Northern California-Nevada" (which covers western Nevada). They fit both linear and exponential forms;

Ariz-NM $Q = 2.1065 + .2253P$, $R^2 = 0.569$ [3]

$Q = 8.205 * 10^{-5} P^{2.891} P_{25}^{1.647}$, $R^2 = 0.538$ [4]

Utah-Colo $Q = -7.9851 + 0.6270P$
$R^2 = 0.746$ [5]

$Q = 38.63 * 10^{-5}P^{2.967}$
$R^2 = 0.787$ [6]

NCal-Nev $Q = -10.986 + .4951P$

$+ 0.0998C + .2578P_m$
$R^2 = 0.835$ [7]

$Q = 8.704 * 10^{-5} P^{3.582}$
$R^2 = 0.711$ [8]

where Q is the mean annual water yield in inches, P is the mean annual precipitation in inches, P_{25} is the 60 minute-25 year return period precipitation in inches, C is the "percent cover density," and P_m is the minimum annual precipitation in inches. Note the negligible role for the site factors of cover, soils, elevation, bare ground, and percent vegetation and litter, which were included as variables in the statistical analysis.

Using the previous example of P = 15 in., the data set means of P_{25} = 1.26 in., C = 20.9 percent, and P_m = 16.2 in, the following water yields are calculated for the linear and exponential equations:

Ariz-NM	Q = 1.272 in/yr
	Q = 0.302 in/yr
Utah-Colo	Q = 1.410 in/yr
	Q = 1.192 in/yr
NCal-Nev	Q = 2.365 in/yr
	Q = 1.421 in/yr

The results suggest a lower regional water yield for Arizona-New Mexico, and illustrate the variety of answers from applying such tools. From a water budget standpoint, the expected streamflow (yield) is but a small fraction of the total input. Furthermore, it should be stressed that the equations are derived from river basin data, with an average drainage area of 89.5 square miles. Given the mountainous topography of the west, and the nonrandom inclination to establish river stations only on flowing streams, the records probably contain substantial base flow and snowmelt from higher elevations. This originates above the pinyon-juniper zone, but flows through it. Thus the equations can be expected to predict high when applied to pinyon-juniper lands and small watersheds.

General Model

A simpler, but widely used method, almost approaching a rule-of-thumb, is drawn from the precedent set by Grunsky (1908, 1915). In general form

$Q = \alpha P^2$ $\quad P < 1/(2\alpha)$ [9a]

$Q = P - 1/4\alpha$ $\quad P > 1/(2\alpha)$ [9b]

with the symbols as previously defined, and α is (of course) a coefficient appropriate to local conditions. It may be determined from data on nearby watersheds, and adjusted by the user's judgment to the situation at hand. Using the previous value of P=15 in/yr representative of pinyon-juniper, and a judged value for α = .004, then

$Q = .004(15^2) = 0.90$ in/yr

This result is of the same scale as those given using Hawley and McCuen's equations. The runoff is only 6 percent of the precipitation; the remaining 14.1 inches would recharge the soil and be available for plant growth.

The calculation hangs dearly on the coefficient α. Formal tables of α are almost nonexistent. Some broad regional values given by Sellars (1965) are presented in table 5. Table 4 gives some data-derived values for watersheds in Arizona. Note the comparison between Sellars "Southwest Desert", and the data-derived Arizona values. Hydrologically, Arizona pinyon-juniper watersheds respond as do deserts. Table 6 gives a suggested structure for synthesizing α values on the basis of local conditions. It has not been field tested.

Table 4.--Data-derived values for pinyon-juniper

Watershed	Area (mi^2)	$\bar{P}$ (in)	$\bar{Q}$ (in)	α (in^{-1})	Data Source
Carrizo Cr, Az	237	17.00	.7618	.0026	Ref 4
Corduroy Cr, Az	213	18.95	.9594	.0027	Ref 4
Beaver Cr #1	0.52	18.19	.77	.0023	Ref 3
Beaver Cr #3	0.57	18.19	.69	.0021	Ref 3

Table 5.--Regional values of the coefficient α

Region	α (1/in)
Rocky Mtns. and Sierra Nevada	.02
Great Lakes, New England	.01-.02
E. Central and W. Coast	.005-.01
Great Plains, Texas, SW Desert	<.005

Source: Sellars (1965)

Table 6.--Guidelines for the selection of the coefficient in pinyon-juniper watersheds

Attribute	Value of α (0.00X 1/in)		
	2 - 6	7 - 9	10 - 15
Exposure	S & SW	W & E	N & NE
Elevation	Low	Medium	High
Summer Rain	High	Medium	Low
Temperature	High	Medium	Low
Soil	Porous	Medium	Tight
Slopes	Shallow	Moderate	Steep

Source: Gifford and others (1975)

Sediment and Erosion

This is a difficult topic for several reasons. First, there is confusion between the upslope land processes of erosion, and the downslope channel processes of transportation, deposition, and even more erosion. Thus, as with streamflow hydrology, the component processes vary with the absolute scale. Contributing upland areas will experience only rill and interrill erosion from overland flow. As these areas join and form larger drainages channel or gully erosion becomes more important, and there is often interim deposition occurring simulataneously. Finally, progressing downstream, reservoirs accept sediment inflow, and trap a fraction of it.

Second, the above processes are driven by water. If there is no runoff there will be no erosion. Thus, because it depends on and draws from hydrology, it is more complex: understanding erosion hangs on understanding hydrology. Unfortunately, as outlined in previous sections, the hydrology techniques are poor. Clearly the matter cannot be treated adequately here. Only the more popular erosion concerns will be covered.

Universal Soil Loss Equation

The most widely used approach to the estimation of erosion is the Universal Soil Loss Equation (USLE), a sister technology to the Curve Number Method. It was developed from and for small upland rainfed agricultural areas. It is

$$A = RKLSCP \qquad [10]$$

where A is the long-term average "point" erosion in tons/acre/yr, R is a rainfall energy factor, K is a soil erodibility factor, L and S are length and slope factors, and C and P are cover and practice factors. To avoid pointless confusion, the dimensional descriptions of R and K have been omitted here.

The R factor depends on the depth, intensity, and number of rainstorms annually, and only operates for storms in excess of 0.50 inches. It may be routinely calculated from rainfall records, and thus may be considered a climatic descriptor, as is, for example, annual snow, or average annual temperature. For the range of pinyon-juniper, the R factor varies from a low of about 15 units in Nevada, to a high of perhaps 50 units in some Arizona locations. As shown in table 7, this may be contrasted with values for typical locations in rainfed agriculture of from about 100 to well over 500 units. Thus, the natural rainfall influences promoting erosion in pinyon-juniper are comparatively low. In fact many eastern U.S. locations may receive more erosive force in a single rainstorm annually than western locations receive in an entire year (Wischemeier and Smith 1978).

Table 7.--R-factor comparisons

Location	R (Ft-tons/acre-hr)
Pinyon-Juniper environments	
Albuquerque, N.M.	25
Elko, NV	16
Flagstaff, AZ	50
Las Vegas, NV	30
Richfield, UT	25
Humid rainfed agriculture	
Columbia, MO	205
Des Moines, IA	150
Houston, TX	425
Indianapolis, IN	175
Miami, FL	560
New Orleans, LA	725
Raleigh, NC	260
Washington, DC	160

Source: Israelsen and others (1980). Values scaled from figs. 5-1 and 5-2.

The K factor reflects the bare soil's inclination to erode. Estimates of it may be taken from soil surveys or by considering the texture, structure, and organic material of the soil, via nomographs or equations. The silty loam textures tend to be the most erosive, and sands and clays the least erosive. This factor may reflect some hydrology in addition to the intrinsic erosion, insofar as there can be no erosion without overland flow. Thus, sands are erosive once flow occurs, but flow is rare because of high infiltration capacities. Flow is frequent on clays, but high clay soils are usually quite cohesive, and resist erosion.

The original application of USLE was to sites disturbed by plowing, thus allowing rainfall to continually react with newly exposed soils. Natural pinyon-juniper sites have evolved without disturbed soils. Distinct profiles have developed, and the surface inclines to a stony cover, armoring the surface. Clearly, USLE should be inapplicable here.

The L and S factors carry the effects of length and slope, as multiples of a standard length (72.6 ft) and standard slope (9 percent). Longer lengths and steeper slopes will have higher factors. Values for L and S may be determined from agency publications (for example, Dissmeyer and Foster [1984], Wischmeier and Smith [1978]) again via tables, monograms, or formulas.

In original agricultural application, the C and P factors represented the separable effects of cover and practice. For forested lands, recent custom has been to combine these into a single C factor, which can be decomposed into nine multiplicative subfactors, not all of which operate simultaneously (Dissmeyer and Foster 1984). This "forested C," or "cover management" factor hangs in soil, cover, and tillage properties.

As an example, for a typical pinyon-juniper site, erosion might be calculated as follows, using Dissmeyer and Foster (1984) and Wisschmeier and Smith (1978) as a guide.

For the pinyon-juniper zone, R = 25. For a stony-sandy soil of moderate permeability, a value of K = .18 tons/yr/R unit is determined. Assuming a slope of 20 percent and a length of 100 ft, LS is found to be 3.1. For the C factor, the soils are considered untilled with 10 percent canopy over bare soil at a height of 2 m, yielding a "C" value of 0.089. Thus, (finally!)

A = 25 x 0.18 x 3.1 x 0.089 = 1.24 tons/acre/yr

As may be evident, the method draws heavily on handbook values of coefficients, and insofar as the calculation is multiplicative, errors are also multiplicative. Since onsite calibration is expensive, difficult, and time-consumptive, on wildlands the method is generally acknowledged to only provide an index or relative value, and not absolute real quantities. This is especially so in the semi-arid western wildlands, whose R factors and untilled soils are conspicuously different from the conditions of original development.

Any effects of land condition or management, such as burning, cutting, chaining, or grazing would be shown in the C factor. Thus, the power of the method is in the judgment, or lack thereof, of the user. There are no known standard USLE plots in the entire pinyon-juniper range, and thus no opportunity to ground estimates on data.

Sediment Delivery

The USLE calculation provides an estimate of erosion on an area of .02 acre. (USLE plots from which the method is drawn are 72.6 ft x 12 ft). Downstream sediment delivered, or "apparent" erosion on larger areas is affected by interim deposition and channel erosion. In reality, long-term sediment flows (tons/acre) from larger areas are usually less than the "point" values of erosion calculated with USLE. This implies process complexity with substantial interim deposition, and has necessitated the additional notion of a "sediment delivery ratio". Sediment delivery ratios for general agricultural regions have been developed as a function of drainage area. An example is given in figure 3. Thus, for our example, if drainage area of (say) 400 acres was used, an SDR of 0.40 might be scaled from figure 3 (or another of its kind), and the apparent net watershed erosion would be

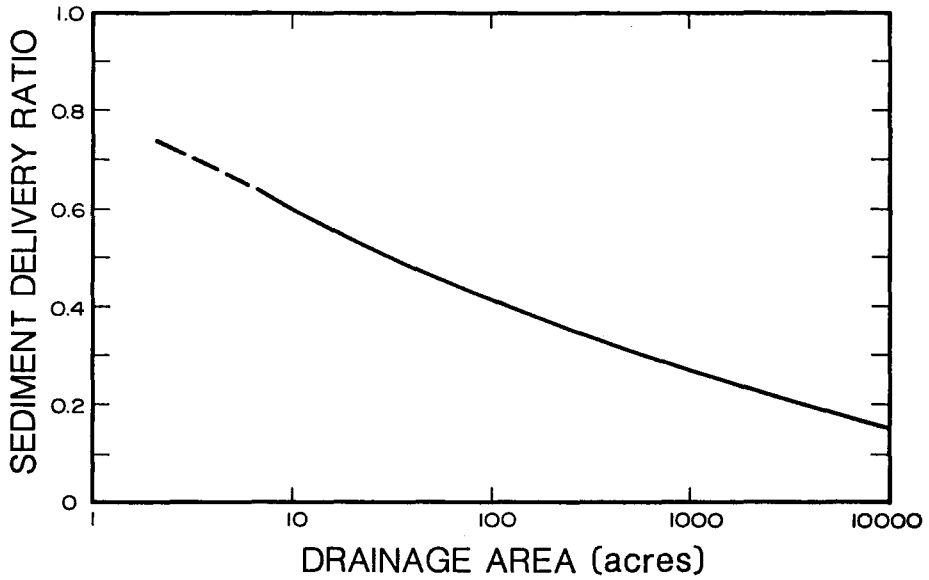


Figure 3.--Generalized sediment delivery ratio-area relationship From Renfro (1975). The curve is derived from a composite of five different studies.

Q_s = 0.40 x 1.24 tons/acre/yr = 0.496 tons/acre/yr

or for the watershed,

0.496 x 400 = 198 tons/yr.

The SDR concept suggests an on-watershed violation of the conservation of mass requirement. Because sediment is being eroded but not all is being delivered, some must be accumulating at spots on the watershed. Since this cannot continue forever, the method leaves this paradox unresolved.

MUSLE

A recent improvisation on USLE is the Modified Universal Soil Loss Equation, or "MUSLE". As given by Williams (1975) in its original reference it is

$$S = 95(Qq_p)^{0.56}\ KLSCP \qquad [11]$$

Where S is the event sediment yield in tons, Q is the stormflow in acre-feet, q_p is the event peak flow in ft^3/sec, and K, L, S, C, and P are as previously defined. The expression 95 $(Qq_p)^{0.56}$ simply replaces R in USLE, and is called the "runoff energy factor." Converting Q and q_p bases, (inches and inches/hour, respectively) brings in the drainage area, or

$$Q\ (acre\text{-}ft) = A(acre)\ Q(in)/12 \qquad [12]$$

$$q_p\ (ft^3/sec) = 1.0083\ A(acre)\ q_p\ (in/hr) \qquad [13]$$

Substituting these identities in [11] and simplifying leads to

$$Q_s = 23.74\ A^{1.12}\ (Qq_p)^{0.56}\ KLSCP \qquad [14]$$

Where Q, q_p, and A are now as given directly above. Making the output of the same dimensions as USLE tons/Acre) is done by dividing by A, so that

$$S/A = 23.74A^{0.12}\ (Qq_p)^{0.56}\ KLSCP \qquad [15]$$

This expression is for individual events and not average annual totals. There is no simple way to sum the above expression over representative values of $(Qq_p)^{0.56}$ to give average annual totals. The values of Q and q_p might be taken from methods described under the Storm Flow section of this paper.

The runoff energy factor is now the portion of equation [10] exclusive of KLSCP. It serves as a hydrology component, obviating the critique of USLE that it depends on hydrology but contains no direct hydrology factor (Hawkins 1985b). It also serves as an event sediment delivery ratio. Thus

$$23.74\ A^{0.12}\ (Qq_p)^{0.56} = R \times SDR \qquad [16]$$

or $SDR = 23.74\ A^{.12}\ (Qq_p)^{.56}/R$

Where R must now pertain to an individual event. This suggests that SDR varies positively with $d^{0.12}$, while experience (see fig 3) shows an inverse relationship--there should be a negative exponent on A, somewhere in the vicinity of -0.2 to -0.3. This occurs because there also exists a relationship between A and q_p (in/hr) because of the watershed effects of routing and transmission which damp out extremes in flow.

The method has not been tested in pinyon-juniper environments. It was found to work well in the Southern Great Plains given that real values of Q and q_p were supplied from field measurements (Hawkins 1985a; Smith and others 1984). For a test over 102 midwestern and southwestern watersheds, it overpredicted on small storms but underpredicted on large storms (Williams, 1975). A study in southern Idaho found a distinct lack of consistency in fitting the constant and exponent in the rainfall energy term (Johnson 1983).

Regional Sediment Yield Study

No discussion of sediment yield in the western U.S. would be complete without including Flaxman's (1972) regional study of deposition in 39 small reservoirs. A regression equation was developed relating measured reservoir deposition to watershed climatic and soil variables. The equation is

$$\text{Log}(100 + Y) = 6.21301 - 2.19113 \log(X_1 + 100) + 0.06034 \log(X_2 + 100) - 0.01644 \log(X_3 + 100) + 0.042501\log (S_4 + 100) \qquad R^2=0.92 \quad [17]$$

where

X_1 = P/T, with P as the average annual precipitation in inches, and T the average annual temperature in ^{o} F;

X_2 = average watershed slope as a percent;

X_3 = percent of soil particles on the upper 2 inches coarser than 1 mm; and

X_4 = a measure of the soil aggradation:

a. For alkaline soils (pH > 7), the positive percent soil < 2 microns.

b. For neutral or acid soils (pH $\leq$ 7), the negative percent of the soil < 2 microns.

c. When the percent of soil particles > 1 mm is in excess of 25 percent, X_4=0, overriding items a) and b) above.

Y = Reservoir sediment deposition, in acre-ft/mi^2/yr and the logarithms are to the base 10.

Several items should be noted here. First, some combinations of inputs calculate to negative numbers, clearly contrary to common sense. Six of Flaxman's sample basin input data sets give such a result. A safe yield input might be about .05 acre-ft/mi^2/yr. Second, the data set was selected from watersheds judged to have "... slope erosion as the only major sediment source." "Watershed areas varied ... from a few acres to more than 50 sq. miles." Third, the role of soil chemistry plays a role compounded with soil texture. For the coarse soils, common to pinyon-juniper sites, X_4 = 0 should be frequent. Fourth, the consideration of watershed area (and thus the complications of sediment delivery) is absent, suggesting trap efficiency-area-sediment delivery compensations in the reservoir designs. Fifth, land condition is manifested in the application of the equation through user-judgment manipulation of X_1. Examples for this are given in the original reference.

For a pinyon-juniper example, applying values previously used of P = 15 in/yr and slope = 10 percent, and choosing T = 55 ^{o}F with a moderately coarse soil such that X_3 = 30 percent and X_4 = 0, Flaxman's equation calculates Y = 0.365 acre-ft/mi^2/yr. Using a reasonable in-place sediment density of 100 lb/ft^3, this is equivalent to 1.25 tons/acre/yr, surprisingly close to the USLE calculation of 1.24 tons/acre/yr.

A limited sensitivity study on Flaxman's equation by Renard and Simanton (1973) showed that X_3 (coarse soil fraction) has little effect on the equation's output, and that the remaining three variables have about equal influence on calculated sediment yield. Also, they found that it underpredicted when checked against observations in southern Arizona.

SUMMARY

There is no unique hydrology specific to pinyon-juniper, but only broad climatic and soils boundaries leading to observed hydrologic performance into which pinyon-juniper (and other vegetative communities) lands fall. Applied hydrology in those settings is largely the same as applied on most wildlands--a collection of mostly empirical judgment guided methods drawing from experiences on agricultural lands or large watersheds. However, the following general outline may be stated:

1. Storm event runoff is rare, and usually of only modest volume. Most storms cause no runoff. Many landscapes in pinyon-juniper show almost no indication of overland flow.

2. Annual water yields from pinyon-juniper watersheds are similarly modest. The large majority of precipitation (about 95 percent) becomes soil moisture. Because of the high evapotranspiration demands on the soil moisture, very little ground water recharge occurs from this source.

3. Rainfall energy inputs to the erosion process on pinyon-juniper lands are among the smallest in the nation. This combined with the low runoffs and (often) stony surfaces leads to correspondingly modest on-land erosion.

Thus, much hydrologic activity is only soil moisture recharge, and/or near the threshhold of surface flow. Most hydrology methods work poorly in these conditions, making predictions error-prone. This is made even more tragic by a

lack of local data upon which to calibrate the methods and by a lack of wildland-specific structure in the agricultural models.

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PRESENT AND FUTURE EROSION PREDICTION TOOLS FOR USE IN PINYON-JUNIPER COMMUNITIES

Kenneth G. Renard

ABSTRACT: Although most of the erosion prediction technology currently used in the United States was developed from research on cultivated agriculture, the physics of the process are such that, with appropriate parameter adjustment, the technology can be transferred to other areas and land use types with appropriate caution. The primary erosion processes in the pinyon-juniper ecological areas, as in other areas, are those associated with raindrop splash erosion and erosion due to the shear of water moving over the land surface. Most models used for most erosion prediction consider erosion in interrill areas, in rills, and in concentrated flow or stream channel areas. Current technology for such prediction involves the Universal Soil Loss Equation, which lumps the processes of rill, interrill erosion, and sediment transport. The paper discusses some recent modifications and improvements to this technology. Also discussed is the effort to develop second generation erosion prediction technology which is physically based, and includes a hydrologic component to provide the runoff estimates required for estimating sediment detachment, transport and deposition at upland sites. The replacement technology is designed to operate on personal computers or small minicomputers, simulates on a storm basis, and aggregates to obtain monthly and annual soil loss values.

INTRODUCTION

Erosion continues to be a problem for conservationists and environmental planners in the United States. Concerns associated with soil erosion involve the offsite pollution consequences of sediment deposition in streams and reservoirs (and adsorbed chemicals associated with such erosion) and the loss in productivity of the soil resource (soil pedon) (Crosson 1984; Follett and Stewart 1985; American Society of Agricultural Engineers 1984). Erosion concerns are not only restricted to those historically called sheet and rill erosion, but also include the erosion associated with concentration of runoff which leads to gully formation, arroyo enlargement and, associated with it, restriction of access to land areas by domestic grazing animals.

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Kenneth G. Renard is a Research Hydraulic Engineer, Aridland Watershed Management Research Unit, Agricultural Research Service, U.S. Department of Agriculture, 2000 E. Allen Road, Tucson, AZ 85719.

PINYON-JUNIPER EROSION CONTROL

Pinyon-juniper acreage, currently estimated at 80 million acres (Sauerwein 1984), is increasing. One must consider the erosion from such an area in a geologic sense, as well as the impact of grazing, vegetation control, and grazing management. Unfortunately, the technology for erosion assessment is weak, whereas, in many instances, the erosion rates and downstream sediment damage are excessive.

Sauerwein (1984), in commenting about management of pinyon-juniper communities, stated, "When a pinyon-juniper forest becomes overcrowded, ecosystem efficiency breaks down. Some part of the system fails. Often, the first to go is the grass and forb understory. Next is the organic surface. Then surface erosion begins, and the overstory suffers. The entire site continues to degrade to a level that nature can maintain. This is not a desirable alternative to good management.

Pinyon and juniper generally grow on shallow stony, or rocky, soils. Maintenance of the soil and organic matter is critical. Even the loss of the organic surface can be disastrous. Retention of the duff layer under pinyon trees is also important."

Although one might argue with the implication that erosion increases as the stand becomes overcrowded (Patric 1985) (e.g., a complete stand would be expected to absorb most of the impact energy of raindrops and increase precipitation interception), the disappearance of the understory would result in more bare soil, which may accelerate erosion. Experiments have indicated that organic matter is important in the erosion process, and that erosion would be expected to increase with decreasing understory and organic matter.

The soil erosion measurements made by Sampson and Weyl (1918) on overgrazed rangelands were among the earliest erosion experiments in the U.S. These studies and research by Chapline (1929) illustrated how grazing and erosion affected soil fertility and the soil water-holding capacity. Unfortunately, these early experiments were not continued, nor were similar experiments performed on pinyon-juniper. Concern for the ecological health of rangelands grew with the general environmental awareness that developed during the late 1960's and 70's, and detrimental erosion was again recognized on rangeland. As a consequence, management plans for rangelands had to consider how management alternatives might affect erosion. Since research had provided little information on rangeland erosion and in pinyon-juniper ecosystems specifically, technology developed for croplands was adapted to the rangeland problem. Because of the uncertainty and lack

of data, many questions arose. The Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978), which has been successfully used on cropland, was adapted to estimate erosion on rangeland (Renard and Foster 1985).

The USLE (Wischmeier and Smith 1965, 1978) is:

$$A = R \times K \times L \times S \times C \times P \quad \text{where:} \qquad (1)$$

A is the estimated average annual erosion rate per unit of area computed by multiplying values for the other six factors. It is an estimate of the average annual sheet and rill erosion from rainstorms on upland areas, and it does not include erosion from gullies or streambanks, snowmelt erosion, or wind erosion. It does include eroded sediment that may subsequently be deposited on the toe of slopes and at other places before runoff reaches streams or reservoirs.

R is the rainfall and runoff erosivity factor for a specific location, usually expressed as average annual erosion index units.

K is the soil erodibility factor for a specific soil horizon, expressed as soil loss per unit of area per unit of R for a unit plot (a unit plot is 72.6 feet long, with a uniform 9% slope maintained in continuous fallow with tillage, when necessary, to break surface crusts and to control weeds). These dimensions were selected because the 1/100 ac erosion research plots used in early erosion work in the U.S. were 72.6 feet long, and had slopes near 9%. Continuous fallow was selected as a base because no cropping system is common to all agricultural areas, and soil loss from any other plot condition would be influenced by residual and current crop and management effects that vary from one location to another.

L is the dimensionless slope-length factor (not the actual slope length) expressed as the ratio of soil loss from a given slope length to that from a 72.6 foot length under the same conditions.

S is the dimensionless slope-steepness factor (not the actual slope steepness) expressed as the ratio of soil loss from a given slope steepness to that from a 9% slope under the same conditions.

C is the dimensionless cover and management, or cropping-management, factor expressed as a ratio of soil loss from the condition of interest to that from tilled continuous fallow.

P is the dimensionless supporting erosion-control practice factor expressed as a ratio of the soil loss with practices such as contouring, strip cropping, or terracing to that with farming up and down the slope.

The term 'universal' in the USLE was given to the equation to assist users who were accustomed to previous equations that applied to very specific regions in contrast to the USLE, which applied, initially in 1965, to all of the U.S. east of the Rocky Mountains, and to the 1978 revision, which applies to all of the United States. Wischmeier (1972) explained, "The name 'universal' soil-loss equation originated as a means of distinguishing this prediction from the highly regionalized models that preceded it. None of its factors utilizes a reference point that has direct geographic orientation. In the sense of the intended functions of the equation's six factors, the model should have universal validity. However, its application is limited to states and countries where information is available for local evaluations of the equation's individual factors." This statement then provides a key element for use of the technology on rangeland (and pinyon-juniper communities). Although the USLE is sometimes referred to as being a 'Midwest' equation, it is much more broadly based. The 48 locations used in the original data base are reasonably well distributed across locations east of the Rocky Mountains. Data from these 48 locations were principally used to determine the effects of soil, topography, cover, and management on erosion. More than 180 locations were used to develop the rainfall erosivity factor, including numerous locations in the western United States. Admittedly, the technology used to develop the erosivity does not adequately consider conditions encountered with orographic precipitation problems, snowmelt, and rain on frozen or thawing soil.

In the early 70's, interest evolved for applying the USLE to noncropland applications such as construction sites and undisturbed land, including rangelands. Since an extensive data base was not available for these applications, Wischmeier (1975) developed the subfactor method to estimate values for the cover management (C) factor. The subfactor method uses relationships for canopy, ground cover, and the "within" soil effects to estimate a composite C value. This development allowed the use of data collected from more basic studies to be used in the USLE. Recognizing the need for data, scientists began erosion experiments on rangeland to develop USLE parameter values, and to evaluate the performance of the USLE on rangelands.

Renard and Foster (1985) discussed the basis of the individual factors of the USLE and the background behind factor development and application for rangelands. They also cited recent research that supported the application of the USLE for rangelands.

Recent discussions regarding the use of the USLE (and the estimates it leads to on rangelands) as an indicator of the condition of the rangeland resource has resulted in increased discussion of the USLE. The U.S. Department of Agriculture (USDA), which uses the USLE as a planning mechanism in its conservation assistance programs, has been subjected to considerable criticism (Schuster 1984; Renard 1984). The issue of using the USLE on rangelands remains unresolved, but more importantly, the use of the USLE for erosion assessment in pinyon-juniper remains a distinct problem.

PROBLEMS OF USING THE USLE WITH PINYON-JUNIPER COMMUNITIES

Many opponents of the USLE cite that it does not work, because it was not developed for rangeland conditions. The data to support this contention

are not available. If such a data base were available, improved USLE factor values or alternate technology could be developed.

There are some significant problems associated with attempting to use the USLE in pinyon-juniper (P-J) communities, including:

(1) Although Hortonian overland flow probably occurs during intense storms, runoff usually occurs as a partial area phenomena.

(2) The rainfall-runoff erosivity factor considers precipitation in the form of rain; yet much of the runoff and erosion in P-J areas is associated with snowmelt, frozen soil, and rain on snow.

(3) The cover-management factor was developed for a more uniform cover than that encountered in P-J areas.

(4) The soil erodibility term in the worst condition, historically, is that associated with a fallow-tilled soil. Tillage activities are not normally encountered in P-J communities.

(5) Recent research indicates the LS factor, presented in Agriculture Handbook 537, may be incorrect for the steep slopes such as are often encountered on P-J sites.

Further discussion on these problems seems warranted.

Partial Area Runoff

Most pinyon-juniper communities have highly variable runoff conditions with little or no runoff originating, except in the open areas between individual trees, especially if the grass density is reduced or almost nonexistent in the openings. Often the soil surface under trees contains an extensive amount of organic matter and a soil profile with a well developed A-horizon having relatively high infiltration rates relative to that in open areas. Such conditions result because the tree canopy successfully absorbs the impact energy of thunderstorms and therefore reduces erosion potential. The net effect may show that beneath a pinyon-juniper canopy, the topography will be higher (the profile deeper) than in open areas. Thus on a single storm event, runoff from the area beneath a tree can be much less as a percentage of the precipitation than in open areas.

Rainfall-Runoff Erosivity

Isoerodent maps (maps of equal annual R values) in the Basin and Range topography which dominate the western United States, and especially pinyon-juniper areas, were developed from power functions relating the average annual value of erosivity to the 2-year frequency rainfall depth expected in a 6-hour duration (P_{2-6}). This P_{2-6} value has been developed and mapped in the western United States, state by state, considering a number of topographic and orographic factors. Despite the efforts that have gone into these developments, there are problems, because there is a preponderance of gage locations in mountain valleys. Furthermore, the technology does not consider the erosivity associated with melting snow, freeze-thaw soil conditions, and rain on snow. Research indicates most erosion (except from channels) occurs from thunderstorm rainfall events, except in the snowmelt-dominated conditions such as the Pacific Northwest winter wheat farming areas of the Palouse (McCool and George 1983). Snow drifting and differential melting in pinyon-juniper vegetation-dominated areas could be a problem requiring special investigation.

Cover-Management Factor

Table 1 presents some values of C for use in the USLE which is reproduced from Agriculture Handbook 537. Of concern to the range scientist or conservationist is how such a table can be used with the heterogeneous conditions of a pinyon-juniper community. Obviously, the lower portion of the table applies for conditions where the raindrops are intercepted by the canopy and then reform and fall at less than terminal velocity.

An alternative to the above approach involves the subfactor technology developed by Dissmeyer and Foster (1981), and also reported by Dissmeyer with examples for forest (1982a) and rangeland (1982b) conditions. Such a subfactor approach is being proposed for use in a revision of Handbook 537 currently underway, as will be discussed subsequently.

Soil Erodibility

The soil erodibility nomograph, presented in Agriculture Handbook 537, was developed from experimental data from many soils in areas east of the Rocky Mountains. Unfortunately, cultivation is not a normal treatment used on rangeland soils, and was one of the conditions involved in the C factor and K factor evaluations/calibrations. Most experimental erosion work in the noncultivated areas of the West has assumed the nomograph is applicable.

A question that arises, and is often applicable in soils encountered on pinyon-juniper vegetation complexes, involves the treatment of coarse fragments in the soil profile. The nomograph assumes that particles larger than 2.0 mm are ignored in the particle-size distribution. Such coarse fragments in the soil profile affect the soil in two ways: the porosity and, in turn, infiltration; and coarse fragments can lead to the formation of an erosion pavement residual at the soil surface as fine particles erode away. Current recommendations are that erosion pavement surface cover be considered as part of the cover-management term (Farrell and Neff 1982; Simanton and others 1984), and the impact on infiltration be accommodated in the nomograph.

Table 1.--Factor C for permanent pasture, range-grazed forest land, and idle land[1] (Wischmeier and Smith 1978)

Vegetative canopy		Cover that contact the soil surface						
Type and height[2]	Percent cover[3]		Percent ground cover					
		Type[4]	0	20	40	60	80	95+
No appreciable canopy		G	0.45	0.20	0.10	0.042	0.013	0.003
		W	.45	.24	.15	.091	.043	.011
Tall grass, weeds, short brush with average drop fall height of 20 in	25	G	.36	.17	.09	.038	.013	.003
		W	.36	.20	.13	.083	.041	.011
	50	G	.26	.13	.07	.035	.012	.003
		W	.26	.16	.11	.076	.039	.011
	75	G	.17	.10	.06	.032	.011	.003
		W	.17	.12	.09	.068	.038	.011
Appreciable brush or bushes with average drop fall height of 6 1/2 ft	25	G	.40	.18	.09	.040	.013	.003
		W	.40	.22	.14	.087	.042	.011
	50	G	.34	.16	.08	.038	.012	.003
		W	.34	.19	.13	.082	.041	.011
	75	G	.28	.14	.08	.036	.012	.003
		W	.28	.17	.12	.078	.040	.011
Trees, but no appreciable low brush. Average drop fall height of 13 ft[5]	25	G	.42	.19	.10	.041	.013	.003
		W	.42	.23	.14	.089	.042	.011
	50	G	.39	.18	.09	.040	.013	.003
		W	.39	.21	.14	.087	.042	.011
	75	G	.36	.17	.09	.039	.012	.003
		W	.36	.20	.13	.084	.041	.011

[1]The listed C values assume that the vegetation and mulch are randomly distributed over the entire area.

[2]Canopy height is measured as the average fall height of water drops falling from the canopy to the ground. Canopy effect is inversely proportional to drop fall height, and is negligible if fall height exceeds 33 ft.

[3]Portion of total-area surface that would be hidden from view by canopy in a vertical projection (a bird's-eye view).

[4]G: cover at surface is grass, grasslike plants, decaying compacted duff, or litter. Grass includes, as cover at the surface, parts which interfere with water flow, and are in contact with the soil during a rainstorm. The height of these parts depends on variety of grass.
W: cover at surface is mostly broadleaf herbaceous plants (as weeds with little lateral-root network near the surface) or undecayed residues, or both.

[5]Multiply values by 0.7 for a grazed forest where organic matter has built up in the topsoil under permanent woodland conditions.

Slope Length-Steepness

Recent research has indicated that the LS factor from Handbook 537 produces values that are too large for steep slopes. The exponential relationship used in the original work was obtained for slopes less than about 20%, and the extrapolation then leads to overestimation. Recent analysis, using additional data and analytical solutions of a physically based model, led to the material contained in table 2, which is now recommended for use on rangelands or other consolidated soil conditions where there is a low ratio of rill to interrill erosion. Care must also be taken in rangeland conditions to ensure that slope lengths are not selected to be excessively long. The raised profile associated with litter and soil beneath pinyon-juniper canopies, and the eroded areas between trees, would indicate slope lengths seldom exceed 200 feet at slopes greater than 10%.

FUTURE USLE WORK

An effort is currently underway to revise the USLE to incorporate recent research results. Most significant in such work is the development of an algorithm to enable computing the cover-management factor (C) using some equations which quantify the subfactor approach.

The procedure is very similar to that presented by Dissmeyer (1982a and b) and Dissmeyer and Foster (1981) for forestland in the southeastern United

Table 2.--Values for topographic factor, LS, for rangeland and other consolidated soil conditions with cover (low rill to interrill erosion -- applicable to thawing soil where both interrill and rill erosion are significant)

Percent	Slope Length (feet)											
Slope	15.	25.	50.	75.	100.	150.	200.	250.	300.	400.	600.	800.
0.2	0.046	0.046	0.047	0.047	0.047	0.048	0.048	0.048	0.048	0.049	0.049	0.049
0.5	0.072	0.073	0.076	0.077	0.078	0.080	0.081	0.081	0.082	0.083	0.085	0.086
1.0	0.112	0.117	0.123	0.127	0.130	0.135	0.138	0.140	0.142	0.146	0.151	0.154
2.0	0.182	0.196	0.216	0.228	0.237	0.251	0.261	0.269	0.276	0.287	0.304	0.316
3.0	0.245	0.269	0.305	0.329	0.347	0.373	0.394	0.410	0.424	0.447	0.481	0.507
4.0	0.302	0.338	0.393	0.430	0.458	0.500	0.533	0.560	0.583	0.621	0.678	0.723
5.0	0.355	0.403	0.480	0.531	0.570	0.631	0.678	0.717	0.750	0.806	0.892	0.958
6.0	0.406	0.467	0.565	0.632	0.684	0.764	0.827	0.880	0.925	1.001	1.119	1.212
8.0	0.499	0.586	0.730	0.830	0.909	1.034	1.132	1.215	1.287	1.410	1.603	1.756
10.0	0.670	0.801	1.020	1.175	1.299	1.496	1.653	1.787	1.904	2.105	2.425	2.680
12.0	0.831	1.006	1.304	1.518	1.690	1.967	2.191	2.382	2.550	2.840	3.305	3.681
14.0	0.983	1.203	1.583	1.859	2.083	2.445	2.740	2.993	3.217	3.605	4.232	4.742
16.0	1.129	1.394	1.857	2.197	2.475	2.927	3.297	3.615	3.899	4.392	5.194	5.850
20.0	1.404	1.761	2.393	2.864	2.253	3.893	4.422	4.881	5.291	6.010	7.192	8.169
25.0	1.726	2.194	3.039	3.677	4.210	5.093	5.831	6.475	7.054	8.076	9.771	11.185
30.0	2.026	2.604	3.658	4.463	5.139	6.271	7.221	8.056	8.810	10.145	12.378	14.254
40.0	2.571	3.354	4.809	5.937	6.895	8.514	9.887	11.104	12.208	14.178	17.505	20.329
50.0	3.049	4.017	5.840	7.269	8.490	10.567	12.342	13.922	15.362	17.943	22.333	26.085

Unpublished information from McCool and Foster 1985.

States, and now used elsewhere. The cover-management factor proposed for rangeland is (J. M. Laflen, USDA-ARS, Ames, IA personal communication, 1984):

$$C = (PLU)\ (PC)\ (SC)\ (SR) \qquad (2)$$

where PLU is a prior land use subfactor; PC is a plant canopy subfactor; SC is a surface cover subfactor, and SR is a surface roughness subfactor. The individual subfactors can be obtained as follows:

$$PLU = 0.45\ EXP(-.012\ RS) \qquad (3)$$

where RS is the mass of roots and residue (kilograms/hectare/millimeter of depth) in the surface 100 millimeters of soil. At present, there are no adjustments in this subfactor to account for differences in grazing intensity. However, the coefficient 0.45 does express the long-term consolidation effects occurring on rangeland due to grazing. Other grazing effects, such as reduced canopy cover, different surface cover, or roughness changes, are reflected in other subfactors.

If the rangeland is tilled, the PLU is assumed as:

$$PLU = (1 - 0.08\ Y)\ EXP(-.012\ RS) \qquad (4)$$

where Y = years since disturbance by tillage; $Y \leq 7$ years.

The relationship of plant canopy to soil erosion was taken from Wischmeier and Smith (1978) and given as:

$$PC = 1 - FC[EXP(-\ 0.34H)] \qquad (5)$$

where FC is the fraction of the land surface covered by canopy, and H is the average canopy height (meters).

Surface cover creates small dams where runoff is temporarily ponded and eroded sediment may be deposited. The surface cover factor is expressed as:

$$SC = EXP(-3.5M) \qquad (6)$$

where M is the fraction of the land surface covered by nonerodible material such as litter, rock, and growing vegetation.

Surface roughness influences soil erosion by reducing runoff volume and velocity, and by ponding surface runoff to cause sediment deposition. The roughness of a surface is expressed as the standard deviation among heights along the surface perpendicular to the slope. The algorithm used to compute the subfactor is:

$$SR = EXP[-.026(RB-6)(1-EXP(-.035RS))] \qquad (7)$$

where RB is surface roughness, and RS is as defined earlier. Tables and pictures for estimating RB are given in the document to assist the user in selecting the appropriate value for the condition being considered.

COMPUTER-ASSISTED EROSION TECHNOLOGY

If computer technology had been available in the 1940 to early 1960 period in any way comparable to that available today, current erosion prediction methods might more closely resemble the Ellison (1947) theory than the empirical form of the USLE. The USLE and its predecessors were structured for ease of use, and to assist planning activities such as the USDA Soil Conservation Service needs for specific farm, ranch, and field conservation programs. The Agricultural Research Service has recently initiated a multilocation and multidiscipline project to develop technology to replace the USLE.

USLE Replacement Technology

Although technology that is physically based has been reported in scientific literature (Foster and Meyer 1972; Simons and others 1977; Negev 1967; Huggins and Monke 1966; Foster and others 1980), all suffer from insufficient validation/experiments to provide parameter values to use a priori. Only the CREAMS model (Foster and others 1980) has received wide interest in USDA; yet even it suffers, because it requires considerable effort to develop input information. It is also relatively expensive to operate, although it has recently been run on personal computers.

The Water Erosion Prediction Project (WEPP), as the USLE replacement project is known, has set a number of conditions and constraints for the model as follows:

(1) Operate on a personal computer;

(2) have a climate-generating routine to simulate storm inputs on at least a daily basis;

(3) have a physically based hydrology routine to provide spatially variable runoff;

(4) have erosion routines for soil detachment and transport by raindrop impact and overland flow for both interrill and rill areas;

(5) have a concentrated flow erosion subroutine;

(6) route sediment for the size distributions as they erode;

(7) include sediment deposition in ponded areas, vegetated areas, and/or at changes in the energy grade line;

(8) consider a variety of topographic forms;

(9) sum soil loss over various time periods as the total of individual storm period soil loss;

(10) be capable of considering conditions for many types of land use (agricultural, urban, disturbed, rangeland, and forest land), and

(11) be "user friendly" so that estimates can be made with minimal effort, and that user errors in parameter estimation are minimized.

The effort, expected to take up to 5 years, is now well underway, and is expected to be applicable to both cultivated and rangeland. Of interest will be whether it will be able to handle the partial area runoff problem regularly encountered on pinyon-juniper areas, and whether it will adequately handle the snowmelt and rain on frozen soil problem. Unless the model can address these problems, additional technology will be required beyond this effort to assist with the pinyon-juniper erosion assessment problem.

DISCUSSION

The hydrology portion of the WEPP project has the important task of considering both temporal and spatial variability in infiltration characteristics. Whereas many hydrology models have used the runoff curve number model of the Soil Conservation Service, USDA (1972), it's anticipated that the current effort will utilize some of the recent progress in quantification of the parameters in the Green-Ampt infiltration relationship with soil properties and management factors such as Rawls and others (1983) have presented. When used with the kinematic flow equations and the use of cascading planes, hydrologic refinement can be accommodated to provide temporal and spatial variability including such topographic modifications as those associated with grassed waterways, ponds, and channels.

The sediment transport and yield part of the model might well be approached using the 1978 development of Shirley and Lane, where they expressed interrill erosion rate (E_I) as a function of rainfall excess rate (R):

$$E_I = K_I R \tag{8}$$

and rill erosion rate (E_R) as:

$$E_R = K_R(Bh^a - q_s) \tag{9}$$

where K_I, K_R and B are respectively interrill coefficient and rill coefficient. The depth (h) exponent (a) is usually assumed equal to the exponent in the kinematic flow equation (reflecting the conditions for laminar or turbulent flow) and q_s is sediment discharge per unit width of the plane.

Using the kinematic flow equations and equations 8 and 9, Shirley and Lane (1978) derived a sediment yield equation by integrating, with respect to time, the sediment continuity equation

$$\frac{\partial(ch)}{\partial t} + \frac{\partial q_s}{\partial x} = E_I + E_R \tag{10}$$

to produce a sediment yield equation as a function of position on the plane. The resulting equation for sediment yield per unit width of the plane, $Q_s(x)$, as a resultant of constant and uniform rainfall excess is

$$Q_s(x) = Q(x)\left[\frac{B}{K} + (K_I - \frac{B}{K})(\frac{1 - e^{-K_R x}}{K_R x})\right] \tag{11}$$

where Q(x) is runoff volume per unit width of the plane, and the other variables are described earlier. Equation 11 expresses the influence of slope length (x) on sediment yield in overland flow.

Experiments will be required, if such a series of algorithms are selected, to evaluate K_I, K_R and B for the many management and soil conditions for which the model might be used. Data are already available to permit many such evaluations from rainfall simulator experiments at the many locations where erosion experiments have been conducted. For pinyon-juniper areas, experimental data will be difficult to obtain with simulators on plots. As an alternative, small natural watersheds may be required so that individual plants will be

contained completely within the experimental boundaries.

The WEPP project will also address the commonly encountered problem of sediment transport in concentrated flow areas. Thus, the technology should be applicable to more complicated topographic features, and will be applicable to estimates of sediment yield, rather than the material eroded from a small landscape element, such as was the case with the USLE.

SUMMARY

Erosion experiments in pinyon-juniper communities have not been conducted like they were on improved agronomic cropland. The spatial variability of the plant canopy poses difficulties when plots of the 12 x 72.6 foot size such as were used for the USLE technology are used. Mature pinyon-juniper plants are often difficult to locate within such a plot and certainly, the root system would be expected to extend well beyond the plot edges. Similarly, drop reformation, following interception by the canopy, might well fall outside the plot boundary. Thus it is difficult to apply USLE technology or even to use rainfall simulators to measure infiltration and erosion from a pinyon-juniper community.

To estimate erosion from a pinyon-juniper plant community, the best approach may be to use current analytical technology such as is being proposed in the USLE revision, which uses a subfactor approach for the estimation of the cover-management factor in the USLE. Better yet, the replacement technology (WEPP) being developed using physically based algorithms and the computing/simulation technology of digital computers offers a more realistic approach to erosion estimation. Of greatest concern, however, is that experiments will be required to provide data on erosion rates from some pinyon-juniper communities so that model parameters may be optimized with data which can then be used for apriori applications.

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ASSESSING RANGE MANAGEMENT ALTERNATIVES

USING SIMULATION MODELS

Everett P. Springer

ABSTRACT: A methodology is proposed to assist land managers in decision making using simulation models as a tool. Two modes of analysis, point in time and time series, are presented, but all examples use the point in time technique. Examples used the EPIC model as the simulation model. The methodology allows land managers to use current technology in the decision making process.

INTRODUCTION

A question often posed to range managers is, "If x number of cows are grazed on a given area, what are the effects on forage production, water resources, and beef production?" The manager is required to make a forecast of the future impacts of these practices. The problem with forecasting the behavior of natural ecosystems is that they are subject to considerable uncertainty. Complete knowledge of all physical and biological factors governing ecosystem functions is not sufficient because the uncertainty induced by climatic factors is still present.

This study will propose a methodology to incorporate uncertainty into an analysis using simulation models. Examples are given using the uncertainty in climate inputs as the source of variability. The technique presented is not new. Hydrologists have been analyzing flood frequency in a similar fashion for considerable time. The intent is to exploit available technology to assist in the decision making process.

BACKGROUND

Models

It is to be emphasized that models are tools and they cannot replace field experience. For purposes here, I have divided models into two basic categories: (1) empirical and (2) parametric.

Empirical models. -- In this category, I include statistical and time series models. These models require data for the relationship to be derived. A form of the model can be postulated a priori, but any physical meaning attached to the parameters is questionable.

A limitation to these types of models is incorporating the impacts of management actions. For example, it is quite difficult to be able to redistribute the nutrients following a fire using one of these models.

Parametric models. -- Parametric models conceptualize processes governing ecosystem function. Parametric models can include empirical models of various components or processes. The structure of parametric models is such that portions of the model can be identified as corresponding to a specific ecosystem component. Hence, it is somewhat meaningful to examine the impacts of management activities. Another advantage of parametric models from a research standpoint is that knowledge of the system is placed into a logical format, and weaknesses in the knowledge base are readily identified.

From the management standpoint, the operational use of parametric models is more difficult because the generally greater number of parameters and state variables make initialization time consuming.

Stochastic Analysis

The models described in the previous section are generally termed deterministic models. A deterministic model has for a given set of inputs a single output. Time series models do not fall into this category because they have a random input term incorporated into their structure. These models are stochastic models and they do not always have the same output because their inputs are changing due to a random component. With deterministic models, a single answer to a given scenario results with no measure of accuracy or confidence. Results obtained from stochastic models by their very nature are random variables which can be assessed using statistical techniques.

Deterministic models can be made stochastic by incorporating uncertainty into the model structure. The following equation is a general model

$$\dot{X}(t) = f[x(t),a(X,t),I(X,t)] \qquad (1a)$$

$$X(0) = X_0 \qquad (1b)$$

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Everett P. Springer is Hydrologist, HSE-12, Los Alamos National Laboratory, Los Alamos, NM, formerly, Hydrologist, USDA-ARS, Northwest Watershed Research Center, Boise, ID.

where X(t) is the derivative vector expressing rate of change of the system state, X(t) is the vector of system state variables, a(X,t) is the vector of parameters, I(X,t) is the input vector for the system, and X_0 is the vector of initial conditions for the system. Uncertainty can enter through any or all of the following, input vector, parameter vector and/or initial condition vector (Soong 1973). The most readily seen avenue for uncertainty to enter equation 1 in modeling ecosystems is through the climatic inputs or the I(X,t) vector.

A random differential equation results when uncertainty is introduced into equation 1. The equation can be analyzed to provide the probability density function (pdf) and/or the moments of the random variable.

Analytical solutions to equation 1 are possible, but are generally restricted to linear, constant coefficient equations. Analytical solutions are powerful because the solutions are relatively inexpensive to obtain.

An alternative solution to equation 1 is to use Monte Carlo techniques which can provide information on the moments and/or cumulative probability of state variables. Monte Carlo techniques have higher simulation costs because replicate model runs are made, and the analyses are not as straightforward as for analytical solutions. Monte Carlo techniques are the only method available for incorporting uncertainty into large compartment models because the nonlinearities that result from simulating so many interrelated processes preclude an analytical treatment especially for the pdf. Tiwari and Hobbie (1976) used Monte Carlo techniques to introduce randomness into parameters, initial conditions and inputs in a simple model of an aquatic ecosystem. The technique proposed here is essentially the same as that used by Arkin and others (1980) for forecasting the influence of climate on sorghum production using a sorghum growth simulation model.

I propose to deal with uncertainty introduced by the weather inputs only. Uncertainty in the initial conditions was not considered because current site conditions will be known. For large compartment models, parameters for many of the processes are unknown or exhibit variability. Including parameter uncertainty for this initial analysis was considered too confusing to be beneficial.

The technique requires the generation of climate sequences for a baseline situation. A management scenario is imposed and the same climate sequences are used. A comparison is made of the results from the baseline analysis to the results of the proposed management scheme. The analysis will be described in more detail in the following discussion.

EXAMPLE APPLICATION

Simulation Model

The model to be used in the following example is the EPIC model described by Williams and others (1983, 1984). EPIC was designed to deal with erosion and productivity assessment for the 1985 Resource Conservation Act (RCA). It was therefore developed to consider primarily agricultural systems and has some limitations for application to rangeland ecosystems. The major limitation are the inability to consider plant species, and at present there is no cattle harvesting capability. Harvesting is accomplished by removing all of the crop above a given harvest height. The reader is referred to the cited articles by Williams and others for a more detailed description of EPIC.

Point in Time Analysis

EPIC has a stochatic climate generation algorithm. By randomly generating fifty different sets of seed numbers, fifty different climatic sequences were obtained. Analysis of the state variable of interest can be accomplished in one of two modes. The first is termed point in time (fig. 1). In this case, the situation at a given number of years in the future is examined. The second analysis uses the time series trace to assess the response. The time series analysis is not conducted in this study, but it is discussed as to its potential. The point in time analysis uses more traditional statistical techniques and is easier to comprehend.

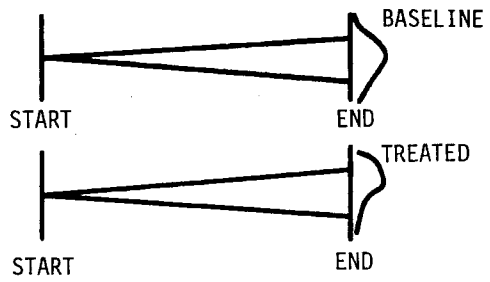


Figure 1.--Graphic depiction of the point in time analysis scenario.

The simulations are for a fifty year time frame using standing live vegetation on Julian day 180 as the response variable. The baseline condition is no harvest of the vegetation. The management action imposed was grazing which was simulated by harvesting the crop at various heights on Julian day 182. Fifty sequences of fifty years were used for each management condition. Three different types of analyses were conducted and are reported in the following.

Probability Plot Analysis

Figure 2 is the probability plot of standing live on day 180 for the no harvest management from year 50 for 50 sequences on normal probability paper. The plotting positions were determined using the Gumbel formula (Haan 1977) which is

$$p(x) = \frac{m(x)}{n + 1} \qquad (2)$$

where p(x) is the rank of ascending order of x, and n is the total number of values. A log normal probability plot (not shown) was also constructed using these data. If either a normal or log normal distribution described these data, the points will fall on a straight line. Neither of the distributions appeared to represent the data over the entire range. In order to complete the proposed analyses, I was most concerned about the lower range of the data particularly below the mean. The best representation of these values was the normal distribution because the degree of curvature is less acute.

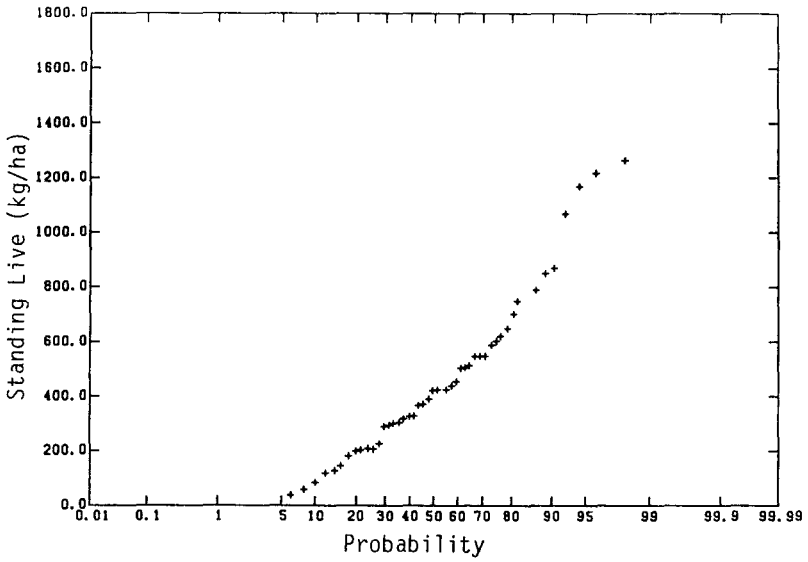


Figure 2.--Normal probability plot of standing live vegetation on Julian day 180 for no harvest management for year 50 from 50 sequences using the EPIC model.

An alternative definition of plotting position in equation 4 is that it represents the cumulative probability density function (cdf) which I defined in the same manner as Mood and others (1978)

$$F(a) = \int_{-\infty}^{a} f(x)\, dx = P[X \leq a] \qquad (3)$$

where F( ) is the cumulative probability density function, f(x) is the probability density function, a is the limit in which we are interested, and P[ ] is the probability function.

For this scenario, the land manager has a critical lower bound of forage at 300 kg/ha. In terms of site management, the forage value should remain above this level. From figure 2, a line drawn from 300 kg/ha intersects the plotted data at approximately 0.30. From equation 3, we have

$$P[X \leq 300] = 0.30$$

which translates to that under a no harvest management scheme, the forage value at fifty years has a 30 percent chance of being below the critical value. These fluctuations are the effects of climate because all other factors, initial conditions and parameters, were constant between the simulations. If the manager decides that the forage level is too high to maintain, then either the critical forage level should be lowered so an acceptable probability of penetrating this level is attained or action must be taken to increase site productivity, e.g. fertilization.

Assuming that the probability level is acceptable, a series of management schemes was imposed which harvest all forage greater than 25, 50, and 100 mm high on Julian day 182, approximately 1 July, every year. The different harvest heights are assumed to represent different levels of grazing. Figure 3 is the normal probability plot of the data from the 25 mm harvest for year 50. Using the 300 kg/ha forage level, there is a 60 percent chance that the forage will be below this level in year 50 if this management is applied. The manager now must decide if this is too high a probability. The same analyses were conducted with the other harvesting heights, and the results are given in table 1.

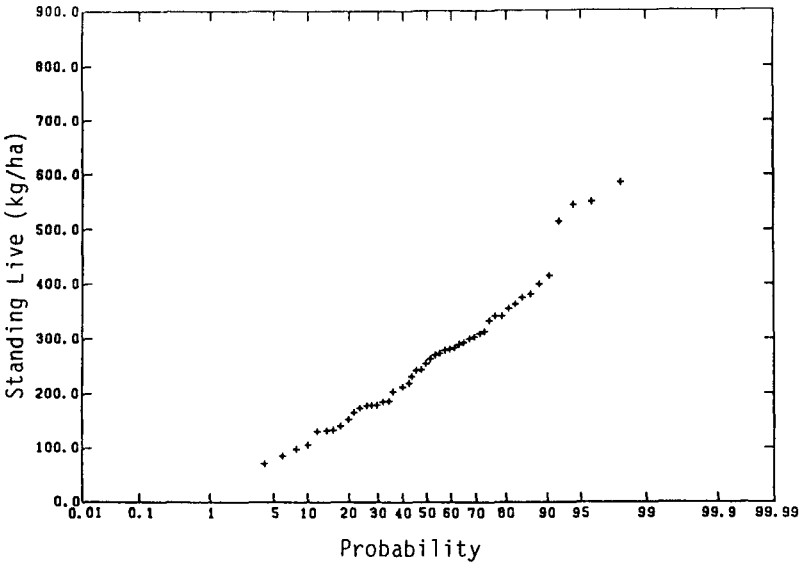


Figure 3.--Normal probability plot of standing live vegetation on Julian day 180 for 25 mm harvest management for year 50 from 50 sequences using the EPIC model.

Table 1.--Statistics for standing live vegetation and probability of exceeding the 300 kg/ha forage limit for year 50 using 50 stochastically generated climatic sequences from the EPIC model

Harvest Height	X (kg/ha)	S (kg/ha)	$P[X \leq 300]$
No harvest	458.0	309.6	0.30
100	409.9	283.0	0.42
50	322.5	168.0	0.52
25	261.6	126.0	0.60

Interpolation of the plotting position. -- By using the plotting positions the probability can be obtained. Using the positions from equation 2 and linear interpolation, the probability for the 300 kg/ha value and no harvest management is

$$P[X \leq 300] = 0.328$$

and for the 25 mm harvest, the probability is

$$P[X \leq 300] = 0.667$$

which is close to the values obtained from graphical analysis. Of course, these results are dependent on the formula used to establish the plotting positions, but this method has the advantage of not requiring any assumption about the nature of the pdf.

Normal approximation. -- If the assumption of normally distributed data is acceptable the analysis becomes much easier and perhaps less costly. The normal or Gaussian pdf is described by its first two moments and in order to determine these, fewer simulations can be conducted. The normal pdf is

$$f(x) = \frac{1}{(2\sigma^2)^{1/2}} EXP\ [(2/\sigma^2)\ (X-\mu^2] \qquad (4)$$

where $f(x)$ is the pdf, μ is the population mean, and σ^2 is the population variance. From sample data, the mean and variance can be estimated as follows

$$\hat{\mu} = \overline{X} = \frac{1}{N} \Sigma\ X_i \qquad (5)$$

$$\hat{\sigma}^2 = S^2 = \frac{1}{(N-1)} \Sigma (X_i - \overline{X})^2 \qquad (6)$$

where $\mu = X$ is the sample estimate of the mean $\sigma^2 = S^2$ is the sample estimate of the variance, and N is the total sample size. Generally fewer simulations are required to estimate these parameters. An example of an analysis of this type is given in the following narrative using table 2 which contains the estimated mean and standard deviation (S^2) of the standing live vegetation for the fiftieth year for 10 sequences of 50 years.

Comparing the statistics in table 2 to those in table 1, some differences exist for the no harvest situation. Values for the 25 mm harvest are quite close which indicates a smoothing effect of the imposed management. Again using the 300 kg/ha level, the probabilities can be computed by the standard normal distribution and the statistics in table 2 as follows for the no harvest management

$$P[X \leq 300) = P(z) = P(\frac{300-438.4}{251.6}) = 0.29$$

and for the 25 mm harvest management

$$P[X \leq 300] = P(z) = P(\frac{300-264.8}{132.5}) = 0.60$$

where P(z) is the cumulative probability for a standard normal deviate. These results are essentially the same as those from the previous examples, but were obtained at a lower cost in terms of computer simulation.

Table 2.--Statistics for 10 sequences for year 50 for standing live vegetation from the EPIC model

Management	X	S
	kg/ha	
No harvest	438.4	251.6
25 mm Harvest	264.8	132.5

Time Series Analysis

As previously noted, the trace of a state variable over the period of time of interest can be analyzed using techniques from time series analysis or stochastic processes (fig. 4). By using the theory of runs, the probability that the state variable will fall below a certain value for a given period can be calculated. This may be of more interest in terms of economic analysis than the point in time analyses.

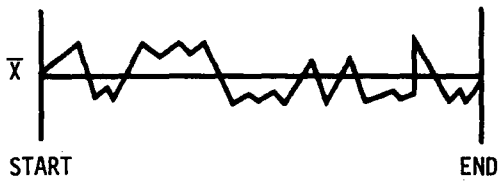


Figure 4.--Graphic depiction of the time series analysis scenario.

CONCLUSIONS

The techniques proposed in this study provide the manager with probability statements about his proposed action. Given the considerable uncertainty that exists in both model construction, parameter identification, and inputs, the methods proposed herein offer a more logical approach to incorporating modeling results into decision making processes.

Current limitations of the techniques are tied directly to simulation modeling. Data are not available of sufficient duration to provide accurate parameter estimates or model validation. Regardless of whether a deterministic or stochastic analysis is used a calibrated/validated model is required.

Only a single state variable was analyzed in this paper, but compartment models such as EPIC have many state variables that can be analyzed in a similar manner.

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WATER HARVESTING POTENTIAL AND APPLICATION AS A MEANS OF RANGE WATER SUPPLY

Gary W. Frasier

ABSTRACT: Water harvesting techniques can provide the necessary quantity and distribution of animal drinking water for the proper management of rangeland resources. Typical water-harvesting systems consist of a catchment area of 700 to 2500 sq. yds. with storage facilities of 10,000 to 90,000 gallons. Total system costs range from $4,000 to $30,000, depending upon the type of materials used and the availability of labor and equipment.

INTRODUCTION

It has long been recognized that much of our rangelands have inadequate supplies of animal drinking water. When there is a poor distribution of animal drinking water, overgrazing occurs on areas adjacent to the water, while areas farther away are frequently unused. Herbel and others (1967) found that cattle would graze at distances of up to 3.5 miles from drinking water supplies. In many places this is an excessive travel distance for proper management of the forage resource. Frasier (1981) showed that when the average animal travel distance was reduced from 1 mile to 1/2 mile, the improved uniformity in forage utilization allowed the animal-carrying capacity to be increased by 30%.

There is no "best method" for increasing range water supplies. Common water development methods include wells, earthen ponds, spring development, water hauling, and pipelines. Each of these techniques have certain advantages and disadvantages. In places where these approaches are not technically or economically practical, water harvesting may be a possible alternative.

Water harvesting is simply the collection of precipitation from a small catchment area that is topographically modified, chemically treated, or covered with a membrane to reduce infiltration. The collected water is stored in a suitable container until it is needed. Water harvesting is not an inexpensive method of water supply augmentation, but it can be used to provide water supplies where other methods are not feasible (Cooley and others 1978).

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Gary Frasier is a Research Hydraulic Engineer, Aridland Watershed Management Unit, Agricultural Research Service, U.S. Department of Agriculture, 2000 East Allen Road, Tucson, AZ.

CATCHMENT AREA

The catchment area is the component of the water-harvesting system that collects and concentrates precipitation. Any area that is reasonably impermeable to infiltration can be used as a catchment surface. Paved highways and roofs of buildings are examples of surfaces designed for other purposes that can be used as a water collection area. The runoff water is diverted into a water storage container. Several types of common catchment treatments being used on operational water-harvesting systems are listed in table 1. The table includes some of the site conditions that must be considered when selecting a treatment, estimated installation costs, treatment life and runoff efficiency (defined as the ratio of runoff to precipitation).

Asphalt-Fabric Membranes

The asphalt-fabric membrane has been used in many places such as the hot deserts regions of the southwestern United States, the tropical rangelands of Hawaii and the high mountain regions of Colorado and New Mexico. The fabric, a random weave fiberglass matting or synthetic polyester filter matting, was unrolled on the cleared and smoothed catchment surface and saturated with an asphalt emulsion. Three to 10 days later, a second asphalt emulsion sealcoat was brushed on the surface to completely seal the membrane. The asphalt hardens as it cures and two to six months after installation the membrane is relatively resistant to damage by wind, animals and weathering processes (Myers and Frasier 1974). Runoff efficiency is nearly 100% and with periodic sealcoat applications at 5 to 7 year intervals the treatment has an expected life of at least 20 years.

Gravel Covered Sheetings

Many types of thin plastic sheetings have been investigated as potential membrane coverings for water-harvesting catchments. Most of these coverings failed in field installations because of mechanical damage to the exposed membrane by wind or animals. Placement of a gravel covering over the thin plastic or tar paper sheetings has been an effective treatment in some areas (Frasier and Myers 1983). The sheeting is the waterproof membrane and the gravel protects the sheeting from mechanical damage and sunlight deterioration. This treatment requires a good periodic maintenance program to insure that the gravel remains in place. Runoff is essentially 100% after the 'threshold' rainfall (the quantity of precipitation required to initiate runoff) has been exceeded (approximately

Table 1.--Site requirements, costs, and performance data for some water-harvesting catchment treatments

Treatment	Site Conditions		Costs[1]		Life	Runoff Efficiency
	Maximum Slope	Surface	Materials	Labor		
	(%)		($/yd^2)	($/yd^2)	(yrs)	(%)
Asphalt-fabric	10	all	$2.00	$0.50	20	95+
Gravel-covered sheeting	5	smooth	1.75	.80	10	85+
Paraffin wax	5	selected soils	1.00	.10	10	75+
Artificial rubber membranes	10	smooth	10.00	.50	20	95+
Sheet-metal coverings	10	all	15.00	.50	20	95+
Concrete	10	all	20.00	.80	20	60+
Rock surfaces		existing	.10	.10	20	30+
Land smoothing	5	selected soils	.00	.20	5	20+
Sodium salts	5	selected soils	.20	.20	10	50+

[1]Approximate onsite costs on a prepared site. Materials are based on 1980 costs. Labor is estimated at a rate of $10.00 per hour per man.

0.1 inch). Effective life of this treatment is about 10 years.

Paraffin Wax

The paraffin wax chemical soil treatment has been used in limited locations. Low melting point paraffin wax (125-130° F), sprayed onto the prepared catchment area, was initially deposited as a thin coating on the soil surface. When the soil surface was warmed above the melting point of the wax by the sun, the wax migrated deeper into the soil, coating each soil particle with a thin layer of wax. The wax treatment does not provide any permanent degree of increased soil stabilization. Instead, the waterproofing is caused by changing the surface tension characteristics between the water and the soil particles in the surface of the catchment. This treatment is not suited for soils containing over 20% clay, and should be used only where the soil temperature will exceed the melting point of the wax during some part of the year (Frasier 1980). The effective treatment life on suitable soils is probably in excess of 10 years, with an average runoff efficiency of 70-95%. Soil erosion of the catchment surface is a potential problem.

Artificial Rubber Sheetings

In the 1950's, many catchments were covered with sheetings of artificial rubber (butyl). The butyl sheetings were relatively easy to install and, based on results from accelerated weathering tests, the coverings had a projected life in excess of 20 years. Unfortunately, many of these installations prematurely failed. These coverings are flexible, and wind vibrating the sheetings against the soil surface rubbed holes in the membranes. These holes, and others caused by rodents or birds, allowed wind access under the sheeting which would rip the covering from the catchment area. Improper installation techniques contributed to many failures (Dedrick 1973).

Properly installed and maintained artificial rubber membranes can be an effective treatment in some areas. The membranes should be installed in a relaxed condition on a smooth surface and protected from wind uplift and vibration. They should be inspected frequently and any damage repaired. A properly installed and maintained surface will yield essentially 100% runoff with an effective life of 10-20 years.

Sheet Metal Coverings

Sheet metal roofs have long been used to collect rain water. Initially, these roof type catchments consisted of an above ground wooden framework in the shape of a shallow 'V' covered with corrugated sheet metal. These catchments were durable, effective water collectors, but the cost of materials and labor for the supporting framework has limited widespread use. Costs have been reduced on some installations by placing the sheet metal on a ground level framework. On some soils, a layer of washed gravel under the sheeting is necessary to prevent metal corrosion by the salts in the soil. Also, steel sheet metal must be coated (galvanized) to prevent rusting. Aluminum sheeting has been used on some installations. Sheet metal catchments are relatively durable, and yield 95-100% runoff (Lauritzen 1967). Life expectancy is in excess of 20 years.

Concrete

Most concrete catchments are relatively small units, primarily because of construction costs. Shrinkage cracks and expansion joints must be periodically sealed with some type of crack sealer. Many concrete surfaces will become partially porous with time, which increases the threshold rainfall. This effect can be partially countered by periodic treatment of the area with the paraffin wax or a water based silicone (sodium silanolate) water repellent. Runoff efficiency is 60-85%, and a life expectancy in excess of 20 years might be anticipated.

Rock Surfaces

Large expanses of rock outcroppings are natural surfaces that can be used as a catchment area. A small masonary dam or water collection channel constructed along the lower edge of the outcropping directs the water to the storage facility. Runoff efficiency from the rock surface may be quite variable, depending upon the porosity of the rock and the number of cracks. The cracks can be sealed using the same asphaltic sealer compounds used for sealing concrete cracks. On some porous rock surfaces, the runoff efficiency can be increased with a water repellent treatment.

Land Forming

One simple catchment treatment is a cleared and smoothed land surface. This treatment is used on some of the most extensive catchment areas in the world, the "roaded" catchments in Australia. The land is shaped in the form of "...parallel ridges ("roads") of steep, bare and compacted earth, surveyed at a gradient that allows runoff to occur without causing erosion of the intervening channels." (Laing 1981). In 1980, it was estimated that there were more than 3,500 of these roaded catchment systems in Western Australia, comprising a total area in excess of 10,000 acres. Many of these catchments have a top dressing, or layer, of compacted clay to increase runoff efficiency (Frith 1975).

These treatments are effective if properly matched to suitable soil types and topographic features. Runoff efficiency is 20-50%, with a life expectanc of 5 years. Improper design of slope angles and overland flow distances can result in serious damage by water erosion to the catchment surface (Hollick 1975).

Sodium Salts

On some soils, the runoff efficiency of compacted soil treatments was increased using a sodium dispersed clay or salt treatment. The sodium salt (common table salt, (sodium chloride) [NaCl]; or soda ash, (sodium carbonate) [Na_2CO_3]) was mixed into the soil or sprayed as a water solution onto the soil surface. During rain storms, the sodium disperses the clay aggregrates. The dispersed cla particles fill the soil pores and form clay lens which restrict the rate of water movement through the soil profile. This treatment is limited to specific sites where the soil has a minimum of 20% clay. Runoff efficiency is 50-80%, with an expected treatment life of 10-20 years. The breakdown o the soil aggregates increases the potential of soi erosion of the catchment surface.

WATER STORAGE

Water storage is a major expense with any water-harvesting system, and often represents over 50% o the total system cost. Any container which prevents seepage and evaporation losses is a potential wate storage facility. Unlined earthen pits or ponds are usually not good means of water storage for a water-harvesting system because of seepage losses. Table 2 lists the types and comparative costs of some general water storage facilities.

Table 2.--Types and approximate costs of water storages (Frasier 1984)

Tank Type	Cost ($/1000 gal)
Prefabricated (wood, steel, fiberglass, butyl, etc.)	200-400
Steel rim with:	
a) Elastomeric lining (butyl rubber)	200
b) Plastic lining (polyvinyl chloride)	160
c) Composite lining	150
d) Concrete bottom	100-200
Plastered concrete (ferro-cement)	110
Excavated earthen tank with:	
a) Exposed elastomeric lining	130
b) Exposed composite lining	100
c) Buried plastic lining	130

Costs are for on-site labor and materials for a 20,000 gallon tank. Materials costs based on 1980 prices. Labor costs estimated at $10/hr.

Prefabricated Storages

There is an almost infinite number of types, shapes and sizes of wooden, steel or reinforced plastic containers that can be used as storages on water-harvesting systems. Small tanks (< 20,000 gallons) are often preassembled and transported to the site intact. Larger capacity tanks usually require on-site assembly from preshaped pieces. Costs and availability in a given area are the primary factors for determining the suitability of these types of storages. Steel, wood, or fiberglass tanks commonly have a projected life in excess of 20 years.

There have been a limited number of installations using artificial rubber (butyl) bags for the water storage container. The butyl bags are susceptible to mechanical damage from animals and problems have been encountered with rainwater and snow accumulating on top of the bag (Dedrick 1973). The potential of mechanical damage limits the use of butyl bags to well protected and frequently maintained installations.

Steel Rim Tanks

These storages are a vertical-wall, cylindrical steel rim with a waterproof liner or bottom. The sides of the tanks are usually constructed from corrugated steel plate sections fastened together with bolts. Typical capacities range from 5,000 to 80,000 gallons, and are used for aboveground or partially buried installations.

One method of sealing steel rim tanks is to place membrane liner inside the tank. Various plastic and artificial rubber (butyl) sheetings have been used as liners. Nylon-reinforced butyl, 20 to 45 mils thick, has been used on some installations. These linings are relatively expensive but have a projected life of 15-20 years. Standard polyethylene (PE) is relatively low cost but is difficult to seam. Polyvinyl chloride (PVC) is easy to seam using heat sealing techniques but is susceptible to sunlight deterioration. A protective coating on the sheeting or a shade roof will reduce sunlight deterioration of the membrane. A typical storage of this type is an above ground swimming pool. With a roof cover to protect the liner, life expectancy of 5-10 years is possible.

A three-ply membrane of an asphalted fabric-polyethylene-asphalted fabric has been used as a tank liner in a few installations. This lining consists of a single sheet of polyethylene protected on both sides by an asphalted-fabric membrane. This lining is relatively resistant to sunlight deterioration and mechanical damage with an expected life of 10-20 years.

Steel rim tanks with poured concrete floors are common storages. The costs of pouring concrete can be a significant factor for remote areas. Backfilling around the base of the tank reduces the problems of the concrete bottoms cracking due to unequal thermal expansion of the steel rim and concrete base. Properly installed tanks have a projected life in excess of 20 years.

Plastered Concrete Tanks

The plastered concrete storage tank consists of a thin (3-4 inch) vertical circular wall of reinforced concrete with a dense plaster coating on the inside and outside surfaces. The sidewall reinforcing consists of two layers of standard concrete reinforcing woven wire. A one inch mesh woven wire (rabbit wire) is fastened to the inside and outside of the reinforcement wire to hold the concrete in place. The tank bottom is poured concrete. Maximum tank dimensions are 6 ft. high and 30 ft. in diameter (30,000 gallons). This storage type requires minimum materials, primarily cement and aggregate, but is relatively labor intensive to construct. Transportation costs of materials to remote sites can be a costly factor. Projected life is in excess of 20 years.

Excavated Earthen Storages

Seepage and evaporation control are two factors which have limited the use of excavated pits or ponds for water-harvesting systems. Both exposed and buried membrane liners have been used to control seepage losses.

Exposed nylon reinforced artificial rubber sheetings (butyl, 20-45 mil. thick) have been used. These linings, when properly installed and not subjected to tensile stresses, have a projected life of 15-20 years. The three-ply liner of asphalted fabric-polyethylene-asphalted fabric, previously described for the lining of steel tanks, has been used as an exposed lining. With a periodic application (5 years) of an asphalt sealcoat, the lining has a projected life of 15-20 years.

Various types of PVC and PE plastic sheeting (12-20 mil. thick) have been used for buried membrane linings. Care must be taken during placement of the soil cover to prevent puncturing the lining. These linings cannot be used on side slopes steeper than 1 verticle to 3 horizontal. Burrowing rodents have caused damage to some buried linings. These factors have limited the use of buried membrane linings to relatively large areas where earth moving equipment can be effectively used. Buried plastic linings have a projected life of 10-20 years.

Evaporation Control

Conserving the water collected from a water-harvesting system is a cost-effective method of maintaining an adequate water supply. Reducing evaporation losses is usually less expensive than increasing the size of the catchment area and/or storage volume. On a typical system in northern Arizona, the cost of the evaporation control was less than 4% of the total cost of the water-harvesting system (Cooley and others 1978). The most effective method of evaporation control is covering the water surface with floating covers or roof-type shades. These techniques are very effective on vertical walled storages which have a constant size surface area. It is significantly more difficult to control evaporation from storages with

sloping sides where the water surface area changes with depth.

At present, the floating cover most widely used on water-harvesting systems is made of a closed cell, 1/4 inch thick, synthetic foam rubber sheeting. This material is easily seamed into a single cover with a contact adhesive. The material is susceptible to damage by mechanical means, but can be quickly repaired with small patches. Wind passing over a tank partially filled with water may disrupt the cover. A simple wire net across the top of the tank will reduce potential damage to the cover from wind. The projected life of the cover is 5-10 years.

Roofs of sheet metal on a framework above the storage have long been an effective method of evaporation control. The roof shades the water and reduces the wind velocity directly above the water surface. In some areas, the roof can be oversized and inverted to serve as an additional catchment area with little increase in cost. Roofs are potentially susceptible to damage by wind and snow loads. Properly installed roofs should have a projected life in excess of 20 years.

MAINTENANCE

Failure to maintain a water-harvesting system will result in the premature failure of the system. The failure to repair even minor damage can result in complete destruction of the entire system. Some types of catchment treatments and storage facilities require more frequent and intense maintenance than others. Most water-harvesting systems can be adequately maintained with biannual inspections and the immediate repair of any problems detected at other times. Scheduled inspection trips usually require less than 4 hours labor per visit.

WATER-HARVESTING SYSTEM DESIGN

For most installations, there will be several combinations of catchment and storage sizes which will provide the required quantities of water. Since water storage is one of the single most costly items, the lowest total-cost water-harvesting system will frequently be one with a reduced storage volume. Small storage systems will usually have some water loss by overflow during wet periods. The computations necessary for determining the optimum relative sizes of catchment and storage are not difficult but are tedious and time consuming when considering all possible combinations of precipitation, water requirements and costs. Frasier and Myers (1983) presented a procedure where the optimum catchment and storage tank sizes for drinking water supply systems can be approximated by a series of hand calculations or with a programable desk-top calculator.

Example-Design of an Animal Drinking Water System

Table 3 presents the precipitation and water requirements of a typical situation where additional livestock and wildlife drinking water supplies are needed on a ranch near Williams, Arizona. Sixty cows use the area for 5 months (Nov-Dec and Mar-May), and 30 deer use the facility yearlong. The cattle require 10 gallons/day/head, and the deer, 2 gallons/day/head. The catchment treatment selected is an asphalt-fabric membrane costing $2.50/sq. yd. with a runoff efficiency of 95%. The storage is a steel-rim tank with a concrete bottom and a floating butyl cover. Total unit storage costs are $135/1000 gallons. The optimum size combination of catchment and storage were estimated using the monthly water balance procedure of Frasier and Myers(1983). Figure 1 shows the sizes of catchment and storage, and the costs of 7 different combinations which will provide the necessary water. The range manager would decide which of the combinations is best suited for his operation, but would probably optimize for the least cost design of about $8000 provided by 3 combinations for this example. In other instances, the minimum cost combination may be more distinct. Some other factors which might enter into the actual sizes selected are; (1) the area available for the catchment apron, (2) the available sizes of the storage tank, and (3) the acceptable level of risk of having insufficient water during periods of below average precipitation. Also the materials and construction techniques selected must be compatible with the expected climatic conditions.

Table 3.--Precipitation and animal drinking water requirements for 60 cows and 30 deer near Williams, Arizona (Frasier and Myers 1983)

Month	Precipitation	Water Requirement
	(inches)	(gallons)[1]
Jan	1.98	1800
Feb	1.98	1800
Mar	1.80	19800
Apr	1.35	19800
May	.63	19800
Jun	.45	1800
Jul	2.79	1800
Aug	3.06	1800
Sep	1.44	1800
Oct	1.26	1800
Nov	1.08	19800
Dec	1.98	19800

[1]Williams, Arizona precipitation adjusted for runoff efficiency of 95%.

SUMMARY

Water-harvesting systems are technically sound methods of water supply for most parts of the world. There is no universally best system. Each site has unique characteristics that will influence the design of the best suited system. Any impervious area or surface is a potential catchment surface. With some exceptions, the higher the runoff efficiency, the greater the unit cost. The major cost item of a drinking water supply system is the cost of the water storage facility. In addition to the total annual water requirement there is also a seasonal distribution of the required water that

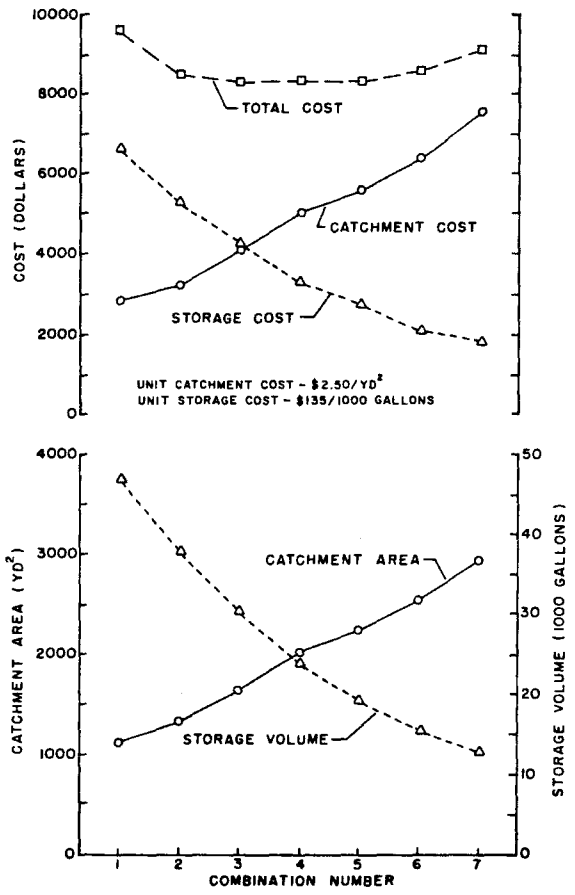


Figure 1.--Relative costs and sizes of 7 different combinations of catchment areas and storage volumes of a water-harvesting system.

must be satisfied by the water-harvesting system. The designer, installer, and user of water harvesting should become as familiar as possible with all techniques, and use the approach that is best suited for local conditions. Maintenance is a critical element of the success of a system. Without a periodic maintenance program the water-harvesting system will not be a satisfactory method of water supply.

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Woodland Wildlife

Chaired by:

Donald A. Klebenow, Professor, Range, Wildlife, and Forestry Department, University of Nevada—Reno

AVIAN IMPACTS ON PINYON-JUNIPER WOODLANDS

Russell P. Balda

ABSTRACT: The purpose of this paper is to bring together information about the importance of birds in consuming and dispersing pinyon pine and juniper seeds. Four seed caching corvids are responsible for placing hundreds of thousands of pinyon pine seeds in subterranean caches each fall when cone crops are heavy. Three species of thrushes overwinter in juniper woodlands, sometimes in high densities, and consume juniper berries as their stable diet. Both tree species appear to rely heavily on birds to disperse their propagules. With wise and clever management practices, birds may be enticed to obtain our management objectives for us.

INTRODUCTION

The perceptive ecologist and conservation philosopher, Aldo Leopold, wrote in his famous "Sand County Almanac" that to remove Pinyon Jays (Gymnorhinus cyanocephalus) from the juniper foothills of the Southwest would result in the death of that community (p. 138, 1949). Leopold made his comment in a philosophical rather than ecological vein. Little did he realize how ecologically accurate he would eventually be proven, especially with regard to the pinyon pines (Pinus spp.). The relationship of the Pinyon Jay to pinyon pines is so strongly interwoven that it may represent one of the best coevolved, mutualistic plant-vertebrate examples known to man. The pines entice the birds to cache their seeds and also provide a critical source of energy and nutrients to the jays. Thus, the birds are provided a source of food, and the pines have their seeds planted in good germination sites. This relationship has only recently been studied (Balda and Bateman 1971, 1972; VanderWall and Balda 1977; Ligon 1978) and apparently went unnoticed by most early ecologists and naturalists. In general, the pinyon-juniper woodland has not attracted many vertebrate zoologists to conduct studies there. Thus, it is not surprising that most (if not all) management decisions concerning pinyon-juniper woodlands were made without consideration for the impact these birds would have on managed areas. Of course, type conversion, the predominant management practice in pinyon-juniper woodlands, indicates a great insensitivity and lack of consideration on man's part for all native, dependent animals in this habitat type.

In addition to the Pinyon Jay, four other species in the Family Corvidae also consume and cache seeds of pinyon pines. Clark's Nutcracker (Nucifraga columbiana) Steller's Jay (Cyanocitta stelleri), Scrub Jay (Aphelocoma coerulescens) and Black-billed Magpie (Pica pica) take advantage (to varying degrees) of large cone crops where their ranges and that of the pinyon pines are sympatric. Except for the nutcracker and Pinyon Jay these species eat a wide variety of food items and do not possess a suite of morphological adaptations specifically designed for the harvest, transport, caching, and eating of pinyon pine seeds. These five species show a "specialization gradient" morphologically, physiologically, and behaviorally in their ability to take advantage of, and respond to, pinyon pine cone crops (VanderWall and Balda 1981). The combined efforts of these five species have undoubtedly played a major role in the evolution of the reproductive biology of the pinyon pines and their present day distribution and abundance (VanderWall and Balda 1977, 1981; Ligon 1978). In no area of North America are pinyon pines found in the absence of one or more of these birds except possibly at the southern end of the pine's distribution.

The breeding and winter bird communities of the pinyon-juniper woodland have been thoroughly reviewed earlier (Balda and Masters 1980). Only pertinent information will be mentioned here.

Although collectively more than 70 species of birds are known to breed in this woodland, no one area contains nearly this number of species. In north-central Arizona the number of species per 40 ha plot ranged from 12 to 24 and averaged 19 (Balda and Masters 1980). Masters (1979) found that the number of species breeding in this woodland was positively correlated with the density of pinyon pine, tree density, and pinyon pine foliage volume. Few of these 70 plus species are restricted to the pinyon-juniper woodland. Balda and Masters (1980) tabulated five obligatory species that are restricted to this habitat type and 13 others that nest in one additional habitat type. Of these 18 species, surprisingly only four (House Finch, Carpodacus mexicanus, Rufous-sided Towhee, Pipilo erythrophthalmus, Brown Towhee, Pipilo fuscus, Plain Titmouse, Parus inornatus) can be considered major pine seed predators which consume large numbers of pine seeds, especially in years of small cone crops.

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Russell P. Balda is Professor of Biology, Department of Biological Sciences, Box 5640, Northern Arizona University, Flagstaff, Arizona.

In north-central Arizona where winter birds of these woodlands have been studied by Grue (1977) and Shrout (1977) a total of 32 species have been recorded. The diversity of species in any 40 ha plot may vary from 10 to 20 between years. Year-to-year variation in densities are also striking. In some years woodlands support high densities of Townsend's Solitaires (Myadestes townsendi) and flocks of American Robins (Turdus migratorius) and Western Bluebirds (Sialia mexicana) too numerous to count. In other years one can walk for hours and see very few birds.

This variability can be accounted for by a combination of a few physical and biotic factors. Overwintering birds apparently require a source of open water and concentrate their activities around natural watering holes and cattle watering tanks. Heavy crops of juniper cones (Juniperus spp.) occur at irregular intervals but a heavy crop generally occurs every two to five years (Tueller and Clark 1975). In years of a "bumper crop" of juniper cones, bird densities may be 70% higher than in years when juniper cones are absent.

Using knowledge about birds of the pinyon-juniper woodlands that use cones from the dominant trees this paper will attempt to:

1) explore bird species similarities and differences as they relate to the reproduction, distribution and density of pinyons and junipers.

2) elucidate the unique characteristics of the pinyon-juniper woodland because of the strong mutualistic relationships existing there.

3) make suggestions as to how these bird-tree interactions help and/or hinder present management practices.

4) explore how knowledge of the activities of specific birds can be incorporated to enhance the success of management procedures.

THE PINYON PINES

This species complex (see Lanner 1975) appears to have evolved in the arid Southwest where the major independent selective pressures or variables (Smith 1975) in the coevolutionary complex were climatic ones. The hot, dry conditions of this region may well have placed severe selective pressures on these trees. In the Southwest these species are the most arid adapted pines but also have a wide distributional range. Because of harsh climatic conditions germination sites were probably at a premium and were restricted to sheltered locations. As the seeds became larger, more "safe" germination sites became usable. Baker (1972) showed that soil moisture strongly influences the amount of energy a species is selected to deposit in its seeds. This energy is used by the seedling to quickly develop a root system sufficient to gather needed moisture. Franklin (1964) showed that a correlation exists between seed size and germination for two species of conifers. The smaller seeded species are restricted to moist sites. The high energy content of large pinyon pine seeds (Little 1938; Botkin and Shires 1948) is also a concommitant adaptation. Large, low energy seeds probably can grow a root system no faster than small, high energy seeds. The production of large, high energy seeds is obviously costly to the tree, and two possible alternatives could have initially been used in the production of seeds: 1) produce only relatively few, high quality seeds per year, 2) produce a large crop of high quality seeds at some interval greater than one year. The first alternative is probably the primitive one.

Initially, conifer seed eating corvids simply took advantage of these large, high energy seeds which were produced under the selective influence of arid conditions. If cone crops were large (i.e. synchronous production with intervening lean years) but sporatic, the seed eaters could not utilize the crop efficiently and would face a period of food scarcity in the near future as the pine seed supply would soon be decimated by all seed predators. Members of the Family Corvidae are inquisitive by nature and often probe in what appears to us to be unlikely places. This behavior may be the proximate mechanism used to initiate caching behavior. If some of these cached seeds germinated and grew to maturity, selective pressures should act on the pines to develop enticer traits. The pinyon pines have wingless seeds for ease of handling, short, spineless cone scales, seeds that are held in cones, and cones positioned for easy vision (VanderWall and Balda 1977). These secondary adaptations arose primarily to entice the corvids to harvest and hide pine seeds in subterranean caches (fig. 1).

THE JUNIPERS

Species in this complex are very often numerically dominant in pinyon-juniper woodlands and in many locations may form pure stands where pinyon pines cannot establish themselves. Junipers are more arid adapted than pinyons and may have the same selective agents operating as do pinyon pines. Yet at the present time these species are becoming more dense in established stands and invading lower elevation grasslands and also higher plant communities in the Great Basin (West and others 1975) replacing grasses, herbaceous vegetation, and shrubs.

Heavy crops of juniper cones occur at irregular intervals. "Berries" form in late summer and are consumed by numerous birds and mammals thereafter. In 1973, a huge crop of berries was produced north of Flagstaff, AZ. Solomonson and Balda (1977) counted about 20,000 berries per cubic meter of juniper foliage. By September 1974, however, only 700 berries per cubic meter remained on the foliage. The remainder were either eaten or had fallen to the ground where they were consumed by

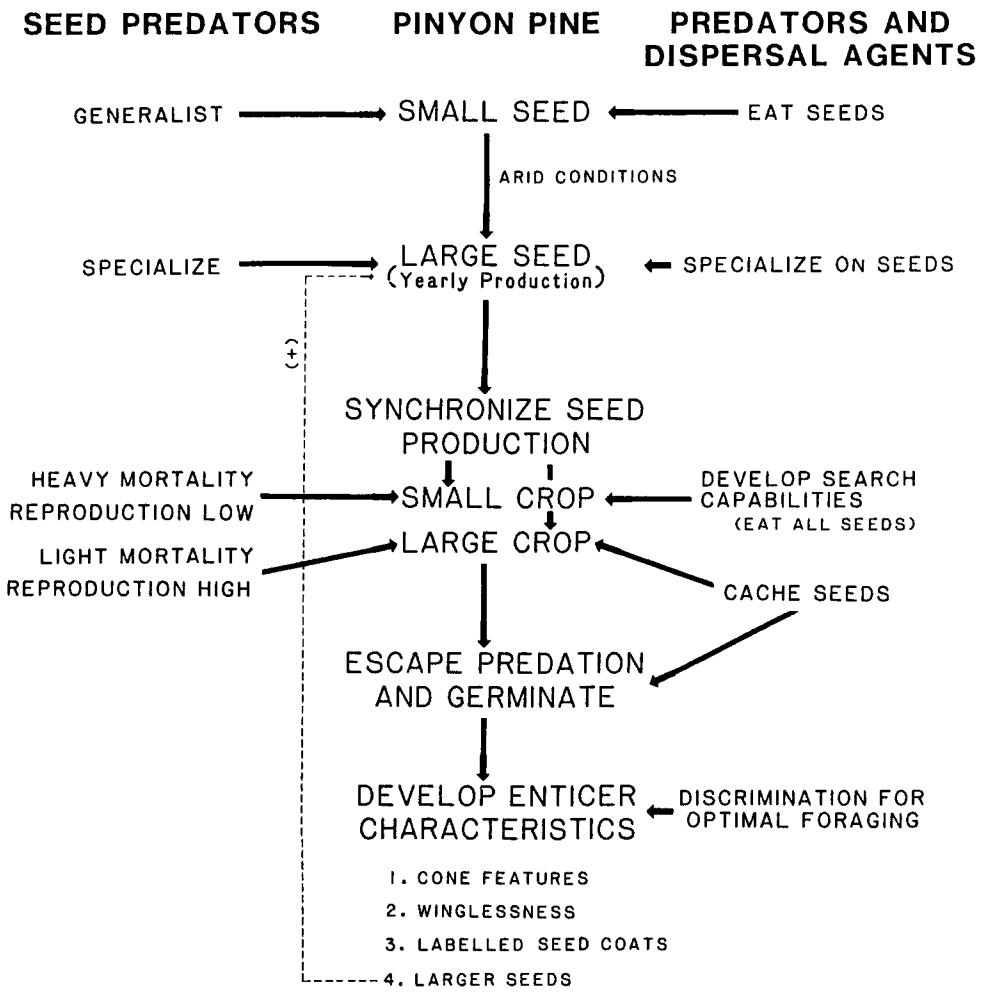


Figure 1.--A word model describing the ecological and evolutionary factors resulting in a mutualistic relationship between birds and pinyon pines.

birds and mammals. Large berry crops may be local or synchronized over relatively large areas; the brightly colored, or conspicuous berries are easily observed from a distance.

Junipers make no attempt to conceal or protect their obvious berries, and birds take advantage of this ready supply of food. The energy content of the fleshy portion of the juniper berry is 1.32 kJ thus making berries a reasonable energy source for birds.

Johnsen (1962) and Solomonson (1978) found that fresh, ripe seeds passed through the digestive tract of birds germinate faster than other seeds. Thus, not only are berries abundant and available, but also those eaten have high dispersal and germination potential.

THE BIRDS

Clark's Nutcracker. This species, a permanent resident of the alpine, mixed coniferous forest descends the mountains when pinyon pine seeds begin to ripen in August (VanderWall and Balda 1977). In summer, individual birds make forays into these woodlands presumably to survey the future cone crop. In late summer and early autumn, nutcrackers usually forage in small, loose flocks. Closed cones are either opened on the branch, but more often detached and carried to a suitable perch for opening. Suitable perches can easily be located by the large number of opened cones beneath them. Cone scales are chipped open in a characteristic pattern (differing from that of mammals) and dark brown edible seeds extracted. The bill of the Clark's Nutcracker is thick, long (x = 31.6 mm, n = 20) tapered, and sharply pointed, allowing them access to seeds in closed cones.

Seeds are deposited in a unique structure, the sublingual pouch. This structure is an expandable sac located in front of and below the tongue (Bock and others 1973). Birds can carry up to 90 medium-sized Pinus edulis seeds in the structure. The pouch may be filled in from five to 45 min. depending on cone ripeness (VanderWall and Balda 1977; VanderWall in prep.).

Nutcrackers are highly discriminatory between edible and diseased and empty ("blasted") seeds. Seeds with yellow to tan seed coats are empty and

left in the cones (VanderWall and Balda 1977). Birds also "bill-click" (rapidly clicking the seed in the mandible) or "bill-weigh" (holding the seed in the bill for a moment) before depositing seeds in the sublingual pouch. These techniques may aid the bird in assessing the quality of the seed (see Ligon and Martin 1974). All pinyon pine seeds (n = 505) removed from nutcracker pouches were edible and potentially viable.

Nutcrackers residing in the San Francisco Peaks near Flagstaff travel a minimum of 7.5 km from harvest area to caching areas. Birds have been observed flying nearly 30 km with sublingual pouches full of seeds. I suspect this distance is even greater under geographic conditions where mountain tops and woodlands are more widely separated.

Nutcrackers commonly cache seeds in the soil but on occasion seeds are placed in rock or bark crevices or in needle clusters of conifers. At a selected site, birds deposit between one and 20 seeds per cache. Seeds are hammered singly with the bill into the soil to depths of between one and three cm. Bill swipes are used to cover the cache with loose soil. Often a leaf or pine cone is then placed on top of the cache to conceal its location (VanderWall and Balda 1977, 1981).

On the San Francisco Peaks nutcrackers cache seeds individually (or in family units) on what appear to be territories scattered throughout the mixed coniferous forest (Abbott, per. observ.). Communal areas on steep, wind swept, south facing slopes are also used by many birds at the same time. These cliffs and steep slopes hold shallow snow cover and are free of snow early in the year thus allowing birds access to their seed caches. One such communal area on the San Francisco Peaks supports a healthy, mature stand of Pinus edulis at an elevation of 2700 m, about 600 m above the pinyon-juniper woodland (VanderWall and Balda 1977).

Nutcrackers, during a mast year will cache seeds for approximately 100 days from August through November. Caching ceases when snow covers the caching area making cache sites conspicuous. During the caching period we estimated that each bird caches between 22,000 and 33,000 pinyon pine seeds (VanderWall and Balda 1977). We conservatively number the population of nutcrackers on the San Francisco Peaks at 250 birds in fall. Thus, in a mast year, Clark's Nutcrackers cache between 5.5 and 8.2 million Pinus edulis seeds in the mixed coniferous forest in north-central Arizona.

Pinyon Jay. This highly social species is a permanent resident of the lower ponderosa pine (Pinus ponderosa) forest and pinyon-juniper woodland. In autumn these birds are in flocks numbering between 50 and 500 birds. Occasionally thousands of birds may be seen together, but flock cohesion appears to be maintained. Birds move widely throughout the pinyon-juniper woodland in search of pine cones. Single flights may be as long as 12 km.

When cones are found, the birds harvest seeds by opening green cones or plucking seeds from ripe ones. These behaviors are similar to those of nutcrackers. Birds discriminate seeds by color and also "bill-click" and "bill-weigh" seeds (Ligon and Martin 1974). Seeds are held in the throat in an expandable esophagus which can hold up to 56 average-sized Pinus edulis seeds. We have removed 655 seeds from the esophagi of Pinyon Jays and all were dark brown and edible (VanderWall and Balda 1981).

Pinyon Jays also have a strong, sharply tapered bill. This allows them to "chisel" into tightly closed cones and to reach deep between cone scales to procure seeds but avoid contact with the copous pitch on cones. Bills of 24 individuals measured 24.9 mm, but this measurement does not reflect a most significant adaptation, the lack of feathers covering the nostrils. These feathers normally retard heat loss from nostrils, but in the case of the Pinyon Jay these feathers could potentially be soiled by pitch. To compensate, birds normally roost on cold nights with their bills tucked snuggly in their scapulars (Balda and others 1977).

At intervals, signalled by loud vocalizations, these flocks leave the harvest area with the birds' esophagi full of seeds. Pine seeds are transported up to 12 km and usually cached in the soil. Caching areas measuring up to 5 ha in size, are discrete, and located on a flock's traditional home range (Balda and Bateman 1971; VanderWall and Balda 1981). A single flock may have up to seven caching areas per home range where all birds cache. These caching areas are often sparsely covered with vegetation, having patches of exposed soil, rocks, and cinders indicating well drained soils. In areas with trees present, birds often cache seeds under the canopy on the south side where snow melt is greatest. This caching pattern is evident from the number of saplings growing in these locations. Caching areas do change over the years, but at present no pattern is obvious.

Caching areas have been located in numerous places. Flocks having a home range in pinyon-juniper woodlands having caching areas therein. These flocks also cache large numbers of seeds in "cabled" areas of woodland (Ligon 1978). Flocks with home ranges in the ponderosa pine forest have caching areas there. Thus, the Pinyon Jay: 1) perpetuates the pines in existing pine covered areas, 2) restocks areas of the woodland where trees have been removed, 3) moves trees up hill into the next habitat type.

Pinyon Jays normally place only one seed per cache, but occasionally up to seven seeds may be placed in a single cache. Birds are industrious and will cache pine seeds as long as seeds are available and caching areas remain snow free. Ligon (1978) conservatively calculated that a single flock of birds in central New Mexico cached up to 4.5 million seeds in a mast year.

Steller's Jay. This permanent resident of the ponderosa pine and mixed coniferous forest visits the pinyon-juniper woodland in years of good cone crops to harvest, transport, and cache pinyon pine seeds. Only those individuals that live at the lower reaches of the ponderosa pine forest appear to harvest and cache pinyon pine seeds (VanderWall and Balda 1981).

Steller's Jays have relatively short, blunt bills (x = 20.6, n = 19) with the upper mandible slightly decurved at the tip. Thus, their bills are not well adapted to opening green cones. In years of intermediate or poor cone crops most all edible seeds are harvested before the cones open. In such years Steller's Jays may go virtually seedless. In most years birds move through the woodlands peering in open cones seeking edible seeds which are extracted from attached cones. Steller's Jays move pinyon pine seeds up hill into the ponderosa pine forest (VanderWall and Balda 1981).

At a feeding station where inedible seeds were dyed dark brown, these jays carried off a sizable number of them. Steller's Jays were never observed to "bill-click" or "bill-weigh" seeds so it is probable that they cannot discriminate seeds as well as nutcrackers and Pinyon Jays. In natural situations, however, it is likely birds discriminate seeds by color.

Steller's Jays, like Pinyon Jays, transport seeds in a distensible esophagus although they can carry fewer seeds than the latter species. Observations at a feeding station and in natural situations indicate that birds carry between nine and 18 Pinus edulis seeds. Seeds are transported no more than five km (VanderWall and Balda 1981, pers. observ.). Pinyon pine seeds are thus cached in ecotonal areas and short distances into the ponderosa pine forest interior.

Of the four species discussed in this account the Steller's Jay appears most catholic in its selection of cache sites. Birds, in a mast year, were observed caching in the soil 31 times (46%), in bark crevices on live tree trunks 15 times (22%), in rock and stump crevices 12 times (18%), and in needle clusters of ponderosa pines 10 times (15%). Most often only one seed is placed in a cache (VanderWall and Balda 1981).

Steller's Jays work industriously at harvesting pine seeds in mast years and may make five to seven round trips with seeds per day. A single bird (using six trips/day; 13 seeds/trip, 100 days) conservatively can cache 7800 seeds in a fall, about half of which are placed in sites where germination potential may be high.

Scrub Jay. This permanent resident is the most uniformly distributed and conspicuous bird of this habitat type. Thus, Scrub Jays may make a significant impact on pinyon pine density and local distribution. Birds maintain year-round territories where most of their activities are centered. Young-of-the-year are aggressively driven off natal territories in August and September.

Scrub Jay bills are short (x = 19.6 mm, n = 20), blunt, and therefore poorly adapted for opening green cones and extracting seeds. During the early part of seed harvest these birds silently approach nutcrackers and Pinyon Jays that are opening cones. At the opportune time Scrub Jays startle the bird opening the cone causing the cone or seed to be dropped. These are quickly retrieved by the Scrub Jay (VanderWall and Balda 1981). It is unlikely any seeds obtained in this manner are cached.

During mast years when cones with edible seeds open on trees, Scrub Jays throughout the woodlands spend considerable time and energy harvesting, transporting and caching pinyon pine seeds. Birds vigorously search through trees for cones and visually examine open cones for dark brown edible seeds. These are plucked from cones while the bird is perched or hovering at the cone. I have occasionally seen a bird pluck a tan colored seed from a cone, but this is not common, as indicated by the large number of tan colored seeds remaining in cones after harvesting ceases.

Scrub Jays do not possess a sublingual pouch or expandable esophagus and must hold and transport seeds in the mouth and bill. Masters (pers. observ.) saw Scrub Jays carrying one to four (n = 19) Pinus edulis seeds and Bent (1946) reports up to five pine seeds in the mouth and bill (VanderWall and Balda 1981). During October of a mast year I observed Scrub Jays transporting four seeds (n = 1), three seeds (n = 17), two seeds (n = 12) and one seed (n = 7) for an average of 2.3 seeds per trip.

Scrub Jays commonly harvest and cache seeds on their territories. Thus, most transport flights are of short duration and distance. Most birds cache within 50 m of the tree from which seeds are obtained but some flights may be up to one km, especially late in the harvest season when birds wander off territories in search of seeds (VanderWall and Balda 1981).

Cache sites are predominantly in the soil. Often all seeds carried are cached within one m of each other and birds appear to prefer to cache along edges (i.e. tree trunks, rocks, stumps, etc.) and openings and treeless areas are avoided. Normally only one seed is placed in a cache. Males and females appear to harvest and cache independently rather than coordinating their activities.

In a single day during a mast crop one Scrub Jay made 23 trips to cache sites. Using an average of 2.3 seeds per trip and 120 (snow free) caching days this bird would have cached 6348 seeds. Thus, a single pair of birds may cache about 13,000 seeds on a territory less than one square km in size.

Townsend's Solitaire. This bird is a winter resident of the pinyon-juniper woodland where it maintains and defends winter feeding territories that average about 0.7 ha during years of a

"bumper" crop of berries and contain from 13 to 25 million juniper berries. In years of sparse berries, territories become much larger. In most years far more berries are defended than can possibly be used, but this may represent an insured investment against heavy snows that cover many berries, and berry consumption by other berry eaters. Solitaires defend their berry supply interspecifically, especially against Western Bluebirds (Solomonson and Balda 1977).

Townsend's Solitaires commonly consume about 240 juniper berries per day or about 36,000 berries per winter (after Solomonson and Balda 1977). Berries are often plucked from branches while the bird perches, but occasionally solitaires hover in front of berry clusters and pluck seeds. Seeds are defecated during flights about the territory and also under heavily used perch sites such as tall trees on the perifery of territories. In good mast years territories abut, and the distribution of juniper seeds having passed through the digestive tract should be uniformly distributed within the pinyon-juniper woodland.

American Robin. This common thrush is also a winter visitor in the pinyon-juniper woodland. It forages in flocks varying from two to 40 birds. They feed on juniper berries obtained from branches or off the ground beneath junipers. As many as 20 birds have been seen foraging together in a berry-laden tree.

A single bird, during a mast year, consumes about 220 juniper berries per day or a total of about 33,000 berries per 150 day winter. In years of low berry production, birds must expend more time and energy locating berries and consequently berry consumption may be higher.

These birds often concentrate around water holes where they number in the thousands. In late afternoon, after an extensive foraging period, birds may fly up to 10 km to favored roost sites at sheltered locations. These flights often take the birds over grasslands, shrublands, "cabled" juniper areas, and mature woodlands. Defecation of juniper seeds and nitrogenous waste during these flights is common.

Western Bluebird. This bird winters in large numbers in the pinyon-juniper woodland. Bluebirds appear nomadic and range over large areas in search of berries and water. Birds may perform a regular foraging "beat" or route, but evidence for this is as yet circumstantial (pers. observ.). Flocks are small, (n = 7) but tightly organized. Densities of bluebirds seem closely correlated with berry density. In years when berries are sparse, birds are rare. This species consumes both juniper and mistletoe berries. The former are picked from branches while perching, or off the ground. Birds often appear to have a difficult time plucking juniper berries from branches but this is not the case for mistletoe berries.

Information, at present, is lacking on the role of this species in the pinyon-juniper woodland, but its density and the fact that it consumes berries suggests it operates as a dispersal agent for both juniper and mistletoe.

DISCUSSION

I know of no other plant community in North America in which the dominant species of plants have coevolved, mutualistic relationships with animals. Both pinyon pines and junipers rely on animals to disperse their propagules, but both have a very different strategy and rely on a different set of birds to accomplish this most important biological event.

One must ask the question why coevolved patterns have come to dominate this woodland but not other plant communities in North America. We can only speculate about such questions and the answer(s) may be of little use to modern day land managers anyway. I would like to make one suggestion, however, just to provide a starting point for such discussions. This woodland exists at the lower limits of climatic conditions to support trees of the genera Pinus and Juniperus (Lowe 1964). This climatic regime has placed strong selective pressures on the trees not only for survival but also reproduction. As mentioned earlier, the number of safe germination sites is positively correlated with seed size. Dry, hot conditions which exist for months in spring and early summer plus the unpredictable summer rains may well place a premium on seeds that can rapidly develop an extensive root system. Juniper seedlings appear more resistant to desiccation than seedlings of pinyon pine and this may in part explain seed size differences between the two. These harsh climatic conditions are also reflected in the densities of breeding birds in these woodlands which are lower than in other habitats dominated by trees.

In sharp contrast, climatic conditions in winter are milder than in most other habitats dominated by conifers. Snowfalls are usually light and snow cover transient. Some insects are active through most of the winter months. These mild conditions are also reflected in winter bird densities and diversity. Some migratory species of birds will go only as far south, in winter, as necessary to survive. In the western U.S. American Robins and Western Bluebirds are such species, and they settle in the pinyon-juniper woodland when conditions there (i.e. a berry crop) insure the birds' survival. Nomadic Pinyon Jay flocks also settle in areas where pine cones are present. The loss of nostril feathers by the Pinyon Jay may have been possible only because winter temperatures are mild in the woodlands. Ligon (1978) presents other adaptations of the Pinyon Jay for this contrast in climatic conditions.

Thus, harsh conditions during the germination season plus relatively mild conditions during the final period of seed maturation may well have resulted in the mode of reproduction seen in these trees. The presence of large numbers of unspecialized berry eaters (solitaires, robins, bluebirds) during the winter and permanent

resident and frequent visitant seed eaters (jays, nutcrackers) may have acted as selective forces for the development of the two different strategies for seed dispersal in the two genera of trees (table 1).

In pinyon pines, seed crops are highly synchronized both locally and geographically. For example, the largest crop of seeds ever recorded (from seed sales) occurred in 1984 (C. Anderson, pers. comm.) in north central Arizona. In contrast, almost no seeds were produced in this same area in 1985. This synchronization may be a direct response of the pinyon pines to seed predation. Ligon (1978) reports that in years of moderate seed production all seeds are consumed by the birds and none are cached. Trees producing seeds among non-producers are assured of having their seeds consumed. In mast years, however, the birds cannot possibly eat all seeds present, and thousands are cached. Caching corvids move seeds within and among habitat types (fig. 1). All studies to date (VanderWall and Balda 1977; Ligon 1978; Tomback 1978) have reported that birds will cache many more seeds than they need or can recover. It has recently been shown (Balda 1980; VanderWall 1982; Kamil and Balda 1985) that seed caching corvids have an exceptional memory that they use to locate seeds even through snow. This payoff is important if the mutualistic relationship is to be maintained. Nevertheless, there is little doubt that birds remember some caches better than others (Balda and Kamil, in press), assuring that some seeds are available to germinate. Thus, at low seed density the birds are seed predators and at high seed density birds are both seed predators and seed dispersal agents (Ligon 1978). Seeds consumed are the cost the tree must pay to have its seeds dispersed (fig. 2).

MANAGEMENT CONSIDERATIONS

Because of the strong mutualistic relationship that exists between seed dispersing birds and the pines and junipers, ignorance of the activities of these birds can seriously alter predicted management outcomes. One would expect a very different outcome in the absence of these birds than what would be found in their presence. The

Table 1.--Differences between pinyon pines, junipers, and the birds that disperse their seeds

Item	Pinyon Pines	Junipers
	TREE CHARACTERISTICS	
Cone	Difficult to penetrate	Easy to penetrate
Edible Material	Seed	Fleshy berry
Synchronization	Relatively high	Moderate
Number of Dispersal Agents	Few	Many
Time Available for Dispersal	Short	Long
Payoff for Tree	High quality germination sites	Varied quality of germination sites
Number of Seeds Available to Germinate	Relatively few	Many
	BIRD CHARACTERISTICS	
Effort to Obtain Energy Return	High	Low
Energy Obtained	High	Moderate
Specialization to Obtain Energy	Some	Few
Time of Payoff	Later	Immediately

group of birds that disperses juniper seeds is also distinct from those that disperse pinyon pine seeds. No known species of bird disperses seeds of both trees.

Avian biologists have often warned that conservation measures applied to nesting habitat may be for nought if the wintering grounds of migratory species are altered. The thousands of robins, bluebirds, and other species that overwinter in pinyon-juniper woodlands of the Southwest must come from vast areas of the western U.S. Eastern Bluebird (Sialia dialis) populations have undergone a serious decline in recent times. No such decline has been detected for the Western Bluebirds at this time but type conversion of the pinyon-juniper woodland will be implicated if such a decline does occur.

Type conversion projects could be predicted to fail or be of short duration because of the high mobility of juniper berry consuming birds and the preference of Pinyon Jays to cache seeds in openings. Thus, these areas will be "reconverted" back to the original vegetation type. Only if very large areas are converted so no seeds are available within the flight distance of dispersing birds can these areas be perpetuated. Currently converted areas adjacent to pinyon-juniper woodlands will quickly revert back to their original state.

Establishment of pinyon pine and juniper within the present confines of the woodland would seem to be handled adequately by Pinyon Jays, Scrub Jays and Townsend's Solitaires. Our knowledge about the behavior of Scrub Jays is sorely lacking because birds are hard to observe and no research support has been forthcoming. If habitat requirements of this species were better known, we may be able to entice birds to settle in areas and regenerate pinyon pine stands.

Managers in pinyon-juniper woodlands may have a unique opportunity presented to them. Birds, as an integral part of this woodland, may in fact, be used to do our management for us. For example, the strategic placement of water holes will attract berry dispersers which will deposit thousands of seeds in the surroundings.

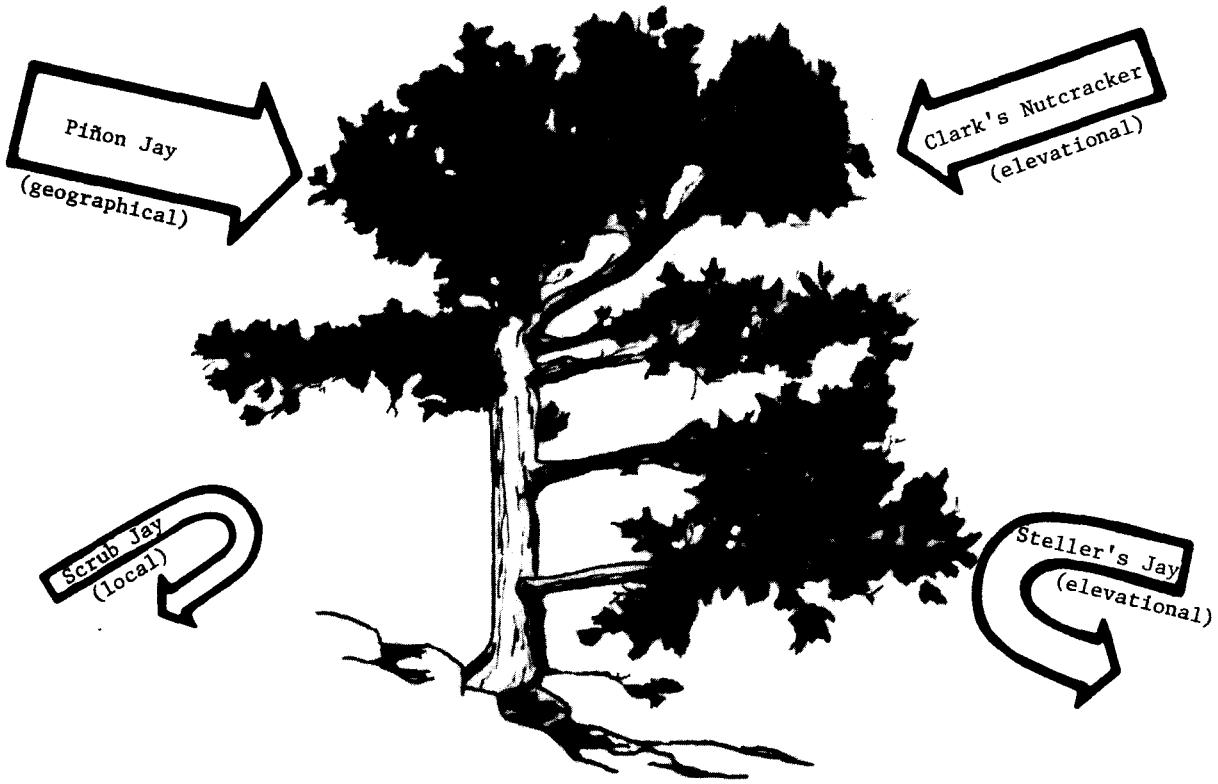


Figure 2.--The influence of four seed caching corvids on the distribution of pinyon pine seeds.

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AVIAN USE OF WATERHOLES IN PINYON-JUNIPER

Alan A. Gubanich and Howard R. Panik

ABSTRACT: Observations at two waterholes in Pinyon-Juniper woodland indicate that surface water is important to many species of birds during late summer and fall. Water with protective shrub cover was utilized more heavily than water in an open, exposed location. Availability of water may play a role in bird distributions in Pinyon-Juniper woodlands.

INTRODUCTION

Available surface water is critically important to many species of birds living in desert areas (Bartholomew and Cade 1963; Gubanich 1966; Fisher and others 1967; Willoughby and Cade 1967; Smyth and Coulombe 1971). Little is known, however, about the importance of water sources for birds in mesic environments, especially environments subjected to seasonal stresses, such as drought. Williams and Koenig (1980) investigated the water dependence of birds in the temperate oak woodland of central, coastal California and found 6 water-dependent species and 18 species of occasional drinkers using a spring during a dry summer. They concluded that surface water may be just as important in determining species distribution and community organization of birds in a mesic habitat as it is in desert environments, especially if that mesic habitat is subjected to seasonal stresses.

Pinyon-Juniper (P-J) woodland is a seasonally stressed environment characterized by hot, dry summers, cold winters, low annual amounts of precipitation (8 to 18 inches), low relative humidity and frequent winds (West and others 1975). In northwestern Nevada the P-J woodland receives most of its annual precipitation in the form of snow. May through October is considered the arid period, with less than 12% of the average annual precipitation occurring during August, September and October (West and others 1975). The purpose of this study was to determine the importance of surface water to the birds of the P-J woodland in northwestern Nevada during this arid period.

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Alan A. Gubanich is Associate Professor of Biology, University of Nevada, Reno, NV; Howard R. Panik is Instructor, Western Nevada Community College, Carson City, NV.

STUDY AREAS

We selected two watering sources for study, each surrounded by P-J woodland but differing in the vegetation immediately surrounding the water.

Virginia Highlands Pond

Virginia Highlands Pond (VHP) is a circular, shallow pond 184 m in diameter and 62 cm deep at an elevation of 1951 m in the Virginia City Mountains, in the northwest corner of Virginia City Highlands. Virginia City Highlands is private land in Storey County, subdivided into mostly 10-acre lots for sale as single-family units. It is located on the north and east sides of State Highway 341, approximately 7.5 km north of Virginia City. The northwest section of the Highlands is still undeveloped except for several dirt roads. The terrain is hilly, with elevations ranging from 1760 m to 2073 m. The area has a parkland appearance, with woodlands of single-leaf Pinyon Pine (Pinus monophylla) and Utah Juniper (Juniperus osteosperma) interrupted by large, open sagebrush shrublands. The pond is located in the shrubland, at the bottom of a bowl formed by hills on all but the east side. The principal source of water is snowmelt.

Vegetation around the pond consists of low-growing shrubs (mean height 0.2 m), predominantly Black Sage (Artemisia arbuscula) and Matchbrush (Gutierrezia sarathrae), along with Bitterbrush (Purshia tridentata), Rabbitbrush (Chrysothamnus vidisciflorus) and Mormon Tea (Ephedra viridis). A few clumps of Big Sage (Artemisia tridentata) occur on the northwest and west slopes. The pond's shoreline is rocky and devoid of vegetation for a distance of 11 to 16 m from the water's edge.

The shrubland eventually gives way to groves of Pinyon Pine and Juniper on all sides of the pond. The closest grove is 35 m to the south. Others are 160 m to the west, 160 m to the north, and 320 m to the northeast. There is a single Pinyon Pine on the north slope 46 m from the water's edge. Thus, animals have to cross a considerable distance of open shrubland to reach the water.

During the late summer and fall the closest known sources of water are Lousetown Creek, a small permanent stream about 3.5 km to the east, and Barrel Springs 4.6 km to the northeast. The nearest homes are 1.5 km to the east.

Jack's Spring

Jack's Spring (JS) is a permanent source of water in the Pine Nut Mountains, Carson City, 15 km southwest of Carson City airport and 32 km south-southeas

of VHP. It is a remnant of cattle ranching operations in the 1940's. Today the land belongs to the Washoe Indians and is closed to ranching. The spring is in a west-facing canyon, which is traversed by a dirt road. At an elevation of 1987 m a broken metal pipe 3½ cm in diameter protrudes from the road. Spring water flows from the pipe and forms a very shallow stream (4 to 20 mm deep) on the south half of the road. About 100 m to the west the stream joins the outflow from a second pipe, then crosses the road and flows into a tiny pond (3.4 m in diameter) formed by water from a third pipe. The combined flows continue down the north side of the road for another 90 m or so.

The habitat around the spring is mature P-J woodland interspersed with clearings dominated by Big Sage, Bitterbrush, and Rabbitbrush. Golden Currant (Ribes aureum), Snowberry (Symphorocarpus sp.) and Wild Rose (Rosa woodsii) are also common. The shrubs and trees line both sides of the dirt road and come almost to the very edges of the stream. Mean distance from water to shrub cover on the upper one-third of the stream is 0.5 m on the south side, 2.5 m on the north side. Thus, animals have very little open area to cross before reaching the water's edge. Mean height of shrubs lining the stream is 0.8 m.

The nearest sources of water are Erastra Spring 2 km to the east, Lebo Spring 5.4 km to the southeast, and Badger Spring 6.2 km to the northwest and 329 m lower in elevation.

METHODS

Between August 24 and November 2, 1984 we observed the two water sources for 129 hours over 18 days: 8 days (54 hours) at VHP and 10 days (75 hours) at JS. At VHP we watched from inside our truck while parked on the south slope, about 30 m from the water's edge. At JS we sat under a Pinyon Pine on the north side of the road just a few meters from the water and watched only the upper 60 m of the stream (this was the longest section of stream with an uninterrupted view).

We recorded every drinking and bathing visit by a bird and the time of the visit. Species not using the water were also noted. Observations began at 0700 or 0730 hours and lasted 6 to 7 hours on most days. Two watches of 9 and 11 hours duration were also made at both sites. The areas surrounding both water sources were also searched on several occasions to determine the bird species inhabiting the areas.

A species was considered a regular drinker or bather if individuals of that species were seen drinking or bathing on half or more of the observation days. Species seen drinking or bathing on fewer than half the observation days were considered occasional drinkers or bathers.

RESULTS

All species seen during the study are listed in the Appendix, tables 1 through 3. Figure 1 summarizes the overall utilization of each water source.

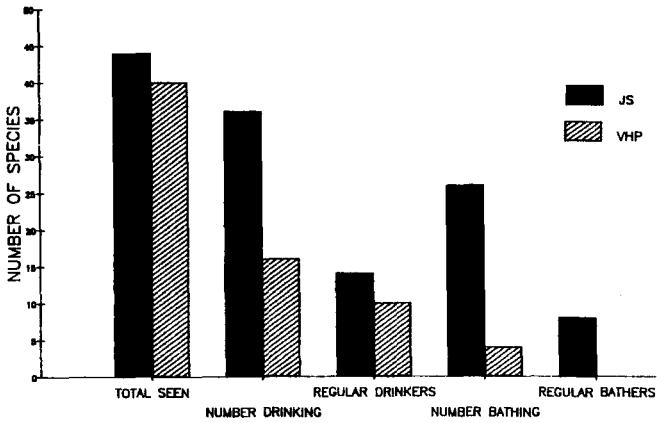


Figure 1.--Water usage by birds at Jack's Spring (JS) and Virginia Highlands Pond (VHP).

Species Utilization

Virginia Highlands Pond.--Forty species of birds were seen at or near the pond (Appendix, table 1). Sixteen species (40%) drank on at least one occasion (fig. 1). Ten species (25%) were regular drinkers and accounted for 95.6% of all observed drinking visits. Twenty-four species (60%) never drank during the study. Four species (10%) were observed bathing, but no species bathed on a regular basis.

Jack's Spring.-- At JS we observed 44 species (Appendix, table 2), 36 (81.8%) of which drank at least once (fig. 1). Fourteen species (31.8%) drank regularly and accounted for 98% of all observed drinking visits. Eight species (18.2%) never drank. Twenty-six species (59%) used the spring for bathing (Appendix, table 3); 8 of those species (18.1%) bathed regularly.

Drinking Patterns

Figure 2 shows the average daily drinking patterns at both water sources, expressed as mean number of drinking visits by all birds during each half-hour of observation.

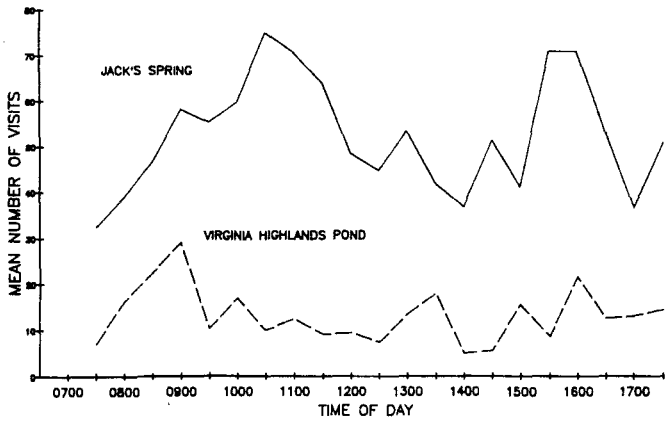


Figure 2.--Mean number of drinking visits by birds every half-hour at Jack's Spring and Virginia Highlands Pond.

Activity at JS was consistently higher than at VHP. Mean number of birds drinking during any given half-hour at JS ranged from two to nine times the number drinking during the same half-hour at VHP. Since we watched only the upper one-third of the stream at JS, these means are underestimates and the actual total activity along the entire stream was certainly much higher.

Drinking took place at all hours of the day at both sites (fig. 2). At JS two peaks of drinking activity occurred, one in late morning (1000 to 1130 hours), the other in late afternoon (1500 to 1630 hours). A different pattern was seen at VHP, where most drinking occurred early in the morning (0800 to 0900 hours), with only minor peaks of activity in the afternoon. However, our afternoon data for both sites are based on fewer observation days than for the morning data and may thus not be as reliable.

Bathing Patterns

Bathing was common at JS but virtually nonexistent at VHP (fig. 3). At JS we observed 3203 instances of bathing by 26 species (Appendix, table 3) but only 15 bathing incidents by 4 species at VHP. Most bathing activity at JS occurred in the morning between 0900 and 1100 hours. It decreased dramatically between 1100 and 1130 hours, then declined slowly throughout the rest of the day.

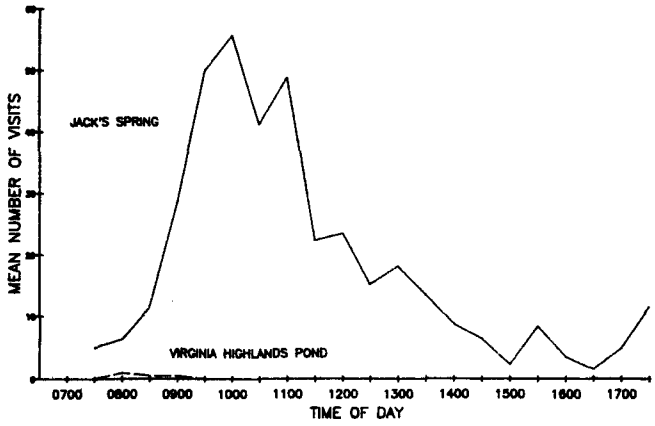


Figure 3.--Mean number of bathing visits by birds every half-hour at Jack's Spring and Virginia Highlands Pond.

Species Differences

The two sites differed with respect to which species drank regularly and how frequently some of those species drank. Some of these differences are shown in figures 4 and 5, others in the Appendix, tables 1 and 2.

Virginia Highlands Pond.--Of the 10 species that drank regularly at VHP, 4 (Red Crossbill, Northern Flicker, Horned Lark, Yellow-rumped Warbler) accounted for about three-fourths (76.6%) of all observed drinking visits (fig. 4). Red Crossbills are generally nomads, wandering from one pine seed crop to another, and are not normally residents of P-J woodland. They were apparently common in the area during our study because of a good pine nut crop that year. Northern Flickers are winter residents and were migrating into (and perhaps through) the area at this time of the year. Horned Larks are summer residents in the sagebrush shrublands and, along with the Yellow-rumped Warblers, which are migrants, were gone by late October. The high frequency of drinking by these latter 3 species is surprising in light of their generally insectivorous diets.

Of the 6 remaining species that drank regularly, 2 (Mountain Bluebird, Chipping Sparrow) are summer residents (they, too, were absent by late October) and 1 (Townsend's Solitaire) is a winter resident. The other 3 species (Dark-eyed Junco, American Robin and Cassin's Finch) are known to breed in P-J woodland, but occur in larger numbers as winter residents. Most individuals of these 3 species were probably migrating into the area at this time of the year.

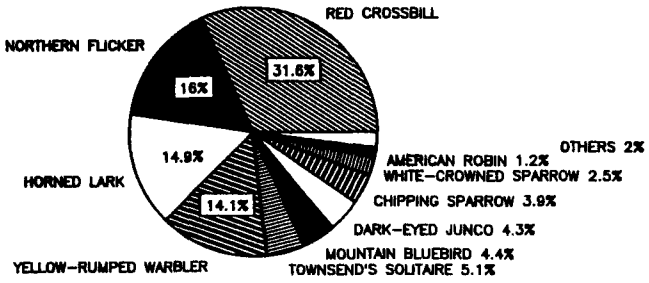


Figure 4.--Frequency of drinking by bird species at Virginia Highlands Pond. Values are % of total drinking instances by all birds throughout the entire study.

Jack's Spring.-- As with VHP, 4 species accounted for about three-fourths (74.2%) of all drinking visits (fig. 5). Cassin's Finches were the most common drinkers; this contrasts sharply with VHP where Cassin's Finches drank regularly but in very low numbers (Appendix, table 1). Townsend's Solitaires and Dark-eyed Juncos were also much more frequent drinkers at the spring than at VHP.

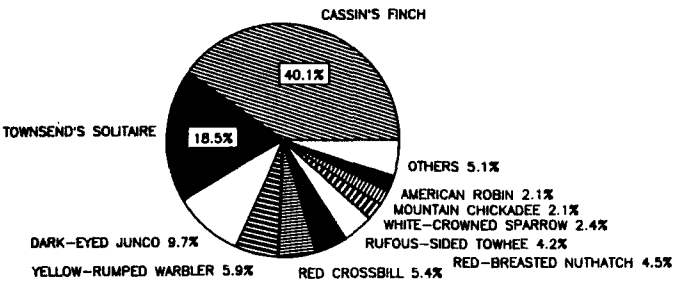


Figure 5.--Frequency of drinking by bird species at Jack's Spring. Values are % of total drinking instances by all birds throughout the entire study.

A number of other species drank regularly at JS but not at all at VHP, even though they were seen regularly in the area surrounding the pond. These

include Red-breasted Nuthatch (winter resident); Rufous-sided Towhee (permanent resident); Mountain Chickadee (winter/summer resident); Scrub Jay (permanent resident); and Steller's Jay (permanent resident). Additionally, White-crowned Sparrows (migrants) drank regularly at JS but only occasionally (2 observation days) at VHP. Four times as many migrants drank at JS; however, most of these were seen only infrequently (Appendix, table 2).

Table 3 (Appendix) lists the birds that bathed at JS. Over 80% of all baths were taken by Yellow-rumped Warblers, Dark-eyed Juncos and Cassin's Finches. Rufous-sided Towhees, Mountain Chickadees, White-crowned Sparrows and Chipping Sparrows were also common bathers. Only 4 species were ever observed bathing at VHP: Chipping Sparrow (7 instances); Mountain Bluebird (3 instances); Yellow-rumped Warblers (4 instances); and American Robin (1 instance).

DISCUSSION AND CONCLUSIONS

Our observations indicate that surface water is of importance to many species of birds in P-J woodland during the arid period of late summer and fall. In fact, several species seem to be water-dependent at this time of year, since they drank regularly at both water sources. These include Red Crossbill, Cassin's Finch, Dark-eyed Junco, Townsend's Solitaire, Chipping Sparrow, Northern Flicker, American Robin, and probably also White-crowned Sparrow and Mountain Bluebird. Horned Larks also seemed to be water-dependent at VHP. Water dependency is perhaps not suprising for the granivorous species, but the American Robin, Townsend's Solitaire, Mountain Bluebird, Northern Flicker and Horned Lark are primarily insectivorous (the first 3 are also frugivorous to some extent) and would be expected to obtain sufficient water from their diet. Perhaps the insect populations on which these species feed decline sufficiently in late summer and fall to necessitate drinking of free water.

The metabolic demands of migration may also make several species water-dependent at this time of the year, including insectivorous warblers. Yellow-rumped Warblers, for example, were common drinkers at both water sources, while 4 other species of warblers drank on various occasions at JS (Appendix, table 2).

Other species are more difficult to categorize with respect to water dependence. Those species that drank regularly at JS but never at VHP (Red-breasted Nuthatch, Rufous-sided Towhee, Mountain Chickadee, Scrub Jay, Steller's Jay) may simply be opportunists, taking advantage of a favorable situation. They may have drunk regularly at JS because the water was close to shrub and tree cover. Birds are generally very nervous when coming to water and are reluctant to lower their heads to drink (Gubanich 1966; Smyth and Coulombe 1971; Fisher and others 1972). Our observations show this to also be true for bathing. Such wariness has long been attributed to the threat of predation. The vegetative structure surrounding these two water sites provides distinctly different situations with respect to predation danger.

At VHP the shoreline is devoid of vegetation and the surrounding hills are covered with very low shrubs (mean height 0.2 m), affording hardly any protective cover. The nearest single tree is 32 m away. Birds drinking or bathing at VHP would be easily visible to a predator, especially an aerial one. At JS, in contrast, a well developed shrub stratum of high-growing shrubs (mean height 0.8 m) is only 0.5 to 2.5 m away from the water, as are numerous pinyon and juniper trees 5 to 7 m or more in height. This vegetation not only limits the visibility of predators, but also allows for quick and easy access to protective cover in the event that a predator does approach. We witnessed many instances of birds scampering quickly into the nearby shrubs and trees whenever a hawk flew into or over the area. This close, available cover probably accounts not only for the drinking activity at JS of those species that never drank at VHP, but also for the much higher total incidence of drinking and bathing at JS.

The study raises several questions. How water-dependent are these species of birds at other seasons of the year? How often do individual birds drink, and how far do they travel to obtain water? Is availability of water a limiting factor on bird distribution in P-J woodlands? Do those areas of P-J woodland that contain free water support a greater diversity of bird species, or greater numbers of any one individual species, than areas without surface water? Beatty (1978) was able to show that in Wupatki National Monument in Arizona, avian diversities were higher in those habitat types that contained available water. Gubanich (1966), however, did not find any increase in breeding densities of desert birds in the vicinity of water-holes in southern Arizona. The situation for P-J woodlands is unknown. In fact, community ecology of birds in general in P-J woodlands has been little studied (Balda and Masters 1980). We suggest that if such studies are ever conducted, it would perhaps be wise to consider water sources as possible determinants of bird species distributions in this habitat type.

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APPENDIX

Table 1.-- Drinking and resident status of bird species seen at Virginia Highlands Pond during late summer and fall 1984. Number of observation days = 8. Total drinking instances = 1520

Species	Number of days seen drinking	Number of drinking instances	Resident status[1]	Drinking status[2]
Northern Flicker (Colaptes auratus)	7	243	WR	R
Townsend's Solitaire (Myadestes townsendi)	7	77	WR	R
Red Crossbill (Loxia curvirostra)	6	480	N	R
Horned Lark (Eremophila alpestris)	6	226	SR	R
Yellow-rumped Warbler (Dendroica coronata)	5	215	M	R
Mountain Bluebird (Sialia currucoides)	5	67	SR	R
Cassin's Finch (Carpodacus cassinii)	5	12	WR/SR	R
Dark-eyed Junco (Junco hyemalis)	4	66	WR/SR	R
Chipping Sparrow (Spizella passerina)	4	59	SR	R
American Robin (Turdus migratorius)	4	18	WR/SR	R
Barn Swallow (Hirundo rustica)	3	5	SR	O
White-crowned Sparrow (Zonotrichia leucophrys)	2	38	M	O
House Finch (Carpodacus mexicanus)	2	5	M	O
Chukar (Alectoris chukar)	1	7	?	O
Lark Sparrow (Chondestes grammacus)	1	1	SR	O
Say's Phoebe (Sayornis saya)	1	1	M	O
Northern Pintail (Anas acuta)	0	0	M	N
Semipalmated Plover (Charadrius semipalmatus)	0	0	M	N
Killdeer (Charadrius vociferus)	0	0	M	N
Turkey Vulture (Cathartes aura)	0	0	SR	N
Golden Eagle (Aquila chrysaetos)	0	0	PR	N
Northern Harrier (Circus cyaneus)	0	0	PR	N
Sharp-shinned Hawk (Accipiter striatus)	0	0	PR	N
Cooper's Hawk (Accipiter cooperii)	0	0	PR	N
Red-tailed Hawk (Buteo jamaicensis)	0	0	PR	N
American Kestrel (Falco sparverius)	0	0	PR	N
Common Nighthawk (Chordeiles minor)	0	0	SR	N
Western Kingbird (Tyrannus verticalis)	0	0	SR	N
Scrub Jay (Aphelocoma coerulescens)	0	0	PR	N
Mountain Chickadee (Parus gambeli)	0	0	WR	N
Bushtit (Psaltriparus minimus)	0	0	PR	N
Red-breasted Nuthatch (Sitta canadensis)	0	0	WR	N
Bewick's Wren (Thryomanes bewickii)	0	0	PR	N
Rock Wren (Salpinctes obsoletus)	0	0	SR	N
Ruby-crowned Kinglet (Regulus calendula)	0	0	WR	N
Water Pipit (Anthus spinoletta)	0	0	M	N
Wilson's Warbler (Wilsonia pusilla)	0	0	M	N
Rufous-sided Towhee (Pipilo erythrophthalmus)	0	0	PR	N
Western Tanager (Piranga ludoviciana)	0	0	SR/M	N
Evening Grosbeak (Coccothraustes vespertinus)	0	0	WR	N

[1]WR = winter resident; SR = summer resident; M = migrant; N = nomad.
[2]R = regular drinker; O = occasional drinker; N = never drank.

Table 2.--Drinking and resident status of bird species seen at Jack's Spring during late summer and fall 1984. Number of observation days = 9.[1] Total drinking instances = 7313

Species	Number of days seen drinking	Number of drinking instances	Resident status[2]	Drinking status[3]
Cassin's Finch (Carpodacus cassinii)	9	2929	WR/SR	R
Townsend's Solitaire (Myadestes townsendi)	9	1352	WR	R
Dark-eyed Junco (Junco hyemalis)	9	710	WR/SR	R
Red-breasted Nuthatch (Sitta canadensis)	9	329	WR	R
Rufous-sided Towhee (Pipilo erythrophthalmus)	9	307	PR	R
Mountain Chickadee (Parus gambeli)	9	156	WR	R
Scrub Jay (Aphelocoma coerulescens)	9	142	PR	R
American Robin (Turdus migratorius)	8	156	WR/SR	R
Northern Flicker (Colaptes auratus)	8	104	WR	R
Yellow-rumped Warbler (Dendroica coronata)	7	435	M	R
Red Crossbill (Loxia curvirostra)	7	394	N	R
White-crowned Sparrow (Zonotrichia leucophrys)	7	173	M	R
Mountain Bluebird (Sialia currucoides)	5	19	SR	R
Steller's Jay (Cyanocitta stelleri)	5	9	PR	R
Chipping Sparrow (Spizella passerina)	4	15	SR	O
Evening Grosbeak (Coccothraustes vespertinus)	3	13	WR	O
Plain Titmouse (Parus inornatus)	3	5	PR	O
Orange-crowned Warbler (Vermivora celata)	3	5	M	O
Williamson's Sapsucker (Sphyrapicus thyroideus)	3	4	M	O
Fox Sparrow (Passerella iliaca)	2	16	M	O
Bushtit (Psaltriparus minimus)	2	5	PR	O
Green-tailed Towhee (Pipilo chlorurus)	2	4	SR	O
Mountain Quail (Oreortyx pictus)	2	4	PR	O
Hermit Thrush (Catharus guttatus)	2	3	M	O
Vesper Sparrow (Pooecetes gramineus)	2	2	M	O
Clark's Nutcracker (Nucifraga columbiana)	2	2	M	O
House Finch (Carpodacus mexicanus)	2	2	M	O
Varied Thrush (Ixoreus naevius)	1	6	M	O
Townsend's Warbler (Dendroica townsendi)	1	3	M	O
Pinyon Jay (Gymnorhinus cyanocephalus)	1	2	PR	O
Cedar Waxwing (Bombycilla cedrorum)	1	2	M	O
Lewis' Woodpecker (Melanerpes lewis)	1	1	M	O
Hermit Warbler (Dendroica occidentalis)	1	1	M	O
Wilson's Warbler (Wilsonia pusilla)	1	1	M	O
Lincoln's Sparrow (Melospiza lincolnii)	1	1	M	O
Western Tanager (Piranga ludoviciana)	1	1	SR/M	O
Golden Eagle (Aquila chrysaetos)	0	0	PR	N
Sharp-shinned Hawk (Accipiter striatus)	0	0	PR	N
Cooper's Hawk (Accipiter cooperi)	0	0	PR	N
Northern Goshawk (Accipiter gentilis)	0	0	PR	N
Red-tailed Hawk (Buteo jamaicensis)	0	0	PR	N
Hairy Woodpecker (Picoides villosus)	0	0	WR	N
Bewick's Wren (Thryomanes bewickii)	0	0	PR	N
Ruby-crowned Kinglet (Regulus calendula)	0	0	WR	N

[1]excludes October 1, 1984 (5 hours) when no birds drank due to falling rain and snow.
[2]WR = winter resident; SR = summer resident; M = migrant; N = nomad.
[3]R = regular drinker; O = occasional drinker; N = never drank.

Table 3.--Bathing and resident status of bird species seen bathing at Jack's Spring during late summer and fall 1984. Number of observation days = 9.[1] Total bathing instances = 3203

Species	Number of days seen bathing	Number of bathing instances	% of total bathing instances	Resident status[2]	Bathing status[3]
Dark-eyed Junco (Junco hyemalis)	9	881	27.5	WR/SR	R
Rufous-sided Towhee (Pipilo erythrophthalmus)	9	279	8.7	PR	R
Mountain Chickadee (Parus gambeli)	9	110	3.4	WR	R
Yellow-rumped Warbler (Dendroica coronata)	8	1003	31.3	M	R
Cassin's Finch (Carpodacus cassinii)	8	718	22.4	WR/SR	R
White-crowned Sparrow (Zonotrichia leucophrys)	5	45	1.4	M	R
Townsend's Solitaire (Myadestes townsendi)	5	13	0.4	WR	R
Red Crossbill (Loxia curvirostra)	5	10	0.3	N	R
Chipping Sparrow (Spizella passerina)	4	39	1.2	SR	O
Mountain Bluebird (Sialia currucoides)	4	5	0.1	SR	O
Ruby-crowned Kinglet (Regulus calendula)	3	18	0.5	WR	O
Orange-crowned Warbler (Vermivora celata)	3	9	0.2	M	O
Red-breasted Nuthatch (Sitta canadensis)	3	7	0.2	WR	O
Bushtit (Psaltriparus minimus)	2	32	0.9	PR	O
Vesper Sparrow (Pooecetes gramineus)	2	5	0.1	M	O
American Robin (Turdus migratorius)	2	4	0.1	WR/SR	O
Wilson's Warbler (Wilsonia pusilla)	2	4	0.1	M	O
Hermit Warbler (Dendroica occidentalis)	2	2	0.06	M	O
Townsend's Warbler (Dendroica townsendi)	1	5	0.1	M	O
Scrub Jay (Aphelocoma coerulescens)	1	3	0.09	PR	O
Fox Sparrow (Passerella iliaca)	1	3	0.09	M	O
Northern Flicker (Colaptes auratus)	1	2	0.06	WR	O
Hermit Thrush (Catharus guttatus)	1	2	0.06	M	O
Western Tanager (Piranga ludoviciana)	1	2	0.06	SR/M	O
Green-tailed Towhee (Pipilo chlorurus)	1	1	0.03	SR	O
Evening Grosbeak (Coccothraustes vespertinus)	1	1	0.03	WR	O

[1]excludes October 1, 1984 (5 hours) when no birds bathed due to falling rain and snow.
[2]WR = winter resident; SR = summer resident; M = migrant; N = nomad.
[3]R = regular bather; O = occasional bather.

EFFECTS OF CHAINING PINYON-JUNIPER ON NONGAME WILDLIFE

James A. Sedgwick and Ronald A. Ryder

ABSTRACT: The effects of chaining pinyon-juniper on nongame wildlife were studied from 1976-1980 in the Piceance Basin, Colorado. Small mammals and breeding birds were sampled in 1976 before treatment and for 4 years (birds) and 3 years (small mammals) following chaining. Seven of the 16 most common species of birds used the control plot more ($P < 0.05$) while only one used the chained plot more. Foliage-and-timber searchers, aerial foragers, foliage nesters, and cavity nesters rarely used the chained plot, whereas some species in the ground searching and ground nesting guilds regularly foraged or nested in the treatment plot. Small mammal species richness was greater on the chained plot than on the control plot, as was the total number of captures of all species combined. However, deer mice (Peromyscus maniculatus) comprised 85% of the total catch, and appeared to be the only small mammal species that benefited from chaining. Pinyon mice were captured only on the control. Varied responses by birds and small mammals to chaining suggest strategies for minimizing its negative effects.

INTRODUCTION

Pinyon-juniper woodland occurs throughout much of the western United States, occupying some 172,000 km^2 of land (Clary 1975). It is characterized by low (5-15 m), slow-growing trees in the genera Pinus and Juniperus, principally pinyon pine (P. edulis) and Utah juniper (J. osteosperma) (plant nomenclature follows Scott and Wasser 1980). This pygmy woodland occurs at elevations ranging from 975 m to over 3000 m (West and others 1975) with juniper being conspicuous at lower elevations and pinyon pine becoming dominant above 2100 m (Ward and others 1974).

Pinyon-juniper woodland has been the object of efforts to convert it to grazing lands to produce additional forage for livestock and big game. Methods commonly used to alter pinyon-juniper include chaining, tree crushing, bulldozing, and prescribed burning. Chaining, the most commonly used technique, involves pulling an 80-200-m-long anchor chain (20-40 kg/link) between a pair of crawler tractors, knocking down the trees (Aro 1975). Historically, the effects of altering pinyon-juniper woodland on nongame wildlife have not been considered (Terrel and Spillett 1975). With a few notable exceptions (Balda and Masters 1980; O'Meara and others 1981), avian ecologists have ignored this ecosystem, and the role of nongame wildlife in the ecosystem dynamics of pinyon-juniper woodlands has been largely overlooked.

Today, nongame wildlife is commonly included in management plans (Evans 1978). Wise ecosystem management requires that assessments be made on the impacts of habitat manipulations on nongame species. The objectives of our study were to assess the effects of chaining pinyon-juniper woodlands on nongame bird and small mammal populations, and to develop management guidelines for these populations with respect to habitat alteration.

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STUDY AREA

The study was conducted in northwestern Colorado in the Piceance Basin, a rolling upland covering some 3500 km^2. Vegetative cover is dominated by pinyon-juniper and upland sagebrush, with smaller amounts of mixed mountain shrub, sagebrush bottomland, and at higher elevations, small stands of Douglas-fir (Pseudotsuga menziesii) or quaking aspen (Populus tremuloides). The climate of the Piceance Basin is arid-steppe with hot, dry summers and dry to moist, cold winters. Most of the basin receives 35.5-38 cm of precipitation annually, with about equal monthly distribution. Mean annual temperature varies from 9.9 C at 1524 m to -0.7 C at 2743 m (Wymore 1974).

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James A. Sedgwick is Wildlife Biologist, U.S. Fish and Wildlife Service, Denver Wildlife Research Center, Fort Collins, CO; Ronald A. Ryder is Professor emeritus, Dep. Fishery and Wildlife Biology, Colorado State University, Fort Collins, CO.

The study area was located approximately 30 km southwest of Meeker, Colorado. A draw ran north-south through the area and east and west facing aspects had slopes of 5-20%. Elevations ranged from 1987-2042 m. Pinyon and juniper were the only tree species on the study plot and were co-dominant. Common shrubs included true mountainmahogany (Cercocarpus montanus), snowberry (Symphoricarpos spp.), antelope bitterbrush (Purshia tridentata), big sagebrush (Artemisia tridentata) and rabbitbrush (Chrysothamnus spp.). Large Saskatoon serviceberry (Amelanchier alnifolia) bushes were dominant in the draw. The grass-forb community included Indian ricegrass (Oryzopsis hymenoides), bluebunch wheatgrass (Agropyron spicatum), needle-and-thread (Stipa comata), Hood phlox (Phlox hoodii), penstemon (Penstemon spp.) and groundsel (Senecio spp).

METHODS

A 12-ha (400 x 300 m) study plot was established in May 1976. Pre-treatment data on birds and small mammals were collected May-July 1976. In September 1976, 16 ha in the study area were chained, 6.8 ha of which were in the study plot. Thus, resulting treatment and control study plots were 6.8 and 5.2 ha, respectively. Bird populations were sampled during May and June 1976-1980 using the International Bird Census Committee spot-mapping method (Svensson 1970). Chained and control plots were each censused eight times per year. Rather than estimating the number of territories for each bird species, we used individual bird registrations to derive indices of relative abundance or bird utilization. Such indices are satisfactory for comparing two areas and may be preferable to estimates of absolute density (Temple 1981). Indices of bird use were calculated for nonbreeders and migrants as well as breeding birds and were expressed as number of birds observed per 100 ha. Two-way analysis of variance was used to test for differences in relative abundance of individual species, feeding and nesting guilds, and total population by treatment and year. Indices of use for the first four and second four censuses each year served as replicates in the analysis of variance. A square root transformation ($\sqrt{\text{registrations} + 0.5}$) was performed on the data since counts for some species included zeros (Steel and Torrie 1960). Bird species diversities were calculated using the Shannon index ($H' = -\Sigma p_i \log_e p_i$) where H' is the diversity index and p_i is the proportion of all individuals in the i^{th} species (Shannon and Weaver 1963). Components of this index are S, species richness, or the number of species occurring, and J, the equitability or evenness of species distribution ($J = H'/\log_e S$).

Small mammal populations were sampled by kill trapping. Snap traps were placed in octagonal grids of 40 stations at 10-m intervals (Smith 1966). Three museum special snap traps were set at each station for a period of 30 days. Thus, each grid was trapped for a total of 3600 trap nights. Traps were checked twice daily and rebaited as necessary with a peanut butter and rolled oats mixture. One grid was trapped on the area before treatment in 1976 and one grid each in the chained and control plots were trapped from mid-May to mid-June 1977-79. Chi-square tests were used to test for differences between plots.

We used a modification of the line-intercept technique (Canfield 1941) to estimate percentage cover of vegetation and dead woody material. We determined cover for each of the grass-forb (<0.5 m), shrub (0.5-2.0 m), and overstory canopy (>2.0 m) layers of vegetation. Forty transects (20 in chained, 20 in control) along which vegetation was measured were selected by establishing a rectangular grid of coordinates and using randomly determined intersections of perpendiculars as starting points. A 30-m tape was stretched between two stakes along the transects and the distance along the tape which was intersected by vegetation or dead woody material was recorded to the nearest centimeter. A vertical rod was used to project the overstory canopy layer to the tape (Mueller-Dombois and Ellenberg 1974). Percentage cover of each vegetative layer and dead woody material was determined as the total distance intercepted divided by the total length of all transects. Measurements were made in July 1979, 34 months after treatment.

Null hypotheses of no difference between treated and control plots, or between years, were tested at the preselected significance level of $P = 0.05$.

RESULTS AND DISCUSSION

Vegetation

Vegetation was dramatically altered by chaining. The pinyon-juniper overstory was uprooted and left on the ground as slash. Few trees were small enough or limber enough to remain standing after chaining. Percentage overstory canopy cover was significantly different between the chained (0.7%) and control (35.9%) plots (χ^2, $P < 0.05$). Some shrubs were uprooted by the chaining process but shrub cover was similar on the control (6.5%) and chained (5.7%) areas. Ultimately, we would expect shrub cover to be greater on the chained area since tree canopies shield light from understory vegetation, and pinyons and junipers may thus inhibit vegetative growth (Tueller and Clark 1975).

The grass-forb layer apparently responded to improved growth conditions since cover of this component was higher in the chained (15.9%) than in the control (2.1%) plot ($P < 0.05$). Dead woody cover, comprised mostly of slash in the chaining and naturally fallen timber in the

Table 1.--Avian use indices (no./100 ha) for pinyon-juniper control and chained plots, 1977-1980

Species	Year								Significance[1]		
	1977		1978		1979		1980				
	Control	Chained	Control	Chained	Control	Chained	Control	Chained			
Black-throated gray warbler (Dendroica nigrescens)	82	2	63	4	77	7	38	4	p		
Chipping sparrow (Spizella passerina)	46	15	24	48	38	50	49	19			
Gray flycatcher (Empidonax wrightii)	50	0	53	7	5	0	33	0	p	y	
Mountain bluebird (Sialia currucoides)	36	13	43	20	19	13	27	21	p		
Mountain chickadee (Parus gambeli)	38	2	36	0	10	0	11	0	p	y	i
Hairy woodpecker (Picoides villosus)	7	7	2	0	38	2	30	2	p	y	i
White-breasted nuthatch (Sitta carolinensis)	19	2	5	0	2	0	16	0	p		
Bushtit (Psaltriparus minimus)	24	0	14	0	0	0	0	0	p	y	i
Mourning dove (Zenaida macroura)	12	0	7	6	0	29	22	23			
Solitary vireo (Vireo solitarius)	10	0	5	4	2	0	22	0	p		
Dark-eyed junco (Junco hyemalis)	17	0	0	0	10	7	8	6			
Dusky flycatcher (Empidonax oberholseri)	12	0	0	2	5	0	8	0	p	y	i
Plain titmouse (Parus inornatus)	10	2	5	0	2	0	14	2	p		
Hermit thrush (Catharus guttatus)	10	0	0	0	2	0	0	0	p		
Rock wren (Salpinctes obsoletus)	0	2	0	13	2	13	0	4	p		
House wren (Troglodytes aedon)	0	0	0	0	0	2	0	4			
Others	31	0	26	4	26	13	33	34			
TOTALS	404	44	284	107	240	136	313	120	p		i

[1] p = significant difference between plots ($P < 0.05$).
y = significant difference between years ($P < 0.05$).
i = significant interaction between plots and years ($P < 0.05$).

Table 2.--Avian use indices (no./100 ha) for the foliage-and-timber searching (FTS), aerial foraging (AF), ground searching (GS), foliage nesting (FN), hole nesting (HN), and ground nesting (GN) guilds for pinyon-juniper control and chained plots, 1977-1980

	1977		1978		1979		1980		Significance[1]		
	Control	Chained	Control	Chained	Control	Chained	Control	Chained			
Foraging Guilds											
FTS	190	15	130	7	132	9	132	8	p		
AF	81	6	75	19	19	6	55	13	p	y	
GS	102	23	53	76	63	108	93	65			i
Nesting Guilds											
FN	239	17	162	67	130	72	161	35	p		i
HN	111	26	91	20	72	17	99	29	p		
GN	23	2	4	16	12	35	19	22			

[1] p = significant difference between plots ($P < 0.05$).
y = significant difference between years ($P < 0.05$).
i = significant interaction between plots and years ($P < 0.05$).

control, was significantly greater in the chaining (30.0%) than in the control (3.8%).

Birds

Bird use (all species) of the control plot was greater than that of the chained plot each year after treatment (table 1). The difference in abundance between plots was most pronounced in 1977, the first year after treatment, when bird use was nearly 10 times greater on the control plot. Increased use of the chained plot and declines in use of the control plot after 1977 resulted in a year by treatment interaction (all species). Individually, 7 of the 16 most common species used the control plot more and one used the chained plot more ($P < 0.05$). Use indices did not differ between plots for four species and there was a year by treatment interaction for four species. Some species, including black-throated gray warbler, gray flycatcher, white-breasted nuthatch, and mountain chickadee were rarely observed in the chaining. Other species regularly foraged (mountain bluebird and mourning dove) or nested (rock wren and chipping sparrow) in the treated plot.

The use index for gray flycatcher differed between years ($P < 0.05$), and several other species were relatively abundant in some years and absent or virtually so in other years. We attributed these patterns to weather, non-breeding season factors, or off-site influences on bird populations (Fretwell 1972).

Three of six foraging or nesting guilds were adversely affected by chaining (table 2). Foliage-and-timber searchers, aerial foragers, and hole nesters used the control plot more than the chained plot ($P < 0.05$). Use of control and treatment plots did not differ for ground nesters; relative abundance of ground searchers in control and treatment plots was dependent on year. In some years, both ground searchers and ground nesters used the control plot more, whereas in other years, they used the treatment plot more. There was a year by treatment interaction for foliage nesters, although bird use was greater on the control plot all 4 years.

Before and after comparisons of the treated and control plots were made by using the ratio of 1976 control plot bird use to 1976 to-be-treated plot bird use as an expected frequency extrinsic to the post-treatment data (Sokal and Rohlf 1969). For all species combined, the 1976 pre-treatment ratio differed from that of the control-to-treatment ratios in all four post-treatment years (χ^2, $P < 0.025$), thus indicating significant declines in bird use after treatment (table 3).

Bird species diversity was greater in the untreated pinyon-juniper than in the chained plot in all post-treatment years (table 4). Evenness of species distribution (J) was similar but species richness (S) was greater on the control plot. The number of species using the chained plot increased from 8 to 16 from 1977 to 1980 but the number of species breeding on the plot was <2 in all 4 years after treatment. The pre-treatment diversity index (2.70) on the treatment plot was greater than in any post-treatment year. The number of species using the plots differed, as did the number of species breeding on the two plots (paired t-test, $P < 0.05$).

Faunal composition of the control and treated plots was quite different. Spearman's rank correlation coefficient (Sokal and Rohlf 1969) was not significant ($S = 0.379$, $P > 0.05$)

Table 3.--Observed and expected[1] bird registrations[2] on control and chained plots, Piceance Basin, 1976-1980

Year	Control		Chained		χ^2	P
	Observed	Expected	Observed	Expected		
Pre-treatment						
1976	148	-	156	-		
Post-treatment						
1977	168	93.5	24	98.5	115.8	<0.01
1978	118	85.7	58	90.3	23.8	<0.01
1979	100	84.7	74	89.3	5.4	<0.025
1980	130	94.9	65	100.1	25.2	<0.01

1 Based on the 1976 pre-treatment ratio 148:156.

2 Expressed as total number of bird registrations/plot/year (all species).

indicating rank order of faunal abundance was different in treatment and control plots. Species dominance was higher in the chained plot, with chipping sparrows accounting for 32% of all bird observations. That sparrow and the mountain bluebird accounted for 48% of the avifauna. The two dominant species in the control were black-throated gray warbler (21%) and chipping sparrow (12%).

Such drastic changes in bird use, species diversity, and composition are reflections of the altered landscape. Chaining modified the environment from one dominated by overstory conifers to one where shrubs, grasses, forbs, and dead woody material were dominant. These changes altered vegetational life form, amount of foliage, distribution of foliage across vegetational strata, height of vegetation, and canopy cover, all of which may be important to birds when selecting habitat (Pitelka 1941; MacArthur and MacArthur 1961; Balda 1969; Wiens 1969). A number of ultimate factors (those not immediately assessed by species when selecting habitat, but which may influence species' survival) were also probably affected by the alteration. These include food availability, number and quality of available nest sites, microclimate, perch site availability, and protection against predators (Sturman 1968; Bock and Lynch 1970).

In an environment where the amount of overstory foliage was markedly reduced, species dependent on foliage and live timber for nesting or foraging declined in abundance. This included foliage gleaners (black-throated gray warbler, solitary vireo, and plain titmouse), live-bark foragers (white-breasted nuthatch), and foliage nesters (gray flycatcher). Removal of snags eliminated nest sites for cavity nesters including mountain chickadee, hairy woodpecker, white-breasted nuthatch, plain titmouse, and mountain bluebird. These species are restricted to later successional stages of forest growth for either nesting, foraging, or both (Thomas 1979).

Chipping sparrow was the only species to regularly forage and nest in the chained plot. Nests of this species were found in the chained plot in 3 of 4 years following treatment, either in shrubs or partially downed timber. Since chipping sparrow usually forages on the ground (Hebrand 1978) and has a variety of nesting site preferences (Stull 1968), it was able to take advantage of the conditions created by chaining.

Dusky flycatchers are typically associated with shrubby habitats with scattered trees, or with open conifer forest (Grinnell and others 1930; Sumner and Dixon 1953). They nested in the treated plot in 1979 and foraged along the pinyon-juniper/chaining ecotone. We found this species common elsewhere in the Piceance Basin wherever there were small openings (ca. 50-100 m) in the canopy or where the density of pinyons and junipers was low.

Only one species in the ground nesting guild nested in the treated plot (rock wren). This species is characteristic of early-successional habitats (Bent 1948; Thomas 1979) and apparently the piles of slash and the openness of the treated plot were sufficient to attract this species. It was a common breeder even in many of the larger chainings (>5 km^2) in the Piceance Basin.

Several other species in the foliage and hole nesting guilds frequently foraged in the chained plot. Mountain bluebirds require cavities for nesting, but have territories which often include open spaces (Power 1966). Because they forage by scanning open ground from low perches and then drop down to seize prey, the new environment created by chaining provided

Table 4.--Diversity indices (H'), evenness (J), richness (S), and number of breeding bird species (B), Piceance Basin, 1977-1980

	Control				Chained			
Year	H'	J	S[1]	B[2]	H'	J	S	B
1977	2.59	0.86	20	10	1.69	0.81	8	0
1978	2.27	0.80	17	9	1.71	0.74	10	2
1979	2.19	0.77	17	9	1.92	0.77	12	2
1980	2.66	0.87	21	11	2.40	0.87	16	2
Means	2.43	0.83	18.8	9.8	1.93	0.80	11.5	1.8

[1] species using plots.

[2] species breeding on plots.

suitable foraging habitat. Hairy woodpeckers require cavities for nesting but they also occasionally foraged in the chained plot. This was possibly in response to the presence of insects infesting the downed timber in the chained plot (Baldwin 1968). Mourning doves were frequently observed foraging in the treated plot. Being ground foragers, they were able to take advantage of the presumed increase in the production of grass and forb seeds in the chained plot (Short and McCulloch 1977). Their large home range and high mobility also probably contributed to their use of this area. Dark-eyed juncos and house wrens used the treated plot in the third and fourth years after treatment. While both usually reproduce in more mature habitats, they often forage in early successional habitats (Thomas 1979).

Generally, species which foraged and/or nested on the ground were less affected by the chaining process than the foliage-and-timber searchers or aerial foragers. Hermit thrush, a ground forager, was not recorded on the chained plot in any of the 4 years of the study. This species is associated with mature forested habitats and forest interiors (Sedgwick in press; Thomas 1979). Those species which were both foliage or hole nesters and foliage-and-timber searchers or aerial foragers were especially uncommon on the chained plot. Franzeb and Ohmart (1978), Szaro and Balda (1979), and O'Meara and others (1981) all found that ground nesters and foragers were less affected by severe habitat alteration than birds dependent on foliage and timber for nesting and foraging.

Small Mammals

More species of small mammals were snaptrapped on the treatment plot (n = 7) than on the control plot (n = 4) after chaining (1977-79). Total captures (all species) were greater on the treatment plot than on the control plot in all 3 post-treatment years, but differences were significant only for 1978 (χ^2, $P < 0.05$, table 5). Total captures (all species, three years pooled) were significantly greater on the treated plot (189) than on the control plot (117). Deer mouse (Peromyscus maniculatus) was the dominant species on both plots and the total catch of deer mice was significantly greater on the treated plot than on the control plot (3 years pooled). Two species of chipmunks, least (Eutamias minimus), and Uinta (E. umbrinus) were more frequently trapped on the treated plot. This difference between plots was significant for E. minimus ($P < 0.05$) but not for E. umbrinus (3 years pooled). Pinyon mice (P. truei) were captured in pinyon-juniper before treatment and only on the control plot after treatment. Plains pocket mice (Perognathus flavescens), golden-mantled ground squirrels (Spermophilus lateralis), cottontails (Sylvilagus spp.) and vagrant shrews (Sorex vagrans) were each captured only twice after treatment (table 5).

Baseline pre-treatment data collected in 1976 provide an estimate of relative species abundance and when compared to post-treatment catches, illustrate the magnitude of small mammal population fluctuations. The number of captures/trap night (all species) was 11.6 times greater in 1976 than in 1977. Although small mammal captures increased in 1978 and 1979 from 1977 lows, captures/trap night were never more than 45% of those in 1976. Changes in small mammal abundance such as these are not uncommon (Pearson 1966; Krebs and others 1969; Lusby and others 1971; Larrison and Johnson 1973). Chew and Turner (1974) attribute such changes either to population density-dependent factors or to annual fluctuations in resources. Greater than average annual precipitation and lower than average summer temperatures in the Piceance Basin in 1975 may have increased food resources, thus resulting in generally greater small mammal productivity. High densities were also recorded in the summer and fall of 1976 for most small mammal species on the C-b Oil Shale Tract (C-b Shale Oil Venture 1977).

Table 5.--Number of small mammals removed by snap-trapping before treatment and on chained and control plots, Piceance Basin, 1976-1979

Species	Pre-treatment[1] 1976	Post-treatment[1] 1977 Control	1977 Chained	1978 Control	1978 Chained	1979 Control	1979 Chained	1977-1979 Total Control	1977-1979 Total Chained
Deer mouse (Peromyscus maniculatus)	253	12	17	48	94	42	49	102 *[3]	160 *
Chipmunks (Eutamias spp.)	43 [2]	1	1					1	1
Least chipmunk (Eutamias minimus)		2	4	0	2	0	2	2 *	8 *
Uinta chipmunk (Eutamias umbrinus)		8	7	1	2	0	3	9	12
Golden-mantled ground squirrel (Spermophilus lateralis)	8	0	2	0	0	0	0	0	2
Cottontails (Sylvilagus spp.)	0	0	1	0	1	0	0	0	2
Plains pocket mouse (Perognathus flavescens)	0	0	0	0	2	0	0	0	2
Vagrant shrew (Sorex vagrans)	0	0	0	0	1	0	1	0	2
Pinyon mouse (Peromyscus truei)	15	0	0	3	0	0	0	3	0
TOTALS	319	23	32	52 *	102 *	42	55	117 *	189 *

1 The study area was trapped for 3600 trap nights in 1976; after treatment the control and chained plots were each trapped 3600 trap nights.

2 Specimens captured in 1976 were not identified to species.

3 *indicates significant differences (χ^2, $P < 0.05$) between plots.

Our results indicate that deer mice respond positively to the conditions that result from chaining. O'Meara and others (1981) in Colorado and Turkowski and Reynolds (1970) in Arizona also found higher deer mouse populations on 1 to 15 year old treated plots than on untreated pinyon-juniper plots. But Baker and Frischknecht (1973) concluded that small mammal populations increased in the second year after treatment and then stabilized, showing no significant difference between treated and control plots after 4 years. Studies at a federal oil shale lease tract in the Piceance Basin 8 to 10 years after chaining found that the total number of deer mice captured over a 2-year period was significantly greater in unchained pinyon-juniper plots than in chained areas, although captures during specific capture periods were often greater in the chained area (C-b Shale Oil Venture 1977). Some of these differences in results may be due to the different times since treatment (1-10 years), the type of treatment (chaining or bulldozing) or site-specific vegetational differences. Studies on the effects of logging in other coniferous types generally agree that populations of deer mice increase following logging although not always in the first year after treatment (Tevis 1956; Gashwiler 1970; Kirkland 1977; Martell and Radvanyi 1977).

O'Meara (1978), working in pinyon-juniper in Colorado found that shrub cover was most highly correlated with the total deer mouse catch. In our study, shrub cover was nearly the same on both treated and control plots; however, percentage grass-forb cover was significantly greater on the treated plot. Thus, there was more ground-level vegetation and presumably greater seed production on the chaining. Moreover, increased ground cover may have made the chaining more attractive to arthropods. Since deer mice are highly opportunistic in food habits, consuming a wide variety of plants, arthropods and seeds (Johnson 1961; Douglas 1969) and because they use almost exclusively ground level resources (Holbrook 1978), increased grass and forb cover may explain the difference in abundance of deer mice between control and treatment plots. Geier and Best (1980) found the abundance of several small mammals, including deer mice, to be

significantly correlated with forb cover. Hooven and Black (1976) attributed increased numbers of deer mice on Douglas-fir clearcuts to increased availability of seeds and insects. The slash, logs, and other debris left as a result of chaining may also influence distribution and abundance of small mammals. Geier and Best (1980), for example, found positive correlations between small mammal numbers and the abundance of woody plant debris. Researchers working for the C-b Shale Oil Venture (1977) believed downed trees bulldozed into slash piles provided additional habitat to a variety of small mammals.

With the exception of chipmunks, captures of all other small mammals were too few to assess differences between plots. O'Meara (1978) livetrapped more chipmunks on each of 1, 8, and 15 year old chainings than on unchained pinyon-juniper, indicating a positive response to the newly created grass-shrub stage. More least chipmunks were captured on chainings than on unchained areas in the C-b Shale Oil Venture Study (1977), but more Uinta chipmunks were captured on unchained areas. There is some indication of a differential response to chaining by chipmunks in this study, where least chipmunks appear to have benefited from chaining and Uinta chipmunks exhibited no distinct preference for either area.

The capture of pinyon mice only in the control area conforms to their dependency on junipers for nesting sites (Armstrong 1972). A winter diet consisting mostly of juniper berries (Armstrong 1972) restricts pinyon mice to unchained pinyon-juniper woodland in that season also. Holbrook (1978) most often captured pinyon mice in areas with tree cover, but also captured some in open, grassy areas.

Golden-mantled ground squirrels were captured eight times before treatment and twice on the chained plot after treatment. O'Meara and others (1981) concluded that this species showed no clear preference for either chained or unchained pinyon-juniper. During the course of the C-b Shale Oil Venture Study (1977), 94 individuals of this species were captured on a chained plot and 67 were captured on an unchained plot.

From 1977-79, seven species were captured on the treated area and four on the control. Similarly, species richness was greater on chained plots (15 species) than on the unchained plots (7 species) in the C-b Shale Oil Venture Study (1977). O'Meara and others (1981), however, captured more species on an unchained pinyon-juniper plot than on any of 1, 8, or 15 year old chained pinyon-juniper plots.

Our results, whether examined alone or in conjunction with those of other studies, are inconclusive for nearly all small mammal species considered. Even data from the various studies on deer mice conflict. More research is needed regarding the effects of chaining, in particular, and habitat manipulation, in general, on small mammal populations.

SUMMARY AND CONCLUSIONS

Given the current emphasis on nongame species as a wildlife resource, the negative effects of pinyon-juniper modifications on nongame wildlife should be minimized whenever possible. Many bird species responded negatively to chaining. Since the objective of chaining is removal of the overstory layer of vegetation, little can be done to minimize impacts on such forest-dwelling species as solitary vireo, gray flycatcher, white-breasted nuthatch, and hermit thrush, for example. These species are intolerant of overstory canopy removal, being restricted to mid-to-late stages of forest succession.

Negative effects of chaining can be minimized for some species, however, by modifying the standard conversion process. Impacts on cavity nesters can be minimized by leaving selected cavity trees standing near the perimeters of chainings. Some cavity nesters of pinyon-juniper woodlands, including American kestrel, northern flicker, house wren, and mountain bluebird, will nest in isolated snags in forest openings (V. E. Scott, pers. comm.). Impacts upon species commonly associated with edges, such as mountain bluebird and chipping sparrow might be minimized if the perimeters of chainings were made irregular, thus creating more edge per unit area of chaining. By using a lighter anchor chain or a cable around the perimeter of designated chainings, more small trees would be left standing. This would create a true ecotone around the chaining perimeter (Plummer and others 1968), which would benefit edge-associated species and also enhance the visual appeal of chainings. Reducing the size of chainings (many chainings in the Piceance Basin are >5 km^2) would also reduce the impact on edge species. Haufler (1979) found that pinyon-juniper breeding bird territories extended no more than 100 m into chainings. By keeping chainings <200 m wide, some forest-associated and edge species would not be as severely impacted.

A few species appeared to benefit from chaining. Rock wrens nested in a small chaining and occurred in the larger chainings in the Piceance Basin. Brewer's sparrow and green-tailed towhee also nested in larger chainings in the Piceance Basin (O'Meara and others 1981). Selection of potential chaining sites which will support shrub growth, especially sagebrush for sage obligates (Brewer's sparrow) or near obligates (green-tailed towhee), is necessary for these species. Vesper sparrow and rufous-sided towhee were common in some chainings in the Piceance Basin and also would probably increase locally in abundance after chaining. Some species were associated with slash (rock wren) and to accomodate these species, slash piles should be left in place. House wrens and dark-eyed juncos

also benefit when slash is left (V. E. Scott, pers. comm.; Franzreb and Ohmart 1978).

Our results indicate that chaining has positive benefits for deer mice and possibly for least chipmunks. Both were associated with slash, ground cover, and in another study, with shrubs (O'Meara and others 1981). Slash is a by-product of chaining, and increases in shrub and ground cover usually occur afterward. The abundance of both deer mice and least chipmunks will probably be greater if slash piles are left in place. The tree-dwelling pinyon mouse was almost certainly negatively affected by chaining; impacts on other species were uncertain.

Overall, small mammal abundance was higher on the treated area. Combined with the openness of chainings, increases in numbers of small mammals should make these areas more desirable for certain raptors as well as mammalian carnivores. The effects on small mammal species richness appeared to be positive (7 species captured in the chaining, 4 in the unchained pinyon-juniper) which may be important relative to secondary impacts on bird and mammal predator populations.

After reviewing our results and those of others, we conclude that variability in the avifauna from site to site, combined with year-to-year changes in bird and small mammal species composition and abundance make site-specific, long-term studies desirable. O'Meara and others (1981), for example, recorded two species of birds breeding on an unchained pinyon-juniper plot which did not breed on our study area. Three species nested on our study area which did not breed on the area O'Meara and others studied. The impacts of alteration will vary from site to site because different sites may have very different species compositions. Differences in elevation, overstory tree species composition, understory development, soil depth, and slope can influence the extent of impacts. Because pinyon-juniper communities are dynamic with obvious year to year fluctuations, studies documenting impacts should be long term.

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EFFECTS OF CABLING PINYON-JUNIPER ON MULE DEER AND LAGOMORPH USE

V. W. Howard, Jr., Kathleen M. Cheap, Ross H. Hier, Thomas G. Thompson, J. Andrew Dimas

ABSTRACT: The effect of two-way cabling on seasonal use of pinyon-juniper (Pinus edulis, Juniperus monosperma, J. deppeana) woodland by mule deer (Odocoileus hemionus), desert cottontails (Sylvilagus audubonii), and blacktail jackrabbits (Lepus californicus) was determined at the Fort Stanton Experimental Ranch and adjacent areas of the Lincoln National Forest, NM. Pellet transect data, collected quarterly from September 1976 to June 1982, were used to compare mule deer and lagomorph use of areas cabled in 1954, and 1975 and adjacent undisturbed areas. Each treatment was replicated at four study sites. Mule deer use of cabled areas was higher during spring and summer than during fall and winter. No seasonal trends were evident on untreated areas. Lagomorph use of areas cabled in 1954 showed no seasonality, whereas, a seasonal use pattern that changed from year to year was observed on the areas cabled in 1975. Lagomorphs exhibited a preference for cabled over undisturbed areas in spring, summer, and fall. Use on undisturbed areas was highest in winter, intermediate in fall, and lowest in spring and summer.

INTRODUCTION

Pinyon-juniper woodlands occupy about 324,000 km^2 of the western United States (West and others 1975). Most pinyon-juniper woodlands are used for livestock grazing (Aro 1971). Fire, chemical, or mechanical methods have been widely used to stimulate understory forage production. Extensive areas in the Lincoln National Forest, NM, were cleared by two-way cabling in the 1950's. Cabling involves use of a steel cable drawn between two crawler tractors. The cable is drawn through the vegetation twice in opposite directions to knock down and uproot trees and large shrubs.

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V. W. Howard, Jr. is a Professor of Wildlife Science in the Department of Fishery and Wildlife Sciences, New Mexico State University, Las Cruces, NM; Kathleen M. Cheap is presently employed by Tamarac National Wildlife Refuge, Rochert, MN; Ross H. Hier is presently employed by Wetland Wildlife Population and Research Group, 102 23rd Street, Bemidji, MN; Thomas G. Thompson is presently with the Department of Statistics, University of Wyoming, Laramie, WY; J. Andrew Dimas is presently with USDI, Bureau of Land Management, Santa Fe, NM.

Research at the Fort Stanton Experimental Ranch, Lincoln County, NM, investigated the short- and long-term effects of two-way cabling on habitat use by mule deer, desert cottontails, and blacktail jackrabbits. Habitat use by these species was compared on areas cabled in 1975, areas cabled in 1954, and on undisturbed pinyon-juniper woodland.

STUDY AREAS

Data were collected on the Fort Stanton Experimental Ranch in the eastern foothills of the Sacramento Mountains in southern Lincoln County, NM, and on adjacent areas of the Lincoln National Forest. Area topography is highly variable, characterized by flat-topped mesas, narrow rocky canyons and ridges, rolling hills and some bottomlands (Wood and others 1970). Bottomland, mesa top, and canyon floor plant associations are dominated by grasses and forbs to the exclusion of woodland. Pinyon-juniper woodland with associated shrub, grass, and forb understories predominate on the slopes and rocky ridges (Rippel 1978).

The climate is characterized by cool, relatively dry winters and springs, and warm, relatively wet summers with cool nights. Temperatures range from a mean annual minimum of 11.1°C to a mean annual maximum of 18.6°C. Annual precipitation averages 34.5 cm (range 15.4 to 72.9 cm) and about 63 percent of annual precipitation occurs as rain during July, August, and September (Pieper and others 1971). Winter snow normally persists only on north-facing slopes and shaded areas (Dimas 1981).

Oneseed juniper (Juniperus monosperma) and pinyon (Pinus edulis) dominated the study sites and alligator juniper (J. deppeana) occurred occasionally. The most prevalent shrub was wavy-leaf oak (Quercus undulata), followed by skunkbush sumac (Rhus trilobata), Louisiana sagewort (Artemisia ludoviciana), and feather dalea (Dalea formosa). Broom snakeweed (Xanthocephalum sarothrae) was a common half-shrub. The dominant grass was blue grama (Bouteloua gracilis). Sideoats grama (B. curtipendula) and wolftail (Lycurus phleoides) also occurred on the study sites. Annual forbs were not abundant but greenthread (Thelesperma filifolium) and annual sunflower (Helianthus annus) were present (Dimas 1981). All sites were lightly to moderately (30 to 60 percent use) grazed by cattle during the study (Thompson 1981).

Selected National Forest lands adjacent to the Fort Stanton Experimental Ranch were cabled two ways in 1954. Treated areas were not seeded and the cabling slash was left in place. Four sites along the boundary of the Fort Stanton Experimental Ranch and the Lincoln National Forest were selected in 1975 to study the effects of cabling on wildlife use in pinyon-juniper woodland. Each study site was divided into three units. One unit contained a portion of the 1954 U.S. Forest Service cabling treatment. A second unit on the Fort Stanton Experimental Ranch was cabled two ways in fall 1975. A third, adjacent unit of pinyon-juniper woodland was designated as an untreated check. The three units at each study site were selected based on similar soil, topography, vegetation, and accessability. Because of cabling constraints, the units vary in shape and range in size from 2.6 to 11.1 ha, averaging 8.0 ha.

METHODS

Six randomly placed pellet transects were established in each treatment unit. Each transect consisted of five 40-m^2 circular plots 30 m apart on a straight line. Each circular plot was searched for mule deer pellet groups. Two 10-m^2 circular plots on each transect were randomly selected and searched for lagomorph pellets. The boundaries of plots were circumscribed using a 3.58-m (mule deer) or 1.79-m (lagomorph) metal chain temporarily attached to a metal stake at the center of each plot. All pellets in the plots were counted and either removed, crushed, or painted to prevent recounting. Mule deer pellet groups were counted only if they contained at least 15 pellets and more than half the pellets in each defecation were within the 40-m^2 sampling area. Each individual lagomorph pellet in the 20-m^2 sampling area was recorded. Cottontail and jackrabbit pellets were recorded but not separated by species.

Both mule deer and lagomorph pellet transects were examined quarterly between September 1975 and June 1982. Transects were examined during September, December, March, and June. Each count represented the accumulation of pellets or pellet groups during the preceding season, except during the winters of 1976/77 and 1978/79, when early snowfall prevented pellet counts in December. March readings for these years represented a combined fall/winter count.

Pellet transect data were converted to mean pellets (lagomorph) or pellet groups (mule deer) deposited/ha/day for each time period. The six transect means were totaled for each treatment site and this mean total was the basis for all statistical comparisons. A split-block analysis of data over time and space (Steel and Torrie 1980) showed a significant treatment x season interaction. A two-way analysis of variance was used to investigate these interactions (Sokal and Rolf 1969). Linear comparison (Steel and Torrie 1980) was used to identify subsets where significant differences were found among factors.

Interaction between treatments and seasons was analyzed. For each cabling treatment and check, daily pellet or pellet group deposition/ha was compared for the seasonal counts collected during the four years starting in the spring of 1977, 1979, 1980, and 1981. Comparisons also were made between the combined seasons of spring/summer and fall/winter for the five years starting in spring 1977 through winter 1981/82. Also, treatment means for 1975-cabled, 1954-cabled, and non-cabled areas were compared within each season. Data from six years were available for comparisons of daily means for spring (1977-1982) and summer (1976-1981). The number of separate fall and winter counts was reduced due to snow and only four years were available for comparisons of fall and winter daily means.

RESULTS AND DISCUSSION

Mule Deer

Mule deer defecation rates were similar over all seasons within treatments (table 1). However, when mean daily estimates for the combined seasons of spring/summer and fall/winter were compared (table 2), a higher mean ($P \leq 0.05$) pellet group/ha/day was found during the spring/summer on the 1975-cabled and 1954-cabled treatments.

Table 1.--Comparisons of pellet groups or pellets/ha/day for mule deer and lagomorphs: individual cabling treatments x seasons (from March 1977 through February 1978 and March 1979 through February 1982, four years)

	Mule deer					Lagomorphs				
	Season					Season				
Treatments	Spr	Sum	Fall	Win	n	Spr	Sum	Fall	Win	n
Cabled 1975[1]	0.519	0.563	0.319	0.232	64	753.08	712.33	898.69	916.21	64
Cabled 1954	0.336	0.440	0.1881	0.222	64	894.71	821.97	1051.20	927.50	64
None	0.205	0.361	0.277	0.141	64	[2]537.11a	1491.92a	668.96ab	839.21b	64

[1]Significant interaction between seasons and years for lagomorphs -- see table 4 for analysis.

[2]Means in the same row with different lowercase letters are significantly different ($P \leq 0.10$).

Table 2.--Comparisons of pellet groups or pellets/ha/day means for mule deer and lagomorphs: individual cabling treatments x season (combined) (from March 1977 through February 1982, five years)

Treatments	Mule deer			Lagomorphs		
	Combined seasons			Combined seasons		
	Spr/Sum	Fall/Win	n	Spr/Sum	Fall/Win	n
Cabled 1975	[1]0.478a	0.246b	40	628.86	793.82	40
Cabled 1954	0.381a	0.203b	40	849.15	863.95	40
None	0.282	0.208	40	523.97	661.63	40

[1]Means in the same row with different lowercase letters are significantly different ($P \leq 0.10$).

Table 3.--Comparisons of pellets/ha/day means for lagomorphs in 1975-cabled treatments: individual year x season (from March 1977 through February 1978 and March 1979 through February 1982, four years)

Year	Season				n
	Spr	Sum	Fall	Win	
1977/78	1190.68	656.21	864.42	780.08	16
1979/80	[1]370.30a	1069.09b	976.11b	814.92b	16
1980/81	551.25a	286.09b	513.54a	570.74a	16
1981/82	900.07a	837.95a	1240.67b	1499.11b	16

[1]Means in the same row with different lowercase letters are significantly different ($P \leq 0.10$).

No difference was found during summer, fall, or winter when comparing cabled and non-cabled treatments during any particular season (table 3). Mule deer defecation rates were greater during spring ($P \leq 0.05$) on the areas cabled in 1975 than on untreated areas, while those on the areas cabled in 1954 were intermediate.

The pinyon-juniper woodland provides many habitat requirements for mule deer. Southern mule deer diets consist mainly of browse, some forbs and a small amount of grasses (Anderson and others 1965; Boeker and others 1972; Short and others 1977). The relative proportion of these plant classes in the diet changes seasonally; the browse proportion usually increases during fall and winter and the forb proportion usually increases in spring and summer. Removal of large trees and shrubs by mechanical methods such as cabling may result in increases in the quantity and/or quality of certain types of mule deer forage (Swank 1956; Cole 1968; Minnich 1969; Terrel 1973; McCullock 1974; Tueller and Monroe 1975; Short and others 1977; Rippel 1978).

Increased use of the cabled areas by mule deer in the spring/summer compared to other seasons may be related to an increase in forage quantity and/or quality, particularly cool season forbs and grasses, in these converted areas. While summer, fall, and winter mule deer habitat use was independent of cabled condition, spring use was dependent. This seasonal attractiveness appears to be related to the age of the conversion. The areas cabled in 1975 received more spring use than those cabled in 1954 which received more use than untreated areas. Seasonally attractive factors may decrease as converted areas pass through several stages to approach woodland climax conditions. Rippel (1978) reported that areas cabled in 1954 generally had smaller trees than control areas but total tree density did not differ between these areas.

Cabling reduced the amount of hiding/escape cover available for a species as large as mule deer because trees and large shrubs were uprooted (Rippel 1978). Several researchers studying mule deer use of large pinyon-juniper conversions have reported a decreasing use of the conversion by mule deer as the distance from the edge of the conversion increases (Minnich 1969; McCulloch 1974; Terrel and Spillet 1975; Short and others 1977). The irregular shape and small size of the areas cabled in 1975, combined with the low tree kill (53 percent) (Rippel 1978) and nonremoval of debris appeared to provide sufficient security for mule deer to use these areas fully.

Protection from adverse weather is a known critical factor in wildlife habitat use in temperate zones. During extreme winter weather, minimization of body heat loss may become more important than caloric intake (Terrel and Spillet 1975). Grasslands and other open areas may be avoided although they contain more forage than

wooded or protected areas (Leckenby 1978). Significant microclimatic differences exist between natural and converted pinyon-juniper. Natural woodland temperatures tend to be more stable, net radiation is higher, and wind and snow conditions are less severe than those of converted sites (Gifford 1973). At Fort Stanton, pronounced changes in vegetation and microclimate on cabled areas could result in increased use of these areas during the milder and more productive spring and early summer months.

Lagomorphs

Lagomorph seasonal use patterns varied among the three cabling treatments (table 1). No differences in use were found among seasons on areas cabled in 1954. Plots on control areas had a higher number of pellets deposited during the winter than during the spring ($P \leq 0.10$) or summer ($P \leq 0.01$). No significant difference in lagomorph pellet numbers was found among other seasons on control areas. Numbers of lagomorph pellets on the areas cabled in 1975 showed a significant interaction ($P \leq 0.001$) between years and seasons. Two-way analysis of variance without replication (Sokal and Rolf 1969) of data collected from areas cabled in 1975 (table 3) indicated no difference in lagomorph use among seasons during 1977/78. Daily defecation rates were lower during spring 1979/80 ($P \leq 0.05$) than those for the other three seasons. "Summer means" from 1980 and 81 were significantly lower ($P \leq 0.01$) than those during the other three seasons. "Winter and fall means" were similar and higher in 1981/82 ($P \leq 0.10$) than spring and summer means. No differences were found between combined fall/winter and spring/summer "daily means" for any of the areas (table 2).

Lagomorphs exhibited higher selectivity among the treatments than did mule deer (table 4). The cabled treatments received more use than the noncabled treatments, except during winter months. Desert cottontails and blacktail jackrabbits are opportunistic herbivores, which feed on a variety of grasses, forbs, and shrubs, and exhibit many seasonal diet changes (Fitch 1947; Hayden 1966; Turkowski 1975; Hansen and Gold 1977; Johnson 1979). In semiarid regions like Fort Stanton, forage selection is influenced by the need to maintain water balance (Hayden 1966). Succulent grasses and forbs are eaten when available, while woody or dry forage is eaten when green forage is unavailable. Considering the great variety of forage species and forms used by these species throughout the year, plant species, per se, are apparently not as important in forage selection as condition of the plant, especially growth stage and moisture content (Turkowski 1975). Cabled areas may produce a greater amount of preferred forage or forage may remain green for a longer period than control areas (Rippel 1978).

The availability of hiding or thermal cover is a major factor influencing habitat use by desert cottontails in pinyon-juniper woodlands (Kundaeli and Reynolds 1972). On Fort Stanton's cabled areas, uprooted trees and debris provided increased hiding and nesting cover over that available on control areas.

At Fort Stanton, similar use of cabled and noncabled treatments by lagomorphs in winter may be caused by two factors. First, lagomorphs may remain more active in the milder microclimate of the natural pinyon-juniper woodland. Second, individuals unable to compete successfully for thermal cover sites in cabled areas may move out of these open areas to minimize energy losses (Linduska 1947). These differential activity patterns and population shifts could cause higher winter pellet counts on control areas than on cabled areas.

Although pellet counts from areas cabled in 1954 showed no seasonal change in daily lagomorph use, the areas cabled in 1975 had seasonal significant changes in use among years. These recently cabled areas represented earlier successional

Table 4.--Comparison of pellet groups or pellets/ha/day means for mule deer and lagomorphs: individual season x cabling treatment (Spring 1977-82, six years; Summer 1976-81, six years; Fall 1977 and 1979-81, four years; Winter 1977 and 1979-81, four years)

	Mule deer				Lagomorphs			
	Cabling treatment				Cabling treatment			
Season	Cabled 1975	Cabled 1954	None	n	Cabled 1975	Cabled 1954	None	n
Spring	[1]0.511a	0.356ab	0.247b	72	824.22c	934.96c	550.90d	72
Summer	0.563	0.398	0.388	72	902.52	1016.63a	604.00b	72
Fall	0.319	0.188	0.277	48	898.67a	1051.20a	668.96b	48
Winter	0.232	0.222	0.141	48	916.21	927.50	839.21	48

[1]Means in the same row with different lowercase letters are significantly different ($P \leq 0.10$).

community stages than either the areas cabled in 1954 or control areas. Such developmental stages usually have poor stability compared with mature stages of succession (Odum 1969). The yearly shift in the seasonal use pattern may be a reaction to the relatively poor stability for these areas to yearly variation in rainfall, temperature, grazing pressure, and other environmental conditions. As succession progresses and stability increases, a consistent seasonal use pattern may emerge.

Cost of two-way cabling was $45 per acre in 1975. This price is excessive for areas of pinyon-juniper which do not have the potential for increasing overall mule deer numbers. Unless a substantial increase of preferred forages could be expected, cabling would be ineffective in areas where winter range is not limited.

SUMMARY

Mule deer use of cabled and untreated pinyon-juniper habitat was similar, except during spring. In spring, use of the areas cabled in 1975 was more than twice that of untreated areas. The areas cabled in 1954 received intermediate use. Higher use of the cabled areas occurred during the combined seasons of spring/summer than fall/winter. No seasonal pattern in mule deer use was observed on untreated areas. Increased seasonal use of cabled areas could be the result of increased spring forage on these disturbed sites. Microclimatic differences between cabled and noncabled woodland may affect mule deer use during critical winter period.

Desert cottontails and blacktail jackrabbits exhibited a preference for cabled areas over adjacent untreated areas during spring, summer, and fall. There was no difference between lagomorph use of the cabled and noncabled areas in the winter. The 1975-cabled areas exhibited a year-to-year change in seasonal use patterns while the 1954-cabled areas showed no seasonality in habitat use. On untreated areas, winter use was higher than spring or summer use, but not different from fall use. No difference was found between fall, spring, and summer use on noncabled areas. Lagomorph preference for cabled areas may be related to increased forage production, forage quality, and increased availability of cover in debris and slash piles.

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THIRTY YEARS OF PINYON-JUNIPER BIG GAME HABITAT IMPROVEMENT PROJECTS: WHAT HAVE WE LEARNED?

Richard Stevens

ABSTRACT: A majority of the fall, winter, and spring big game and livestock ranges in the Great Basin are located in the pinyon-juniper type. During the past three to four decades many of these rangelands have been treated mechanically and seeded. Techniques, procedures, equipment, and plant materials have changed, improved, and increased over the years. Modern methods and materials, when applied, can result in improved wildlife value compared to the values that have been derived from older pinyon-juniper improvement projects. With time, major vegetational changes have occurred in all pinyon-juniper improvement project areas. Vegetational changes within combined seeded and native communities have been influenced by community makeup, use, management practices, and the adaptability of the seeded species to site characteristics. Cattle can be used as a tool for improving wildlife values on pinyon-juniper improvement project areas. Juniper and pinyon trees on chained and seeded areas are more a result of poor kill during chaining than they are of reinvasion.

INTRODUCTION

Within the Great Basin, a major proportion of the fall, winter, spring, and, in some locations year-round, big game and livestock ranges are located in the pinyon-juniper type. During the past three to four decades improvement work, primarily anchor chaining and seeding, has been done on many of these rangelands. (Plummer and others 1968; Vallentine 1980; Jordan 1981).

Efforts to convert pinyon-juniper woodlands to more productive big game ranges by improving production of grasses, forbs, and shrubs started in the 1950's (Plummer 1958). The goal of most pinyon-juniper range improvement projects has been to eliminate competitive trees and to seed or otherwise establish more desirable species.

Wildlife value assessments and evaluations of pinyon-juniper conversion efforts have generally been made on areas that were seeded with one or few species or with species that were not adapted to the site. Species seeded and location, size, and shape of many conversion projects have not always produced the most desirable benefits for big game. Techniques and procedures used on many sites would not or should not be used today. Unfortunately, many outdated approaches to big game pinyon-juniper conversion efforts continue to be used, and many adverse opinions and attitudes regarding pinyon-juniper conversion are based on results from less successful projects.

Although many big game range pinyon-juniper conversion efforts over the past 30 years have not fully fullfilled expectations, today's projects can be successful if the information, plant materials, and equipment available are fully utilized. Long- and short-term studies, observations, and experiences have all contributed to the knowledge that is available today.

VEGETATIVE CHANGES WITHIN PROJECT AREAS

To have a better understanding of vegetative responses following chaining and seeding, permanent vegetative belt transects were established in 1963 and 1964 on recently chained and seeded pinyon-juniper (*Pinus edulis-Juniperus osteosperma*) ranges in central Utah. At five locations, four-way exclosures were constructed. The exclosures are 300 by 300 feet square, and consist of four 150- by 150-foot sections (fig. 1). One section is open only to mule deer (*Odocoileus virginianus*), a second to blacktail jack rabbits (*Lepus californicus*), a third to both deer and rabbits, and a fourth is closed to these animals and cattle. An outside area of comparable size is open to deer, rabbits, and cattle.

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Richard Stevens is Project Leader and Wildlife Biologist, Utah Division of Wildlife Resources, Ephraim, UT.

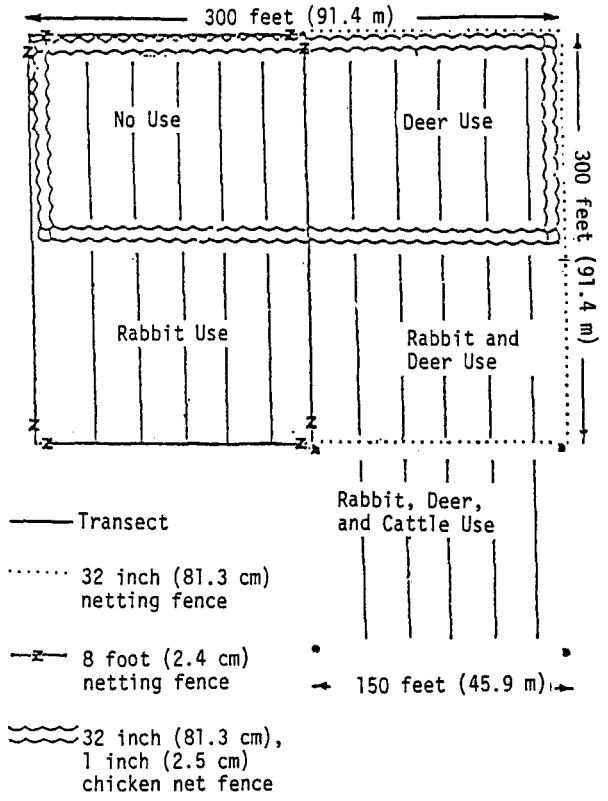


Figure 1.--Four-way exclosures and comparable outside areas.

Within each of the five sections or grazing treatment areas, five permanent 100- by 1-foot belt transects were randomly established to measure herbaceous plant numbers, production, and ground cover. Overlying these transects, 100- by 4.356-foot transects were established to measure shrub and tree numbers, size, production, and cover. Measurements have been made in each exclosure at 1- to 4-year intervals for the past 22 to 23 years. At the Fountain Green exclosure all shrubs and trees (total population) were mapped according to their location, width, height, and age class in all five grazing treatments in 1964 (second season following chaining and seeding), 1973, and 1984.

Information from the five exclosures regarding changes in percent cover of trees, shrubs, grasses, and forbs (Stevens and others 1977), population dynamics of pinyon, juniper (Stevens and others 1975), basin big sagebrush (Artemisia tridentata tridentata), black sagebrush (A. nova), and white rubber rabbitbrush (Chrysothamnus nauseosus albicaulis) (Stevens 1986), and forage production (Plummer and others 1970a) have been published.

Table 1.--Percent cover associated with Manti four-way exclosure under grazing treatments--1964, 1972, and 1982

	No use			Rabbit use			Deer use			Rabbit and deer use			Rabbit, deer and cattle use		
Year	1964	1972	1982	1964	1972	1982	1964	1972	1982	1964	1972	1982	1964	1972	1982
Perennial Grasses	41.8	35.4	34.3	32.6	33.0	39.8	40.8	43.3	42.1	32.5	35.6	39.1	34.3	30.5	43.0
Cheatgrass brome	11.9	T[1]	T	9.4	1.0	.3	4.5	T	T	15.0	.7	.5	5.5	T	T
Alfalfa	3.7	7.2	7.3	8.2	9.1	4.0	6.9	5.9	12.3	2.5	6.0	1.0	6.2	3.7	6.2
Forbs (Less Alfalfa)	.5	T	T	1.3	.6	.2	.6	T	.6	1.0	.7	.5	.2	T	.8
Shrubs	1.9	3.7	6.0	.5	.7	1.9	1.6	.2	1.8	.5	1.0	1.0	.1	.2	T
Trees	3.9	5.4	5.6	6.6	4.4	5.0	1.1	1.6	1.8	.5	1.8	3.2	5.3	.9	.6
Litter	26.5	31.4	30.1	28.6	35.0	36.8	26.1	26.9	23.4	35.0	33.2	45.0	27.6	39.9	37.5
Bare ground	7.8	12.1	15.3	12.1	13.3	9.1	14.5	15.2	15.1	11.5	16.1	7.5	18.2	19.5	14.1
Rock	2.0	4.3	2.0	.7	2.9	2.9	3.5	6.9	2.9	1.5	4.9	2.2	6.0	5.3	4.0

[1]T=less than 0.1 percent.

Response Of Grass and Forbs

Percent cover has been a fair indicator of community makeup within each treatment area associated with each exclosure. Manti exclosure is representive of all exclosures (table 1). Fairway wheatgrass (Agropyron cristatum) has proven to be the most dominating species. Native perennial grasses (Indian ricegrass [Oryzopsis hymenoides], bluebunch wheatgrass [A. spicatum], and bottlebrush squirreltail [Sitanion hystrix) increased in numbers and cover for 3 to 5 years following tree removal, and then decreased as fairway wheatgrass began to dominate. Numbers of fairway wheatgrass plants and cover increased under all treatments. Least increase occurred with no grazing and with moderate use (deer and rabbits). The largest increases occurred under the heaviest use (rabbits, deer, and cattle combined). Increase in numbers with heavier use appears to be more a result of individual plants breaking up than of actual reproduction. Similar break up has been observed with Indian ricegrass and Russian wildrye (Elymus junceus).

Numbers of plants of the major rhizomatous grasses (intermediate wheatgrass [A. intermedium], 'Luna' pubescent wheatgrass [A. trichophorum], and 'Southern' or 'Lincoln' smooth brome [Bromus inermis]) have been variable, being very responsive to use and precipitation, decreasing as use increases, and increasing as precipitation increases. Cheatgrass brome (B. tectorum) was in all communities following chaining. This annual has remained in all communities, regardless of grazing treatment; however, numbers of plants are highest with rabbit, deer, and cattle use.

Alfalfa (Medicago sativa 'Ladak' and 'Nomad') over the years (1962-82) has done fairly well on all sites (fig. 2). Performance has been superior on sites with better soils and higher annual precipitation. For all grazing treatments between 1962 and 1982, numbers of alfalfa plants slowly declined, more with increasing degrees of use. Percent cover and forage production fluctuated with precipitation and were affected by degree of use, decreasing as use increased. However, total alfalfa production and cover increased over the years; even with a decrease in numbers, individual alfalfa plants increased in size (fig. 2). Following chaining, annual forbs were fairly abundant (6,000 to 8,000 per acre) (table 1). As the

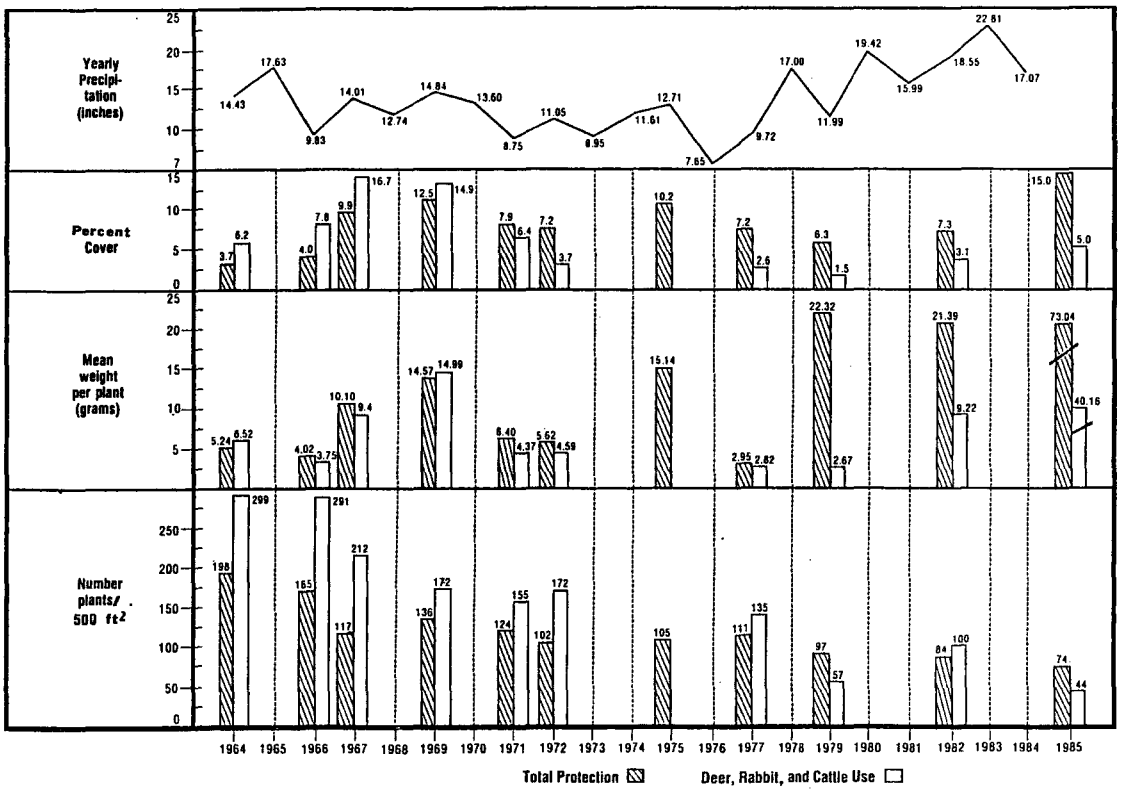


Figure 2.--Number of plants, mean weight per plant, and percent cover for alfalfa under no use (total protection) and combined rabbit, deer, and cattle use between 1964 and 1985, Manti exclosure. Annual precipitation at Manti exclosure from 1964 to 1985.

seeded perennials established, the annuals were essentially eliminated (100 to 200 per acre) from all communities, except where the heaviest grazing (rabbits, deer, and cattle) occurred.

Shrub Response

Slow-growing shrubs (antelope bitterbrush [Purshia tridentata], Saskatoon serviceberry [Amelanchier alnifolia], mountain mahoganies [Cercocarpus ledifolius and C. montanus], cliffrose [Cowania mexicana], green ephedra [Ephedra viridis]) associated with all five exclosures have not done well (decrease in numbers, little growth) when grazed and growing in competition with perennial grasses. Faster growing shrubs (rubber rabbitbrush, big and black sagebrush, fourwing saltbush [Atriplex canescens]) have, however, been able to establish, grow, and even reproduce, even while receiving considerable grazing pressure and when growing in competition with healthy perennial grasses. Total percent cover by shrubs increased substantially with no use, less with moderate use (deer and rabbits), and changed little (no increase in size) with deer, rabbit, and cattle use combined.

In an effort to increase shrub numbers and production on the Fountain Green Wildlife Management Area, cattle were permitted to graze the site in early spring (May-June) during 13 of 22 years. All shrubs associated with the Fountain Green exclosure were located and mapped in 1964, 1973, and 1984. Black sagebrush numbers were similar in all five treatments. One black sagebrush plant was located in 1964, 2,754 in 1973, and 3,306 in 1984. There were only 10 white rubber rabbitbrush plants in all five grazing treatment areas in 1964. A dramatic increase to 622 plants occurred between 1964 and 1973, followed by a nearly 40 percent decrease in total numbers between 1973 and 1984 to 371 shrubs. There was at least a 65 percent reduction in the total number of rabbitbrush plants in four of the grazing treatments (total protection, rabbit, deer, and combined rabbit and deer) between 1973 and 1984. However, with combined deer, rabbit, and cattle use rabbitbrush numbers increased from 47 to 239 during the same period.

At Fountain Green, total numbers of basin big sagebrush plants appear to have been affected by grazing treatments (table 2).

Increased shrub numbers did not appear to adversely affect grass and forb forage production where no grazing occurred, or where rabbit use, deer use, and rabbit and deer use combined took place. Grass and forb forage production was

Table 2.--Total number of basin big sagebrush plants in 1964, 1973, and 1984, associated with five treatments of the Fountain Green exclosure

Treatment	1964	1973	1984
Total protection	8	426	333
Rabbit use	15	558	401
Deer use	7	358	173
Rabbit and deer use	3	453	274
Cattle, rabbit, and deer use	19	223	456

substantially lower when cattle, deer, and rabbit use were combined. With this treatment, big sagebrush and rubber rabbitbrush numbers showed the greater sustained increase. This was the only grazing treatment (fig. 3) that (1) had a substantial increase in bare ground; (2) had the least amount of introduced perennial grasses; (3) had the lowest density of seeeded perennial forbs; and (4) had the greatest amount of soil disturbance from grazing animals.

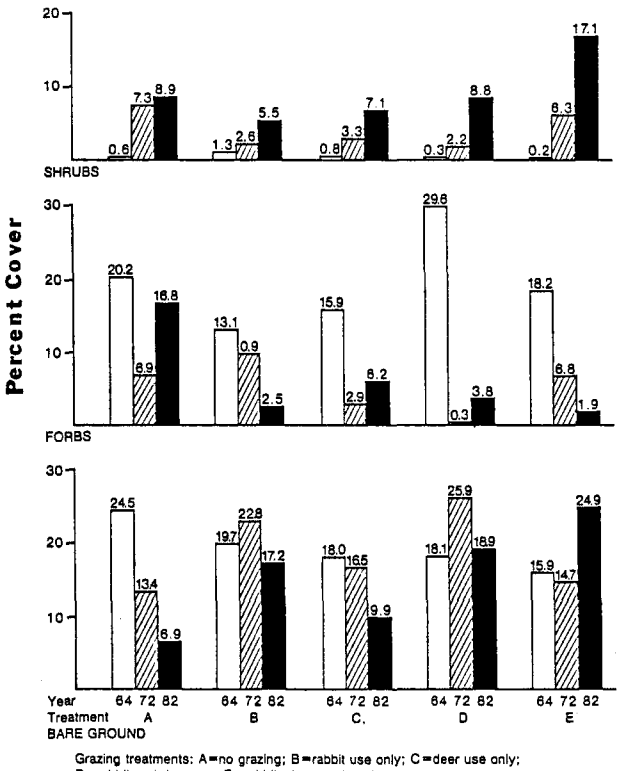


Figure 3.--Percent bare ground and percent cover of forbs and shrubs in 1964, 1972, and 1982, Fountain Green exclosures, five grazing treatments.

Tree Responses

An idea that has been prevalent but not necessarily true is that most live trees that are present on chained and seeded pinyon-juniper sites are a result of reinvasion (reproduction).

Studies and observations on pinyon-juniper sites (over 250,000 acres) chained and seeded by Utah Division of Wildlife Resources personnel show that there is growth of trees that were not killed at chaining time. Reproduction does occur, but generally it has not kept up with death rate. Areas with singleleaf pinyon (P. monophylla) have experienced more reinvasion than those with pinyon. No major reinvasion has been identified with Utah juniper. Exclosure study data (table 3) demonstrate that a considerable number of trees can live through chaining; however, a good number will die within the first few years, especially those that are partially uprooted.

Seedlings of both pinyon and juniper did appear on our study sites (table 3). Reproduction of pinyon did not keep up with natural attrition. Similar results occurred with junipers on all but the most ideal site (South Hollow--fertile, deep soil, 18 inches precipitation) where total numbers of Utah junipers increased by 12 percent (60 to 68 per acre) in 20 years. Within all five exclosures, the widest trees and those with the most dense foliage occur within the nonuse area. Tree width and foliage density decreased as use increased.

BASIC REQUIREMENTS FOR PRODUCTIVE BIG GAME RANGES

What have we learned in the past 30 years with regard to improving big game pinyon-juniper ranges? Probably the most significant publication that summarizes research and experience is by Plummer and others (1968). They outlined 10 principles that should be followed in any range restoration effort. It has been

Table 3.--Population dynamics of pinyon and Utah juniper trees associated with permanent transects in South Hollow and Manti four-way exclosures on two chained and seeded pinyon-juniper sites in central Utah

Areas and tree species	Number of live trees following chaining (1963)		Number of trees alive in 1982 that were alive in 1963, following chaining		Number of trees recruited (reproduction) between 1963 and 1982 [1]	Number of trees alive in 1982 that were recruitment trees		Total number trees alive in 1982		
	No.	Per Acre	No.	Percent Change		No.	Percent Change	No.	Per acre	Percent Change
South Hollow[2]										
Pinyon	16	64	4	-75	10	7	-30	11	44	-31
Utah juniper	15	60	8	-47	12	9	-25	17	68	+12
Subtotal	31	124	12	-69	22	16	-27	28	112	-9
Manti[3]										
Pinyon	22	88	12	-45	11	5	-54	17	68	-33
Utah juniper	55	220	28	-49	42	18	-57	46	184	-16
Subtotal	77	308	40	-48	53	23	-56	63	252	-18
Total	108	216	52	-52	75	49	-37	91	182	-16

[1]Actual number of recruitment trees may be more. Reproduction and death may have occurred between counts. Trees counted: Manti: 1963, 1966, 1967, 1969, 1971, 1972, 1977, 1982; South Hollow: 1963, 1967, 1972, 1977, 1982.

[2]Chained and seeded 1962, trees first counted 1963. Channery silt loam. Annual precipitation 18.1 inches.

[3]Chained and seeded 1962, trees first counted 1963. Cobbly loam. Annual precipitation 13.8 inches.

demonstrated forcefully and conclusively on hundreds of thousands of pinyon-juniper acres that where all 10 principles are followed, successful wildlife restoration projects have occurred. The 10 principles have been called the "Ten Commandments of Range Restoration." The additional knowledge and experience gained since 1968 is complementary to these principles. These principles and information pertinent to big game ranges are:

1. Are proposed changes in the pinyon-juniper community necessary and desirable?

The goal of most range improvement projects is to alter or change a plant community with undesirable characteristics to one with desirable characteristics. The range site must have the potential to support the proposed changes ecologically and economically (Koehler 1975; Wagstaff 1983). A manager must determine if a change in the makeup of a community is necessary or desirable. The area with the most potential for improvement may not be the area that should receive the improvement efforts. Generally, efforts are directed to areas with high potential, like bottoms that have deep soil. Areas of highest winter big game use are generally west-and south-facing slopes. Therefore, improvement efforts should be directed to areas of greatest use, rather than areas of greatest improvement potential.

Many so-called wildlife pinyon-juniper improvement projects have resulted in less productive wildlife ranges. What may be beneficial to one class of grazing animals may not necessarily be beneficial to another (Short and McCulloch 1977; Urness 1979; Reynolds 1980). Care must be taken when the decisions are made relative to (a) whether to treat or not to treat (does the proposed area need additional and improved wildlife values?); (b) how much to treat to provide maximum bennefits for the target species; (c) when to treat; (d) what techniques and procedures are to be used to obtain desired results; and (e) which species to seed so that desired benefits can be achieved.

2. Terrain and soil type must be suitable for making the desired changes.

The potenial productivity of a site must be considered when planning a restoration project. For most range sites in the Intermountain area, the Soil Conservation Service's class 3 soil survey has sufficient information to determine the potenial productivity of a site. Potential herbage production varies with soil type (Jameson and Dodd 1969). For pinyon-juniper and sagebrush-grass sites in Utah, Stevens and others (1974) determined the site characteristics that significantly affect a site's potential productivity. Sites with low potential are generally those with low precipitation, low water holding capacity, and very coarse, rocky, shallow, alkaline, or saline soils.

The stature and growth form of species on an area can give a manager a good idea of the site's general productivity potential (Koehler 1975). Areas having a predominance of dwarf pinyon or juniper trees generally have shallow soils and low productivity potential. Likewise, the growth, form, and stature of dwarf basin big sagebrush, black sagebrush, fourwing saltbush, and other species may also indicate low site potential. The occurrence or absence of some species can give indications of the soil pH. The presence of chenopods indicates that the soil pH is basic. The species or subspecies of sagebrush that occur within pinyon-juniper stands can be used as indicators of a site's potential productivity. Descending order of potential productivity of site, indicated by the presence of various sagebrushes, is: mountain big (A. tridentata vaseyana), basin big, Wyoming big (A. tridentata wyomingensis), and black. (McArthur 1983a, 1983b; Winward 1983).

In most cases, terrain will determine how much of an area will be treated and what technique and equipment will be required. Terrain can be used to create leave strips, corridors or islands of trees, maximize border effect, and limit opening size, features essential to productive wildlife and esthetically pleasing improvment projects (Williamson and Currier 1971). Where improvement projects are done may be more important than size of openings, number and size of leave strips, corridors, islands, and amount of border effect.

Improvement projects should be done where the animals are, or where they are to be transplanted. In winter, deer and elk use is generally less on north and east slopes and in bottoms, especially those with roads running through them. Maximum improvement efforts should be made where maximum use occurs.

3. Precipitation must be adequate to assure establishment and survival of planted species.

Average annual precipitation and its distribution are perhaps the most important site factors to consider in planning a pinyon-juniper restoration project (Stevens and others 1974; Koehler 1975). Average annual precipitation and

its distribution coupled with the occurrence of indicator plants can be important guides in determining what species can be established successfully. Adequate moisture during germination and establishment is the most critical precipitation criterion to be considered (Jordan 1983).

4. Competition must be low enough to assure planted species can establish and persist.

For a seedling to establish, it must have the opportunity. Reliable methods and equipment have been developed (Koehler 1975; Larson 1980; Davis 1983) that can reduce undesirable competition, which could be pinyon-juniper trees or other species within a pinyon-juniper stand. Some equipment and technique options are: cabling, discing, undercutting, plowing, selective herbicide use, fire, and combinations of these. Twice-over anchor chaining is the most common method. Type of chain and how the anchor chain is dragged between two crawler tractors can enhance or reduce wildlife values. Lightweight chains and cables are good choices when it is desirable to leave some trees and shrubs. Dixie and Ely chains are effective in removing both shrubs and trees. Chains dragged taut or in half circle patterns between two tractors will result in lower tree kill. High-percentage tree kill is achieved when sites are chained or dragged in loose, J-shaped patterns.

There are a number of advantages to leaving downed trees in place rather than piling or burning. Some advantages are (a) improves infiltration, (b) increases ground cover, (c) provides escape and thermal cover for wildlife and livestock, (d) encourages big game use, (e) decreases livestock trailing, (f) improves seedling establishment, (g) improves esthetics, and (h) eliminates costs of piling and burning.

Where pinyon-juniper stands are not dense, wildlife values can be improved by seeding desirable species among the trees. Sites can be prepared with single-tractor anchor chains, disk chains, disk plows, and pipe harrows.

The methods used do not have to completely eliminate the undesirable plants, but should reduce their density enough to minimize direct competition for moisture and space, especially during germination and establishment.

5. Plant only species, subspecies, varieties, strains, and selections that are adapted to the site and needs of the area.

The foundation of a successful pinyon-juniper restoration project has proven to be selecting plants adapted to the site being treated (Rehfeldt and Hoff 1977; Stevens 1981). There is no substitute (manipulation or management) for proper species selection. One of the prime factors contributing to pinyon-juniper restoration project failures is seeding unadapted species. Selected plants must be able not only to establish, but to also maintain themselves over time. Proper species selection does not necessarily mean seed sources have to be at or near the proposed seeding site (Stevens 1983a).

When selecting species to seed that are adaptable to a site, individual site characteristics and requirements have to be considered first. Next in importance is seed availability, and last are project objectives. However, if seed is unavailable, or species adapted to the site will not accomplish project objectives, project objectives may have to be altered. Characteristics of individual species that may need to be considered when selecting those to be seeded are: seedling vigor, ease of establishment, cold hardiness, moisture requirements, aggressiveness, longevity, drought and heat tolerance, soil texture adaptation, and tolerance to soil salinity.

Additional characteristics that need to be considered are: grazing tolerance, season of year when forage is available and usable, palatability, nutritive value, forage yield, adaptation to being seeded in mixtures, seed production, rate and amount of recovery following grazing, and growth form. The project objectives or needs of the area should be considered when selecting species to establish. If the need is winter forage that extends above the snow, upright, taller growth forms of rapid-developing (basin big sagebrush, mountain big sagebrush, Wyoming big sagebrush, white rubber rabbitbrush, basin wildrye [E. cinereus]) and slower growing (bitterbrush, cliffrose, mountain mahoganies, serviceberry, green and Nevada ephedra [E. nevadensis]) plants should be considered. When the need is spring and early summer succulents, one should look at semi-evergreen species like Lewis flax (L. perenne lewisii), Palmer penstemon (Penstemon palmeri), small burnet (Sanguisorba minor), and forage kochia (Kochia prostrata), and early developing species like Pacific aster (Aster chilensis adscendens), balsamroot (Balsamorhiza, spp.), showy and Nevada goldeneye (Viguiera multifora var. multifora and var. nevadensis), yellow sweetclover (Melilotus officinalis),

lomatium (Lomatium spp.), alfalfa, globemallow (Sphaeralcea spp.), bottlebrush squirreltail, 'Paiute' orchardgrass (Dactylis glomerata), Indian ricegrass, Russian wildrye, and hard sheep fescue (Festuca ovina duriuscula).

Rhizomatous and aggressive species (intermediate wheatgrass, 'Luna' pubescent wheatgrass, 'Southern' or 'Lincoln' smooth brome, 'Ephraim' crested wheatgrass [A. cristatum], Pacific aster, forage kochia) should be candidates on areas with erosion problems.

When pinyon-juniper improvement started in the 1950's, seed of less than five adapted species were available. Continual research and development has demonstrated that there are many species adapted to the pinyon-juniper types (Jordan 1981; Wasser 1982; Rumbaugh 1982, 1983, 1984; Asay 1983; Ferguson 1983; Koniak 1983; McArthur 1983b; Shaw and Monsen 1983; Stevens 1983a, 1983b; Stutz 1983; Asay and Knowles 1985; Rumbaugh and Townsend 1985; Stevens and others 1985). Today, seed of over 50 species adapted to the pinyon-juniper type is available.

6. Multispecies seed mixtures should be used.

Planting mixtures of various adapted grasses, forbs, and shrubs is recommended. There are many reasons to use mixtures rather than single or two- or three-species seedings; some are:

a. All seedings are on areas that have diverse microclimates; each microclimate may require a different species. Soil conditions (O'Rourke 1967), moisture availability, and ambient and soil temperatures change markedly within short distances (Gifford 1975), resulting in variation in seeding success and productivity of any species (Plummer and others 1955). Risk of failure is minimized with mixtures (Cook 1962; Plummer and others 1968; Olsen and Hansen 1977).

b. Better and more rapid ground cover and soil stabilization is provided by mixtures and combinations of species having different phenologies and root levels (Koehler 1975; Provenza and Richards 1984).

c. Nitrogen-fixing plants included in mixtures can increase production and protein content of associated species and help replace soil nitrogen (Heinrichs 1975; Rumbaugh and others 1981).

d. Seedings that incorporate a number of species are more esthetically pleasing than single-species plantings (Davidson 1970). Grass or grass-dominated seedings portray a most drab appearance from midsummer on.

e. Nutritional quality, quantity, and variety for both livestock and game can be provided and enhanced through mixtures (Barnes and Nelson 1950; Rogler and others 1962; Campbell 1963; McKell 1975; Tueller 1979; Otsyina 1980; Welch 1983; Provenza and Richards 1984).

f. Growth periods vary among species. Mixtures can extend the period when succulent forage is available (Frischknecht 1963; Plummer and others 1970a, 1970b; Rumbaugh and others 1981; Provenza and Richards 1984; Stevens and Davis 1985).

g. Total production and forage quality can be enhanced with mixtures (Cornelius and Tolbot 1955; Stitt 1958; Hervey and Everson 1959; Gomm 1964; Kelcher and Heinrichs 1965; Bleak 1968; McArthur and others 1978; Otsyina 1980; Jordan 1981; Otsyina and others 1982; Provenza and Richards 1984).

h. Plant communities consisting of a number of species and classes of plants provide desirable and usable habitats for additional animal species (McArthur and others 1978; Reynolds 1980; Jordan 1981). As diverstiy of a plant community increases so does use, and the variety and diversity of the animal community increases. Monospecies seedings are generally unproductive wildlife ranges (McKell 1975).

i. Multispecies seeding can decrease the chance of destructive insect infestations (Haws 1978; Provenza and Richards 1984) and disease outbreaks.

With mixtures, care must be taken in determining the proportion (number of pure live seed per pound) of each species in the mixture. Many well-intended mixtures have ended being dominated by one species. One reason is that the mixture was proportioned by pounds, rather than number of pure live seeds per pound. This can result in most of the viable seeds being of one or only a few species within the mixture. Care needs to be taken in determining number of pure live seeds per pound for each species in the mixture. Seed size greatly affects the number of seeds per pound; for example (table 4), 1 pound of fairway wheatgrass has about the same number of seeds as 15.4 pounds of antelope bitterbrush, 3 pounds of smooth brome, and 5.8 pounds of small burnet. Mixtures should include various plant types--grasses, forbs, shrubs, trees, late and early developers--and deep- and shallow-rooted species. Another reason

that some seedings are dominated by one or two species is that slower developing and less aggressive species (antelope bitterbrush, fourwing saltbush, mountain mahoganies, cliffrose, serviceberry, ephedra, balsamroot, penstemons, cicer milkvetch [Astragalus cicer], sweetvetch [Hedysarum boreale]) were seeded (small amount of seed) with fast-developing, aggressive species (fairway wheatgrass, crested wheatgrass, intermediate wheatgrass, pubescent wheatgrass, smooth brome). If drilled, the slower developing, less aggressive species should be seeded in individual drops away from aggressive species. On chaining projects when aerial seeding is employed, the less aggressive species are best seeded separately with a Hansen seeder, seed dribbler, or thimble seeder.

7. Sufficient seed of acceptable purity and viability should be selected and planted.

It is important to determine proper seeding rate. Excessive seed of one or all species in a mixture makes improvement projects needlessly expensive and can cause seedling competition among species. Skimpy seedings, however, may jeopardize proper stand establishment or sufficient establishment of any species in the mixture. Skimpy seedings may require longer periods of time to reach maximum productivity and thin stands are more subject to invasion of undesirable plants (Hull and Holmgren 1964). It is best to figure seeding rate on a pure live seed (PLS) basis. PLS is determined by multiplying percent purity by percent germination. If a seed lot has a PLS of 83.7 and the goal is to seed 2.5 PLS pounds, 2.99 pounds (desired PLS pounds divided by PLS) of seed would need to be used.

Table 4.--Number of seeds per pound for selected grasses, forbs, and shrubs compared to number of seeds per pound of fairway wheatgrass

Species	No. of seeds per lb at 100 percent purity	Pounds of seed (100 percent purity) required to equal the number of seeds in 1 pound of fairway wheatgrass
GRASSES:		
Wheatgrass, fairway	319,600	1.0
Brome, smooth	106,000	3.0
Fescue, hard sheep	633,500	.5
Orchardgrass	600,000	.5
Ricegrass, Indian	188,300	1.7
Wheatgrass, crested	192,800	1.7
Wheatgrass, intermediate	88,100	3.6
Wheatgrass, pubescent	102,800	3.1
Wildrye, Russian	210,000	1.5
FORBS:		
Alfalfa	213,800	1.5
Burnet, small	55,100	5.8
Flax, Lewis	278,300	1.2
Milkvetch, cicer	113,700	2.8
Sweetclover, yellow	258,600	1.2
SHRUBS:		
Bitterbrush, antelope	20,800	15.4
Mountain mahogany, birchleaf	55,000	5.8
Rabbitbrush, white rubber	693,000	.5
Sagebrush, mountain big	1,924,000	.2
Saltbush, fourwing	55,400	5.8
Winterfat, common	112,300	2.8

Care should be taken to ensure that seeding rate is adjusted to the type of equipment being used (drilling generally requires one-third to one-half less seed than does broadcasting) and changes in site conditions (an area with 5 percent native cover would require more seed than an area with 25 percent native cover).

8. Seed must be covered properly on a seedbed that is adapted to the site and environmental conditions.

Proper seed to soil contact is most important. To germinate and establish, seed needs to be in contact with soil and moisture. A majority of seeds require some type or amount of soil coverage. Soil can also act as an anchor on seed, especially for hairy or fluffy seed (for example, winterfat [Ceratoids lanata]) that can be blown and moved around when not anchored. Depth of planting is generally governed by size of the seed. However, it is also influenced by special requirements of individual species. As a general rule, seeds should not be covered more than three times the thickness of cleaned seed. Seeding too deeply is a major reason for failure. Species like winterfat, rabbitbrush, some sagebrush, asters, and forage kochia (Stevens and Van Epps 1984; Stevens and others 1986) are best seeded on a disturbed surface with no covering. Indian ricegrass, however, should be seeded 2 to 3 inches deep. Soil type and condition can also influence seeding depth. Some species prefer firm seedbeds; others do best in loose soil. Species and equipment should be used that are adapted to site condition and yearly moisture patterns.

Leaving downed trees in place will provide microclimates that can protect seed and seedlings, resulting in increased seedling establishment.

9. Plant in the season providing the most favorable conditions for establishment.

The most successful and productive results from direct seeding in the Great Basin have resulted from late fall and winter seedings (Stevens 1981). Spring seeding of species that germinate quickly, such as winterfat, alfalfa, and small burnet has resulted in some success. Spring seedings without supplemental water are, however, not generally recommended. Late fall and winter seedings are desirable because:

a. Seeds are in the ground during early spring when soil moisture is high and thus available for germination, seedling emergence, and growth before heat and drought of late spring and summer occur.

b. Inherent seed dormancy of many species is overcome.

c. Loss of seed to small animals and birds is reduced. Hibernation seasons have begun and most seed- eating birds have migrated.

Seeding too early in the fall can result in precocious germination following storms and unseasonable warm fall temperatures and loss of seedlings to frost and to mammals and birds. Wildings, seedlings, and nursery stock are generally most sucessfully transplanted in the spring when the ground is still wet and there are chances of spring storms following transplanting. Fall transplanting is generally not recommended (Stevens 1981; Stevens and others 1981; Crofts and Carlson 1982).

10. Good grazing management of the newly seeded area must occur.

As a general rule newly seeded areas should not be grazed for at least two growing seasons following seeding. Poorer sites and those seeded with slow-developing species may require up to four seasons of nonuse. When grazing is allowed, it should be conservative.

CONCLUSIONS

Big game ranges within the pinyon-juniper type can be improved by mechanical means and seeding, if today's techniques, procedures, equipment, and plant materials are employed. There are basic range improvement principles and wildlife requirements that need to be followed and considered if improvement projects are to be successful. Shrubs that will establish and provide an abundance of desirable forage are the big sagebrushes, black sagebrush, fourwing saltbush, rubber rabbitbrush, and forage kochia. Alfalfa over the years has proven to be the most productive, persistent forb that is seeded on pinyon-juniper ranges. Cattle can be used as a management tool to enhance big game ranges. Live juniper and pinyon trees on chained and seeded pinyon-juniper sites are more a result of poor kill during chaining than they are of reinvasion.

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MULE DEER RESPONSE TO WILDFIRE IN GREAT BASIN PINYON-JUNIPER WOODLAND

D. Waive Stager and Donald A. Klebenow

ABSTRACT: Mule deer (Odocoileus hemionus) habitat use, as indicated by pellet and track counts, varied with successional stage following burning of pinyon-juniper woodlands. In early years following burning, forbs were abundant and mule deer pellets and tracks were most dense near the edge in unburned cover. Shrub cover and density increased to dominate sites by 16 years after fires and mule deer use on the burned areas became more general. Deer use was greater than on unburned areas and widespread throughout the 24-year-old burns. Mule deer use was greater in burned areas versus unburned sites 115 years following fire. Grass, shrub, and tree response to fire was still evident 115 years following fire.

INTRODUCTION

Over 40 million hectares in the western United States are covered by pinyon-juniper woodland (Lanner 1975). The vegetation type has expanded into adjoining shrub/bunchgrass range, enhanced, presumably, by fire prevention and grazing by livestock (Burkhardt and Tisdale 1976; Aro 1971; Barney and Frischknecht 1974).

Since fire is a natural ecological factor controlling pinyon-juniper invasions, prescribed burning is a logical management tool for keeping portions of this woodland type in a sub-climax (McCulloch 1969; Wright and Bailey 1982), a condition that facilitates mule deer habitats (Leopold 1950; Miller 1963; Tausch 1973).

Mule deer respond to the changes brought about by fire. Ideal habitats for deer usually contain combinations of diverse plant communities (Tueller and Monroe 1975) where deer consume several forages to maintain good condition and survival (Pederson and Harper 1978). The preferred habitat of deer usually includes subclimax stages of woodland communities (Miller 1963; Tausch 1973).

Our knowledge of how mule deer use pinyon-juniper habitats impacted by fire is limited, although good data on mule deer-fire relationships have been provided by McCulloch (1969), Asherin (1973), and Ffolliott and Thill (1977). The use of fire as a management tool requires a prediction of plant succession and animal response to habitat changes. To help predict long-term vegetation and animal use obtained by controlled burning, this study investigated wildfires of eight ages. Objectives of the study were to determine mule deer response to successional changes following wildfire in singleleaf pinyon-Utah juniper (Pinus monophylla-Juniperus osteosperma) communities, and patterns of use on burned and adjacent woodland areas. In this paper we extend the knowledge of mule deer habitat use in the Great Basin by comparing responses of deer to successional communities that varied in the period of time that they were last impacted by wildfire. Specifically, 11 sites were examined at seven locations in Nevada and California, representing 8 ages of wildfires (table 1). Elevations were between 1950 m and 2240 m, average 2148 m, and mule deer season of use varied. Densities of deer were unknown. We assumed deer use of burned and unburned areas was related to their habitat preference and not a response to variables to be tested by further research.

STUDY AREAS

The 2-year-old Mt. Wilson fire occurred in the Wilson Creek Range of eastern Nevada. After the burn, the area was seeded to crested wheatgrass (Agropyron cristatum), intermediate wheatgrass (Agropyron intermedium), smooth brome (Bromus inermis), and yellow sweet clover (Melilotus officinalis). The area has been fenced and protected from livestock grazing since the fire. The burned area is presently in a grass-forb successional stage. Deer are present on the burn mainly during the summer, but disperse to lower slopes in spring and fall.

The 2-year-old China Garden and 3-year-old Rock Creek fires occurred in the Sweetwater Range of California. Both burns were in a grass-forb successional stage. They were broadcast seeded with crested wheatgrass, smooth brome, orchard grass (Dactylis glomerata), nomad alfalfa (Medicago sativa), and white sweet clover (Melilotus alba). These two burns were protected from livestock grazing and are in an important mule deer wintering area.

The 4-year-old Davis Creek, 16-year-old Cottonwood Creek, and 17-year-old North Fork Cottonwood Creek fires are in the Quinn Canyon Range of the Humboldt National Forest in eastern Nevada. The Davis Creek burn was a perennial forb plant community while the Cottonwood Creek burns were in a shrub-dominated successional stage. All three areas have received

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Waive Stager is Range Conservationist, Bureau of Land Management, Elko, NV 89801, and Don Klebenow is Professor, Department of Range, Wildlife and Forestry, Renewable Resources Center, University of Nevada, Reno, NV 89557.

Table 1.--Characteristics of 11 burned pinyon-juniper wildfire sites in Nevada and California

Site	Elevation (m)	Years since fire	Existing plant community in burn	Preburn understory community	Post-burn treatment	Type of mule deer habitat
Mt. Wilson, Nevada	2285	2	Grass-forb	Artemisia tridentata/ Purshia tridentata	Seeded & ungrazed	Mainly summer, some spring-fall
China Garden California	1950	2	Grass-forb	A. tridentata/P. tridentata	Seeded & ungrazed	Winter
Rock Cr., California	2070	3	Grass-forb	A. tridentata/P. tridentata	Seeded & ungrazed	Winter
Davis Cr., Nevada	2440	4	Perennial forb	Cercocarpus ledifolius	Grazed	Summer
Cottonwood Cr., Nevada	2375	16	Artemisia tridentata	C. ledifolius/A. tridentata	Grazed	Summer
N. Fk. Cottonwood Cr., Nevada	1980	17[1]	A. tridentata	A. tridentata/A. nova	Grazed	Spring-fall, open winters
Ward Mountain, Nevada, No. 1	2085	24, 115[2]	A. nova	A. tridentata/A. nova[3]	Grazed	Summer
Ward Mountain, Nevada, No. 2	2180	24	A. tridentata/ Purshia glandulosa	A. tridentata/P. glandulosa	Grazed	Summer
Ward Mountain, Nevada, No. 3	2110	45, 115[2]	A. nova	A. nova/P. glandulosa[3]	Grazed	Summer
Ward Mountain, Nevada, No. 4	1985	115	A. nova/A. tridentata/ P. glandulosa	A. nova/A. tridentata/ P. glandulosa	Grazed	Summer
Ward Mountain, Nevada, No. 5	2170	115	A. nova/A. tridentata/ P. glandulosa	A. tridentata/A. nova/P. glandulosa	Grazed	Summer

[1]Appeared to have been burned twice, but unable to determine time since the first fire.
[2]Two ages indicate site had burned twice.
[3]Preburn understory refers to the younger age as these sites were burned 115 year ago.

yearly cattle use since burning. The first two burns received summer deer use, while the third is primarily spring-fall range and secondarily winter range during years of light snowfall.

Twenty-four, 45- and 115-year-old wildfires were sampled on the west slopes of Ward Mountain in the Egan Range of eastern Nevada. The 24- and 45-year-old fires reburned parts of the area covered by the 115-year-old fire. All these burns were in a shrub-dominated stage of succession. In the past, sheep used Bureau of Land Management (BLM) and U. S. Forest Service lands in this area. Presently, both sheep and cattle use the BLM lands, but only cattle forage on the U.S. Forest Service lands. Deer use Ward Mountain principally during the summer.

METHODS

Vegetation and ground cover were sampled both inside and outside the burns using 0.1-ha macroplots (Stager 1977). Twenty macroplots were sampled at each site; 10 in each of the burned and adjacent woodland areas. Canopy cover of shrubs and trees were estimated along a 30-m line intercept transect in each macroplot. Density of each tree species was determined by counting all trees within the macroplot. Density of each shrub species was determined by counting shrubs in three, 10-m^2 plots. The three plots were equal subdivisions of 1 X 30 m belt transect. Basal area cover of forbs and grasses was estimated by species in 15, 30 X 60 cm plots placed within each macroplot. Also, within each macroplot, ground cover was estimated at 60 points directly beneath the four corners of the 30 X 60 cm plots. Cover categories sampled were litter, bare ground, rock, pavement, and vegetation. Wedges of pinyon trees were collected from 10 fire-scarred trees in each burned area and the year of the fire determined by counting the annual growth rings since the fire scar.

For comparing deer use on the burned versus adjacent woodland areas, pellet groups and tracks were counted on 0.001-ha (20 X 0.5 m) belt transects laid parallel to the burn edge on each site. Twenty-five transects were positioned within each of the following distances from the burn edge: 0-50, 50-100, 100-200, 200-300, 300-400, and 400-600 m. This sampling scheme was used both inside and outside the burn. Only dark, unbleached pellet groups were counted.

Two-way analysis of variance and Duncan's multiple range test were used to determine statistical differences in vegetation and ground cover variables between burned and adjacent woodland areas of each site and between ages on the sites that had burned twice. Two-way ANOVA's and Duncan's multiple range test were also used to test for differences in deer use, as measured by pellet group and track densities, on burned and adjacent woodland areas and among ages on sites that had burned twice. To test for significant differences in deer use in relation to distance from the burn edge in burned and adjacent woodland areas, one-way ANOVA's and Duncan's multiple range test were used. Deer activity was related to vegetational and topographic conditions by stepwise multiple regression and correlation. All statistical differences discussed in the text are at the 0.05 level of significance.

PLANT SUCCESSION

The 115-year-old burn sites (table 1, Ward Mountain No. 4 and No. 5) were the only sites with significantly more grass cover on the burned than on the adjacent woodland areas (fig. 1). Ward Mountain No. 1, a 24-year-old burn, had less grass cover than in the adjacent woodland area. Note, however, that the unburned portion at this site and the unburned 45-year-old site were located within the 115-year-old fire. On this site, No. 3, grass cover after 45 years was as great as on the 115-year-old burn used for comparison.

Basal area cover of forbs, annual and perennial, on the 2-, 3-, 4-, 16-year-old, and one of the 24-year-old (No. 2) burns was significantly higher on the burned areas than on the adjacent woodland areas. Annual forbs on the 2-year-old China Garden burn were 83 percent of the total forb cover. Annuals on the 2-year-old Mt. Wilson and 3-year-old Rock Creek burns made up 43 percent and 56 percent of the total forbs, respectively. Composition of forbs was 34 percent annuals through 4 years, and thereafter was mainly perennial forb cover in the burns.

Shrub canopy cover was less on the 2-, 3-, and 17-year-old burns compared to the adjacent woodland area, and the difference on the 4-year-old burn was not significant (fig. 1). The other burns, ages 16 through 115 years, had greater shrub canopy cover on the burned areas. On Ward Mountain 24-year (No. 1) and 45-year-old (No. 3) burns, shrub cover was significantly greater than on the two adjacent woodland areas which were actually 115-year-old burns.

Shrub densities, not included in figure 1, paralleled the shrub cover. The 2-year-old Mt. Wilson burn had a significantly lower density of shrubs than the adjacent woodland area. Burns 16 years and older had significantly higher densities that their adjacent woodland areas.

Tree canopy cover on the burns was significantly lower than on adjacent woodland areas on all sites except the North Fork Cottonwood Creek and the 45-year-old Ward Mountain burns. Note the similarity in the tree cover of the Ward Mountain No. 1 and 3 "unburned" woodland areas and the two 115-year burned sites. All of these sites were in the fire that occurred 115 years previously and tree cover ranged from 5 percent to 10 percent.

The pattern of succession in these 11 burns corresponds overall with existing knowledge. In Arizona, Arnold and others (1964) found that annuals were usually most abundant in the second growing season after wildfire in pinyon-juniper woodland. Perennial forbs and half-shrubs replaced the annuals after the fourth and sixth growing seasons. After wildfire in Utah, annuals reached a maximum development in the third to fourth years and were replaced by a perennial grass-forb stage by the fifth to sixth year (Barney and Frischknecht 1974). The change from annuals to perennials found by this study seems to be about the same or slightly slower than those reported in Arizona and Utah. The 2- and 3-year-old burns were still in a grass-forb stage of succession with little shrub cover. Following this successional stage, the literature indicates shrubs will usually become dominant (Arnold and others 1964; Barney and Frischknecht 1974).

On our 16- and 17-year-old burns, the shrub cover was already advanced at 42% and 17%, respectively (fig. 1). These burns were not large, 57 and 6 ha in size, respectively. Following the fires, they were not protected from grazing (table 1), which may have concentrated livestock in the burns and contributed to the reinvasion of shrub species as described by Barney and Frischknecht (1974).

All the burns 16- through 115-years old were in a shrub-dominated stage of succession when sampled. Although we were unable to determine the age, the "unburned" part of the North Fork Cottonwood Creek site appeared to have been burned sometime before the latest fire of 17 years ago, and it was still in a successional stage dominated by shrubs. This would explain why tree cover on this site was not significantly different between the burned and unburned areas.

In our study, the 115-year-old burns had only 6 percent as much tree cover as was found on Barney and Frischknecht's (1974) 100-year-old burn in Utah.

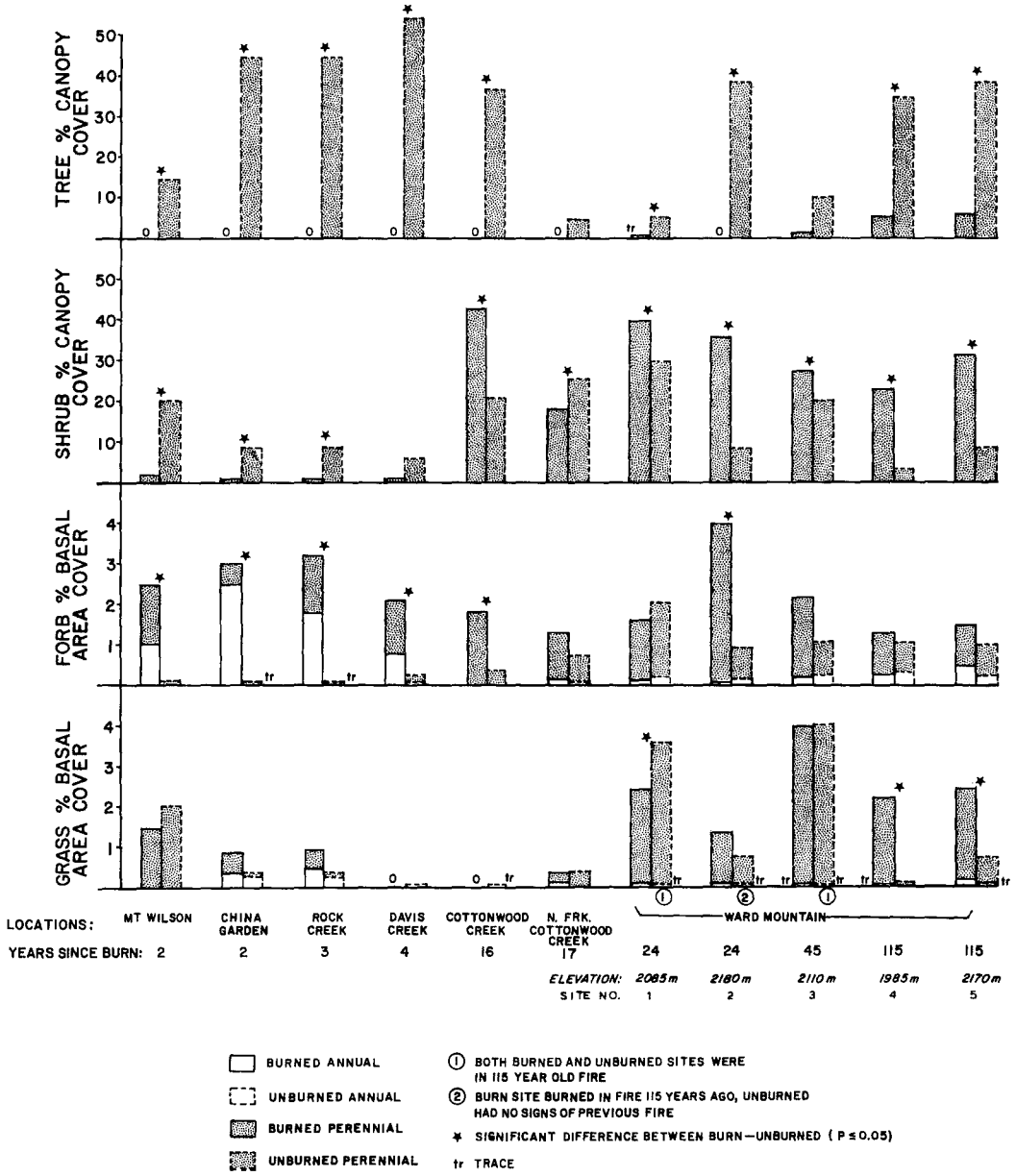


Figure 1.--Characteristics of vegetation on burned and unburned areas in Great Basin pinyon-juniper woodland.

MULE DEER RESPONSE TO SUCCESSION

The densities of pellet groups and tracks generally related to successional change (fig. 2). On the 2-, 3-, and 4-year-old burns there were more signs of deer on unburned areas than on burns except for Mt. Wilson and the tracks on the 4-year-old Davis Creek burn sites.

In the burns from 16 to 24 years since the fire, just three of the eight measures of deer activity indicated significant differences between the burned and unburned sites. Tracks on the Cottonwood Creek site and pellet groups on the Ward Mountain No. 2 site, 24-years old, indicated more deer use on burned area. The Ward Mountain No. 1 24-year-old site had more tracks per hectare in the unburned pinyon and juniper.

The 45-year-old burn had few signs of mule deer use, and for the little use that occurred there was no indication of preference for burned or unburned areas. At 115 years, the Ward Mountain No. 4 site had the same pellet group densities on both burned and unburned, but approximately 2.5 times more tracks on the unburned portion.

At the Ward Mountain No. 5 site, both tracks and pellet group densities were significantly greater on the burned portions of the area.

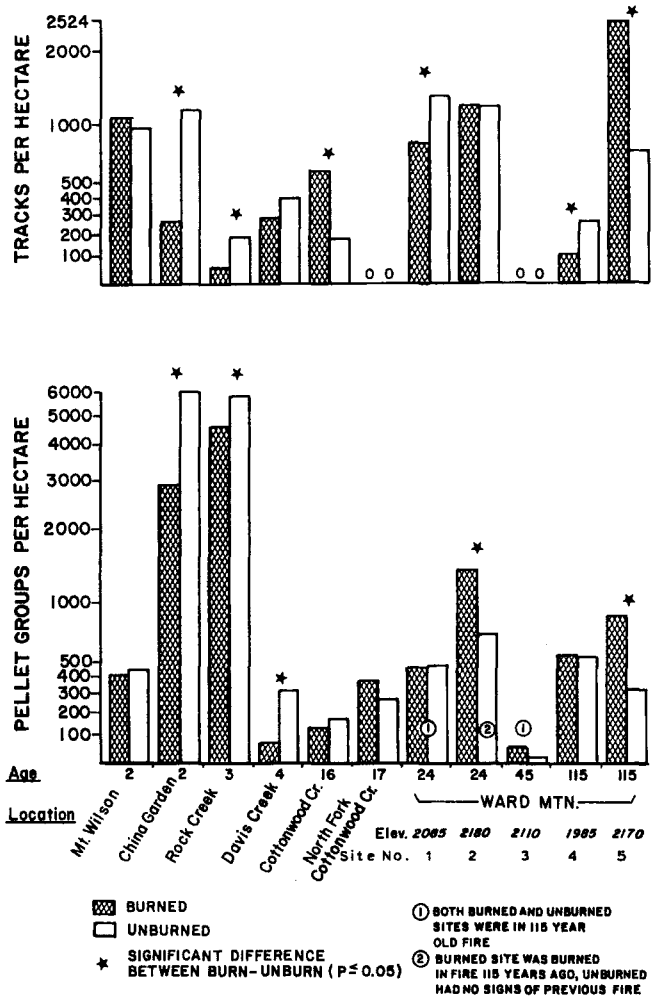


Figure 2.--Mule deer pellet group and tract densities on burned and unburned areas in Great Basin pinyon-juniper woodlands.

In general, deer favored unburned areas from 2-4 years after a fire. During the 16- through 24-year-old ages, there was general use of both burned and unburned sites. By 115 years there still may be general use of both burned and unburned habitat, with a tendency favoring some burned sites.

Several site characteristics related to mule deer sign. Increases in pellet group densities were associated with increases in big sagebrush density (R^2=0.65) and increases in desert bitterbrush cover (R^2=0.27). These two shrubs are sources of both food and cover for mule deer.

Cover of forbs (fig. 1) was positively correlated (R^2=0.42) with pellet group densities. Overall, important habitat characteristics that correlated with use on the Ward Mountain burns were increases in percent slope, big sagebrush density, vegetation ground cover, and forb cover. These factors explained 91 percent (R^2=0.91) of the variation in pellet group densities.

MULE DEER RESPONSES TO BURN EDGE

On 2-year-old burns, the greatest densities of pellet groups occurred in the unburned areas within 100 m or less of the burn edge (fig. 3). Similarly, on the China Garden study site, tracks were most abundant within 200 m of the edge in the unburned areas. On Mt. Wilson, track densities were greater near the edge on both the burned and unburned areas, but unlike the pellet and track distributions on the other area, there was a decreasing gradation of track densities extending into both burned and unburned portions.

Both 2-year-old burns were in a grass-forb successional stage. There were few shrubs, and no trees, in either burn (fig. 1). The attraction of the burn to mule deer was displayed by the greatest densities of pellets and tracks near the edge, with most of them occurring at the unburned edge. Within the Mt. Wilson burn only the track densities were significantly greater 50-100 m out from the unburned pinyon-juniper.

On the 24-year-old burns, no edge effect of deer use was found (fig. 4). In fact, both pellet groups and tracks were less abundant 50 or 100 m from the edge than at greater distances from the edge. On Ward Mountain No. 1 site pellet group densities were greater at 50-100 m than at 0-50 m into the burn. Beyond 100 m into the burn pellet groups were intermediate in density compared to the low density in the 0-50 m zone and the high densities at 50-100 m, but the differences were not significant. Greater densities of tracks were found 100 to 600 m into the burn than at the edge.

Tracks in the unburned portion of the Ward Mountain No. 1 site, displayed a similar pattern of being lower near the burn edge and more abundant beyond 100 m. In the 100 to 400 m zone, they were more abundant than in the burned area. Pellet group densities followed a pattern similar to the tracks, but differences were not as distinct with ranges of densities overlapping at various distances from the edge.

On Ward Mountain No. 2 site, there were greater densities of both tracks and pellet groups at distances far out into the burn than close to the unburned edge (fig. 4). In the unburned portion, pellet groups were distributed from the edge out to 600 m but the differences were not significant. Greater pellet group densities were found in the burned 100-200 m and 400-600 m zones than in the unburned habitat. Tracks were also more abundant in the burn than in the unburned pinyon-juniper woodland.

The Ward Mountain No. 1 site had greater densities of tracks in the unburned than in the burned areas, suggesting a preference for the unburned pinyon-juniper woodlands. The Ward Mountain No. 2 site, which is part of the same 24-year-old burn had greater densities of both tracks and pellet groups in portions of the burned area compared with the unburned area,

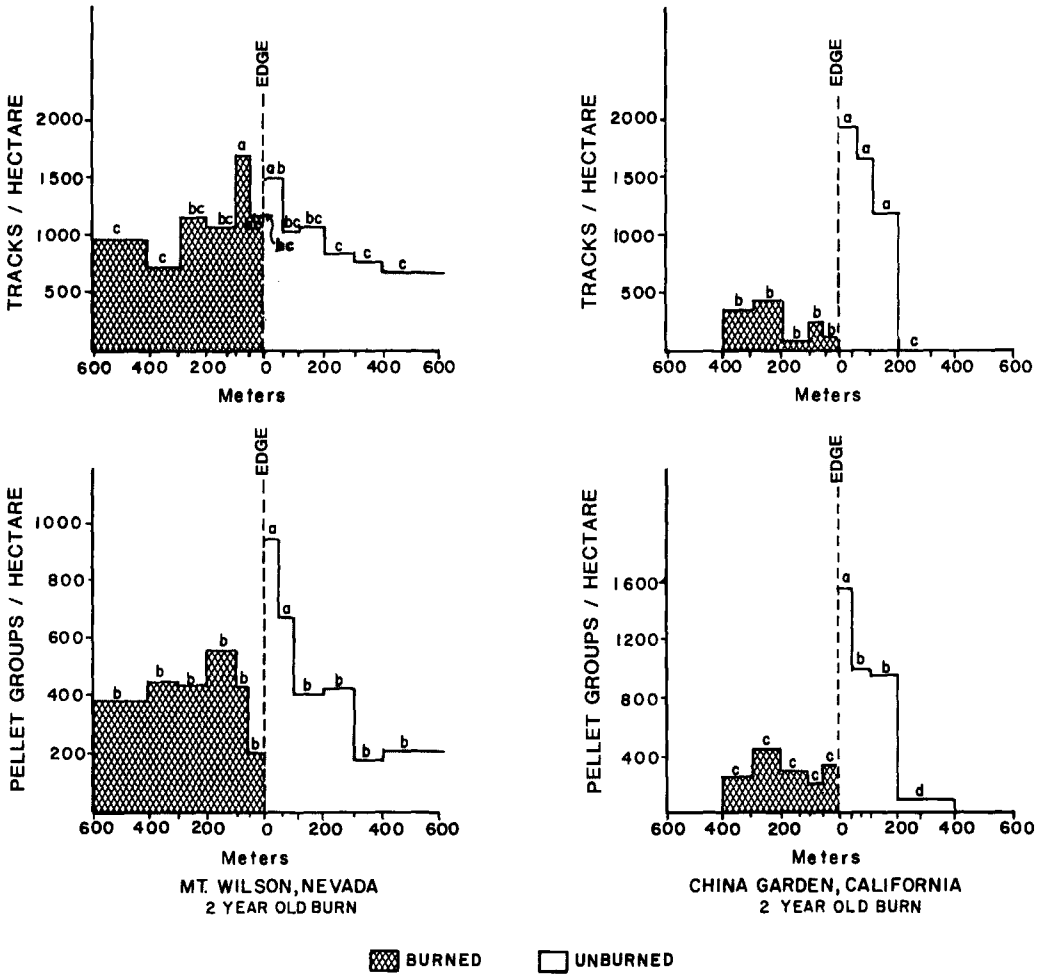


Figure 3.--Distribution of mule deer pellet groups and tract densities relative to the burned edge of 2-year old fires. Different letters indicate a significant difference at the 5 percent level.

suggesting a preference for the burned pinyon-juniper woodland.

Habitat use was not in accordance at all sites. Figure 2 also demonstrates this conflict in results. The differences may be explained by footnote 1 of figure 4. The unburned portion of the Ward Mountain No. 1 site had been burned 115 years previously. It was not at the same successional stage as the unburned area of the Ward Mountain No. 2 site. Tree canopy cover was only 5 percent on the No. 1 unburned site but was 38 percent on the No. 2 site (fig. 1). On the No. 2 site, with no sign of the unburned portion ever having been burned, shrub canopy cover and forb basal area cover was significantly less than on the unburned areas. Perhaps the 115-year-old burn of the No. 1 site was more suited or at least as well suited to mule deer as the 24-year-old burn adjoining it. Alternatively, the 24-year-old burn at the No, 2 site must have been more suited to mule deer that the denser, later stage of succession, adjoining pinyon-juniper woodlands.

Support for this scenario is gained by examination of results from the 115-year-old burn, Ward Mountain No. 5 site (fig. 5). Mule deer signs were significantly greater in the burn than in the adjoining unburned areas. In the unburned areas, an edge effect seems apparent, yet these results are misleading since the unburned location was too narrow to sample more that 100 m from the edge. The burned areas were used throughout with greater densities of both tracts and pellet groups tending to be nearer the edge than toward the center of the burn.

SUMMARY AND CONCLUSIONS

To summarize the pattern of succession on the areas studied, forbs were the most abundant class of vegetation in early years following fire. Approximately half of the cover of forbs was composed of annuals on the 2- to 4-year-old burns. Forb cover was maintained up to 24 years and grass cover was maintained as late as 115 years following the fires.

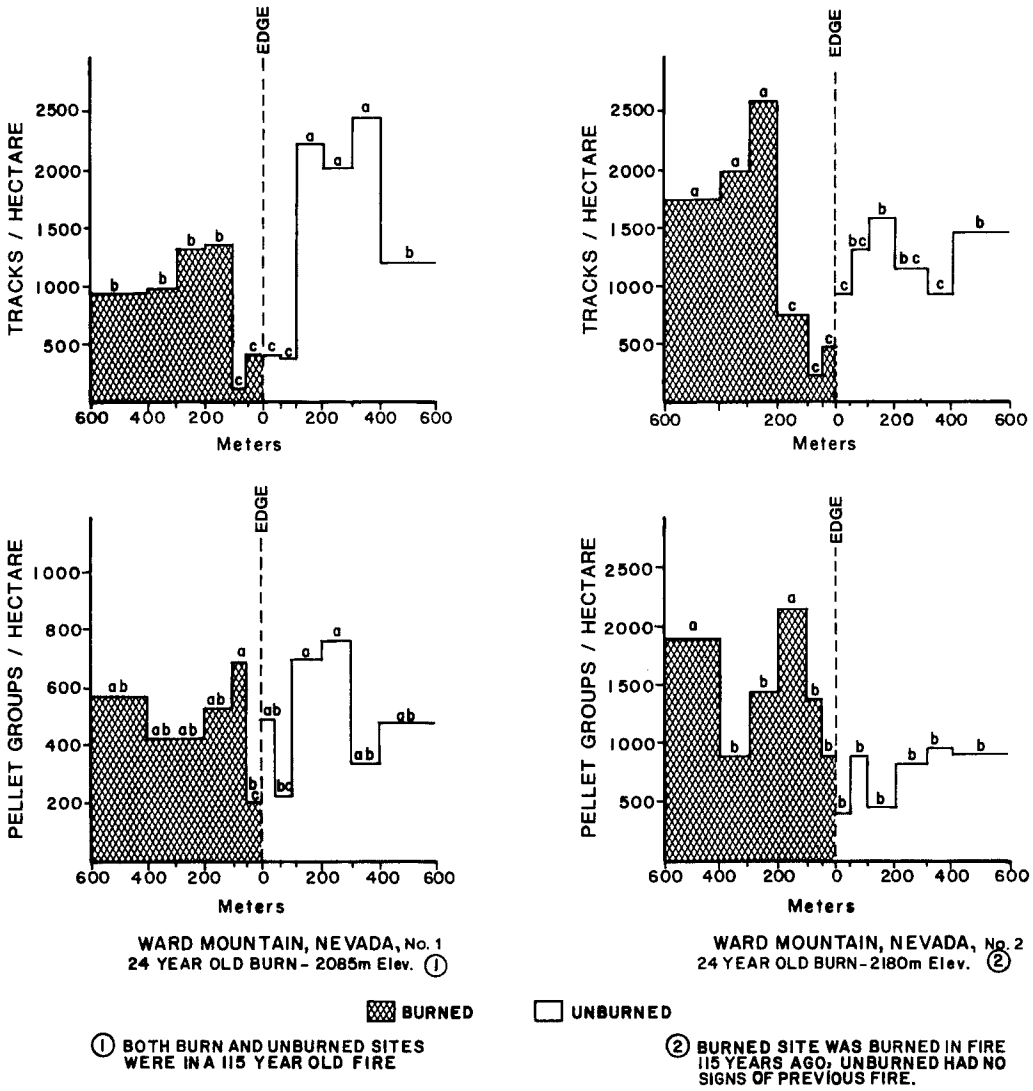


Figure 4.--Distribution of mule deer pellet groups and track densities relative to the burned edge of 24-year old fires. Different letters indicate a significant difference at the 5 percent level.

Shrubs had recovered on the 16-year-old burn and, typically, were more abundant on the burned areas than on adjacent unburned areas from then through all ages up to 115 years following fire. On two sites, comparing 24-year and 115-year old burns, the younger burn areas had a greater canopy cover of shrubs than the older burns, however, shrub cover was maintained on the 115-year-old areas. Fire impacts on pinyon and juniper trees were still very evident 115 years following fire on the Ward Mountain sites.

Mule deer used unburned areas more than the burned when fires had burned 2 to 4 years earlier. On the 16-year through 115-year burns, deer used burns equally or more than adjacent woodland areas. One exception was that tracks were less abundant on one 115-year-old burn than on the adjacent unburned area. the 115-year-old burns appeared to be in a successional stage desirable for mule deer.

During the first few years following fire, mule deer tended to use edges, particularly the unburned ones. By age 24, burns had recovered to the point that deer use was found throughout the burned area. Although some edge effect was noted, the mule deer generally used the entire areas of the 24- and 115-year-old burns.

Overall, successional stages promoted by wildfire in pinyon-juniper woodland favored mule deer. The impact of fire lasted a long time. Burns were still used after 115 years, suggesting that the frequency of fire needed to sustain productive mule deer habitat by low, greater that 100-year intervals. Still, the need also exists to refine the role that regional deer densities have in mediating use of burned and nonburned areas which vary in successional stage.

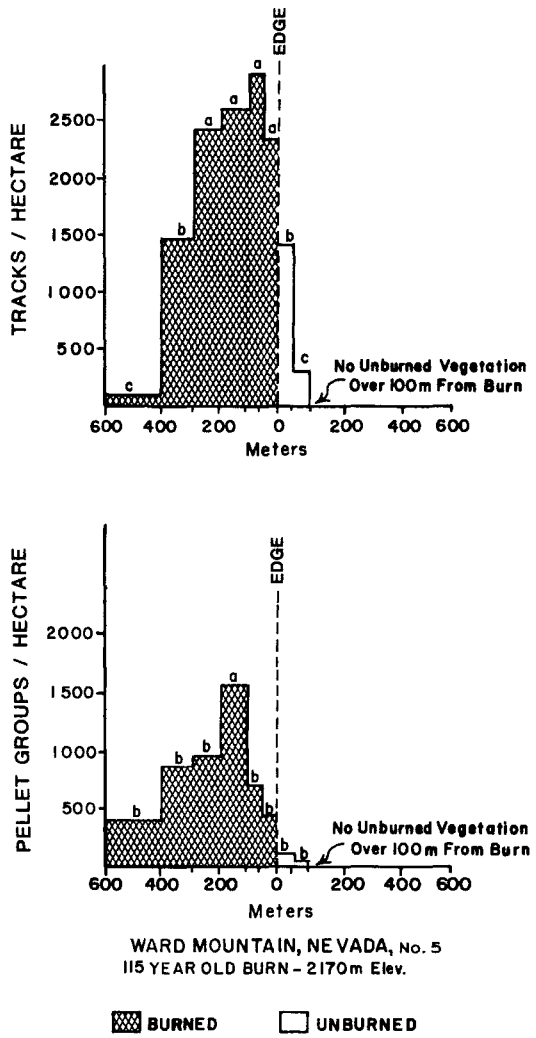


Figure 5.--Distribution of mule deer pellet groups and track densities relative to the burned edge of 115-year old fires. Different letters indicate a significant difference at the 5 percent level.

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PINYON-JUNIPER CONFERENCE: CONFERENCE SUMMARY

John C. Buckhouse

INTRODUCTORY REMARKS

It was a pleasure to attend this series of meetings, to visit with so many concerned people, and to update on the many exciting things that are happening in the pinyon-juniper woodlands of the West.

I am reminded again that we have so much to learn from each other and each other's points of view. It was enjoyable to be part of that learning process at this 1986 conference.

Many thanks are appropriate: Thank you to the some 300 individuals who attended; to the University of Nevada-Reno, the Intermountain and Rocky Mountain Stations, and to the Bureau of Land Management who sponsored the conference; and special thanks to the steering committee, Richard Everett, and the local arrangements committees.

OBSERVATIONS AND REACTIONS

The following comments are my reactions to the conference:

In a sense I recognize this as having elements of good news and bad news. The good news is that in pinyon-juniper research and management we have come a long way during recent years. In the past 10 years we have moved from incidental studies on this type to concerted regional--and even national--concerns. The bad news is two-fold: (1) Some of the initial excitement of discovery seems to no longer be present. For example, I heard several people say, "I've heard all that before" following some of the talks, even some of those which dealt with areas which were unheard of as few as 10 years ago! I caution us all not to fall into the sophomoric trap of being jaded to issues simply because the concept may have been presented once before. (2) I call this a trap since the second part of the bad news is that even though we have come a long, we still have a long way to go!

Talk presented at the Pinyon-Juniper Conference, Reno, NV, January 13-16, 1986.

John C. Buckhouse is Associate Professor of Watershed Management, Department of Rangeland Resources, Oregon State University, Corvallis, OR.

KEYNOTE SPEAKERS AND SESSIONS

Kendall Johnson, Frank Ronco, Jim Young and Jerry Budy, Jim Doughty, and Fred Gifford each did excellent jobs in their General Session presentations.

During the Introduction on Monday morning, Bob Buckman started things rolling. He mentioned the need for greater understanding of the ecological secrets of this vegetation type. He pointed out the needs for advancement of multiple resource values and the role of politics and international involvement. Dave Tidwell pointed out that we can no longer look at pinyon-juniper simply as weeds; that a productive forest and a mosaic of species make for better land stewardship--that our management ought to be proactive rather than reactive.

Synecology

Paul Tueller's session was excellent. The initial theme that the ecological relationships, typing, and classifications are still a hodgepodge rang clearly. This is an obvious need in the pinyon-juniper type: Without logical and detailed classification, the management of the land is destined to remain "broad brush" and only approximate in its applicability.

Paleobotany

This session, chaired by Julio Betancourt, was fascinating to me. The mind-expanding concept of prehistoric pinyon and juniper occupancy of western regions is very stimulating. Julio himself gave a summary which was excellent. There are many unanswered questions and a great need for further research here, but what a fascinating area of study--and what wide reaching consequences it may have!

Fire

It is always a pleasure to listen to Henry Wright and his "pyromaniacs"! This is an area where it seems we are becoming increasingly sophisticated. The technology and predictability of results has become quite good. This is an example of excellent research which has resulted in pragmatic managerial implications.

Economics

The long-standing bugaboo of pinyon-juniper research and management was capably addressed by Lawrence Garrett and his speakers. It is significant that the thinking seems to be that any given practice probably cannot be justified on economic grounds, but that when the whole picture of erosion prevention, habitat management, watershed values, wildlife, and various commodities are taken in total, the multiple-use concepts and values of these lands become viable.

Inventory and Classification

Jim Hagihara and his speakers covered some very important and interesting concepts. The need for interagency cooperation in ecological classification was a recurring theme.

Silvics and Silviculture

This session was perhaps best described by Jerry Budy and his "zoom-boom/doom-gloom" analogy. There are many doom-gloomers, but with tenacity and forward thinking, I'm hopeful, as I know Jerry and other foresters are, that it can indeed be zoom-boom.

Woodland Conversion

This was a very optimistic session. The examples like Tom Bedell's Bonneview Ranch case history or the plant materials reports pointed out again that research and management can work hand-in-glove to produce productive and viable resource areas.

Nutrient Cycling

This session was an intellectual turn-on for me. The fascinating aspects of this research from classical recycling observations to the role of microbes are very important and very interesting. As we better understand the implications of these aspects of ecology, we can move logically to predict the results of managerially induced changes.

Plant-Water Relations

Perhaps Rick Miller was typical of this group of scientists as he was able to demonstrate aspects of juniper physiology and how it relates to water consumption. The entire session had many managerial overtones which were exciting.

Range Management

Rex Pieper and his session speakers were able to present a number of cause and effect facts and figures--"If you do this, you'll get that." My major professor during graduate school used to say, "There's no data like no data." The scientists in this session will get no criticism from him, or from me, on that score!

Woodland Hydrology

This session was another example of increased sophistication of our thinking and research in the last several years. Water balance, models, and prediction tools for this resource, perhaps the most valuable of resources, are constantly being developed and tested.

Wildlife

Don Klebenow and his reporters presented a number of important considerations in the final session. They shared the value(s) of their specific concerns and pointed out clearly how wild species fit into an honestly developed multiple resource management scheme.

CONCLUSIONS AND ATTITUDES

The sessions were, in my opinion, excellent. They were stimulating and helpful. I am particularly pleased that individuals of differing specialities and philosophies came together to share ideas and experiences and to cooperate in building realistic and comprehensive resource management data bases. I applaud each session chairperson and each speaker. This was a worthwhile experience for all who participated.

At the next conference of this kind, however, perhaps additional sessions in archeology and sociology, and possibly even in resource management philosophy, may prove beneficial. I suggest this in view of discussion which began to develop on the session floor and during the breaks on the final day of the conference. Differences in cultural and/or philosophical backgrounds in each of us are evident. Yet concern for our God-given natural resources is equally evident. A preservationist viewpoint of small human populations living in natural harmony is appealing. A humanistic approach is also appealing. Ecologically based management, conservation if you will, which maintains the amenities of the land, supports a moral land ethic, provides room for spiritual and aesthetic renewal, and concurrently provides for the secular needs of mankind is appropriate and proper.

It seems to me that a career in natural resource management is as challenging as any I can imagine--and the personal rewards, as well as the benefits which will accrue to our children and to our children's children, are too important to ignore. It is an exciting, though humbling and sometimes scary, challenge.

As C. M. Loudermilk said in the 1930's, "You can no more maintain a civilization on an eroding resource base than you can build a house on shifting sands." Those involved with natural resources share that same ethic--and that's what makes it all worthwhile.

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Everett, Richard L., compiler. Proceedings--pinyon-juniper conference; 1986 January 13-16; Reno, NV. General Technical Report INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station; 1987. 581 p.

Includes more than 90 papers bringing together research accomplishments of the last 10 years including ongoing research on the ecology and management of pinyon-juniper ecosystems. Scientist and management points of view are presented.

KEYWORDS: *Pinus edulis, P. monophylla, Juniperus* spp., synecology, paleobotany, fire, economics, inventory and classification, silviculture, woodland conversion, nutrient cycling, plant-water relations, range management, woodland hydrology, woodland wildlife

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

The Intermountain Research Station territory includes Montana, Idaho, Utah, Nevada, and western Wyoming. Eighty-five percent of the lands in the Station area, about 231 million acres, are classified as forest or rangeland. They include grasslands, deserts, shrublands, alpine areas, and forests. They provide fiber for forest industries, minerals and fossil fuels for energy and industrial development, water for domestic and industrial consumption, forage for livestock and wildlife, and recreation opportunities for millions of visitors.

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