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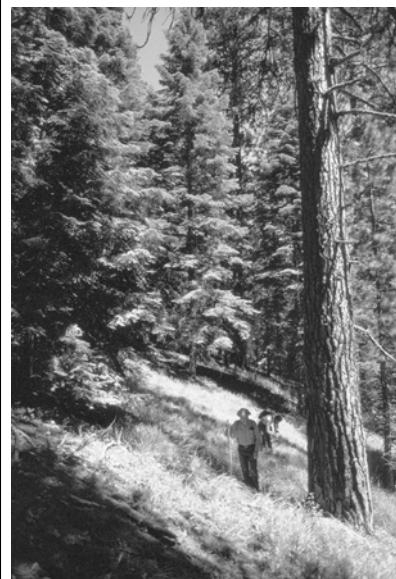
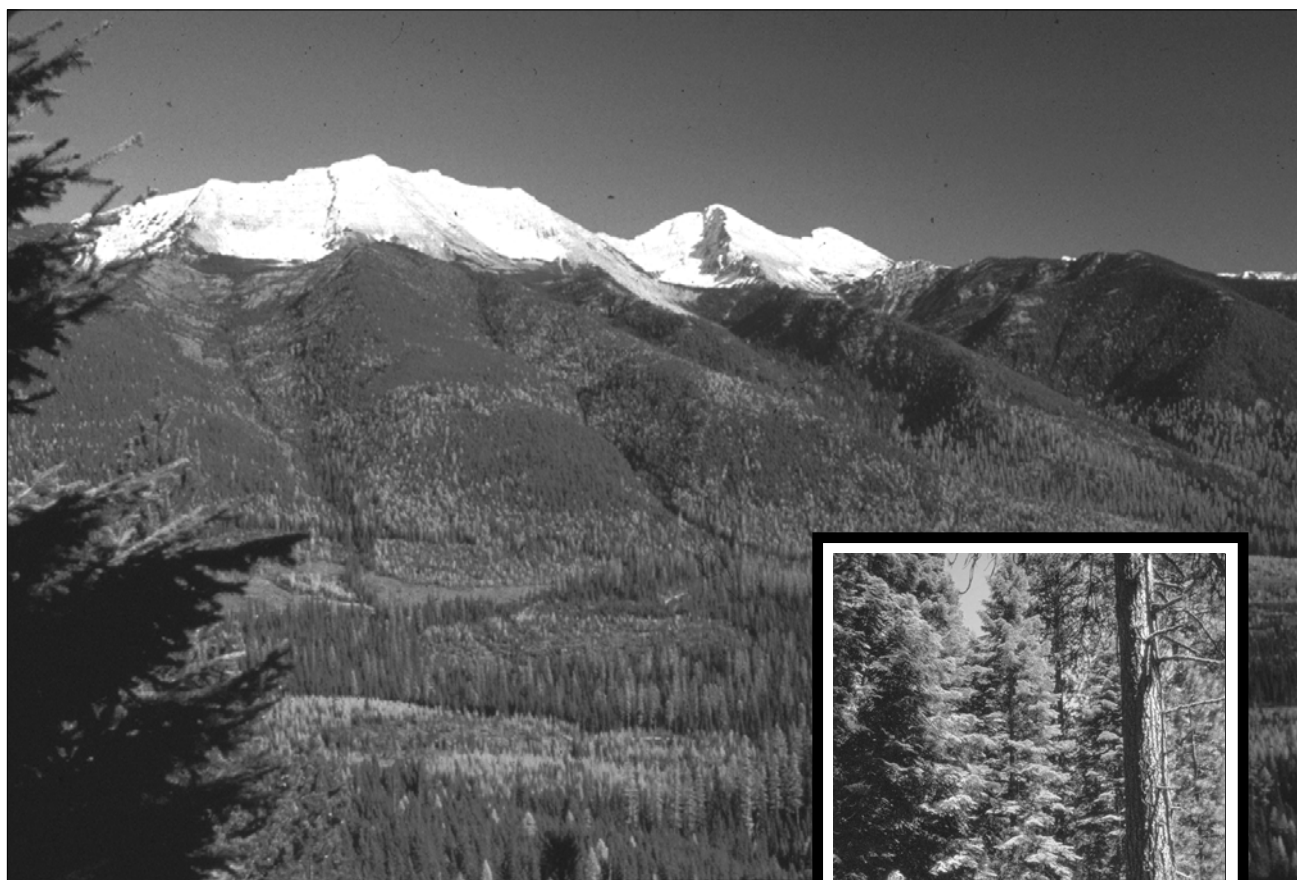
Proceedings
RMRS-P-19

May 2001



Proceedings: National Silvicultural Workshop

**October 5–7, 1999
Kalispell, Montana**



Barras, Stanley J., ed. 2001. **Proceedings: National silvicultural workshop**; 1999 October 5-7; Kalispell, MT. Proceedings RMRS-P-19. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 85 p.

Silviculture, as an integrative discipline, must combine management skills with scientific and technical knowledge in the management of forests and woodlands. While traditionally, silviculturists worked in fine resolution landscapes, today's practitioner must look at encompassing both larger geographic areas (adjacent stands, watersheds, regions, subregions) and wider objectives (trees as well as wildlife, commodities, recreation, sustainability, biological diversity, air quality, and ecosystem resilience). The 12 papers in this proceedings explore the past, present, and desired future of silviculture's role and practice. Examination of disturbance ecology in ecosystem management includes natural and induced disturbances, and management options. Discussion of desired future conditions includes the importance of understanding the connection between ecological values and social values, as well as historic reference conditions as they relate to creating forest plans. A section on inventory, monitoring, and adaptive management looks at multiresource and multiscale data assessments and temporal continuity; included are design alternatives and a discussion of how to adapt silvicultural prescriptions. Case studies throughout the proceedings help the reader understand the practical applications, the successes, and the need for further work.

Keywords: disturbance regimes, disturbance ecology, landscape, ecosystem management, stand structure, successional reserves, adaptive management

The Editor

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Proceedings: National Silvicultural Workshop

**October 5–7, 1999
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Editor:

Stanley J. Barras, Ph.D.

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Section I: Overview Papers



The Role of the Silviculturist at Multiple Scales

Russell T. Graham
Barry Bollenbacher

Abstract—Traditionally, silviculturists have been involved with fine resolution landscape assessments. Today, silviculturists are asked to go beyond that scale to look at a wide range of objectives (including wildlife, commodities, sustainability, diversity, and ecosystem resilience) on scales ranging from landscape to adjacent stands, watershed, regions, and sub-regions. As the issues facing natural resource management become more complex, more contentious, and more political, assessments will become an integral part of management, putting the silviculturist in a vital role of looking over a broad range of temporal and spatial scales.

Introduction

The practice of silviculture in the United States can trace its roots to late in the 19th century when Schlich (1896) and others started organizing the methods and concepts of the discipline. During the 1900s, silviculturists tended forests using both art and science to meet the objectives of landowners (Hawley 1937; Toumey 1928). During this time the majority of wood products produced in the United States were used by developing towns and cities throughout the Western and Midwestern United States (Hutchison 1942). By the end of the 20th century, the practice of silviculture entailed developing methods and systems for establishing and maintaining communities of trees and other vegetation that people value (Nyland 1996; Smith and others 1997). To develop these systems silviculturists depend on a plethora of knowledge including zoology, botany, ecology, physics, wildlife, silvics, pathology, soils, engineering, law, economics, and many others (Nyland 1996). Silviculture evolved, to become an integral component in the management of forests and woodlands and is essential to most adaptive management models (fig. 1).

As we begin a new millennium silviculturists are being asked to design silvicultural systems for diverse objectives ranging from maintaining and renewing ecosystems to producing wildlife habitat and commodities. Moreover, the silviculturist is often asked to design systems to sustain the integrity, diversity, and resiliency of ecosystems. Treatments are applied to stands to meet these objectives but they need to be placed in context of adjacent stands, landscapes, and watersheds. Different stand treatments often need to be

interspersed across landscapes and planned to occur over decades and even centuries. Silviculturists are very knowledgeable about vegetation and vegetation dynamics and this places them in the role of teachers both within their respective organizations and to the general public. To be effective and efficient in prescribing stand level treatments to meet this diverse array of objectives and to fulfill the many other obligations of the position, silviculturists need to be involved at many different spatial and temporal scales.

Scales

There are several different notions of scale and often there is confusion between geographic extent and data resolution (Haynes and others 1996). Geographic extent refers to the area covered by an assessment and resolution describes the amount of detail incorporated in the data describing the geographic extent. Broad-scale (regional) assessments use coarse resolution data to address issues for national and regional planning, mid-scale (sub-regional) assessments use

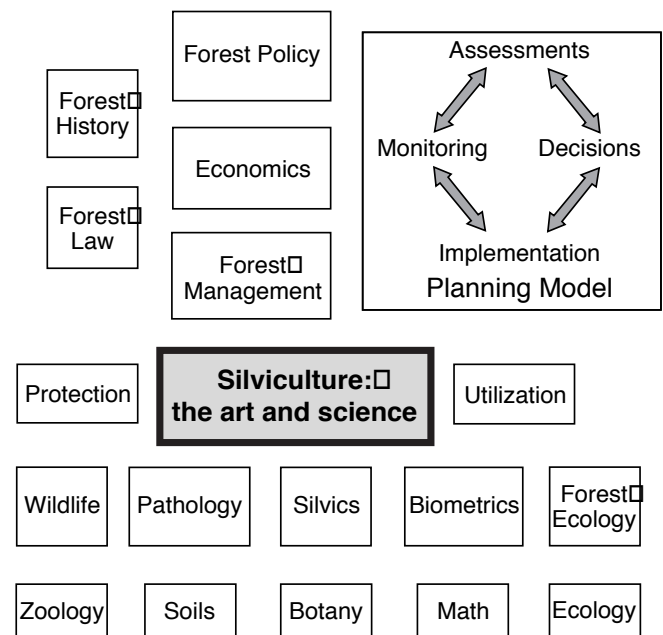


Figure 1—Silviculture is an integrative discipline well founded in the basic sciences. This knowledge combined with management skills and technical knowledge make the practice central to the management of forests and woodlands (adapted and modified from Nyland 1997).

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midresolution data to address issues at the state and regional planning levels, and fine resolution data in small scale (landscape) assessments are used for Forest and District planning. In addition to these spatial scales, temporal scales ranging from minutes (measured in seconds) to millennia (measured in centuries) can be used to describe natural resources. Depending on the issue, location, or need, a variety of scales can be displayed in assessments to inform the public about decisions on natural resource management.

Assessments

Assessments have always been part of forest management. At a local level silviculturists used exam to design stand treatments, while wildlife biologists used habitat surveys and animal censuses to plan hunting seasons and habitat improvement projects. But it became apparent that the cumulative effects of these local management actions and the ever expanding resource issues facing today's managers crossed jurisdictional and ecosystem boundaries (FEMAT 1993). The protection of northern spotted owl (*Strix occidentalis caurina*) habitat, the harvesting of temperate rain forests, and the protection of anadromous fish habitat in the Columbia River Basin are examples of these kinds of contentious resource management issues. Therefore, to make informed natural resource decisions the need for understanding and addressing these issues requires assessments at and across different spatial and temporal scales.

At the largest geographic extent or the broadest scale, assessments describe resources and conditions at sub-continental, continental, and global scales. Global warming, world climate, ocean temperature, or ozone assessments fall into this category. Satellite technology, large-scale models, or even expert knowledge are used to complete these assessments. They use coarse resolution data and are used for national and international planning (Hulme and others 1999).

Regional assessments are used for national and regional planning and cover millions of acres (table 1). Forest health, catastrophic wildfire, anadromous fisheries, community stability, and timber harvests were only some of the issues addressed by the Interior Columbia River Basin (ICRB)

Table 1—Attributes and characteristics typically associated with different kinds of ecological assessments.

Attribute	Assessment
Region	Regional (broad), sub-regional (mid), landscape (small)
Size (acre)	Millions to billions, thousands to millions, tens to thousands
Geographic extent	River basin, multiple watersheds, watershed(s)
Organizational hierarchy	Multiple watersheds, watershed, streams, and vegetation patterns
Data resolution	≥250 acres (coarse) ≤250 acres (mid) ≤50 acres (fine)
Map scale	≥1:100,000 1:100,000 1:24,000
Planning level	National/regional Regional/state Forest/district, silviculturist participation desired, critical

assessment. This assessment described the social, economic, terrestrial, aquatic, and landscape components covering 23.6 million acres of the inland Northwestern United States. Coarse resolution data were used in this assessment covering the majority of the Columbia River Basin. The assessment was organized around multiple watersheds and the detail of information reported was in the order of 250 acres for landscape elements (in other words, vegetation) and states and counties for economic and social elements (in other words, income, population) (fig. 2) (Quigley and others 1997; Hann and others 1997).

In contrast to the large continental and world assessments, the issues addressed at regional scales are more specific but still relatively general. Issues such as ecosystem health, areas or wildlife at risk, sustainability, or long-term productivity are often addressed at this broadscale. The information produced at these scales usually draws conclusions and makes inferences about large areas or subunits of large areas. For example, the ICRB assessment divided the interior Columbia River Basin into 13 ecological reporting units (ERU) each having similar terrestrial and aquatic characteristics. Data were summarized for each ERU and conclusions drawn about the ecological condition of each area. Similarly, the ICRB assessment used 164 subbasins for addressing ecological integrity and landscape patterns (fig. 3). In addition to describing common attributes, these broad-scale assessments can identify unique features that may provide development opportunities or be areas of concern needing special care or protection. For example, the broadscale assessment of the ICRB identified stream reaches dispersed throughout the Basin that were key salmonid strongholds potentially needing protection (Lee and others 1997).

Using midresolution data, subregional assessments are often conducted covering states or smaller areas (fig. 4). The



Figure 2—The interior Columbia Basin assessment used coarse resolution data to describe a large portion of the inland Northwestern United States. These kinds of assessments are used for regional and state planning.

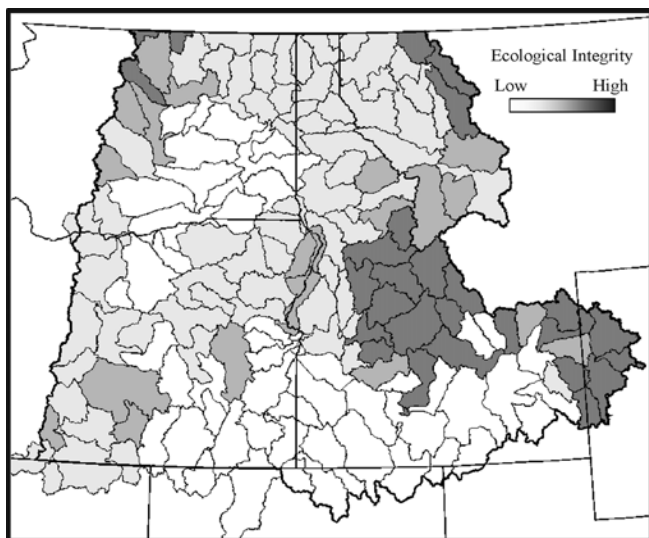


Figure 3—Ecological integrity was rated for watersheds throughout the interior Columbia Basin. The silviculturist has the knowledge experience to be involved in these kinds of assessment processes.

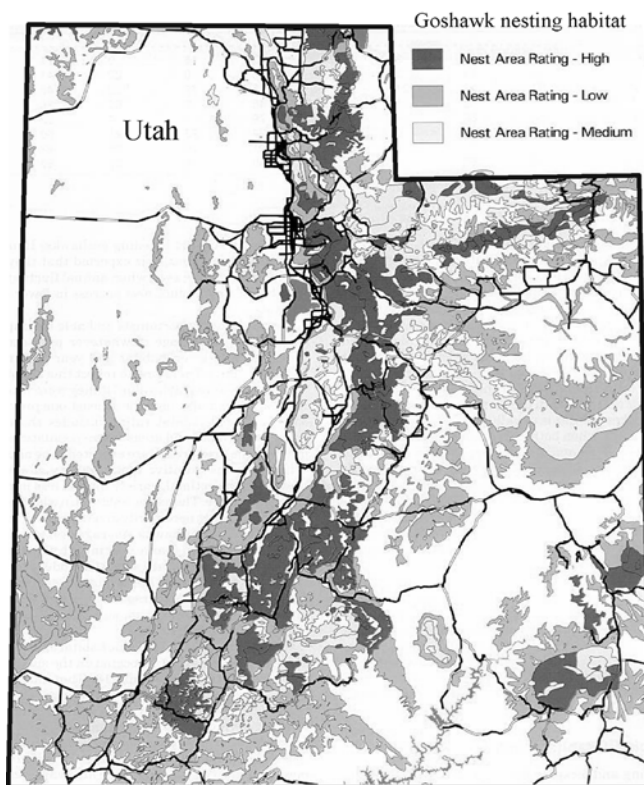


Figure 4—Mid-scale assessments use medium resolution data to describe ecosystems and are usually more specific in the issues they address. This map shows nesting habitat in Utah and the silviculturists of Utah were instrumental in developing these nest area ratings.

extent of these assessments usually covers multiple watersheds with landscape elements displayed with resolutions less than 250 acres and socioeconomic elements commonly derived from county data (table 1). The map scales used in these assessments can range from 1:24,000 to 1:100,000. The issues addressed at this scale are similar in nature to those addressed at the broader scale, but they are usually more specific. For example, instead of addressing general questions about plants or animals, mid-scale assessments may address one species such as the northern goshawk (*Accipiter gentilis*) or one ecosystem such as the pinyon/juniper (*Pinus edulis/Juniperus osteosperma*) woodlands (Graham and others 1999b). At these mid-scales, present and predicted ecosystem conditions are commonly displayed as are more specific descriptions and locations of vegetation, species, communities, and risks.

Silviculturists, biologists, and most resource managers and specialists are most comfortable collecting and analyzing fine resolution data over watersheds, stands, and other small areas (table 1). These landscape assessments are ordinarily conducted at the District and Forest level within the Forest Service to plan and implement vegetation, watershed, and range projects. Both landscape and socioeconomic assessments at this scale are often conducted using fine resolution data with vegetation sampled using patches less than 50 acres while economic and social information are collected using households as the sample unit. Questions and issues addressed at this scale are usually site specific such as the location of culverts impeding fish passage in a particular stream, or describing fire risk near cabins at a particular lake. For example, the landscape assessment of the Coeur d'Alene Mountains in northern Idaho determined the proportion of stands containing western white pine (*Pinus monticola*) in watersheds for use in restoration management strategies (fig. 5).

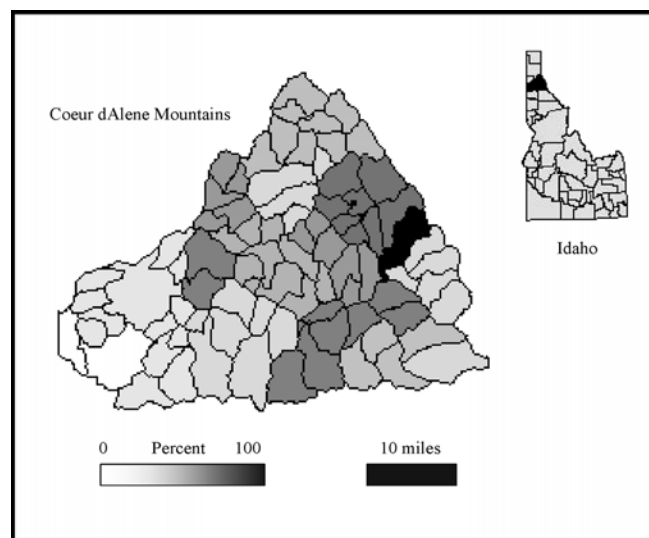


Figure 5—This map shows the proportion of stands in watersheds of the Coeur d'Alene Mountains where western white pine is currently present. The silviculturist should be an active player in these landscape assessments.

Assessment Applicability and Silviculturist Involvement

The silviculturist can, and should, play a variety of roles in assessments. By being involved early and continuously through the assessment process, silviculturists can integrate their knowledge (displayed in fig. 1) into recommendations which may become future Forest Plan standards or guides. The consequence of not being involved is that standards and guides used to direct forest practices coming directly from recommendations developed in assessments will not contain their knowledge. Silviculturists prescribe the majority of the treatments applied to a forest and they need to ascertain that standards and guides affecting treatments are ecologically sound and applicable. Moreover, a silviculturist can help develop assessment recommendations that are not prescriptive (in other words, by defining silvicultural systems) but describe desired conditions that meet management objectives.

Involvement in the assessment process allows silviculturists to recognize the utility of assessments, which depends on the need, issue, scale, and decisions to be made. In addition, the silviculturist can insure the findings and data from assessments are properly applied. In general most silviculturists, wildlife biologists, hydrologists, and managers are most comfortable collecting, analyzing, and using fine resolution data describing stands, stream reaches, or other small areas. Because of this comfort, there is a tendency to utilize fine resolution data gathered at small scales for mid and broad-scale assessments even though fine resolution data may be inappropriate for use at larger scales (Graham and others 1999a). When coarse resolution data from broad assessments are used to describe small areas it is easy to criticize them as wrong, when in reality they are misapplied. Similarly, if the processes, assumptions, and scope of the assessment are not well understood it is easy to assume the assessment is not applicable for addressing a certain issue or condition.

Silviculture is an integrative discipline thus it is critical that silviculturists should participate in sub-regional and landscape level assessments (fig. 1). At the broadest scale, the silviculturist needs to be aware of processes and content of the assessment and understand what contributions these assessments provide towards planning forest treatments. Broad-scale assessments, such as the ICRB provide context for activities at the Region and Forest level while sub-regional assessments provide context for activities at the Forest and District level. By providing context, assessments disclose the conditions or circumstances that surround the situation, proposed treatment, or decision. For example, the context for a Forest Plan amendment defining northern goshawk habitat might be the amount of habitat throughout the region and the administrative and native threats to the existing habitat. Broad scale assessments can also identify unique areas such as salmonid strong holds or ecosystems in peril such as the western white pine and pinyon/juniper systems (Hann and others 1997; Lee and others 1997; Graham and others 1999b). They can also show how common a situation may be. For example, in the interior Columbia River Basin cheat grass (*Bromus tectorum*), an introduced

invasive species, is very common occurring in all 97 counties. Broad scale assessments can also be used to set priorities. For example, broad scale assessments might show how wildfire regimes changed, threatening the integrity of various forest and woodland ecosystems. This information can be used to establish prescribed burning programs or wilderness fire plans.

It is imperative that a silviculturist be involved at the sub-regional level because they have the knowledge and integrative skills to be a key player in designing, leading, completing, and using midscale assessments. Most importantly the silviculturist can make certain the assessment is used properly, validate the information presented, and show its value for making informed decisions. Information available at this scale can be used to define areas at risk from various threats and can define management opportunities. For example, these kinds of data can indicate where vegetation treatments may reduce the risk of catastrophic wildfire or where the greatest risk for landslides may occur. Additionally these data can readily be used to plan and implement landscape level treatments by not only providing context for activities, but help define and/or locate landscape level elements such as wildlife travel corridors, late-successional forest reserves, goshawk foraging areas, or recreation sites. Also at this level, integrated information is often presented for which the silviculturist is well qualified to evaluate. These integrative systems include rating ecological integrity, valuing animal habitat, or defining wildfire risk.

Traditionally the silviculturist has always been involved with fine resolution landscape assessments. Since the early 1970s, silviculturists have been prime players in Forest Service Forest Plans or even smaller Unit Plan assessments. Additionally, fine resolution data were often used for small areas (Ranger Districts) to develop timber, range, or wildfire plans. These assessments describe resource amounts, timber volumes, fuel loading, and other site specific resource characteristics. Recently (1990s), landscape assessments have been used to address local resource issues such as Douglas-fir beetle (*Dendroctonus pseudotsugae*) epidemics or urban interface wildfire hazards. If these assessments apply procedures and concepts similar to those tested and used in subregional or regional assessments, their connectivity, usefulness, and efficiency can be greatly improved. No other person has more knowledge or understanding of the data and information collected and analyzed at this scale than does the silviculturist. It is critical that they be involved in assessing forest and woodland resources at this scale.

In the unlikely event that a completed assessment does not cover the issues a silviculturist is dealing with, or does not contain the necessary products to make an informed decision, the procedures, methodology, data, and concepts described in the assessment may be applied to address these short-comings. If no assessment product is available that meets the need, the first source of information considered should be data collected for an assessment but not reported on in the desired manner. For example, the ICRB assessment produced over 150 data layers of the entire interior Columbia River Basin at a variety of resolutions. These data are available for summarization and analysis (Quigley and others 1996). If no data are available for meeting the need,

the procedures, models, concepts, and techniques used in assessments are appropriate for developing new information. Using techniques similar to those employed in completed assessments will encourage the compatibility and usefulness of the new information. It is imperative that the silviculturist be involved with these approaches for developing new information.

Conclusion

As we enter the new millennium the personnel of the Forest Service are being asked to do more with less. Assessments, planning, consultation, consolidation, implementation, monitoring, and litigation are only a portion of the items keeping silviculturists occupied daily. Even though there are more duties required of the silviculturist than there is time, being involved in assessments and understanding their consequences, procedures, data, and information is critical. As the issues facing natural resource management become more complex, more contentious, and more political, assessments and their completion and use will become an integral part of management. Therefore, because silviculture is the center of forest and woodland management, the silviculturist needs to be creative, persistent, and innovative to ensure that they find the time and resources to be involved with assessments over various temporal and spatial scales.

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Disturbance Ecology in the Northern Rockies: One Perspective

Al Harvey
Penny Morgan

Abstract—Since early 1900s forestry, ecology and related professions have been aware that *external* disturbances had important effects on the development of vegetation. However, the *integral* part they play in ecosystem development and sustainability across time and space was largely underappreciated. Failure to provide appropriate disturbances can place stable and productive species and ecosystems at great risk. Seral western white pine and ponderosa pine are prime examples. Solutions to several critical problems are available and must be more widely implemented, with the support of all parties...soon. It is already too late to prevent significant losses.

Disturbances Typical of the Inland Northwest

Although fire has been the dominant physical force affecting the evolution and development of most interior western forests (Arno 1980), many other forces are also active and may be even more important locally, depending on windows of opportunity. For example, given proper stand developmental history, localized drought, snow, ice, winds, tip-overs, etc., can all incite major changes, including responses from native insects and pathogens. The current problem with the Douglas-fir beetle (*Dendroctonus pseudotsugae* Hopk.) is a good case in point (Carree 1998). Frequent importations of exotic vegetation, insects or pathogens probably were not rare to the region in the past but are obviously even less so in the face of increasing human activities. White pine blister rust (*Cronartium ribicola* J. C. Fisch.) is a classic example of an import causing far-reaching changes (Harvey and others 1994; Monnig and Byler 1992). Changing climate is not unique to this region (Mehring 1985), but is likely to become more important to future forest management (Franklin and others 1991). Two examples are: (1) the relatively recent (2,000–2,500 year) appearance of western red cedar (*Thuja plicata* Donn.) and western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) that accompanied an increase in temperature and moisture in the region (Mehring 1985; Whitlock 1992), and (2) locally moving ecotones in pinyon-juniper (*Pinus edulis* Engelm. *Juniperus monosperma* [Engelm.] Sarg.) and ponderosa pine (*Pinus ponderosa* Laws.) woodlands as a result of localized drought

(Allen and Breshears 1998). However, perhaps the greatest potential for bringing about change in current forests, mostly destabilizing change, will be the backlash from lack of physical disturbances during their development (Baker 1992). Thus we have the current dominance of late seral and climax species, with related health problems, in forests throughout the region (Atkins and others 1999; Harvey and others 1992; Monnig and Byler 1992). In effect, lack of physical disturbance may produce greater and longer lasting biological change than the most spectacular of physical disturbances.

Implications of Changing Disturbance Regimes

Landscape-level changes in disturbance regimes have ramifications not only from the standpoint of creating current forest conditions (Hann and others 1997; Quigley and others 1996; Lemkuhl and others 1994), but also in changing the history of their development. Since the biotic history of forests in the region is relatively short (a few thousand years) we should expect that vegetative communities are not well enough developed to be stable in the face of substantial change (Whitlock 1992). Thus, we can expect them to be reactive. The lack of, or change in, historical disturbance regimes has radically altered regional forests, leading to broadscale conversion of dominant vegetation, primarily favoring climax species (Quigley and others 1996) but without normal successional processes. So, not only are regional forests outside their historic norms (historic range of variability [Morgan and others 1994]), they got there without the “normal” successional processes that provide specific types of preceding vegetative and possibly soil developmental histories. Therefore, current vegetation can be viewed as largely “off-site,” both spatially and temporally, above- and belowground (Harvey and others 1999). That condition is likely to have undesirable impacts on the future stability, productivity and sustainability of these forests.

Current Conditions and Their Connection to Disturbances

Interior forests show large-scale changes in species compositions and accompanying above- and belowground structures and nutrient distributions. For the most part, changes are characterized by a general shift from open ponderosa pine to closed pine and/or Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) stands in dry ecosystems (Covington and others 1994; Gast and others 1991). In moist forests, the change has been from tall, moderately closed pine/larch

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(*Pinus monticola* Dougl. ex. D. Don/*Larix occidentalis* Nutt.) to relatively short closed grand fir/hemlock/cedar (*Abies grandis* [Dougl. ex. D. Don.]) stands (Byler and others 1994; Harvey and others 1994; Moeur 1992; Monnig and Byler 1992). The lack of fire in dry ecosystems (Covington and others 1994) and the importation of white pine blister rust into moist ecosystems (Monnig and Byler 1992) essentially changed the workings of two of the most productive, stable and forgiving (in terms of both management and natural disturbances) ecosystems in north America. As a result, these ecosystems have changed to ones dominated by species not capable of doing so under historic conditions. The lack of physical disturbances has now opened the door to major biological disturbances! Further, blister rust now also threatens many populations of high altitude and southwestern five needle pines (Keane and Arno 1993; Hawksworth 1990).

Where Are We Headed?

With the possible exception of stands dominated by western red cedar on especially moist sites and ponderosa pine on dry ones, productivity, value, and stability of seral species dominated ecosystems exceeded that of most other species combinations throughout the heart of the interior west. As a result of frequent actions from a variety of insects and pathogens, and related fuel accumulations, dominance by climax species will likely lead to significant losses in both productivity and longevity (Harvey and others 1999).

The shallow rooted, low and dense crowns of climax species (Minore 1979) will lead to more strongly horizonated soils with larger accumulations of litter on the surface than characteristic of forests dominated by seral species (Harvey and others 1999). This can lead to rapid immobilization of nutrients, especially nitrogen, in surface horizons. Located at the surface, nutrients are subject to the losses associated with any severe disturbance, especially fire. In the absence of disturbance, nutrient tieup can lead to vegetative stagnation, in moist, cool forests, perhaps within a single generation (Bormann 1995; Kimmens 1994).

The potential, and perhaps likely ultimate outcome of effectively eliminating appropriate disturbances will be forests dominated by species with high nutrient demands, where nutrient storage may be increased but cycling rates increasingly depressed. This will lead to a cycle of increasing stress, with associated endemic insect and pathogen activities creating a domino effect that destabilizes ecosystems (excessive mortality and more frequent fire). Thus, this leads to inappropriate sensitivity to and long-term damage from the same disturbances that once created a highly productive and stable forest ecosystem that was well adapted to intrinsic disturbances, including historical fire cycles and the activities of native insects and pathogens.

As seral species increasingly lose their ability to attain at least a codominant position, they will lose their ability to produce seed. And, without disturbance-related openings, any of the shade intolerant seedlings that are produced will quickly lose out to competition from large numbers (4–6,000 ha (10–40,000 acre)) of shade-tolerants (Graham 1990).

Perhaps most important in this species conversion process is a potential change in genetic strategy of the dominant conifers (Rehfeldt 1994). This change, from one of wide

adaptability and tolerance for endemic insects and pathogens (seral species) to one of narrow adaptive capacities likely predisposed to stress (climax species), may make these forests highly susceptible to destabilization (Harvey and others 1999). In historic forests dominated by seral species, insects and pathogens probably served as stabilizing agents, removing maladapted late seral and climax species relatively early in stand development, preserving only the best of the latter and generally encouraging dominance of the long-lived serals (Harvey and others 1999; Lehmkuhl and others 1994). Such a radical change of endemic processes in dominant ecosystems is likely to have far reaching (largely undesirable) effects on the productivity, stability and management (or lack thereof) of regional forests (Atkins and others 1999; Harvey and others 1994, 1999; Monnig and Byler 1992).

A Window to the Future

Since we are continuing to lose ground with seral species, especially with western white pine and ponderosa pine, it is evident that current approaches have not been and will not likely be sufficient to restore those ecosystems. This loss has become abundantly clear as a result of widespread fire and overcrowding in dry forests and from the salvage logging of infected western white pine. Large trees infected in the 1940s and 1950s gradually succumbed to a combination of the rust and western pine beetle (*Dendroctonus ponderosae* Hopkins) during the last 20 years. The largest tree on “white pine drive” in northern Idaho was removed as a hazard to the public in 1998. In 1975, that area was still deserving of the name. Today there is hardly a white pine to be seen there and, when was the last time you visited a classic ponderosa pine-dominated forest stand in a Douglas-fir habitat type?

Without aggressive intervention, sufficient to change current trends, the outlook for many native ecosystems, particularly those featuring ponderosa pine and western white pine as the primary serals are obviously not good. Although some current efforts have had success and workable solutions for most problems inherent to both dry and moist forests are available (Covington and others 1994; Oliver and others 1994a,b; Mutch and others 1993; McDonald and Hoff 1991), they have not been applied broadly enough to substantially alter present trends. A continuing lack of appropriate disturbance is probably the greatest single threat, with the possible exception of more exotic pests, to future sustainability and productivity of interior western forests.

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Overview of Developing Desired Conditions: Short-Term Actions, Long-Term Objectives

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Abstract—A number of modeling tools are required to go from short-term treatments to long-term objectives expressed as desired future conditions. Three models are used in an example that starts with determining desired stand level structure and ends with the implementation of treatments over time at a landscape scale. The Multi-Aged Stacking Assessment Model (MASAM) is used for assessing sustainable stand structures. Simulating Vegetative Patterns and Processes at Landscape Scales (SIMPPLLE) is initially applied to assess risks from disturbance processes on the current landscape without management treatments, but with fire suppression. The frequencies of process occurrence from these simulation results are input into the Multi-resource Analysis and Geographic Information System (MAGIS), an optimization modeling system, for scheduling activities that reduce these risks and address other management objectives while trying to attain desired future conditions. The derived treatment schedules are used in additional SIMPPLLE simulations to examine the change in risk of natural processes. The resulting economic impacts associated with trying to achieve the long-term desired future conditions are finally quantified by putting not only the final treatment schedule, but also the changes from disturbance processes from the final set of SIMPPLLE runs into MAGIS.

Introduction

Desired future conditions have been quantified for some time at the individual stand level. From the beginning of the requirement for silvicultural prescriptions we have developed means to quantify desired future conditions, to communicate them to others, and to identify what treatments are necessary to achieve and maintain them. These have always been tailored to management objectives. As our management objectives have changed so have our desired future conditions. As our objectives have changed to a focus of restoring ecosystem health and functioning, we have changed to scales above the individual stand. We have expanded our definition of desired future conditions to include the level of disturbance processes that are acceptable and necessary to achieve them. Our techniques and tools for describing and defining desired future conditions have improved to enable us to move from the stand level to the landscape level.

In: Barras, Stan J., ed. 2001. Proceedings: National Silvicultural Workshop; 1999 October 5-7; Kalispell, MT. Proc. RMRS-P-00. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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In addition to considering treatment alternatives for individual stands, we need to consider strategies for applying the treatments at landscape scales. Given the number of acres involved and limited budgets, it is clear that treatments cannot be accomplished in all areas in which they are needed. Are some strategies more effective than others? Is it more cost-efficient to first treat the plant communities where it takes the least intervention to achieve desired future conditions, or to treat those that need more treatments and costs may be higher? Is it better to treat stands whose degree of departure from the desired future condition results in a high probability for a disturbance process versus one that has a low priority for a disturbance event regardless of how far it is from the desired future conditions?

Models and decision support systems can provide information and analyses to aid managers in addressing these questions (Mowrer 1997). Our objective of this paper is to give an overview of a set of models/tools that can help in designing and applying treatments to achieve desired future conditions.

Our overview uses one stand level model and two landscape models, one for simulation and one for optimization. The stand level model is "Multi-Aged Stacking Assessment Model" (MASAM) for Western Montana ponderosa pine (*Pinus Ponderosa* Laws.) (O'Hara 1996). The landscape simulation model is "Simulating Vegetative Patterns and Processes at Landscape Scales" (SIMPPLLE) (Chew 1995 1997). The optimization model is the "Multi-resource Analysis and Geographic Information System" (MAGIS) (Zuuring and others 1995).

Model Descriptions

The stand level model, MASAM, is used to help quantify and evaluate a variety of multiaged ponderosa pine structures. MASAM was developed from a study of data from western Montana and central Oregon to quantify the dynamics of multiaged stands and to assess stand growth stocking relationships. The methodology differed from previous whole-stand approaches in several respects: it defined the total available three-dimensional growing space with leaf area index (LAI); it incorporates age structure by dividing stands into cohorts and determining appropriate growing space requirements for each cohort rather than for the entire stand; and it provides flexibility to assess a wide variety of stocking alternatives.

MASAM is a spreadsheet model that requires the user to specify a number of variables, which describe the desired future structure condition. These variables include: number

of cohorts, or age classes, total leaf area index (LAI), number of trees per cohort, and percent of LAI per cohort. The values assigned are a function of management objectives and forest health considerations. MASAM helps a user to determine if a desired structure is sustainable for a given annual growth rate for a particular site, cutting cycle length or ownership objective. If the cutting cycle is too short to regrow the harvested volume, the system is not sustainable. If sufficient growing space is not created during the reproduction method treatments, then replacement cohorts will not regenerate and the desired structure is not sustained.

The simulation model SIMPPLLE is a stochastic model that predicts changes in vegetation over time and space by using a vegetative state/pathway approach. A vegetative state is defined by dominant tree species, size class/structure, and density. These states are grouped by an ecological stratification of habitat type groups (Pfister and others 1977). The change between vegetative states is a function of natural disturbance processes, including insects, disease, and fire, and management treatments. The probability of a natural process occurring in a given plant community is determined by attributes of the state it is in, its past processes and management activities, the vegetative pattern as identified by its neighboring communities and their past processes. The probabilities determined for each plant community in a landscape are used in a classical monte carlo method (McMillan and Gonzales 1965) to simulate the location and timing of process occurrence. Once a process occurs for a plant community, logic is used to model its spread to neighboring plant communities.

SIMPPLLE helps in understanding landscape interaction between disturbance processes, plant community conditions, and patterns of communities. The system helps us to predict probable scenarios of the location and probability of insect, disease, and fire processes on the landscape. Treatments can be scheduled to change existing conditions and the pattern of conditions thus having an impact on the probability, the origin, and the spread of processes. This information can be used to help identify if the desired future conditions for a large number of stands are sustainable.

The optimization model MAGIS is a spatial decision support system for planning land management and transportation-related activities on a geographic and temporal basis in the presence of multiple and sometimes conflicting objectives (Zuuring and others 1995). An objective to maximize or minimize and other objectives as constraints that must be achieved are specified, and the system selects the location and timing of activities that best meets these specifications and calculates the effects. The objective and constraints are selected from the management relationships within MAGIS, which tabulate output quantities, acres with specified characteristics, miles with specified characteristics, costs, and net revenues. Management relationships can be calculated for an entire planning area, or specific portions such as individual watersheds.

Example Application

The area used for this example is a 58,038-acre planning unit, Stevensville West Central, in the Bitterroot National Forest in Western Montana. The area extends from the

Bitterroot River upward to the Bitterroot Range divide in the Selway-Bitterroot Wilderness. Species composition ranges from ponderosa pine, Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco), and western larch (*Larix occidentalis* Nutt.) mixtures at the lower elevations, to lodgepole pine (*Pinus contorta* Doug.), whitebark pine (*Pinus albicaulis* Engelm.) and alpine larch (*Larix lyallii* Parl.) at the upper elevations. For this application example we have selected the drier, warmer habitat types in the Douglas-fir series (Pfister and others 1977) to focus on. These are habitat types in which ponderosa pine is a major seral species, but Douglas-fir is the climax species. The current composition of the species in this area has only 1 percent in pure ponderosa. A mixture of ponderosa pine with Douglas-fir comprises 44 percent of the stands. Thirty six percent of the area is nonstocked and the remainder is in mixtures of larch, Douglas-fir and ponderosa pine. Within these acres 29 percent of the area is in pole size classes. Thirty six percent are nonstocked. Multistory conditions exist on 17 percent of the area that correspond with the mixture of ponderosa pine and Douglas-fir species composition. None of the multistory structure is pure ponderosa pine.

Step 1

The first step in the applications of these tools is the identification of what structure is not only desired but also sustainable at the stand level. Our concept of desired conditions for these habitat types that are ecologically sustainable are multiaged ponderosa pine stands. Arno and others (1996a,b) reported presettlement ponderosa pine stands in western Montana consisted of low densities in intermediate and large size classes, with very little representation in size classes below about 4 inches. This age structure was the result of localized disturbance/regeneration events that allowed small even-aged groups of trees to become established, and frequent low severity, low intensity surface fires that periodically killed or reduced the density of the lower canopy while leaving the upper canopy relatively unharmed (O'Hara 1996). A MASAM display for a four cohort structure designed for the moderately warm and dry habitat types within the planning area is shown in figure 1. There are currently no areas within the habitat types that meet these desired future conditions.

Step 2

SIMPPLLE helps to provide the basis at the landscape scale for understanding the difference between current vegetative conditions and the desired future condition. SIMPPLLE was used to model the disturbance processes of light and severe western spruce budworm (*Choristoneura occidentalis* Freeman), mountain pine beetle (*Dendroctonus ponderosae* Hopkins) in both lodgepole pine and ponderosa pine, root disease (*Armillaria* sp.), and three intensities of wildfire: light-severity fire, mixed-severity fire, and stand-replacing fire. Two sets of 20 stochastic simulations of 5 decades were made starting with the current vegetative conditions. One set was made with the only management activity being fire suppression, the second set without fire

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1		USER SPECIFIED VARIABLES								
2	TOTAL Leaf Area Index (LAI)	6								
3		Cohort 1	Cohort 2	Cohort 3	Cohort 4	TOTAL				
4	Number of Trees/Cohort	18	24	30	36	108				
5	Percent of LAI/Cohort	40	30	20	10	100				
6										
7		DIAGNOSTIC INFORMATION								
8		Cohort 1	Cohort 2	Cohort 3	Cohort 4	TOTAL				
9	Leaf Area Index/Cohort ECC	2.4	1.8	1.2	0.6	6.0				
10	Leaf Area Index/Cohort BCC	1.4	1.0	0.5		2.8				
11	BA/Cohort (ft ² /ac) ECC	52.6	36.4	20.9	12.6	122.5				
12	BA/Cohort (ft ² /ac) BCC	27.3	16.7	10.5		54.5				
13	Avg. Growth/CC (ft ³ /ac)	21.9	15.0	9.9	2.0	48.8				
14	Avg. Tree Growth/CC (ft ³ /yr)	1.2	0.6	0.3	0.1					
15	Quadratic Mean DBH/Cohort	23.2	16.7	11.3	8.0					
16	Tree Vigor (in ³ /ft ² /yr)	59.9	42.8	63.1	30.5					
17	ECC SDI	69.0	54.4	36.5	25.2	185.1				
18	BCC SDI	40.8	29.2	21.0		91.0				
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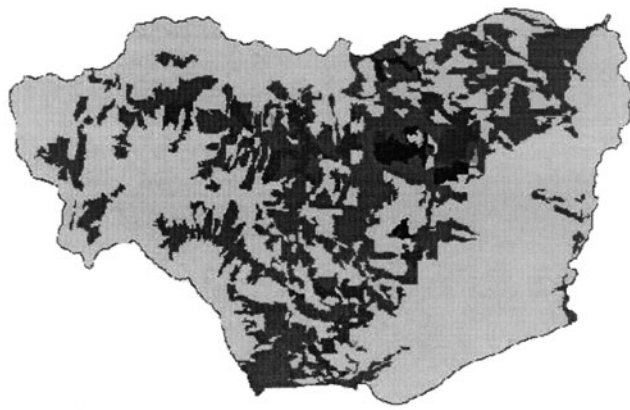
suppression. Two additional sets of simulations were made starting with all of the acres in the selected area in the desired future conditions. No management activities are scheduled to keep them in this condition. Fire suppression was applied in one set of simulations and removed in another set. The levels of processes are displayed for all four sets of simulations in table 1.

Table 1—Average acres of processes per decade across five decades.

Conditions	Stand replacing fire	Mixed severity fire	Light severity fire	Root disease
Current with fire suppression	1877	1198	417	2835
Current without fire suppression	5728	6398	5119	639
Desired with fire suppression	306	542	559	1281
Desired without fire suppression	2875	5702	7478	360

Current conditions without fire suppression result in approximately equal amounts of stand replacing fire, mixed severity fire and light severity fire. Under desired conditions, the level of stand replacing fire is considerably less than that under current conditions. The relationships between the types of fire processes change from the current to desired conditions. Under desired conditions, light severity fire is the most dominate type followed by mixed severity fire and stand replacing fire being the least. Root disease under desired conditions is approximately half of what it is under current conditions with and without fire suppression.

The frequency of occurrence over five decades for each process is kept track of for each plant community. We can use this simulated frequency to represent an estimate of the risk of these natural processes occurring on an individual stand over that period of time. An interpretation is made of what frequency of processes represent the greatest risk to achieving desired future conditions. For example a high risk for mixed severity and light severity fire may not be considered as a potential problem. These processes by removing understory vegetation can help achieve the desired future condition sooner. A high probability of western spruce budworm may be viewed as a greater risk because it is associated with



Risk values		
0	light spruce budworm	>= 50%
1-2	mountain pine beetle	>= 50%
3-4	stand replacing fire	<= 10%
5-6	severe spruce budworm	>= 50%
7-8	stand replacing fire	11-20%
10	stand replacing fire	>= 21%

Figure 2—Example of a risk map for disturbance processes.

stands that have multistory structures composed of tolerant species. An example of a risk map is displayed in figure 2.

Step 3

In Step 3, MAGIS is used to develop a schedule of treatment activities for the landscape using treatments necessary to move the plant communities to the desired future conditions. In addition to the values from a risk map, management relationships for other issues, sediment production, big game hiding cover, and pine marten habitat by drainages, and net revenues are utilized. However in these MAGIS runs, the only change in plant communities, other than the treatments, is stand development, succession. The results from this step are treatment scenarios that are both spatially and temporally specific, and are responsive to both costs and resource effects. One map of treatments by decade is shown in figure 3. This is only one scenario. Many other scenarios could be developed using different combinations of resource objectives.

Step 4

In Step 4, this schedule of stand treatments proposed by MAGIS is incorporated into SIMPPLLE. Stochastic simulations are ran to predict the frequency of the natural processes occurring on the landscape, given this proposed schedule of treatments. The impact of the treatments on the disturbance processes can be quantified. However all the treatments are often not achieved. Sometimes the occurrence of a disturbance process will change stand conditions prior to a scheduled treatment being applied. A treatment schedule that has little impact on disturbance processes may

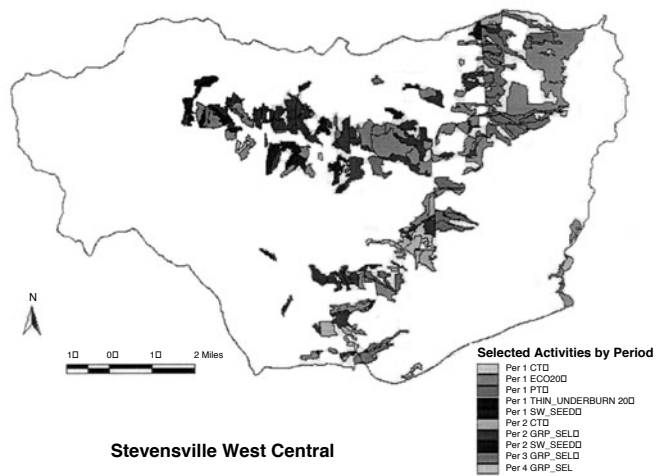


Figure 3—Example of scheduled treatment developed from MAGIS.

turn out to be difficult to implement before processes change stand conditions.

Step 5

To complete the analysis, one of the SIMPPLLE simulations, the resulting treatments that did get applied and the change in stands as a result of all processes are put into another MAGIS run. In this application, all decisions are fixed into the model, and MAGIS is simply used to compute the results. These results include fire suppression costs computed from the predicted fire processes, the treatment costs and benefits, and benefits and costs to other resources such as water quality and wildlife habitat. The results of these simulations can be compared with the results of the “no action” simulations to measure the effectiveness of the treatment scenario. These computations include the effects of the natural processes as well as the management treatments, and provide estimates of the resource impacts associated with “no action” as well as with the treatment scenario.

Discussion

The choice of desired future conditions at both a stand and landscape level must be conditions that can be sustained within a dynamic landscape. The decision must be made by looking at tradeoffs between where we can go within landscape patterns and what we can maximize while working with limited budgets and multiple resource objectives. Often resource effects of trying to get to desired future conditions are based only on the proposed treatments, and the effects of the interaction of the treatments and natural processes ignored.

More than one tool/modeling system is needed. Three tools, developed independently, have been used in a complementary fashion to accomplish designing desired future conditions for individual stands and extending them to

landscape scale applications. The integration of stand level tools and landscape level simulation and optimization models such as SIMPPLLE and MAGIS have the potential for developing spatially-specific scenarios for achieving desired future conditions and providing quantification to use in trade-off analysis at landscapes scales. This provides the opportunity to better understand, manage, and monitor landscapes.

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Section II: Disturbance Ecology



Range and Variation in Landscape Patch Dynamics: Implications for Ecosystem Management

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Abstract—Northern Rocky Mountain landscape patterns are shaped primarily by fire and succession, and conversely, these vegetation patterns influence burning patterns and plant colonization processes. Historical range and variability (HRV) of landscape pattern can be quantified from three sources: (1) historical chronosequences, (2) spatial series, and (3) simulated chronosequences. The last two sources were used to compute HRV for this study. Spatial series were characterized from aerial photographs of 10 similar landscapes on the Bitterroot National Forest, Montana. The LANDSUM model was used to simulate landscape patterns for three landscapes on the Flathead National Forest. Landscape metrics were computed using FRAGSTATS. Results can be used (1) to describe landscape characteristics, (2) to develop baseline threshold values, and (3) to design treatment guidelines for ecosystem management.

Introduction

Vegetation patch dynamics reflect the cumulative effects of disturbance regimes and successional processes on the landscape (Baker 1989; Bormann and Likens 1979; Crutzen and Goldammer 1993; Pickett and White 1985; Wright 1974). Northern Rocky Mountain landscape patterns are primarily shaped by fire and succession, and conversely, these patterns will invariably influence future burning patterns, plant colonization and development processes (Keane and others 1998; Hessburg and others 1999b; Turner and others 1994; Veblen and others 1994). It follows, then, that some general characteristics of disturbance regimes may be described from landscape patch characteristics and dynamics (Hessburg and others 1999b; Forman 1995; Swanson and others 1990). For example, large, severe fires will probably create large patches and these patches on a landscape may indicate stand-replacement fire regimes (Baker 1989; Keane and others 1999). Using this inference, patch and landscape characteristics could be used to assess, plan, and design ecosystem management activities. For

example, the range of patch sizes on a landscape over time could be used to design the size of a prescribed fire so that it is not bigger, or smaller, than what would have occurred historically (Cissel and others 1999; Swetnam and others 1999; Mladenoff and others 1993). Current landscape conditions could also be compared with summarized historical landscape conditions to detect ecologically significant change, such as that brought on by fire exclusion and timber harvesting (Baker 1992, 1995; Cissel and others 1999; Hessburg and others 1999b; Landres and others 1999).

Landscape structure and composition are usually characterized from the spatial distribution of patches—a term synonymous with stands or polygons. Many types of spatial statistics, often called landscape metrics, are used to quantitatively describe patch dynamics of landscapes (Turner and Gardner 1991; McGarigal and Marks 1995). Landscape metrics statistically portray distributions of patch shape, size, and adjacency by patch class (in other words, label or name) across many scales (for example, patch, class, to landscape) (Cain and others 1997; Hargis and others 1998). These metrics are important because they allow a consistent, comprehensive, and objective comparison among and across landscapes, even though many metrics cannot be tested for statistical significance as yet (Turner and Gardner 1991). Landscape metrics are calculated by importing spatial data layers, usually from a Geographic Information System (GIS), into any of the many landscape metrics programs available (for example, FRAGSTATS; McGarigal and Marks 1995; r.le, Baker and Cai 1990).

Landscapes are usually described by a digital thematic layer in raster (for example, grid or pixel map) or vector (for example, line maps) format. The layer contains geo-referenced polygons (in other words, patches) often described by dominant species cover type, but any theme can be used to label patches, providing there is an existing classification (Hessburg and others 1999a). The selection and categories of the mapped theme are important to interpreting landscape patch dynamics (Keane and others 1999). Different categories or themes (for example, cover type and structural stage) will generate entirely different sets of landscape metrics for the same area. So, the detail inherent in the theme design can have a significant influence on the landscape metrics analysis. Thematic layers are usually created from a spectral classification of satellite imagery (Verbyla 1995) or an interpretation of aerial photography (Hessburg and others 1999b).

In: Barras, Stan J., ed. 2001. Proceedings: National Silvicultural Workshop; 1999 October 5-7; Kalispell, MT. Proc. RMRS-P-00. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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A useful concept for planning and designing landscape treatments is historical range and variability (HRV) (Parsons and others 1999, Landres and others 1999). We define HRV as the quantification of temporal fluctuations in ecological processes and characteristics prior to European settlement (in other words, before 1900). Naturally, HRV is highly scale-dependent. Fluctuations at the stand-level might be characterized by changes in the stand basal area or snag density, whereas at the landscape-level, HRV might refer to the fluctuation of patch size, cover type area, or fractal dimension. The HRV concept is invaluable to ecosystem management because it defines threshold boundaries of acceptable change (Swetnam and others 1999). For example, management activities can be designed to create patch distributions that are within the HRV to ensure ecologically sound treatments (Hessburg and others 1999b). Moreover, HRV can be used to assess the condition of a landscape or stand to prioritize or select for proactive management such as restoration (Hessburg and others 1999b).

The range and variation of historical patch dynamics can be quantified from three main sources. First, a chronosequence (in other words, a sequence of maps of one landscape from many time periods) can be input to landscape metric programs and the results summarized across the time span. This is the best source for computing HRV, but unfortunately, chronosequences of historical landscape conditions are absent for many western landscapes because aerial photography or satellite imagery are rare or nonexistent prior to 1930.

Second, a spatial collection of maps from many similar landscapes taken from one or more time periods can be gathered across a geographic region and input to landscape metric programs (Hessburg and others 1999b). This spatial series essentially substitutes space for time (Hessburg and others 1999a) and assumes that landscapes in the series have similar environmental conditions, such that all mapped entities have the same probability of occurrence across all watersheds. Since aerial photography is absent prior to 1900, historical spatial series can be created from similar remote, unsettled watersheds mapped with the earliest imagery possible (Hessburg and others 1999b). One of the biggest limitations of this source is that landscapes are rarely similar in their potential to support similar vegetation. Landform, relief, soils, and climate play major roles in dictating the distribution of vegetation communities across a landscape. However, landscapes can be grouped according to the processes that govern vegetation, such as climate, disturbance, and species succession (Hessburg and others 1999b).

The third method of quantifying HRV involves simulating a landscape to produce a chronosequence of simulated maps to compute landscape metrics. This approach assumes that both succession and disturbance are simulated accurately in space and time, and that the spatial properties of the disturbance simulation are reflected in the patch dynamics (Keane and others 1999). Unfortunately, most landscape fire succession models are overly simplified representations of complex ecological processes, and, as such, they are probably more valuable for comparison than prediction (Keane and others 1999).

This paper presents two approaches for estimating landscape patch metric HRV. First, a spatial series was created for 10 Bitterroot National Forest (BNF) watersheds to assess HRV for lodgepole pine landscapes. Then, the LANDscape Succession Model (LANDSUM) model was used to spatially simulate historical processes on three Flathead National Forest (FNF) landscapes to create simulated chronosequences to calculate patch metric HRV for these areas. Results from this effort can be used to plan and implement landscape ecosystem management activities.

Methods

Spatial Series

Seven BNF landscapes, composed primarily of lodgepole pine (*Pinus contorta*) of about 600 ha in size, were mapped from 1996 aerial photos using the methodology described by Hessburg and others (1999a) (table 1). All landscapes were assumed to represent historical conditions and have the potential to support high coverage of lodgepole pine. Polygons were delineated by BNF personnel based on textural differences in the dominant vegetation stratum. Many attributes were assigned to each delineated polygon, but we only selected the attributes of cover type and structural stage as key polygon descriptors for this project (table 1). Cover type was assigned as the tree species having the plurality of vertically projected canopy cover; non-forest cover types were lumped together. Structural stages were defined by tree diameter size classes associated with stand developmental processes (table 1).

We augmented these seven small landscapes with three larger landscapes (4,000 to 15,000 ha), also found on the BNF (table 1). Polygons on these large landscapes were delineated using the same methodology, but as part of the Interior Columbia Basin Ecosystem Management Project (ICBEMP) in 1995. The three ICBEMP landscapes were mapped from aerial photographs taken in the mid 1930s to describe historical conditions.

Simulated Chronosequences

The LANDSUM is a spatially explicit, deterministic vegetation dynamics simulation model with disturbance treated as a stochastic process (Keane and others 1997). LANDSUM is a polygon-based model, unlike its pixel-based parent CRBSUM, which was developed for coarse scale applications (Keane and others 1996). LANDSUM is based on the conceptual multiple pathway fire succession-modeling approach presented by Kessell and Fischer (1981). This approach assumes all pathways of successional development will eventually converge to a stable or climax plant community called a Potential Vegetation Type (PVT). A PVT identifies a biophysical setting that supports a unique and stable climax plant community. There is a unique set of successional pathways for each PVT present on the landscape (Arno and others 1985). Successional development of a polygon is simulated as a change in structural stage and cover type (in other words, succession class) simulated at an annual time step. Disturbances disrupt successional

Table 1—General descriptions of landscapes used in this study. BNF is the Bitterroot National Forest, ICBEMP is BNF watersheds digitized for Interior Columbia Basin Ecosystem Management Project, FNF-LANDSUM is the Flathead National Forest LANDSUM watersheds.

Landscape	Project	Size	Dominant cover type	Dominant stage
		<i>ha</i>		
Beaverwoods	BNF	766	Lodgepole pine	Pole
Cow Creek	BNF	334	Douglas-fir	Pole
Gibbons	BNF	593	Douglas-fir	Small
Lick Creek	BNF	667	Douglas-fir	Pole
St. Joe	BNF	476	Subalpine fir	Pole
Sawmill	BNF	276	Subalpine fir	Small
Sweeney	BNF	248	Douglas-fir	Small
Sweeney-Joe	BNF-ICBEMP	4,300	Subalpine fir	Small
Roaring Lion	BNF-ICBEMP	6,573	Subalpine fir	Nonforest
Sleeping Child	BNF-ICBEMP	14,398	Subalpine fir	Small
Stillwater	FNF-LANDSUM	14,182	Subalpine fir	Pole
North Fork	FNF-LANDSUM	8,945	Subalpine fir	Pole
South Fork	FNF-LANDSUM	18,038	Subalpine fir	Small

Mapping entity	Map categories or classes
Cover type	1-Pipo, 2-Pico, 3-Psme, 4-Abla, 5-Abla/Pien, 6-Pial, 7-Laoc, 8-Laly, 9-Pial/Pico, 10-Wet meadow, 11-Alpine meadow, 12-Rock, 13-Pial/Laly, 14-Aspen/Cottonwood, 15-Water, 16-Shrubland, 17-Cropland, 18-Tsme, 19-Grass/Forb, 20-Burned over, 21-Nonforest
Structural stage	1-Nonforest, 2-Seedling/sapling trees (0-4 in DBH), 3-Pole tree (4-9 in DBH), 4-Small tree (9-20 in DBH), 5-Medium tree (20-40 in DBH), 6-Large tree (40+ in DBH)
CT-SS combinations	Every logical Cover type/Structural stage combination from the first two entities. For example, a CT = Pial, and SS = nonforest would NOT be a logical cover type.

Note: Pipo-ponderosa pine, Pico-lodgepole pine, Psme-Douglas-fir, Abla-subalpine fir, Pien-spruce, Pial-whitebark pine, Laly-alpine larch, Tsme-mountain hemlock, Laoc-western larch, Nonforest-Includes several categories of nonforest that differ in tree seedling sapling cover.

development and can delay or advance the time spent in a succession class, or cause an abrupt change to another succession class. Occurrences of human-caused and natural disturbances are stochastically modeled from probabilities based on historical frequencies.

Three FNF landscapes were simulated for 1,000 years using the LANDSUM model (table 1). Initial input maps for each landscape were created by delineating and digitizing polygons from historical aerial photography (circa 1930s) by FNF personnel. Landscapes were defined by watershed boundaries. Successional pathway and disturbance parameters were taken from the CRBSUM effort and modified to represent local conditions (Keane and others 1996). LANDSUM output statistics and maps were generated every 20 years for cover type, structural stage, and cover type, structural stage, and cover type-structural type (CT-SS) combination.

Landscape Metric Analysis

We selected cover type, structural stage, and cover type-structural stage combination (CT-SS) maps for landscape metric evaluation. Cover types were selected because they describe species compositional patch dynamics. Structural

stages are used as surrogates to describe size and age class. Lastly, CT-SS maps describe patch dynamics in classes most meaningful to management, which most closely describes a stand, best indicates successional status, and matches those results and analyses done by Hessburg and others (1999a). Spatial data layers were imported into the FRAGSTATS spatial pattern analysis program to compute landscape metrics that was then summarized and analyzed with SAS statistical software.

We computed landscape metrics at two levels. At the landscape-level, metrics were summarized for the entire landscape without stratification by other mapped categories (Hessburg and others 1999b). At the class level, metrics were summarized across the landscape but stratified by classification category to provide detail and context for interpretation of landscape level results (Forman 1995; Chen and others 1996; Hargis and others 1998).

We selected a set of landscape metrics that may be useful in ecosystem management for comparing, prioritizing, and restoring landscapes. Hargis and others (1998) found that only a small set of indices was needed because of redundancy and dependency between metrics (Turner and Gardner 1991). It is also important to match the landscape metric with the biological processes that influence landscape structure (Chen and others 1996). Patch density (PD, patches per

100 ha), mean patch size (MPS, ha), and patch size coefficient of variation (PSCV, percent) were selected because they represent the direct effect of disturbance processes. The landscape patch index (LPI) is maximum percent of the landscape occupied by one patch. It was selected because it represents the upward bounds of patch or burn size. Because edge, shape, and fractal dimension metrics are highly correlated and quite similar in these landscapes, they were not included in this study. Diversity indices, such as Simpson's (SIDI) and Shannon's indices, are descriptive but they are not very informative for management decisions because they combine elements of patch richness and evenness (McGarigal and Marks 1995). Relative patch richness (RPR) rates the richness in patch classes on a scale of zero to 100 (100 have all patch types possible). Evenness, expressed as computed level of diversity divided by the maximum possible diversity for a given patch richness, describes the degree to which the landscape is composed of one patch class. We selected the modified Simpson's evenness index (MSIEI) on the scale of 0–100 percent to evaluate evenness. Mean nearest neighbor (MNN) describes the average distance to the nearest polygon of a different class. Lastly, contagion (CONTAG), a number between 0–100, measures the interspersion and dispersion of patches across a landscape. Landscapes with clumped or aggregated patch types have high contagion values (Li and Reynolds 1994).

We selected four statistics to describe each metric. The average across all landscapes is used as a target or reference

metric and the standard error indicate the level of variability in that metric. The maximum and minimum values of that metric across landscapes are used as boundary or absolute threshold constraints.

Results and Discussion

Spatial Series

Landscape-level FRAGSTATS output is summarized in table 2 for the three mapping classifications across the 10 BNF landscapes. Nearly every landscape from the BNF data set (excluding ICBEMP landscapes) had low patch density, moderate patch sizes, and large variation in patch sizes. These landscapes were similar in patch size (LPI, MPS, PSCV) and contagion (CONTAG). However, individual BNF landscapes had patches that were highly variable in size, shape, and contagion with coefficient of variations often exceeding 200 percent. Douglas-fir and subalpine fir patches were often the largest in size and had the greatest variation, perhaps indicating some lasting effects of fire exclusion. However, the largest structural stage patches were not in the older, large size classes. Cover type metrics were quite similar to structural stage metrics because of the small number of patches on the landscapes.

The Bitterroot National Forest ICBEMP landscapes were quite different in composition and structure when compared

Table 2—Landscape metric statistics for spatial series of BNF lodgepole pine landscapes. The Sawmill landscape is included for comparison purposes. . LPI-landscape patch index, PD-patch density, MPS-mean patch size, PSCV-patch size coefficient of variation, RPR-relative patch richness, MSIEI-modified Simpson's evenness index, CONTAG-contagion.

Landscape metric	Sawmill	Average	Standard error	Minimum value	Maximum value
Cover type					
LPI (%)	41.1	31.8	4.0	14.1	50.3
PD (100 ha ⁻¹)	8.0	4.6	1.1	0.7	10.5
MPS (ha)	12.6	42.7	13.3	9.6	146.9
PSCV (%)	200.4	209.6	18.0	101.1	335.4
RPR (%)	46.2	50.2	2.9	36.0	64.0
MSIEI (%)	69.0	62.7	3.8	45.0	85.0
CONTAG (%)	47.0	54.8	2.4	41.1	65.2
Structural stage					
LPI (%)	43.4	30.5	3.9	16.2	57.7
PD (100 ha ⁻¹)	11.2	6.1	1.4	0.6	11.7
MPS (ha)	8.9	42.1	16.1	8.6	169.4
PSCV (%)	236.2	227.0	36.9	153.3	544.1
RPR (%)	67.7	81.7	1.7	66.7	83.3
MSIEI (%)	79.0	70.7	4.0	48.0	87.0
CONTAG (%)	38.5	47.6	2.5	36.5	66.0
Cover type/Structural stage (CT-SS) combination					
LPI (%)	20.3	12.7	1.8	5.6	24.6
PD (100 ha ⁻¹)	14.1	9.2	2.0	1.5	17.7
MPS (ha)	7.1	21.4	6.5	5.7	66.6
PSCV (%)	142.5	148.7	11.4	110.1	236.8
RPR (%)	18.9	30.9	3.2	18.9	49.1
MSIEI (%)	87.0	71.8	2.7	59.0	87.0
CONTAG (%)	39.1	49.7	1.9	39.1	58.3

with the other seven BNF landscapes. Mean ICBEMP patch size (MPS) ranged from 61 to 147 ha while patch density (PD) went from 0.68 patches per 100 ha to 1.65 per 100 ha. Surprisingly, the coefficient of variation (PSCV) was around 200 percent, similar to that of the small BNF landscapes. ICBEMP landscapes tended to (1) be higher in elevation (in other words, composed of higher amounts of subalpine fir, whitebark pine), (2) contain higher amounts of non-forest and rock cover types, (3) have higher proportions in early seral stages (except for Sleeping Child), and (4) be created from earlier photography. As a result, ICBEMP patches were larger with higher variation and higher contagion. Patch shapes were more irregular, being controlled by topography and the large size of these landscapes (Chen and others 1996). Large ICBEMP landscapes tend to have more diverse biophysical settings, which increase the number of possible cover types and topographical constraints (Swanson and others 1990). And, ICBEMP landscapes were created from photography more representative of historical conditions since 1930s aerial photography was used.

It was interesting that results from Hessburg and others (1999a) were similar to those computed for the 10 BNF landscapes, considering they used 132 watersheds from a region quite distant from the Bitterroot valley. This may indicate that fire processes are similar on landscapes that support lodgepole pine (Heinselman 1981; Peet 1988; Wright 1974). The small number of historical landscapes present in

the BNF-ICBEMP sample ($n = 3$) may limit the applicability of these results to management planning.

Simulated Chronosequences

Landscape metric statistics are summarized for the South Fork FNF landscape in table 3, with the 500-year averages of metrics computed from the North Fork FNF landscape included as reference. Patch sizes (MPS) are roughly comparable between the BNF and FNF landscapes, but patch densities (PD) and patch size variations (PSCV) were quite different due to the simulation of fire. South Fork cover type patches were larger than the structural stage and CT-SS patches (table 3) because simulated fires created many patches on the landscape, but most progressed along similar successional pathways composed of the same cover type (Keane and others 1997). Mean nearest neighbor (MNN) was substituted for RPR to illustrate that it could be a useful metric for landscape management. Simulated Stillwater landscape results are not presented due to lack of space.

The FNF landscapes had much higher patch densities than BNF landscapes because the spatial simulation of fire created many smaller patches by the end of the simulation. This effect is also evident by the large PSCV values in the structural stage and CT-SS classifications (table 3). Initial input FNF landscapes, like the BNF landscapes, were mapped with minimum polygon sizes around 5 ha, but simulated

Table 3—Landscape metric statistics for simulated chronosequence of South Fork FNF landscape. Ave 500 yr simulated conditions of FNF North Fork landscape is for reference. LPI-landscape patch index, PD-patch density, MPS-mean patch size, PSCV-patch size coefficient of variation, MNN-mean nearest neighbor, MSIEI-modified Simpson's evenness index, CONTAG-contagion.

Landscape metric	North Fork	Average	Standard error	Minimum value	Maximum value
Cover type					
LPI (%)	49.6	33.1	0.5	29.0	36.2
PD (100 ha ⁻¹)	27.5	19.7	3.3	0.3	48.9
MPS (ha)	21.8	36.8	16.6	2.0	368.1
PSCV (%)	270.0	220.1	41.58	83.6	918.4
MNN (m)	177.9	220.1	58.5	58.1	1208.0
MSIEI (%)	39.6	44.9	1.3	37.0	60.0
CONTAG (%)	60.4	59.7	0.55	55.9	64.7
Structural stage					
LPI (%)	62.7	24.4	1.0	13.4	36.2
PD(100ha ⁻¹)	22.2	58.4	6.0	0.6	117.5
MPS (ha)	20.7	15.4	6.1	0.9	176.2
PSCV (%)	2537.0	2874.0	189.1	210.2	4603.0
MNN (m)	173.0	125.2	31.8	44.1	1175.7
MSIEI (%)	31.8	56.0	1.2	43.0	79.0
CONTAG (%)	66.5	50.9	0.8	42.7	59.5
Cover type/Structural stage (CT-SS) combination					
LPI(%)	31.3	17.0	0.8	12.5	29.5
PD (100 ha ⁻¹)	52.9	129.6	12.7	0.7	271.9
MPS (ha)	10.5	7.8	3.5	0.4	146.7
PSCV (%)	2371.3	3263.0	194.4	200.8	5441.0
MNN (%)	235.0	173.5	38.9	65.6	1519.5
MSIEI (%)	42.3	48.4	0.9	39.0	73.0
CONTAG (%)	51.1	52.0	0.85	42.4	62.2

fires continually sliced polygons so that, by the end of the simulation, the minimum polygon size was less than 1 ha. We are developing GIS techniques to modify simulated layers to make them comparable through time using GIS techniques of smoothing and nibbling.

Management Implications

An interesting finding is the apparent dissimilarity in landscape metrics across mapping classifications. Metrics computed from cover type patches are somewhat different for the same landscape described by structural stage or CT-SS combinations (tables 2 and 3). There were approximately twice as many CT/SS combination patches as there were cover type patches or structural stage patches. This then halved the size (MPS), increased the density (PD), and increased the variation (PSCV). Interestingly, some metrics computed for CT-SS combination maps were very similar to those computed for all other maps (see CONTAG, MSIEI, RPR). This illustrates the importance of matching of management objectives to map design and construction to facilitate planning and ensure the appropriate ecological attribute is being assessed.

The Sawmill and North Fork landscapes are presented as *target landscapes* in tables 2 and 3 to compare spatial patch characteristics to HRV and to determine patch parameters for treatment design. Four patch metrics (PD, MPS, MSIEI, and CONTAG) for the Sawmill landscape were consistently outside the standard error bounds for the HRV of BNF landscapes, yet within the minimum and maximum values for cover type, structural stage, and CT-SS. This might indicate that the landscape is outside historical conditions. The North Fork 500-year average landscape metrics were not within any standard error bounds, and outside of most maximum-minimum ranges, for almost all metrics and for all classifications (table 3). Unlike the Sawmill watershed, this is because the topography, potential vegetation, and fire regime of the North Fork watershed is quite different from the South Fork drainage, even though the two are in the same geographical region. This illustrates the importance of clustering landscapes in a spatial series based on landscape processes rather than composition or structure.

We can roughly estimate the target size and maximum allowable boundaries of possible restoration treatments from mean patch size (MPS) or LPI statistics (tables 2 and 3). The maximum and minimum patch size can be assessed from four statistics at four levels of confidence. The standard error can be used as the most conservative estimation of patch variability. The next confidence level would be to apply the maximum and minimum range of patch size coefficient of variation (PSCV) to the mean patch size. A more lenient alternative to this approach is to use the maximum PSCV instead of the mean PSCV. The next most liberal level estimation of range of variability uses the minimum and maximum values. Hessburg and others (1999b) recommend the 80th percentile of mean patch size as a more realistic maximum patch size. Lastly, the largest patch can be bounded from the largest patch index (LPI).

Summary and Conclusions

This paper demonstrates how the historical range and variability (HRV) of landscape composition and structure can be described from landscape metrics computed from two sources, spatial series and simulated chronosequences, using the FRAGSTATS program. Landscape metric statistics quantifying HRV can then be used to assess, prioritize, compare, and design landscapes for possible restoration treatments. Spatial series and simulated chronosequences are suitable sources to compute landscape structure, but each has major limitations. Spatial series assume that all landscapes are similar in environmental conditions, which is often not the case. Simulations of chronosequences rely on inexact computer models that often contain oversimplifications of disturbance and succession processes. However, since historical chronosequences are essentially unavailable, these two sources currently provide the best data sets for quantification of HRV.

These spatial metric analyses illustrate the importance of assessing landscape structure and composition of individual watersheds prior to treatment to determine management and planning parameters. The high variability between and across landscapes makes a "one-size-fits-all" set of recommendations difficult. Landscapes are shaped by the timing and severity of past disturbances, such as fire, and, fire spread and intensity are influenced by topography and vegetation, which are extremely variable across landscapes (Hessburg and others 1999a; Swanson and others 1994). Therefore, it is essential that landscapes be mapped using appropriate vegetation classifications so that patch dynamics can be quantified to provide a guide for design and assessment of treatment opportunities.

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Changes in Plant Communities After Planting and Release of Conifer Seedlings: Early Findings

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Abstract—Plant diversity, density, and development data from an extensive research program in conifer plantations in northern California suggest changes in plant community composition after site preparation and many kinds of release. Based on 17 studies, the average number of species per study area after 10 years was 25 with composition of 1 conifer, 1 hardwood, 8 shrubs, 12 forbs, and 3 graminoids. Species ranged from 13 to 46. Density, foliar cover, and height varied by treatment and type of vegetation present. Density in a mixed shrub community, for example, ranged from 902 to 18,168 plants/acre after 10 years and in a mixed shrub-grass community from 147,400 to 254,900 plants/acre. Additional data are presented on the fate of a serious invader, side-by-side development comparison of two vigorous shrubs, and changes in species composition in several vegetation density classes in a plantation after 27 years.

Introduction

To manage the land effectively, the forest ecosystem manager of the future will need information on plants, animals, fish, insects, fungi, and even genes (McDonald 1999). For plants, knowledge of species composition, density, and development could be critical, both for individual species and for communities of species. Although much information is available on economic species like pine and fir seedlings, little is available on currently uneconomic species that often have worth by providing wildlife, scenic, water, medicinal, and other amenity and commodity values to society. The conventional plantation may even provide values of equal or greater worth than those derived from the eventual harvest of trees.

Recognition that the vegetation management base must be broadened to include detailed information on currently uneconomic species is increasing. Gordon (1979) recommended that foresters begin to build a database for vegetation that is expected in specific areas. Wagner and Zasada (1991) stated that forest managers across North America need to consider the potential effect of non-crop vegetation on nearly every acre of newly forested land. O'Hara and others (1994) noted that future forestry must embrace "a mix of commercially valuable and non-valuable species." Aune

and others (1993) suggested that greater within-stand species variation will be desired in the future and "the growing and planting of high-quality seedlings of hardwood trees, shrubs, and other flowering plants is now expanding to meet multi-resource objectives." Rietveld (1992) noted an increased demand for diverse tree and shrub nursery stock, especially for species that provide food and shelter for wildlife.

McDonald and others (1996) noted that within the ecosystem management concept, a major need is for knowledge on silviculture treatments that will provide desired plant communities at specific times in the future. Silvicultural treatments imply disturbance, and that in turn implies planned disturbance, such as that caused by site preparation and plantation release.

The importance of disturbance in forest ecosystems has long been of interest to ecologists and in general has been focused on the successional relationships of plant communities. In general, succession was thought to be governed mostly by competition and predation. Disturbance was viewed as an uncommon event that occasionally caused major changes to the composition and structure of communities. More recently, however, interest has focused on the nature of disturbance itself and on the cause and effect of disturbance events. For example, Reice (1994) argued that disturbance is ubiquitous and frequent relative to the life spans of the dominant taxa. Thus communities are always recovering from the last disturbance. Furthermore, the size and extent of the disturbed areas modifies the ensuing disturbances—creating an ever-changing environment. To the silviculturist, this condition means that modeling plant succession is even more difficult. Considerations of competition, predation, and ubiquitous (but ever-changing) disturbance must be considered.

Sousa (1984) provides some specifics of disturbance applicable to patches ("plantations" in this paper) that are helpful. First of all, the environment of plantations differs with size, and the environment within a plantation is seldom, if ever, homogeneous. This difference alone allows for much variation in the composition, abundance, and development of species in plantations. Second, small plantations have a greater perimeter-to-area ratio than large plantations and thus are filled more quickly with fewer species than large ones. These species tend to be similar to those on the edge and less opportunity is available for succession. Conversely, large plantations tend to have more species present, and those with wind-dispersed and soil-bank reproductive strategies (Grime 1979) are favored, along with the usual species from root crowns, rhizomes, and large propagules.

In: Barras, Stan J., ed. 2001. Proceedings: National Silvicultural Workshop; 1999 October 5-7; Kalispell, MT. Proc. RMRS-P-00. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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Each plantation is different, and therefore each has various amounts of different species with different growth and competition potentials. This characteristic presents both an opportunity and a challenge to the vegetation manager. The opportunity is to manage for one or more of the additional values noted above; the challenge is to recognize that competition levels to the planted conifer seedlings may vary, and could be excessive.

An extensive research program on vegetation management alternatives in northern and central California was begun in 1980 and continues today (Fiddler and McDonald 1987; McDonald and Fiddler 1993). Forty-two related studies, mostly installed between 1981 and 1990, comprise the program. Two other studies, entitled "Shrub Development Comparison" and "Long-term Plant Succession," are included in this paper to complement the research program. All are concerned with plantation release, not site preparation. The overriding objective was to provide a scientific basis for the application of new and existing vegetation management techniques.

Although the planted conifer seedlings are readily seen in a young plantation, only the largest and most competitive of the other plant species are noticed, and even they are seldom counted or their development studied. In truth, almost all plant species in young plantations are unknown, the number and development of plants of each species is not quantified, and the future role of most species in the plant community is only surmised. The literature is scant. McDonald (1999) recorded the diversity, density, foliar cover, and height of every species that was present in a small clearcut over a 5-year period in the northern Sierra Nevada; and Bailey and others (1998) and Schoonmaker and McKee (1988) studied the understory vegetation and the species composition and diversity of vegetation in western Oregon.

This paper describes the post site-preparation plant community and changes in its diversity, density, foliar cover, and height over a 10-year period; contrasts the early development of two common and aggressive shrub species, and reports succession over a 27-year period in one plant community in northern California.

Methods

Physical and Biological Environment

Study locations, including the two complementary studies, range from latitude of 39°N to 42°N and from longitude 121°W to 124°W. The climate is best described as Mediterranean with long, hot, dry summers and cool, moist winters. Daily summer temperatures vary from 60°F to 106°F and winter temperatures from -10°F to 50°F. Average annual precipitation ranges from 35 to 80 inches, with 40 to 80 percent falling as snow. No precipitation from mid-May through mid-September is common. Soil moisture is the factor most limiting to growth. Elevations vary between 3,000 and 6,500 feet, and slopes between 5 and 35 percent. The study areas are located in conifer plantations in the general forest zone; not in riparian, roadside, or slash disposal areas. Site quality of study areas rates as average to above average. An above-average site, for example, would support ponderosa pines (*Pinus ponderosa* Dougl. ex Laws. var. *ponderosa*) that average 70 feet tall in 50 years.

Ponderosa pine and Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) seedlings were the conifer species most often studied, with Jeffery pine (*Pinus jeffreyi* Grev. & Balf.), red fir (*Abies magnifica* A. Murr.), and California white fir (*Abies concolor* var. *lowiana* [Gord.] Lemm.) occasionally examined.

Because the climate and site quality of the study areas were conducive to colonization and rapid growth by a myriad of plant species, the logged areas or converted brushfields must be prepared for planting. Mechanical clearing, usually with a bulldozer, created piles or windrows of slash and other vegetation, which almost always were burned. Broadcast burning was used as a site preparation tool as well.

After site preparation, each study area was temporarily bare and in a condition receptive not only to planted pines and firs, but also to propagules of many hardwoods, shrubs, forbs, and graminoids. Common hardwoods included vigorous sprouts of Pacific madrone (*Arbutus menziesii* Pursh), tanoak (*Lithocarpus densiflorus* [Hook. & Arn.] Rehd.) and California black oak (*Quercus kelloggii* Newb.). Prominent shrub species, both from seeds and root-crown sprouts, were several species of manzanita (*Arctostaphylos* spp.), ceanothus (*Ceanothus* spp.), wild cherry (*Prunus* spp.), and others. The most abundant forbs were from the genera *Cirsium*, *Phacelia*, *Chimaphila*, *Trientalis*, *Stephanomeria*, *Lotus*, *Galium*, and *Vicia*. Graminoids included species from the genera *Carex*, *Bromus*, *Achnatherum* (*Stipa*), and *Festuca*. Bracken (*Pteridium aquilinum* [L.] Kuhn var. *pubescens* Underw.) was the most common fern.

Study and Design

Among the 42 individual studies, 25 were located in National Forests, 2 on State of California land, 2 on USDI Bureau of Land Management acreage, 2 on privately owned land, and 1 on an Indian Reservation. The two complementary studies were located on the Shasta-Trinity National Forests near Mt. Shasta. The studies embraced the full range of vegetation management techniques, which included direct, indirect, and conifer seedling enhancement (genetics). Direct manipulation treatments included manual release, chemicals, mulching, mechanical (machines), and grazing. Indirect methods involved using such environmental factors as shade and organic matter, and conifer enhancement was through breeding. In all the studies, density and development of the conifers and other vegetation in the various treatments were compared to an untreated (not released) control. The study period was 10 years, which was about the time that crowns of the conifers would be closing in the treatments with the least competing vegetation.

All studies had three to six replications. The experimental design was completely random, or randomized block with analysis of variance and Tukey tests as the analytical tools. Each replicate (plot) in each treatment consisted of about one-seventh acre on which were 30 to 35 conifer seedlings surrounded by two or three rows of buffer. Of these seedlings, 15 to 30 were randomly selected for sampling, which usually was performed in the fall.

Sampling of shrubs, forbs, and graminoids took place on five randomly selected, seedling-centered milacre (0.001 acre or 43.56 ft² of area) subplots. Quantified parameters

included density, foliar cover, and height. In most instances, number of plants was quantified for density, but for a few species the number of stems or fronds was recorded. A list of all plant species on study plots was maintained and monitored at each visit. Study areas were measured annually for the first 2 years after treatment, with most areas being measured the third through fifth, seventh, and tenth years as well.

In the first complementary study, deerbrush (*Ceanothus integrerrimus* H. & A.) and greenleaf manzanita (*Arctostaphylos patula* E. Greene) from a local seed source were grown in small peatpots and outplanted in spring 1992 on a site of high quality. The study area was open (no overstory) and maintained constantly to be free of competing vegetation. The experimental design was 3 plots with 25 plants of each species per plot. Number of stems per plant, crown diameter, height of tallest stem, and phenology (leaf development, onset and duration of flowering, seed production and dissemination, leaf fall) were recorded at various times throughout the year from 1992 through 1995.

The second complementary study was located in a large, mature brushfield on a below-average site near Mt. Shasta. Before site preparation by windrow and burn, the principal shrubs were greenleaf manzanita, snowbrush (*Ceanothus velutinus* Hook.), and Sierra plum (*Prunus subcordata* Benth.). After site preparation, greenleaf manzanita and snowbrush invaded mostly from dormant seeds in the soil and Sierra plum originated vegetatively from belowground structures. In addition to the planted ponderosa pines, a few herbaceous species from seeds in the soil or from seeds that blew in on the wind became established. Earlier work from 1961 to 1965 had left a wide range of shrub densities, and when the study began in 1966, these were separated into four shrub categories: no-shrub, light, medium, and heavy shrubs with values of about 5,000, 10,000, and 15,000 plants/acre separating the categories.

Results

Plant Community Relationships

The post-site preparation plant community on average or better sites in northern and central California is characterized by rapid colonization of species having several regeneration strategies. Hardwoods and shrubs from root crowns,

shrubs and forbs from dormant seeds in the soil, and forbs and grasses from seeds that are wind-blown comprise the categories of species from the most common strategies. A few shrubs and ferns also develop from belowground structures, such as rhizomes and root sprouts. Together, the various species of vegetation gain in abundance and grow rapidly. In general, species that arise from root crowns or rhizomes dominate. But many early seral species become established during the first few years after site preparation. Their populations can be huge and, at least for a year or two, temporarily exclude nearly all other species. Bull thistle (*Cirsium vulgare* [Savi] Ten.) is a good example. Its peak density in a new plantation on a good site in the northern Sierra Nevada of California was 34,000 plants/acre at age 2 (McDonald and Tappeiner 1986). Two years later, its density had fallen to just over 3,400 plants/acre.

Based on 17 studies with 10 years of data, the average number of natural species (not planted seedlings or non-native species) per study area, by vegetation category, were conifers, 1; hardwoods, 1; shrubs, 8; forbs, 12; graminoids, 3; and ferns 0. Thus the mean number of species after 10 years was 25. The range was 13 to 46 species per study. In eight studies, the number of species increased over that present one year after site preparation, in eight studies the number of species decreased, and in one study the number remained the same. However, for studies with a species gain, the increase was 38 percent; for those with a decline, the decrease was 12 percent.

In six study areas, we recorded number of species by treatment. Average number of species after 10 years was chemical (Velpar), 13; manual release, 22; grazing, 22; and control 20.

For those study areas where the various categories of vegetation were present, average density in the controls ranged from 2,604 ceanothus plants/acre to 82,250 forbs/acre (table 1). And values after 10 years showed that density had increased from 19 to several hundred percent over initial values. Foliar cover values, which ranged from 2 to 38 percent, also had huge increases after 10 years except for forbs, which had declined by 93 percent. Average height also showed large increases over the 10-year period.

For results among treatments, data (including that for planted ponderosa pine) for all treatments after 10 years, are reported for three typical study areas having different plant compositions. In a community composed primarily of

Table 1—Average density, foliar cover, and height of vegetation in the control, northern California, 10 years after treatment.

Category	Density			Foliar cover			Height		
	Mean	Pct ¹	Range	Mean	Pct ¹	Range	Mean	Pct ¹	Range
		<i>plants/acre</i>			<i>pct</i>			<i>ft</i>	
Manzanita ²	14,495	+19	933–60,267	26	+H ³	1–62	4.1	+H	1.8–7.2
Ceanothus ²	2,604	+20	900–4,933	16	+H	3–56	4.4	+H	1.5–11.5
Combined shrubs ²	24,608	+H	950–118,300	38	+H	1–71	3.9	+H	1.1–9.5
Graminoids ²	64,172	+H	3,333–184,000	3	+H	T ⁵ –8	1.8	+H	0.5–3.7
Forbs ²	82,250	+H	27,300–137,200	2	–93	0	1.2	+92	0.6–1.8

¹Percent change between initial value at beginning of study and value in table.
²Number of study areas with manzanita was 12; ceanothus 7; combined shrubs 13; graminoids 8; forbs 2.
³+H = more than three-fold increase.
⁴Trace.

mixed shrubs, average density over all treatments ranged from 902 to 18,168 plants/acre. Foliar cover ranged from 40 to 73 percent (McDonald and Fiddler 1995). If the community was composed primarily of mixed shrubs and grass, similar values were 147,400 to 254,900 plants/acre and 32 to 75 percent foliar cover (McDonald and others 1996). If the community was made up of shrubs, forbs, grass, and ferns, its density over all treatments after 10 years ranged from 182,345 to 223,500 plants/acre and its foliar cover from 65 to 71 percent (McDonald and Fiddler 1997).

The density and development of the various categories of vegetation in a young conifer plantation is a function of the release treatment, and the survival and growth of the conifer seedlings in the plantation is a function of the kind, amount, and timing of the vegetation with which they compete. Thus the response of the various categories of vegetation and the planted pines to treatment is interrelated. In general, manual release, if applied two times as grubbing, discriminates against shrubs from dormant seeds in the soil and leads to a community of forbs and grasses. Here the planted conifers grow well. If release is chain-sawing shrubs and hardwoods, the plant community is little affected unless the shrub stubs are treated with a selective herbicide. If the release treatment is grazing or mechanical (large machines), the plant community is not significantly affected, and the conifer seedlings develop according to the degree of competition present. Mulches of various kinds and sizes of material, if large enough and present long enough, obviously stifle invasion and lead to competition-free conifer seedling growth. Because most foliar herbicides are selective, the ensuing community can be manipulated as desired. In general, the plant community after treatment consists of what is originally there minus most plants from the most competitive species.

Timing of treatment is critical. Release the first year after planting is most effective, but done in the next 2 years is worthwhile (McDonald and Fiddler 1993). Early release allows the pines and firs to continue the growth trajectory established in the nursery without interruption, which in turn enables them to capture site resources in an accelerating manner. Interruption of the growth trajectory by competing vegetation often means death of the seedling or unacceptable development.

In only one study was a nonnative species noted. It was yellow star-thistle (*Centaurea solstitialis* L.), probably brought into the area on a hunter's pickup. Although it persevered for 10 years, it had peaked in density and foliar cover, and was declining at the end of the study (table 2).

Revegetation of new plantations is best described as chaotic. Not only do plants originate from all five classical regeneration strategies that Grime (1979) described; past stand history, and the type of treatment that we employed also influence them. Many species, a huge variety in density and development, and every conceivable distribution pattern for every species characterized the vegetation. However, plant succession 10 years after site preparation and release seems to have a few common threads. In general, plant species that develop the most roots and the deepest root systems are the ones that dominate. Replacement of annuals and biennials by perennials is another trend.

Competition relationships also are numerous and the subject of other papers. However, one fact stands out, and that is that release is not an option—it is essential. Competing vegetation is well adapted to the plantation environment—perhaps better adapted than the nursery-grown conifer seedlings. Study after study has shown that the conifer seedlings must be released if they are to grow at the potential of the site (McDonald and Fiddler 1993).

Shrub Development Comparison

Early survival and development of deerbrush and greenleaf manzanita clearly favored deerbrush although there were both similarities and differences (McDonald and others 1998). As to similarities, deerbrush and manzanita both sustained moderate early mortality (17 versus 11 percent, respectively) and almost no subsequent mortality, developed multiple stems on most plants (5.6 versus 3.6 stems per plant, respectively), maintained the initial proportion of plants with multiple stems (89 versus 76 percent), and grew rapidly. For differences between species, deerbrush showed the most dynamic development. Its strategy was to develop a clump of stems on most plants during the first growing season; manzanita had a similar strategy, but it did not become manifest until the second season. By the end of the second growing season, deerbrush produced significantly more stems per plant, was taller, and had wider crowns than greenleaf manzanita (table 3). Deerbrush also began producing flowers and setting seed during the third growing season, while greenleaf manzanita did not produce flowers or seed during the 4-year study.

Long-Term Plant Succession

When this study began in 1966, the natural plant community in all density classes consisted of 6 shrubs, 10 forbs, and

Table 2—Density, foliar cover, and height of yellow star-thistle on 15 milacre plots in one study in the northern Sierra Nevada, 1983–1992

Year	Density		Foliar cover		Height	
	Mean	Range	Mean	Range	Mean	Range
	 plants/acre		 pct....		 ft	
1983	438	0–2,250	1	T ¹ –7	1.5	0.6–2.3
1988	10,138	250–30,250	4	T–12	1.9	0.9–3.0
1992	1,850	0–7,125	T	T	1.6	1.3–2.1

¹T = trace.

Table 3—Mean height and crown width of 62 deerbrush and 67 greenleaf manzanita plants, Mt. Shasta, California, 1992–1995.

Item	Year	Species	Mean	Root mean square error	F ¹	P ¹
				<i>inches</i>		
Height	1992	Deerbrush	5.5	3.99	0.81	0.370
		Manzanita	4.9			
	1993	Deerbrush	18.8	9.52	15.73	0.001
		Manzanita	12.3			
	1994	Deerbrush	32.1	12.26	39.97	0.001
		Manzanita	18.6			
Crown	1995	Deerbrush	40.4	13.88	41.21	0.001
		Manzanita	24.9			
	1992	Deerbrush	5.6	3.24	4.29	0.040
		Manzanita	4.3			
	1993	Deerbrush	29.4	11.85	80.20	0.001
		Manzanita	10.9			
	1994	Deerbrush	42.9	12.37	125.70	0.001
		Manzanita	18.8			
	1995	Deerbrush	51.5	12.79	120.45	0.001
		Manzanita	27.0			

¹Statistical terms: F denotes the F ratio; P is the probability of a greater effect than measured.

1 grass (McDonald and Abbott 1997). When the study ended in 1992 the community consisted of five shrubs, two forbs, and one grass. However, two shrubs, both forbs and the grass consisted of only a few plants in the entire study area. Thus the plant community before intervention by silviculturists consisted of essentially 3 shrub species, increased to 17 species plus planted ponderosa pines after site preparation and release, and after 27 years was back to the original 3 shrubs plus the planted pines.

Discussion and Conclusions

Silviculturists traditionally apply a controlled disturbance to a forest ecosystem to create a desired species composition, number of plants, and stand structure that will yield the amenities and commodities needed by society. Inherent in this disturbance is a goal to guide the course and rate of secondary plant succession toward a mature forest. This goal is accomplished by enhancing the environment for desired species and making it less suitable for undesirable species. Eliminating or reducing the number of species is not a goal, but reducing the number of plants of the most competitive species is.

We found that colonization of plant species after site preparation is rapid and dynamic. Many plants of many species from all major categories quickly invade and occupy the area. During the first 10 years, 13 to 46 species were present. Number of species increased in some study areas and decreased in others. Composition of the typical natural plant community after 10 years was 1 conifer, 1 hardwood, 8 shrubs, 12 forbs, and 3 graminoids. Except in the Velpar treatment, species composition did not differ markedly among treatments, including the control. Although the number of

plants differed greatly among treatments, the number of species did not.

For the Velpar treatment, the decrease in number of species was mostly in the shrub category, although all vegetation categories showed reductions. On our study sites, Velpar persists in the surface soil for about 3 years—a timespan that allowed the conifer seedlings to grow rapidly in a virtually competition-free environment. After 3 years, the surface 4 to 6 inches of soil is free of Velpar and species of forbs and annual grasses with shallow root systems can become established. Taproot-developing shrubs from dormant seeds in the soil still cannot become establish, however. By the time that deeper-rooted species are free to establish, the shade and capture of site resources limit the survival and growth by the conifer seedlings.

Not only is the number of species quite large, so is the number of plants. Data from the three typical, but different, plant communities, showed densities that ranged from 902 to 254,900 plants/acre and foliar cover values that ranged from 32 to 75 percent after 10 years.

The density and development data for the non-native yellow star thistle portrayed the resilience of the native plant community to it. After 10 years, this serious invasion was being contained, and although density and height values on some plots were still high, they were declining. And horizontal development, as manifest in foliar cover, was reduced to only a trace. Given enough time and the lack of further disturbance, forested ecosystems tend to be remarkably resilient.

The comparison of deerbrush and greenleaf manzanita was an attempt to answer the question: “Which is the more competitive species?” However, two shrub species having similar dates of origin and growing side-by-side, are almost impossible to find in nature. Thus, we grew and outplanted

the deerbrush and greenleaf manzanita seedlings to facilitate the comparison.

At least for the first 4 years and based solely on plant size (as opposed to soil moisture and nutrient use), deerbrush was the most competitive species. More stems per clump mean a wider clump, and this, plus being taller, allows occupation of a larger area sooner than rival greenleaf manzanita. And by being able to produce seed soon after disturbance enables at least some new plants to occupy favorable microsites that would quickly become occupied by other vegetation, especially on good sites.

The progression from 3 to 17 and then back to 3 species in the long-term plant succession study cuts to the very heart of vegetation management. Purely in terms of number of species, the time and labor of converting the brushfield into a plantation seems questionable. But, although the number of species is small, one huge difference in the most successful (no shrub) treatment has been achieved—a traditional arborescent pioneer, ponderosa pine, has been established by vegetation management, and 30 years later is growing at the potential of the site. Establishing trees is the critical first step. Eventually, shade-tolerant conifers also will become established (or be planted) and form the mixed-conifer forest that originally occupied the area. Certainly more species of plants and animals will find the forest environment more conducive to establishment than if the area had remained a brushfield. And because the stand-destroying frequency of fire in a forest is lower than that in a brushfield, the chance of a debilitating fire has lessened.

Vegetation management can direct trends in early plant development and species succession, and through various treatments achieve specific combinations of species desired by the ecosystem manager. Our extensive study in northern and central California is providing insight to the density and development of many species and categories of vegetation in conifer plantations that have been released in many ways. The extensive database and the relationships so formed should be helpful to managers who are attempting to restore ecosystems on disturbed forestland.

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Simulating Historical Disturbance Regimes and Stand Structures in Old-Forest Ponderosa Pine/Douglas-fir Forests

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Abstract—Forest Service land managers, with the collaborative assistance from research, applied a disturbance based restoration strategy to rehabilitate a greatly-altered, high risk Northern Rocky Mountain old-forest ponderosa pine-Douglas-fir stand. Age-class structure and fire history for the site have been documented in two research papers (Arno and others 1995, 1997). Silvicultural treatments using stocking reduction through a normal timber sale offering and prescribed fire to simulate disturbance processes, were used to restore a semblance of historical vegetative conditions. These actions should improve tree vigor of the old-forest and promote ponderosa pine regeneration, while reducing the risk of significant mortality due to wildfire, root disease or bark beetle through reduced competition and open spacing. Other resource objectives were achieved including enhancement of big game winter range and flammulated owl habitat, retention and creation of wildlife snags, stimulation of fire dependent species, improved aesthetics, commodity production, and road closure/rehabilitation. Post harvest re-measurement reflects successful application of disturbance simulations. High prescribed fire severity with resulting mortality, illustrates the risk of restoration activities and the requirement of good execution. Photographs from four permanent camera points document pre-harvest, post-harvest, and post-burn conditions.

Introduction

Wildland fire, historically and dramatically, influenced the landscapes of the inland west. For example, within the 2.1-million acres (0.85-million ha) Lolo National Forest in Western Montana, 24 percent of the forest area, over 500,000 acres (202,000 ha), burned, on average, every decade prior to active fire suppression of the early twentieth century (USDA FS 1994). Of these acres, two-thirds burned every 10 to 50 years in low-severity fires as defined by fire ecology research (Applegate 1998, Smith and Fischer, 1997). These episodes of wildland fire had a significant effect on basic vegetation

structure, composition, pattern and the associated ecological processes that were sustained on the landscape (Williams 1996). The resulting plant communities and canopy structures also provided a critical niche for several wildlife species such as pileated woodpeckers (*Dryocopus pileatus*) and flammulated owls (*Otis flammeolus*).

Ponderosa pine (*Pinus ponderosa*), and western larch/Douglas-fir (*Larix occidentalis*/*Pseudotsuga menziesii*) forest types are adapted to and sustained by these historically frequent low-severity wildland fires (Stickney 1990). Prior to 1900, nearly 50 percent of these low-severity burned sites were dominated by open grown stands of old-forest trees comprised of single-storied, multiaged stands (Arno and Harrington 1998; Losensky 1993). Low-severity fires periodically killed most of the immature trees and occasionally some of the larger mature trees, singly or in groups. Infrequently, tree regeneration survived to maturity, maintaining dominance of fire-adapted conifers.

Today very few open grown old-forest stands remain. For example, recent Lolo National Forest inventory listed ponderosa old-forest at nearly 12,000 acres (4,850 ha) and western larch/Douglas-fir old-forest at 24,000 acres (9,700 ha). Both total only about 6 percent of the old forest ponderosa pine and western larch/Douglas-fir acres that was historically present (USDA Forest Service 1999). As a result of fire exclusion and early-day logging of larger trees, the low-severity fire regime sites have become multi-storied of varying densities of overstory ponderosa pine with dense thickets of understory Douglas-fir or other more shade tolerant species (Fiedler and others 1997).

Many species of wildlife are dependent upon open grown old-forest ponderosa pine/Douglas-fir or western larch/Douglas-fir forests. In upland habitats in the Northern Rockies, pileated woodpeckers nest exclusively in large diameter ponderosa pine or western larch snags (McClelland 1977). Flammulated owls nest in abandoned pileated woodpecker cavities and forage on insects in open understories (Wright 1996). Wright concluded that fire exclusion, which results in increasingly dense understories, might make old-forest ponderosa pine stands unsuitable for flammulated owl foraging.

Other species are not exclusively dependent on old-forest ponderosa pine or larch, but utilize this community type as one of several preferred habitats. These species include black-backed (*Picoides arcticus*) and three-toed (*Picoides tridactylus*) woodpeckers which forage on bark beetles (such as *Dendroctonus*, *Ips* and *Pityophthorus*) and wood borers (*Cerambycidae* and *Buprestidae*) resulting from periodic

In: Barras, Stan J., ed. 2001. Proceedings: National Silvicultural Workshop; 1999 October 5-7; Kalispell, MT. Proc. RMRS-P-00. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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insect or fire mortality. According to Hutto (1995) exclusion of periodic fire in these communities makes them relatively unsuitable for black-backed and three-toed woodpeckers. Elk (*Cervus elaphus*) and mule deer (*Odocoileus hemionus*) forage on sprouting shrubs occurring after low-intensity burns (Hillis and Applegate 1998). Various studies in the west (Hillis and Applegate 1998, Leege 1978) have shown that periodic burns can increase forage production from 200–2000 percent. While much of the forage for elk on winter ranges is associated with young forests, the scattered large overstory trees of old-forests allow deer and elk to better cope with severe winter weather (Baty and others 1996) due to greater snow interception by old-forest overstories.

These multi-storied stands are now at risk for major disturbances such as disease and insect epidemics and high-severity stand replacing fires. Also at risk are specific habitat niches for many wildlife species that are adapted to the more open grown old-forest character.

Silvicultural prescriptions developed by an interdisciplinary team, implemented through timber harvests, are designed to partially simulate historic fire disturbances. These treatments were designed to achieve desired sustainable ecosystems, meet Forest Plan objectives, and provide amenities and commodities for society. In this paper, we describe a specific silvicultural prescription, representative of many being implemented through timber harvests, to simulate historic disturbances and stand structures thus achieving desired forest conditions within the Lolo National Forest.

Ecosystem Management and National Forest Plans

Ecosystem management has guided National Forest and other agency management since the early 1990's. Ecosystem management reemphasized efforts to provide for sustainable ecosystems and public needs. Generally, ecosystem management uses an ecological approach to achieve management objectives (Robertson 1992). More specifically, ecosystem management employs that ecological approach to meet multiple-use management goals of national forests and grasslands by blending the needs of people and environmental values in such a way that national forests and grasslands represent diverse, healthy, productive, and sustainable ecosystems (Bartuska 1993).

Ecosystems are dynamic. The composition and structure of the plant component are shaped and sustained on the landscape not only by natural succession, but also by disturbances such as fire, wind, drought, insects, pathogens, and humans. Wildland fire not only influenced the pattern and structure of the landscape, it was also significant in determining which plants and animals would dominate, which would be suppressed, and which would be excluded (Agee 1993). Fire is a key process in ecosystem dynamics, function, and sustainability.

Listed within the portion of the Lolo Forest Plan (USDA Forest Service 1986) that covers the landscape historically dominated by frequent, low-severity fires, are many goals and objectives. The goals and objectives are to provide a socially acceptable and healthy environment and diverse ecosystems, and to provide habitat for viable populations of

all indigenous wildlife. At the same time, there is specific emphasis to provide quality big game winter range as well as timber production.

Management planning strategies that consider historical conditions and processes appear to have advantages for maintaining biological diversity and ecological processes in the development of treatment alternatives and should appropriately result in recovery of biologically diverse and sustainable ecosystems (Arno and Harrington 1998; Arno 1997; UCRB 1997; Kaufmann 1994).

Research Application

Studies by Arno and others (1995, 1997) have detailed the fire history and resulting age-class and structure on several 2.5-acre (1 ha) plots in old-forest sites on the Lolo and Bitterroot National Forests within historically frequent low-severity fire regimes. Forest restoration on one of these research sites, the Whitehorse area, was planned and executed based on historic stand data and is the focus of this discussion. This project, which includes commercial tree removal and reintroduction of fire, is representative of many forest restoration projects being conducted on the Lolo National Forest.

Additional research on the Whitehorse stands was conducted by Hejl and Woods (1991). Their research focused on identifying songbirds dependent on old-forest ponderosa pine communities. They found a sizable assemblage of songbirds both strongly and weakly associated with old-forest ponderosa pine communities.

The research provided the baseline stand, fire history, and wildlife data. These data were used to develop long-term management strategies which will eventually attain historic stand structures. On both dry and moist sites, the major changes in stand structure between 1900 and the 1990s were an increase in basal area and in the number of trees per acre as well as the development of an understory of shade-tolerant trees (Arno and others 1995). Re-introducing fire alone will not restore most old-forest stands because of unprecedented accumulations of duff and ladder fuels. The dense understories, including many trees whose crowns extend into the overstory canopy, cannot now be killed by fire without damaging the old-forest trees (Harrington 1991). Growth and vigor of the old trees also have declined noticeably in many stands while mortality has increased (Arno and others 1995). To restore a semblance of self-perpetuating pine, it is necessary to reduce the understory mechanically and thereafter control understory development using prescribed fire.

Site Description

The Whitehorse project area is confined to a rather small landscape of approximately 400 acres (162 ha), on the Ninemile Ranger District in the Fish Creek drainage about 35 miles (56 km) west of Missoula, Montana. It is positioned between proposed wilderness and industrial private ownership at mid elevation, 4,000 to 4,800 ft, (1,200-1,500 m) on a steep, mildly convex, south-facing slope. The landform is dissected with minor ridges and draws which create changes

in environmental conditions. Consequently, four habitat types (Pfister and others 1977) occur within the old-forest restoration treatments. The research plot (100 m² or roughly 2.5 acres) lies on the two most common habitat types, Douglas-fir/blue huckleberry (*Pseudotsuga menziesii* / *Vaccinium globulare*), and Douglas-fir/pinegrass (*P. menziesii* / *Calamagrostis rubescens*), which are moderately warm, dry to moist and cool dry sites.

The mean fire interval has been determined at approximately 26 years beginning in 1636 with no evidence of fire since 1897 (Arno and others 1995). Stand replacement fires were probably rare. This classic dry site fire regime with frequent fires of low-severity would also include the extreme southeast portion of the project area which is Douglas-fir/ninebark ninebark phase (*P. menziesii*/ *Physocarpus malvaceus*-*Physocarpus malvaceus*). These three habitat types are in Fire Group 6 with a mean fire interval range of 16 to 42 years (Davis and others 1980; Fischer and Bradley 1987). A fourth habitat type, grand fir/twinflower (*Abies grandis* / *Linnaea borealis*) occurs in a draw along the western edge of the restoration treatment. It is considered a warm moist site depicted by Fire Group 11. Fire intervals in such moist sites are generally longer, though in this case the past fire interval would be influenced by the frequency of the adjacent, more prevalent regime (fig. 1).

Mortality from other disturbances such as bark beetle, root disease or windthrow contributed to large openings within these stands and an increase in fuel loading. A specific example is annosum root disease (*Heterobasidion annosum*), which can accelerate with harvesting (Hagle 1992).

Prior to treatment, the research plot representing the stand had a predominant, single broad-aged old-forest component with a layered structure of ponderosa pine and Douglas-fir. The oldest individual ponderosa pine on these dry types exceeds 500 years of age (Arno and others 1995).

Most trees in this old-forest became established during a 70-year period (1700–1770) despite intervening surface fires (fig. 1). This major age group became established after

surface fires in about 1687 and 1698. Its rapid early growth suggests that these fires (and perhaps associated root disease and bark beetle attacks) may have created openings by killing many of the overstory trees. Before treatment, the plot had 7 live trees and about 4 dead trees/acre (17 live and 10 dead trees/ha) (post-1900 mortality) as well as several older dead trees (1800s mortality) that were established before the late-1600s fires. So, an open “shelterwood” overstory of at least 12 trees/acre survived the 1698 fire, and an age class, 1700–1770, developed beneath it. Some of these pines became suppressed and today are only about 12 inches d.b.h. (30.5 cm) and 40 feet tall (12.2 m) at approximately 250 years of age. This is less than half the diameter and height of the dominant trees in this age group (Arno and others 1995). Stocking levels in excess of 180 ft² of basal area/acre (41 m²/ha) exceed historic conditions. Older age classes of ponderosa pine and western larch exhibit a decline in vigor which is accentuated with increased competition (Arno and others 1995, 1997).

Prior to treatment, the stand was overstocked with many small-diameter old-forest ponderosa pine of 250 or more years of age and younger understory of Douglas-fir. Because of this heavily stocked overstory, understory trees were almost exclusively slow-growing Douglas-fir less than 90 years old. Since 1900 the basal area of the stand had increased from 152 ft²/acre to 187 ft²/acre (34.9 to 42.9 m²/ha) 61 percent of which is Douglas-fir (table 1) (Arno and others 1995).

Restoration Strategy

Based on the philosophy of ecosystem management and direction contained in the Lolo National Forest Plan, specific management objectives for this project area are to restore and maintain ponderosa pine type old-forest character, reduce the risk of stand replacement wildfire, simulate historical disturbance regimes through fire application, and provide for wildlife habitat. The restoration strategy involves stocking reduction and the return of fire (Arno 1988). The silvicultural treatments applied were single tree selection cutting and group tree selection harvests. The high residual stocking level of the single tree selection cutting, with a regeneration goal, could arguably be called intermediate cutting involving both thinning and improvement harvests to remove undesirable trees and reduce stocking density. Group selection harvests are primarily a result of sanitation/salvage cutting Douglas-fir within active armillaria root disease areas (*Armillaria ostoyae*). The group

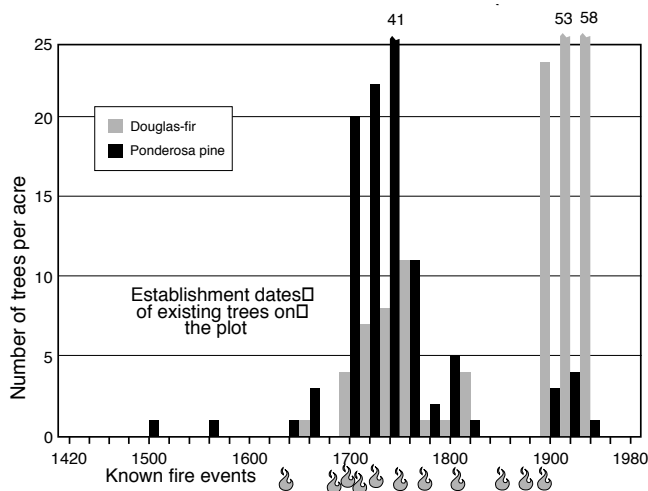


Figure 1—Whitehorse Creek old-growth plot Lolo-3 (adapted from Arno and others 1995).

Table 1—Comparison of overstory tree stocking and species composition expressed as basal area (square feet per acre) in 1900, historic, 1991, pre-harvest and 1997, post-harvest, in the Whitehorse area (Arno and others 1995; unpublished, Rocky Mountain Research Station, Missoula, MT).

Species	1900	1991	1997
PP	113 (73%)	126 (67%)	82 (82%)
DF	39 (27%)	61 (33%)	18 (18%)
Totals	152	187	100

selection was applied on less than 5 percent of the restoration area. These actions were taken to improve tree vigor of the old forest, and promote ponderosa pine regeneration, while reducing the risk of significant mortality due to wild-fire, root disease or bark beetles.

The stocking reduction objective was accomplished by removing, through timber harvest, excess understory trees and a portion of the overstory (fig. 2,3). The target was to retain an average of 45 trees/acre (111 trees/ha) of the desired dominant and codominant trees in an irregular



Figure 2—Photo Whitehorse stand prior to treatment.



Figure 3—Photo Whitehorse stand after commercial timber harvest.

spacing averaging 100 ft² of basal area/acre (23 m²/ha). There were fewer old-forest trees in the western most draw occurring on grand fir/twinflower habitat type. Here the target residual basal area was 80 ft²/acre and about 45 trees/acre (18 m² and 111 trees/ha).

The timber sale involved five other units of tractor and skyline yarding and road construction. These other harvests consisted of 13 acres (5 ha) of clearcut with reserves, and 66 acres (27 ha) of shelterwood final cut with reserves. The old-forest restoration involved 70 acres (28 ha) of single tree selection and group tree selection. All of the harvest areas were planned for underburning, with ecosystem maintenance burning planned for an additional 63 acres (26 ha). The overall intent was to accomplish as much of the restoration needs as possible within the small drainage with no subsequent entry for a period of 40 years.

Lab incubation of samples confirmed the presence of annosum root disease in ponderosa pine which appeared more active in a portion of the area that had been salvage logged in the past (Hagle 1992). The concern that this disease would accelerate with harvesting was addressed with a borax stump treatment by the purchaser within eight hours of felling.

The submerchantable excess understory was reduced through slashing and underburning. The partial slashing by the timber purchaser after harvesting augmented the fuel loading to allow better understory mortality during prescribed burning. Approximately 100 stems/acre (247 trees/ha) of understory conifers were left standing with a high level of expected fire mortality. This treatment will better ensure the objective of understory removal is met.

The partial slashing treatment was added in exchange for omitting the leave tree protection requirement. A change largely as a result of conditions created by the purchaser's election to skyline and tractor yard tree length. The yarding technique removed tree tops and limbs that until recently were routinely left on site. Without this material on site, it became imperative to augment the fuel loading with partial slashing of the submerchantable understory. Fuel augmentation is to increase the amount and continuity of drying fuel and expand the season when ignition could take place. At the same time, leave tree protection, which is manual removal of logging debris from the base of leave trees, was not needed.

The tree length yarding practice is a harvesting trend brought about with the increasing occurrence of processing equipment at landings. One faller teamed with a processor can do the work of three fallers that limbed and bucked in the woods. This reduces the purchaser's costs in payroll and state mandated workman's compensation. It also alleviates the difficulty in filling and maintaining logging crews. On the other hand, it creates problems in maintaining woody debris for long term soil productivity, wildlife habitat, and regeneration microsites.

Underburning was applied following timber harvesting and slashing to reduce severe wildfire risk, to rejuvenate shrubs and other fire adapted species, and to provide site preparation for natural regeneration of seral plants (fig. 4). Objectives of the underburn are important to specify so proper burn prescriptions can be developed (Harrington 1991). Specific desired ranges for treatment effects included reducing vegetation litter and duff reduction less than 1/4

inch (0.64 cm) depth spread evenly over 20 percent of the area for natural regeneration of ponderosa pine and western larch. Additionally desired were extensive small woody fuel reduction, 40 to 100 percent top-kill of shrubs, retention of 5 to 10 tons/acre (11.2 to 22.4 megagrams/ha) of woody debris greater than 3 inches (7.6 cm) diameter, and 60–90 percent understory tree mortality, while limiting overstory mortality to less than 10 percent. The burn objectives are achieved at specific fuel and soil moisture contents, plant phenology, and ignition techniques. Improved shrub and grass vigor results as harvesting opens the overstory crown layer allowing more sunlight to reach the forest floor, and underburning stimulates sprouting. Another response from underburning is the resin production that is stimulated at the base of fire-scarred residual ponderosa pine (Smith and Arno 1999). This may increase decay resistance which increases the durability and longevity of future snags.

Restoring stand structures and reintroducing fire to these historically low-severity fire regime ecosystems is not without risk. With the long absence of wildland fire, some old-forest tree mortality is unavoidable due to excessive stress and high fuel loadings (Arno and others 1995). The underburn, which was envisioned as both a site preparation treatment and an ecosystem maintenance burn, was planned for hand ignition under moderate spring conditions.

Results and Discussion

The two-fold, overarching objectives of these treatments are closely related and include: (1) returning these landscape ecosystems to a more sustainable and resilient condition; and (2) simulating historic disturbance regimes, stand densities, species compositions and stand structures. The silvicultural treatments of stocking reduction and underburning have begun the process of ecosystem restoration, the culmination of these objectives.

The commercial timber sale accomplished much of the stocking reduction through single tree selection and group tree selections in 1998. The post harvest overstory remained predominately old-forest ponderosa pine and Douglas-fir (fig. 2,3 and 4). Younger age classes of both species were also still intact but at significantly reduced levels.

The average volume per acre removed was 6,000 board feet per acre. These were mostly understory Douglas-fir trees, but also included some of the overstocked 1700 to 1770 era old-forest ponderosa pine and Douglas-fir. The total stocking, at least within the research plot, was reduced to 100 ft²/acre (23 m²/ha) (table 1). The sale of 1,467 thousand board feet of sawtimber was sold at \$345.52/thousand board foot, sealed bid, in September 1993 with only two bidders. Subsequent timber harvests to maintain this highly valuable old-forest are expected in 40 years to regulate stocking and species composition. Future entries are expected to yield 4,000 to 6,000 board feet/acre. Underburning will be an important companion treatment with timber harvests in replicating the natural disturbance regimes that created and sustained this relatively open old-forest. High aesthetic and wildlife values of large diameter trees of this old-forest remain. Such treatments will also greatly reduce the risk of stand-replacement fire.



Figure 4—Photo Whitehorse stand after fire application.

The successional numbers of Douglas-fir brought about by fire suppression were removed through timber harvest, partial slashing, and underburning. The timber harvest removed about 55 percent of the trees and about 34 percent of the basal area. Post harvest plot remeasurements (unpublished, Rocky Mountain Research Station, Missoula, MT) show that Douglas-fir composition was reduced from 33 percent to 18 percent (table 1). Stand structure is now predominately single-storied and likely resembles historic conditions, which represents a change from the multi-storied pre-treatment stand (fig. 2,3 and 4).

Reintroducing fire to this site after a 102-year absence was realized with a 1998 spring underburn. Though originally planned for hand ignition, a helicopter equipped with a sphere dispenser was used instead to save time and money. All five units of the timber sale, 149 acres (60.3 ha) and an ecosystem maintenance burn, 63 acres (25.5 ha) were ignited in one day at a cost of \$66/acre. Within the old-forest restoration, the prescribed fire treatment resulted in a low-severity burn on 55 acres (22.3 ha) (79 percent) and a mixed to high severity on 15 acres (6.1 ha) (21 percent). The prescribed fire successfully reduced the density of the shade tolerant seedlings, saplings, and immature conifers. However, this fire also caused severe crown scorch in the overstory in 21 percent of the restoration treatment, which represented 12 percent of the immediate contiguous southfacing landscape. Unfortunately, the highest level of overstory mortality occurred within the research plot, truncating the opportunities for further research. Although acceptable at the landscape level, the mixed to high fire severity which was primarily the result of an aggressive ignition pattern, was not desired at the stand level. Ignition strip width and time interval between strips are key controls of prescribed fire intensity. This points out the inherent

risks and that any deviation from the burn plan, expected forecast, or estimated fuel loading can result in greater fire impact than desired. In retrospect, objectives would have been better achieved through either hand ignition and/or full slashing of shade tolerant conifers which would require less subsequent fire intensity. However, narrow aerial ignition strips at the proper duration can be successful under these conditions. This experience highlights the varying degrees of control/risk presented by the range of restoration activities, in other words, prescribed fire, timber harvest, and other cultural practices.

Species adapted to and dependent upon frequent low-severity fire benefited by these treatments. Immediately following the prescribed burn the forest floor looked as though a summer wildfire had occurred. The forest floor surface was significantly charred by fire, but the high duff moisture content resulted in partial duff retention. About half the litter layer was consumed, being partially protected by moisture content. Most of the understory vegetation was consumed above ground, but undamaged below ground. This enabled fire-adapted shrubs, grasses and forbs to quickly respond and utilize available nitrogen.

Improved old-forest tree vigor is anticipated with reduced competition and the potential flux of nutrients. Following an initial increased risk of bark beetle infestation to fire-injured trees, this risk should lessen because of reduced stocking. Research on nearby Sawmill Gulch, found that two approximately 800 year-old pines on this site grew slowly (mean annual radial increments of about 0.02 inch or 0.5 mm) for more than 100 years prior to about 1525, followed by accelerated growth (two to three times as fast) for several decades after disturbance (Arno and others 1995).

Snags and snag replacements remain at 4 to 6/acre (10 to 15/ha), somewhat grouped across the landscape. This density of snags and live replacements exceeds the density recommended in the Regional Snag Protocol (Samson and others, in preparation). Cavity nesters such as pileated woodpeckers and flammulated owls should find excellent nesting and foraging opportunities indefinitely, assuming that longterm management will include frequent prescribed underburns.

Both the scattered and concentrated overstory mortality created excellent foraging opportunities for black-backed and three-toed woodpeckers. Both species were observed foraging in the area during the summer of 1999. Research by Caton (1996) suggests the area should provide foraging opportunities for these two species for next 5 to 6 years.

Conclusions

Historic fire and stand structure research has given Lolo National Forest managers an excellent basis to plan and implement scientifically-based silvicultural treatments to simulate historical disturbance regimes and stand structures in old-forest ponderosa pine/Douglas-fir. These in turn have resulted in a greater appreciation of, and enhanced habitat for many low-severity fire adapted and dependent plants and wildlife species.

Interdisciplinary silvicultural prescriptions designed to simulate historical disturbance processes and implemented through commercial timber harvests provide for ecosystem integrity, resiliency and sustainability (Fiedler and Keegan 1997). Although our detailed silvicultural prescriptions are written at the stand level scale, their cumulative effects at the landscape scale determine successful management. At the stand and landscape level initial and maintenance treatments are extremely important ecologically as demonstrated by past successes. These ecosystems in turn will be able to provide amenity and commodity values for society.

The excessive overstory mortality experienced on 15 acres (6 ha) of the project area emphasizes the challenge managers face in reintroducing fire to old-forest ponderosa pine communities. While managers must continually apply adaptive management to avoid undesirable mortality, it should be recognized that some mortality of old ponderosa pine is inevitable. Managers should strive to meet mortality goals at the acre scale, but recognize that success should also be measured at the stand and landscape scale.

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Vegetative Conditions and Management Options in Even-Age Stands on the Monongahela National Forest

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Abstract—In 1998, personnel with the Northeastern Research Station and the Monongahela National Forest initiated a comprehensive survey of even-age stands that regenerated between 1964 and 1990. Preliminary results indicate that clearcutting was successful in regenerating these young stands with a variety of woody and herbaceous plant species. Early cleanings using crop-tree management techniques and control of wild grapevines (*Vitis* sp.) are recommended to enhance the development of desirable tree species that meet specific management objectives. Ecological classification appears to be useful in prioritizing silvicultural treatments at the stand level, thus facilitating control of vegetative conditions at larger scales for a variety of management objectives.

Introduction

The production of woodland benefits is closely related to vegetative conditions within a forest. For example, forest vegetation provides food, shelter, and breeding habitat for wildlife communities as well as commodity products and recreational amenities for people. As the composition and structure of the vegetation changes, so does the flow of benefits. Similarly, vegetative conditions are closely related to the ability of plants to compete for light, water, and soil nutrients and the availability of these resources after a planned or natural disturbance. Increased emphasis on maintaining the productivity of forest ecosystems calls for a better understanding of how plant communities on a given ecological site regenerate and develop in response to disturbance. Forest managers need such information to manage vegetation on relatively small land units and ultimately to maintain the production of desired benefits at larger scales such as forests and landscapes.

There are more than 1,200 young, even-age stands that regenerated after clearcutting between 1964 and 1989 on the Monongahela National Forest (MNF) in West Virginia (WV). Clearcut harvest was applied to individual stands and

the subsequent regeneration and growth of these stands has influenced the distribution, structure, and composition of vegetation at a much larger scale. The total area regenerated on the MNF after clearcutting is more than 30,000 acres. In addition, these stands are located on distinct ecological landtypes (ELT) that recently were described and mapped as part of the National Hierarchical Framework of Ecological Units. Species composition and site variables such as elevation, aspect, slope, slope position, and soil characteristics define each ELT. Because the harvest operations occurred across the forest at different times, these stands range in age from 10 to 35 years. The result is a mosaic of stand conditions that can provide valuable insight into the patterns of vegetative structure and species composition at different stages of development after major disturbance on a range of ecological sites with varying characteristics.

In keeping with the theme of this workshop, this paper describes how silviculturists can use stand-level information and an ecological classification system to facilitate control of vegetative conditions at larger scales for a variety of management objectives. In 1998, personnel with the MNF and Northeastern Research Station initiated a comprehensive study of even-age stands regenerated by clearcutting on the MNF. The purpose of the study was to (1) describe current stand structure and species composition, (2) define silvicultural treatments needed to maintain or achieve desired future conditions, and (3) relate stand conditions to ecological classification such that results can be extrapolated from the stand level to larger management scales. Although results reported here are limited in scope, additional data will be collected from more ELTs and age classes to complete the descriptive phase of this study. A second phase will focus on defining and testing silvicultural options needed to protect resources and sustain the production of multiple woodland benefits following major disturbance.

Background

In central Appalachian hardwood forests, natural reproduction of woody species usually is abundant and well distributed after both clearcutting and partial cutting operations. Reproduction occurs from advance seedlings that became established before the harvest, new seedlings that develop from seeds stored in the forest floor, and sprouts from the stumps of cut trees or wounded roots (Beck 1988).

In: Barras, Stan J., ed. 2001. Proceedings: National Silvicultural Workshop; 1999 October 5-7; Kalispell, MT. Proc. RMRS-P-00. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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The eventual species composition of the dominant vegetation depends on many factors. The most important are (1) the amount of light available to new reproduction, (2) shade tolerance of the species present, (3) abundance of advance seedlings, (4) site quality, and (5) influence of adverse factors such as deer, insects, pathogens, spring frosts, and interfering plants. Partial cutting practices favor the reproduction of a few shade-tolerant species, while clearcutting favors the reproduction of numerous species that differ in shade tolerance (Trimble 1973; Miller and Kochenderfer 1998).

In the early stages of stand development in Appalachian hardwoods, there are hundreds of codominant trees competing for light, water, and nutrients. As the stand matures and competition for site resources becomes severe, tree mortality occurs until the overstory is composed of 50 to 75 codominant trees/acre (Smith and Lamson 1986). The silviculturist can prescribe early cleanings and vine control treatments to assure that the overstory is composed of vigorous trees that best meet management objectives.

Early cleanings can be prescribed in young hardwood stands to enhance the production of multiple woodland benefits. For example, crop-tree management has been used to maintain overstory species diversity and production of mast for wildlife habitat, increase tree vigor and resistance to insects and pathogens, and improve species composition and stand quality for timber production (Perkey and others 1993). The basic strategy of crop-tree management is to reduce competition around certain trees so that they become more vigorous and remain a productive part of the forest community. Once management objectives are defined, the desirable crop trees are identified and given a crown release by eliminating adjacent trees. This treatment liberates site resources for use by the selected crop trees. The released trees develop larger crowns and root systems that enable them to become more competitive on the site and develop into the dominant overstory (Miller 2000).

The uncontrolled spread of wild grapevines (*Vitis* sp.) can severely damage young hardwood stands (Trimble and Tryon 1979). Vines originate from seeds stored in the forest floor or as sprouts from existing stems, and climb up with new hardwood regeneration after a canopy disturbance. Grapevine damage usually occurs during the dormant season when the crowns of affected trees break under the weight of wet snow and ice. Vine foliage also reduces the growth and vigor of host trees by competing for available sunlight during the growing season. Consequently, vines can damage any tree species and in turn adversely affect the production of many woodland benefits. Because they are very intolerant of shade, wild grapevines can be controlled by cutting under a closed canopy or by applying herbicides (Smith 1984).

Study Areas

The even-age stands surveyed in 1999 were located on the Cheat Ranger District of the MNF in north central WV. The topography consists of low ridges dissected by northeast-southwest valleys. Elevations range from 1,800 to 3,600 ft above sea level. In general, the soils are medium textured and well drained, derived from sandstone shale with occasional limestone influence. The average soil depth exceeds 3 ft. Annual precipitation averages 57 inches and is well

distributed throughout the year. The growing season averages 145 frost-free days.

When clearcutting began on the MNF in 1964, the central Appalachian forest consisted of second-growth hardwoods that regenerated naturally after large-scale cutting between 1905 and 1910. The second-growth stands often contained three age classes when silvicultural treatments began: scattered old residuals from the early cutting, new reproduction that became established after the early cutting, and reproduction that became established after the death of the American chestnut (*Castanea dentata*) in the 1930s (Carvell 1986).

MNF personnel according to the National Hierarchical Framework of Ecological Units (McNab and Avers 1994) described Landtype associations and series. Landtype associations occupy the landscape scale from thousands to hundreds of acres. They contain repeatable patterns of soil and vegetation groupings that are further delineated at the ELT scale.

The initial phase of data collection focused on three ELTs: sugar maple-basswood (SM-BW) series, sugar maple-red oak (SM-RO) series, and red oak (RO) series. These series represent traditional classifications such as moist cove sites, moist midslope sites, and dry midslope sites, respectively. The ELTs are described as follows:

- Sugar maple-basswood series (SM-BW). Sugar maple landtype association. Elevation 2,900 to 3,200 ft, maple overstory 30 to 40 percent. Basswood overstory cover at least 10 percent and sugar /understory cover at least 10 percent.
- Sugar maple-red oak series (SM-RO). Sugar maple landtype association. Elevation 3,400 to 3,800 ft, slope 30 to 40 percent, located primarily on southerly slopes. Red oak overstory cover at least 10 percent and sugar maple overstory/understory cover at least 10 percent.
- Red oak series (RO). Red oak landtype association. Elevation 2,700 to 3,000 ft, slope 30 to 40 percent, Red oak overstory cover at least 10 percent and not in the sugar maple groups.

Methods

Data were collected from randomly selected even-age stands on the Cheat Ranger District of the MNF. Each stand regenerated naturally after clearcutting. The harvest operation included the removal of merchantable logs and felling of small stems ≥ 2.0 in d.b.h., thus each new stand comprised a single cohort of reproduction. For inclusion in the study, minimum stand size was 8 acres and minimum stand age was 8 years. Size and age restrictions were established to reduce variation associated with small stands and very young stands that have not completed the stand initiation stage of development (Oliver and Larson 1996). Within each ELT, stands were selected randomly to provide data from a range of age classes.

Fixed-area plots were used to collect all vegetation data. Aspect, elevation, slope, and slope position were recorded for each plot. For woody vegetation, 0.025- and 0.05-acre circular plots were used in stands ≤ 15 years old and ≥ 16 years old, respectively. Species, d.b.h., crown class, and stem origin were recorded for all trees ≥ 1.0 in d.b.h. on each plot. In

addition, stem quality, crown vigor, and vine damage were recorded for all stems in the dominant and codominant crown classes, and for all oak stems in the intermediate class.

Stem quality was based on two characteristics: risk of mortality and potential timber grade. Trees were rated as good if there was no evidence of risk factors such as severe lean, poor attachment, insect damage, cankers, rot, wounds, or low forks that might threaten their long-term survival. Trees also were rated as good if they had a straight, clear bole that leads to higher product value. Trees were rated as poor if they exhibited risk factors or low potential grade.

Vine damage was divided into three categories: (1) vines present, crown damage imminent in the next 5 years, (2) vines present, crown damage evident and high risk of irreversible damage in the next 5 years, and (3) vines present, crown damage evident and irreversible. These categories were defined to help clarify when and where vine-control treatments might provide maximum damage control.

For herbaceous vegetation, percent cover by species was measured on four 1-m² circular plots located at cardinal directions on the perimeter of each woody vegetation plot. The surveys of herbaceous vegetation were conducted from early June through July.

Similar vegetation data were collected in nearby 80- to 90-year-old second-growth stands that had regenerated following large-scale cutting between 1905 and 1910. These stands had not been disturbed for approximately 40 years prior to data collection and were located adjacent to or in close proximity to clearcut stands on the same ELT. Data from the second-growth stands were compared to data from the young even-age stands to examine the general relationship between stand age and species composition within a given ELT.

Data were summarized by age class and ELT. For this preliminary report, a graphical analysis is presented to show trends in species richness for herbaceous species, basal area distribution for woody species, quality distribution for overstory species, and risk distribution for overstory species affected by wild grapevines.

Results and Discussion

Data were collected from 26 even-age stands that regenerated after clearcutting and 19 undisturbed second-growth stands on three ELTs (table 1). Even-age stands averaged 15 acres and ranged in size from 8 to 25 acres. Stand acreage was not available for the undisturbed second-growth stands. The even-age stands ranged in age from 8 to 33 years. The age of second-growth stands exceeded 80 years as these stands regenerated after the heavy cutting at the turn of the century. Woody species were tallied on 604 plots and herbaceous species were tallied on 2,416 plots.

Herbaceous Vegetation

In undisturbed stands, herbaceous species richness declined along a moisture gradient from the SM-BW sites to the RO sites (fig. 1). In even-age stands less than 15 years old, the number of herbaceous species present was approximately equal to or greater than the number present in undisturbed stands within the same ELT. On the SM-BW and SM-RO sites, the number of herbaceous species declined as stand age increased. However, on the RO sites the number of herbaceous species was greatest in stands 16 to 26 years old.

High species richness in very young stands resulted from the increase in light reaching the forest floor following removal of the canopy. After clearcutting, light was less limiting to plant development, so species present before the harvest were joined by light-demanding species after the harvest. Once the canopy closed, the number of herbaceous species declined because those intolerant of heavy shade did not continue to occupy the site.

Woody Vegetation

In general, the overstory in the young even-age stands was composed of the same species that dominated the older second-growth stands. For example, the majority of basal area in 31- to 33-year-old stands and second-growth stands

Table 1—Summary of study sites and sample plots by ecological landtype.

Ecological landtype	No. of stands	Average plot size	Age of trees	No. of herb plots	No. of stem plots
		<i>acre</i>	<i>year</i>		
Sugar maple-basswood	3	15	10–14	188	47
	4	17	23–29	256	64
	6	NA ^a	80+	348	87
Sugar maple-red oak	7	13	10–11	408	102
	3	15	14–15	108	27
	2	19	31–33	100	25
	7	NA ^a	80+	272	68
Red oak	2	11	8–10	96	24
	2	18	16	136	34
	3	16	25–26	168	42
	6	NA ^a	80+	336	84

^aAcreage not available for unmanaged second-growth stands.

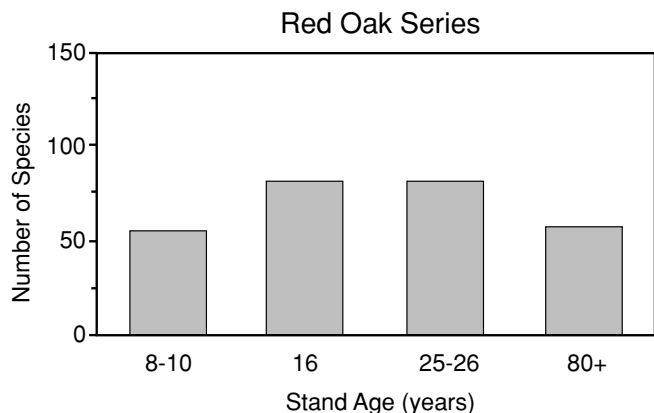
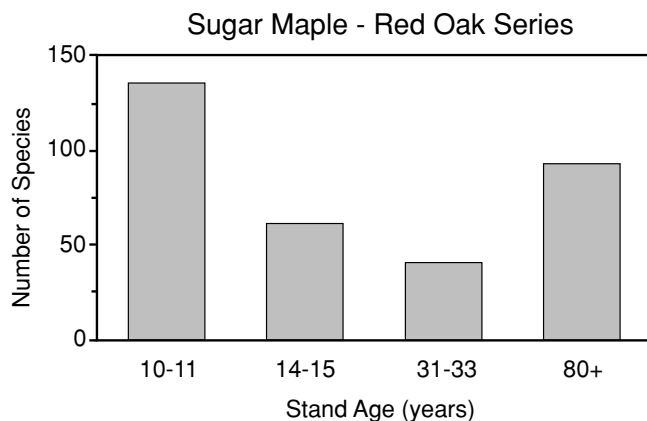
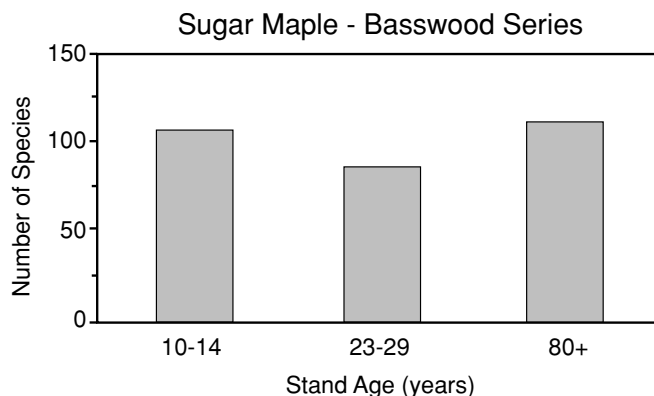


Figure 1—Number of herbaceous species observed within sample plots by stand age and ecological landtype.

on the SM-RO site was occupied by yellow-poplar (*Liriodendron tulipifera*), red oak (*Quercus rubra*), black cherry (*Prunus serotina*), sugar maple (*Acer saccharum*), red maple (*Acer rubrum*), basswood (*Tilia americana*), and sweet birch (*Betula lenta*) (fig. 2). It is important to note that red oak and black cherry occupied a majority of basal area in the second-growth stands while sugar maple and red maple occupied a majority of the basal area in the 30- to 33-year-old stands. On the SM-BW sites, species composition in the 23- to 29-year-old even-age stands was similar to that in the second-growth stands, although the proportion of yellow-poplar and black cherry was greater in the 23- to 29-year-old stands. On

the RO sites, the 23- to 26-year-old stands had a much lower proportion of basal area occupied by red oak and chestnut oak and a higher proportion occupied by yellow-poplar and black cherry than the second-growth stands (fig. 2). In addition to the species listed in figure 2, the even-age stands contained 18, 11, and 10 hardwood species on the sugar maple-basswood, SM-RO, and RO sites, respectively.

Differences in species composition between the second-growth stands and young even-age stands can be attributed to at least two important factors. First, species composition is affected by the availability of stored seed, advanced seedlings, and sprouts immediately after harvest operations

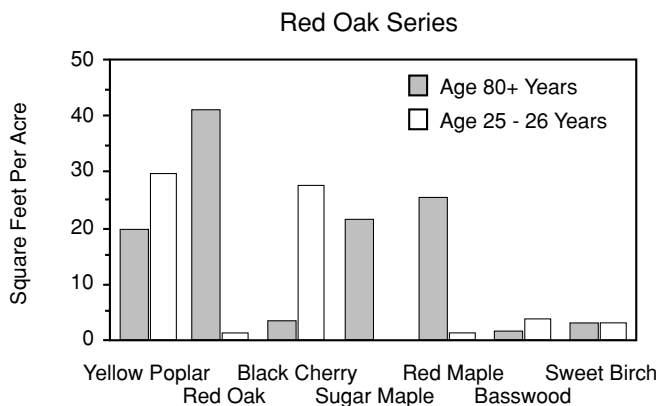
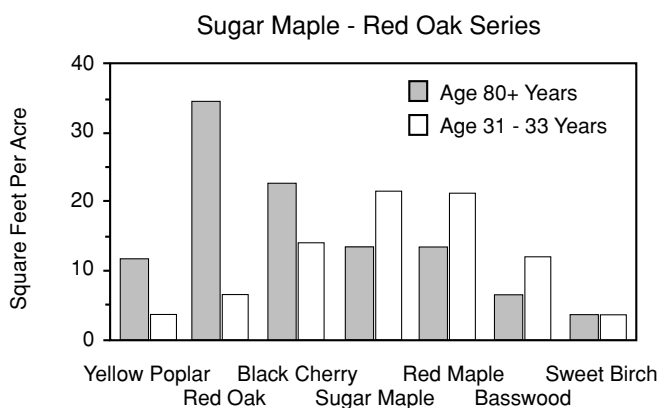
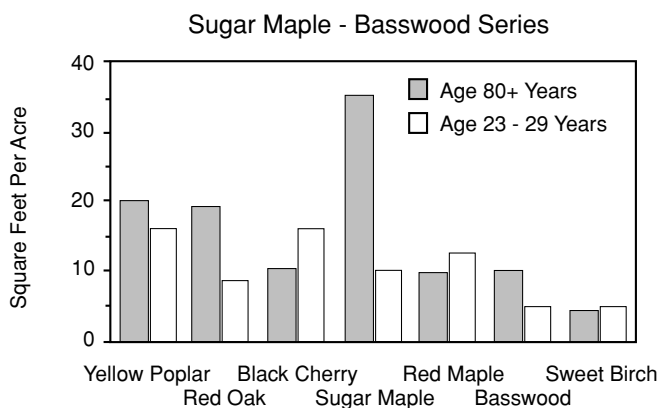


Figure 2—Average basal area/ac by stand age, species, and ecological landtype.

(Beck 1988). These primary sources of regeneration exhibit natural variation over time, so some variation in species composition is due to the timing of the harvests. Second, there was a different pattern of disturbance that followed harvest operations. White-tailed deer (*Odocoileus virginianus*) have a dramatic influence on hardwood regeneration (Tilghman 1989), and the young stands developed during a period when deer populations were relatively high.

Wildfires also influence competitive relationships among hardwoods (Van Lear and Watt 1990). Fire followed the heavy cutting at the turn of the century when the second-growth stands developed, yet fire was absent after clearcutting in the even-age stands. It follows those future disturbances, both natural and planned, will continue to influence species composition of the overstory.

A closer look at the characteristics of individual trees in the even-age stands revealed that each stand had many trees of good quality in the overstory. The data also indicated that numerous species are represented in the overstory, so the young even-age stands are capable of producing a wide range of benefits in the future. For example, stands on the SM-BW sites contained good, codominant trees in each species and age group (fig. 3). Early cleanings could be used to enhance future

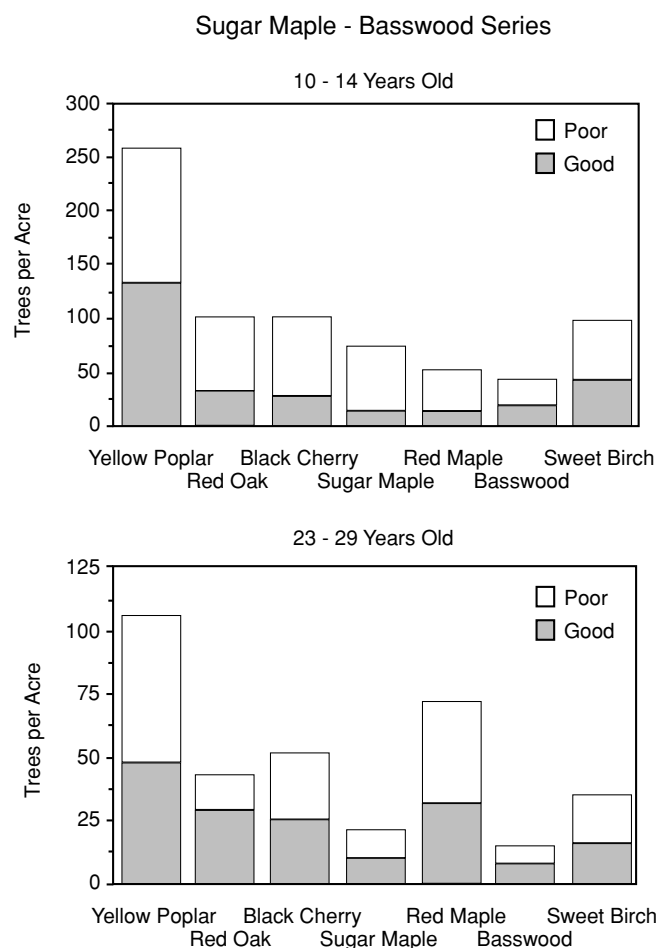


Figure 3—Average number of overstory stems/ac by stand age, species, and stem quality on the SM-BW series sites.

Table 2—Relative product market value and relative wildlife food value for Appalachian hardwoods.

Species	Relative product market value ^a	Relative wildlife food value ^b
Yellow-poplar	26	14
Black cherry	100	96
Red oak	60	100
Chestnut oak	21	100
Sweet birch	4	41
Basswood	17	14
Red maple	21	51
Sugar maple	28	51

^aValue relative to black cherry computed from Monongahela National Forest quarterly transaction evidence prices for January 1998.

^bValue relative to oaks computed from Martin et al. 1951.

most production and product values by favoring northern red oak and black cherry crop trees (table 2). Crop-tree management also can be used to enhance recreation or watershed values (Perkey and others 1993).

The opportunity to control overstory species composition declined in older stands. In general, the number of codominant trees in each species group declined due to natural competition. On the SM-RO sites, there were 25 good-quality, codominant red oaks per acre in the 10- to 11-year-old stands and fewer than 10 per acre in the 31- to 33-year-old stands (fig. 4). Crop-tree management still would be beneficial in the older stands, but earlier treatments provide more flexibility in achieving long-term goals for species composition. If treatments are delayed too long, some species may drop out of the overstory. For example, chestnut oak (*Quercus prinus*) crop trees were present on the RO sites in the 8- to 16-year-old stands but absent from the older stands (fig. 5). Crown release enhanced the growth and survival of chestnut oak crop trees in young stands (Miller 2000). As a result, early release of only several chestnut oak crop trees per acre would be effective in sustaining this species.

Wild Grapevines

It is well documented that young hardwood stands are susceptible to damage by wild grapevines (Smith 1984; Trimble and Tryon 1979). The proportion of overstory trees affected by vines varied by ELT (fig. 6). For the SM-RO and RO sites, the proportion of good quality codominant trees with vines increased with stand age. On the SM-RO sites, the proportion of good quality codominant trees with vines increased from 6 to 17 percent as age increased from 10–11 to 31–33 years. On the SM-BW sites, the proportion of good, codominant stems with vines decreased from 14 to 5 percent as age increased from 10–14 to 23–29 years. This apparent reduction in vine damage with increased stand age probably is the result of natural variation in the stands sampled. Vine damage usually increases as even-age stands develop (Smith 1984).

It is important to note that nearly every stand had numerous good-quality trees threatened by damage from vines. Consequently, vine control treatments may be needed to

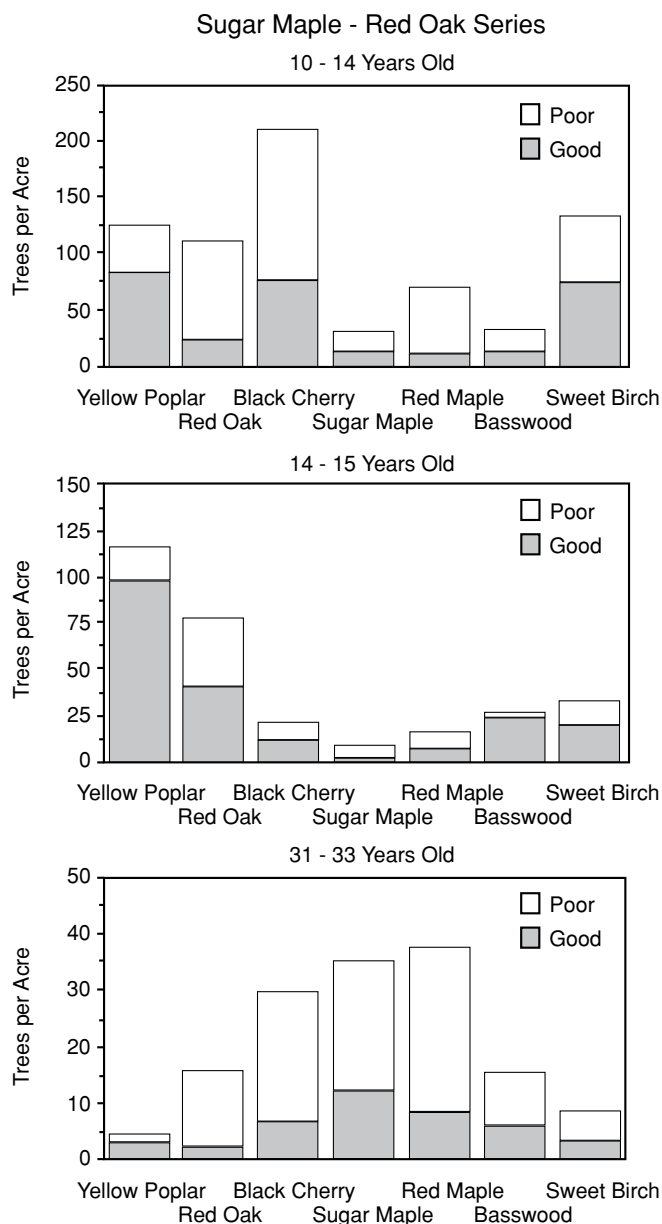


Figure 4—Average number of overstory stems/ac by stand age, species, and stem quality on the sugar maple-RO series sites.

prevent vines from damaging or killing trees that are needed to meet management objectives. The fruit of wild grapevines is valuable for wildlife, so forest managers must consider the tradeoff for controlling the spread of vines among overstory trees. Treatments can be prescribed to prevent excessive damage to crop trees and leave some vines as food for wildlife (Smith 1984).

Summary

Preliminary results summarized in this report represent an example of the type of information that silviculturists

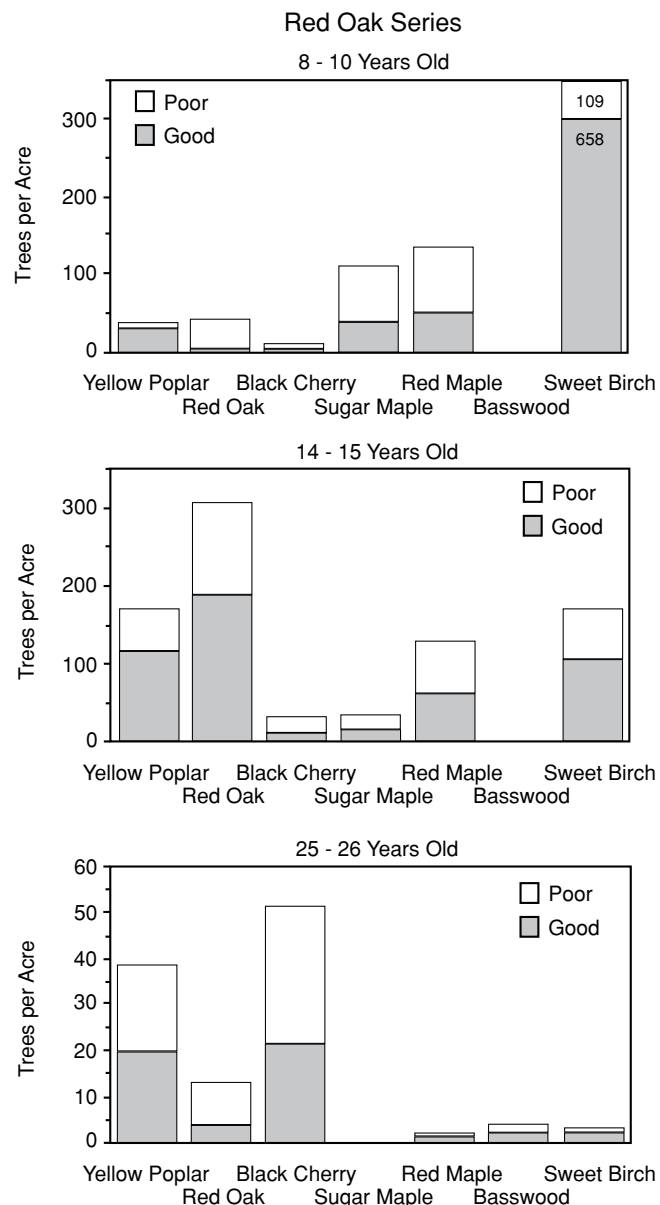


Figure 5—Average number of overstory stems/ac by stand age, species, and stem quality on the RO series sites.

need to manage vegetation and sustain the production of multiple woodland benefits. Information on the status of vegetative conditions on small land units clarifies the potential for achieving management objectives in the future. The data indicated that young hardwood stands that regenerated after clearcutting on the MNF contain hundreds of codominant trees per acre in various species groups. Because of the relatively high species diversity on each of the ELTs surveyed, these stands are capable of producing a variety of benefits. Once management objectives are defined and vegetative conditions are quantified, forest managers can describe and evaluate strategies for achieving desired future conditions.

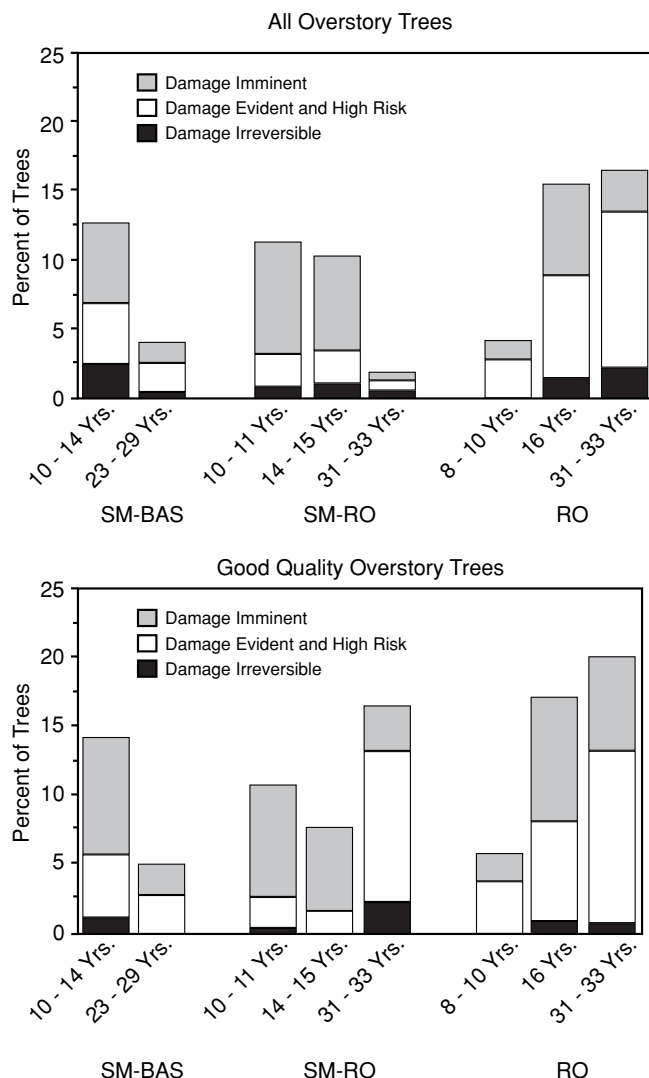


Figure 6—Average percent of overstory trees with vines by stand age, risk/damage class, and stem quality for sugar maple-basswood (SM-BAS), sugar maple-red oak (SM-RO), and red oak (RO) ecological landtypes.

The production of multiple woodland benefits such as timber value, esthetics, recreation, and wildlife habitat can be increased by silvicultural treatments. Vegetation structure and species composition changes over time as plants within a forest community compete for limited site resources. Silvicultural treatments can be prescribed to influence competitive relationships among the species present and manipulate vegetation dynamics such that the production of preferred woodland benefits is enhanced. For example, early cleaning treatments can be applied to favor the long-term survival and growth of mast-producing species. Crown release of selected oaks and black cherry can increase the proportion of these species in the overstory as well as the vigor of individual trees, thus increasing the long-term production of mast on the site. Moreover, by favoring species that provide both mast and high timber value, a single

silvicultural treatment can enhance the production of multiple benefits (table 2).

Silvicultural treatments can be applied to numerous stands with similar characteristics, providing a means to manage vegetation on a larger scale using an ecological approach. By aggregating stands with similar ages and site conditions, the silviculturist is better able to prescribe treatments based on an understanding of how vegetation will respond on a given site. For example, the proportion of overstory trees threatened by grapevines increased in both the SM-RO and the RO sites as stand age increased. This suggests that vine control should be focused on certain growing sites when stands are relatively young. As a result, vine control projects can be prioritized according to ELT and stand age using site classification maps and harvest records.

This report presents preliminary information from an ongoing study that covers a relatively large area of forestland in the central Appalachians. The study is intended to include stand data from a wide range of age classes on many additional ELTs; data collection and analysis will continue for several years. As more data are available, a more rigorous analysis will clarify the relationship between vegetative conditions, ecological site factors, and management options. The methods described could serve as a model for silviculturists who seek to manage forest resources for multiple benefits using an ecological classification system. A second phase of the study will field test the effectiveness of silvicultural treatments in achieving management objectives. Results of the study will provide insight into how certain growing sites and plant communities respond to planned disturbances.

Acknowledgments

A portion of the funding for this study was provided by the CROPS (CReating OPPortunities) Initiative to address the management of overstocked stands on a national level. Information can be obtained from the USDA Forest Service, Washington, DC. Additional funding was provided by WUEM (Wood Utilization Options for Ecosystem Management), a multidisciplinary Forest Service research effort to evaluate alternative silviculture, harvesting, and wood utilization options in the South, West, and Northeast. Information can be obtained from the Forest Products Laboratory, Madison, WI. We thank Linda White, Monongahela National Forest, for providing maps and historical information on the study sites.

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Section III: Achieving Desired Future Conditions



Understanding the Connection Between Historic Range of Variation, Current Social Values and Developing Desired Conditions

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Abstract—Relationships between the development of desired conditions based on today's social values, and an understanding of the historic range of variability (HRV) are key to the implementation of ecosystem management. Relevant to the discussion are wildlife habitat values, forage production, economics related to wood resources, aesthetics and visual quality, changes in predicted and actual fire intensity especially within the urban interface. Potential risks to air quality, and risks associated with changes in insect and pathogen activities, and significant degradation of soil and aquatic resources are also discussed. The HRV for western larch and ponderosa pine cover types are described in terms of vegetation composition, structure, pattern and areal extent at broad- and mid-scale. They are also described in terms of broadscale fire regimes and mid-scale processes mediated by insects and pathogens.

Introduction

Understanding the significance of the historic range of variability (HRV) or "reference conditions" can give land managers a tool to judge the feasibility, or the probability of providing for current day social values on public lands. Western larch and ponderosa pine forest communities are particularly useful for exploring the connection between

social values and the ecological values represented by HRV because these forest types make up much of the interface areas between forest and human communities.

Although there is evidence that humans used forests of the Northern Rockies for thousands of years, more intense use and sometimes, conflicting uses have increased significantly in the past 100 years. Because of this, the implications for managing outside of historic disturbance regimes become more significant. Vegetative disturbance prior to European settlement produced vegetative mosaics in ponderosa pine and western larch cover types that allowed for frequent, low intensity fires and infrequent insect and disease outbreaks. As human settlement increased after the turn of the century, the need to protect settlement from wildfire increased. Therefore, fire suppression became a significant factor causing the distribution of vegetation cover types to shift to trees that had once been held in check by frequent fires. These included Douglas-fir, grand fir, subalpine fir, western redcedar, and western hemlock in place of ponderosa pine, western white pine, lodgepole pine, and western larch. These forested settings became much more susceptible to large outbreaks of insects, diseases and large wildland fires. The change in vegetation and subsequent change in disturbance regimes affected a variety of social conditions, including location and need for protection of human settlements, reduction of vegetative size classes, availability of forage, and recreation settings.

Shrubland/grassland cover types also provide important social values in terms of wildlife habitat and forage for livestock. Big game winter ranges are most commonly associated with the open conifer, shrubland/grassland interface. With the exclusion of fire and invasion of housing tracts, this important habitat and resource has declined. This decline has resulted in reductions of important forage for both livestock and wildlife, often pitting the two herbivore classes against one another for priority use. Losses of these cover types have also occurred on private land due to urban interface and development, making the social value of these cover types even greater on public lands.

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A variety of demographic research has indicated that migration from urban to rural settings has increased significantly in the past 20 years, particularly in the West. Due to both expansion of urban boundaries and the desire to “live in the woods,” more people are building homes in the urban/wildland interface. That same urban/wildland interface is also showing a significant change in the fire interval and intensity. Data from the Upper Columbia River Basin (Quigley 1997) indicates that both fire intervals and the percent of crown fires have increased five-fold since the 1950s. Although the public is beginning to recognize the need for prescribed fire to decrease tree density and the risk of wild fire, they also are concerned about the potential effects on their “backyard,” along with health risks associated with increased smoke.

Historic Forest Land Use

When European settlers arrived in the upper Columbia River basin, they found vast, untouched forests. Of greatest interest to these early settlers were stands of western white pine, ponderosa pine and western larch that occupied the lower elevations of the mountain ranges. All of these species were highly valued for their wood. Mills sprung up across the region to exploit the abundant wood supplies. A 1945 Forest Service report indicates that Montana and Idaho forests had about 14 percent or 31 billion board feet of the nation’s total standing sawtimber inventory of ponderosa pine at that time. By contrast, the nationwide western larch sawtimber inventory was estimated to be about 24 billion board feet in total with Montana and Idaho forests supporting over 15 billion board feet.

Economics were a major factor in determining which of the forest types and the types of areas were harvested. Beyond meeting local demand for development, the most valuable and marketable wood was white pine, followed by ponderosa pine. Value was highly dependent upon accessibility, because log transportation was by railroad, chutes, and river drives.

In many cases, the highest quality, easiest to reach timber was found on state and privately owned lands. These lands were located frequently at the lower elevations of major drainages. Federally held lands, which were managed by the USDA Forest Service, were not as desirable for harvest by the major mills because they were often situated in rougher terrain, at higher elevations and supported stands which contained substantial amounts of inferior species such as lodgepole pine, Douglas-fir, grand fir and subalpine fir.

In a 1926 Timber Management Plan for the Lolo National Forest, it is stated, “Until the private timber becomes more scarce, the large mills will not seek Government timber. Because it will require heavy outlays for railroads or flumes, the timber in most of the larger drainages will eventually go to owners of large sawmills. These chances are the most inaccessible now and will probably be among the last in demand.” This same plan reports that between 1907 and 1925, harvest from the Lolo NF had amounted to 176.7 million boardfeet or about 9.3 million per year. This forecast proved to be true. It was not until after World War II that there was significant demand for the national forest timber

in Region One. Technology, developed during the war, allowed a rapid tapping of the huge reserves. The bulldozer, cheap petroleum, and the diesel-powered truck changed the character of logging and allowed cheap access to the timber on the National Forests. Soon an extensive road system was extended across the forests. Sale economics were seriously considered, thus the harvest focused on the species of highest value, western white pine, ponderosa pine, and western larch.

Historic Range of Variability for Western Larch and Ponderosa Pine Cover Types

Although the attributes of interest to characterize vegetation are likely to be similar at all scales; the level of detail in these attributes will vary considerably according to the scale of analysis. For example, cover type is of interest at all scales but at the broadest scale, broad physiognomic classes such as “shade intolerant forest” may provide sufficient information; whereas at the mid scale, this cover type may be characterized as “ponderosa pine”; and at the fine scale it is identified as a “ponderosa pine/Douglas-fir/grand fir forest type.” The data available at each scale largely dictate the level of detail we can use to characterize historic range of variability. For the purpose of this paper, broad scale is defined as the Interior Columbia River Basin, the mid scale as an ecological section or group of sections identified by the National Forests contained within the sections, and the fine scale as a project area or stand. Following are examples of both broad- and mid-scale HRV descriptions. At the scale of the stand, many local studies have been completed documenting fire histories and successional pathways the stands have taken over time (Arno and others 1985; Shearer 1986). The context of both the broadscale and mid-scale HRV provides a means to interpret the finer resolution data on such things as site fire history as it relates to the broader fire regimes. Similarly, insect and disease activities in stands are considered within the context of broader scale historic range of variability of the insect and disease regimes.

Broad Scale Vegetation—The findings at the broad scale, Interior Columbia River Basin, give us a partial view of the historical dynamics and how composition of the western larch and ponderosa pine forests have changed over time. In describing ecological changes in space and time, the Columbia River Basin Assessment defined HRV as 75 percent of the full range of historical conditions prior to Euro-American settlement (Quigley and others 1997). This range is described for the basin through model simulations and by potential vegetation groups and physiognomic types in table 1.

Simulations completed for the Columbia River Basin Assessment indicated that western larch and ponderosa pine historically occupied from one-third to over one-half of the basin (Quigley and others 1997). Current extents of the ponderosa pine and western larch cover types are considerably less compared to their calculated HRV (table 2). For the Basin as a whole, a 2 percent reduction in ponderosa pine and 36 percent reduction in western larch cover types have occurred. Much of this area has changed to the more shade tolerant grand fir and Douglas-fir forests.

Table 1—Changes in coverages of broad classes of vegetation.

Potential vegetation group	Physiognomic types	Historic range of variability	Federal lands current percent	All lands current percent
Dry forest	Early-seral shade intolerant forest	7–15	17	15
	Mid-seral shade intolerant forest	16–21	25	35
	Late-seral shade intolerant multi-forest	7–10	10	8
	Late-seral shade intolerant single-forest	21–47	4	5
Moist forest	Early-seral shade intolerant forest	14–23	14	13
	Mid-seral shade intolerant forest	28–35	33	36
	Late-seral shade intolerant multi-forest	14–17	4	3
	Late-seral shade intolerant single-forest	7–10	1	1

Also based on the Columbia River Basin Assessment, forest densities have increased significantly. A large portion of the current forests consists of overstocked conditions atypical of the historical period. Quigley and others (1997) reported a shift toward a more homogeneous landscape with a significant increase in mid-seral forest communities at the expense of the early and late-seral forest communities (table 1).

For the historical period, prior to Euro-American settlement, the influence of mixed severity and high severity fire regimes probably led to the persistence of residual large-tree structures of approximately 20 percent canopy cover commonly throughout the range of the western larch and ponderosa pine cover types (Quigley and others 1997). This large-tree structure, that occurred as single trees or in large groups, is currently much less abundant.

Broadscale Fire Regimes—Reference conditions in terms of composition, structure, and pattern of forests in the Northern Rocky Mountains developed under characteristic fire regimes. The findings for the Interior Columbia River Basin show major changes in fire severity potential in the current period. Table 2 indicates the significant overall shift in fire regimes for the Northern Rocky Mountains.

Midscale Vegetation—At the mid-scale, various studies have provided more detailed resolution of the attributes of

HRV. Both Hessburg (1999) and Hagle and others (1995) relied on aerial photographs taken as part of a broad forest survey in the 1930s (USDA 1948). Hessburg (1999) used the photos to analyze vegetation changes in a sample of 6th HUC code watersheds from two National Forests, the Flathead National Forest in Montana and the Wenatchee National Forest in Washington. From this, they developed landscape composition, structure and pattern statistics to help guide management. In describing vegetation change in space and through time, Hessburg (1999) defined HRV as 80 percent of the full range of historical conditions prior to Euro-American settlement. This range was described for composition structure and pattern within selected sample 6th HUC code watersheds and used a comparison of photo-interpreted attributes from the 1930s photos to present day interpretations to identify trends in specific landscape attributes. They reported a significant decrease in areal extent of western larch cover type from historic to present on the Flathead National Forest, and only a minor decrease overall in the extent of ponderosa pine cover type on the Wenatchee National Forest (table 3a).

In addition to the land coverage and patch size changes for western larch (table 3b), Hessburg (1999) found significant changes in structure classes on the Flathead National Forest. Reductions in the early-seral structure classes were

Table 2—Fire regime changes in the Northern Rocky Mountains.

Severity/frequency class	Historical	Current	Absolute change	Proportional change
			<i>percent</i>	
Lethal frequent	0.4	6.8	6.4	1600
Lethal infrequent	10.8	35.6	24.8	229.6
Lethal very infrequent	15.4	30.2	14.8	96.1
Total lethal	26.6	72.6	46	172.9
Mixed frequent	26.3	0.1	–26.2	–100
Mixed infrequent	19.4	22.0	2.6	13.4
Mixed very frequent	4.0	0	–4.0	–100
Mixed very infrequent	9.1	0	–9.1	–100
Total mixed	58.8	22.1	–35.3	–60.0
Non-lethal frequent	1.2	0	–1.2	–100
Non-lethal infrequent	4.4	4.8	0.5	9.1
Non-lethal very infrequent	8.7	0.1	–8.6	–98.9
Total non-lethal	14.3	4.9	–9.3	–65

Table 3a—Cover type changes reported by Hessburg (1999) for two National Forests of the Columbia River Basin.

Cover type	Historical mean	Current mean	Mean difference	Proportion
	----- percent -----			
Western larch ^a	7.8	6.4	-1.4	-0.18
Ponderosa pine ^b	55	53	2	-0.04
^a Flathead National Forest				
^b Wenatchee National Forest				

Table 3b—Changes in patch size reported by Hessburg (1999) for two National Forests of the Columbia River Basin.

Cover type	Historical mean	Current mean	Mean difference	Proportion
	----- acres -----			
Western larch ^a	209	111	-98	-0.47
Ponderosa pine ^b	286	31	-255	-0.89
^a Flathead National Forest				
^b Wenatchee National Forest				

observed, as well as increase in the dense, mid-seral structure classes.

Change land in coverage of ponderosa pine on the Wenatchee National Forest was minor, but changes in patch size were highly significant with an 89 percent reduction in mean patch size (table 3b). Hessburg (1999) also reported significant changes in structure classes in this sample. Reductions of early-seral structure classes were accompanied by an increase in the dense, mid-seral structure classes, and a very significant reduction of the old forest structure classes.

Hagle and Johnson (1999) analyzed changes in a 76,000-hectare sample (6th code HUC scale) drawn from the 8 ecological sections of north Idaho and western Montana (Bailey and others 1994). Cover types and structure classes were interpreted using the 1930s photography as well as the maps and survey data resulting from the 1930s federal forest survey (Lewis and Stipe 1999). Forest composition and structure were compared to survey data and true color photography of the same locations taken in 1975. Changes over this roughly 40-year period, in the absence of both fire and timber harvest, were studied to better understand the successional roles of insects and pathogens.

This study provides further evidence of substantial changes in the vegetation in a relatively short time (table 4). Although vegetation in the landscapes occurring in 1935 may not represent the true historic range of variability across the ecological sections, it is likely to be a much better measure than were the conditions in 1975 or in the present.

In the dry potential vegetation types (PVTs), much of the ponderosa pine cover type had converted to Douglas-fir with only about half remaining in pine cover type. The real change may have been even more dramatic as indicated by the 1975 forest type in which nearly two thirds of the former pine type had a majority of Douglas-fir (by basal area) by 1975.

In the moist PVT types, western larch cover type was even more likely to be replaced by a variety of more shade and competition-tolerant species. Douglas-fir, grand fir and, somewhat surprisingly, lodgepole pine made the greatest gains in former western larch cover type (table 5). At higher elevations, subalpine fir increased considerably in the larch type.

Like the ponderosa pine type, little of the landscape that has converted to other species will revert to western larch

Table 4—Ponderosa pine forest type^a and western larch forest type in 1935 and 1975. Change over 40 years in dry and moist potential vegetation types (PVT), respectively. (Hagle and Johnson 1999)

Physiognomic group	Tree species	1935 (hectares)	1975 (hectares)	Net change	Proportion change
		----- percent -----			
Dry PVTs	Ponderosa pine	26.8	16.3	-10.5	-0.39
Moist PVTs	Western larch	20.2	10.8	-8.2	-0.41

^aForest type was based on the most populous three tree species in a polygon.

Table 5—Fate of the 1935 western larch cover type: 1975 cover type and forest type of polygons, which were western larch in 1935. (Hagle and Johnson 1999).

1975 Cover type	Percent (hectares)
Western larch	25
Douglas-fir	19
Grand fir	19
Lodgepole pine	14
Subalpine fir	8
Cedar or hemlock	8

without the disturbance of fire or active management to provide opportunities for regeneration.

Changes in Fire, Pathogen and Insect Regimes Lead to Further Changes in Vegetation Patterns—The ability of ponderosa pine to maintain site dominance in the absence of fire or active management depends on their size and density. Stands of large pines which fully occupy the site have a much higher probability of retaining pine cover type than those which are young or have open canopy (table 6). Least likely to retain site dominance are seedling and sapling stands of pine. Without natural fire or active management few sites occupied by young or open stands of pine will still have pine cover types just four decades later.

Insects and Pathogens in the Landscape

As both native components of the forest, and, as in the case of white pine blister rust, established exotics, insects and pathogens alter landscape conditions through their activities. In turn, landscape conditions greatly affect the way in which insects and pathogens function. Hagle and others (1999) found that, in the absence of fires or active management, insects and pathogens controlled about 80 percent of successional changes. Despite their high level of activity over most of the pine and larch types, clearly, insects and pathogens alone do not maintain HRV. Tree species composition and the distribution of structure classes have changed in the absence of fire. As the landscape has changed, so have the ways in which insects and pathogens function in the landscape.

Table 6—Polygons with ponderosa pine cover type in 1935. Influence of developmental stage on retention of pine covers type. (Hagle and Johnson 1999).

1935 Structure class	Still pine cover type in 1975 (percent hectares)
Seedling/sapling	34
Pole-size, dense	41
Large trees, close canopy	76
Pole to large trees, open canopy	44

Pine Forests: Bark Beetle-Dominated Dynamics

In the seedling and sapling stage of pine forests relatively few insects or pathogens have significant effect on stands. Western gall rust, and root weevils girdle and kill individual trees but seldom greatly affect tree density. Needlecasts such as *Dothistroma* and *Elytroderma* are chronically severe in some areas and can slowly kill a majority of young ponderosa pines producing low-density forests, which mimic the effects of frequent low-intensity fires. Microclimate and genetics of local populations of both pines and pathogens greatly affect the course of development of gall rust, root weevils and needlecasts. For the most part young pine forests are genetically suited to offer resistance to local pathogens and insects. An advantage has resulted from long-term site dominance by ponderosa pine on these sites maintained by frequent partial-replacement fires.

Pole stage and overmature stands favor bark beetles in pine forests. These forests have left behind their childhood diseases once they reach an average diameter of about 6 inches. At this stage, their greatest threat is probably overcrowding. If the competition doesn't kill them, bark beetles may. Until the stands average about 12 inches in diameter, pine engraver beetles, known as *Ips* beetles to many, prey heavily on stands weakened by competition and drought. They attack groups of trees, creating gaps, and probably mostly improving the overall condition of most of these overly dense, young forests. A recent study of successional patterns moderated by insects and pathogens found 45 percent of pole stage ponderosa pine stands sampled became low-density stands with large tree components over a 40 year period (table 7), with pine bark beetles pushing the changes (Kegley 1999). Almost another 40 percent were still classified as pole stage after 40 years, an expected outcome from consistent pressure from bark beetles. Harvested units were excluded from the statistics in this study and no fires occurred in the 48,800-hectare sample, which was scattered across northern Idaho and western Montana.

As the phloem thickens, *Ips* beetles move their attack to the occasional top of weakened or damaged trees. They are supplanted by the mountain pine beetle as the dominant stand influence. Infrequent large outbreaks and incessant small groups of mountain pine beetle kills were undoubtedly once a dominant force in pine type landscapes. The fuels generated by beetle groups and outbreaks probably fed ground fires into crown fires and provided mixed severity burns as well as the occasional stand-replacing event. Kegley (1999) found that more than 1/3 of large-tree stands were impacted sufficiently by bark beetles to be converted to seedling, sapling, or pole stage stands (fig. 1) in just 40 years. Another 40 percent of stands became low-density stands, which still had a significant component of large trees. Less than 20 percent of stands, which had been typified by large trees and closed canopies, remain in this condition throughout the 40-year period.

Where fires were not forthcoming or incomplete, individual survivors grew in relatively open conditions and were able to achieve great size and age. At this stage, stem decays became important sources of cavity nesting habitat. As heartwood decay advances in these individuals, breakage by

Table 7—Changes in overall size and density of Douglas-fir stands between 1935 and 1975, mostly as a result of root diseases and Douglas-fir beetle activities.

1935 structure class	Percent of Douglas-fir cover type in 1935	1975 structure class	Percent of 1935 structure class
Seedling/sapling	11	Seedling/sapling	4
		Small trees	48
		Large trees with close canopy	40
		Large trees with open canopy	7
Small trees	57	Seedling/sapling	3
		Small trees	56
		Large trees with close canopy	3
		Large trees with open canopy	37
Large trees with close canopy	1	Small trees	34
		Large trees with open canopy	58
Large trees with open canopy	32	Seedling/sapling	12
		Small trees	21
		Large trees with close canopy	5
		Large trees with open canopy	59

physical forces such as wind, snow or ice slowly removes a tree or two at a time. Western pine beetle is also important in killing these large, old trees. Generally, the attack involves only one or a few trees but does not reach outbreak proportions as sometimes seen in mountain pine beetle attacks. Annosum root disease has probably always played a minor role in pine forests but that role is poorly understood. Old individuals are seen to develop advanced root infections, which lead to slow decline, often with the final blow dealt by western pine beetle. The root pathogen is also seen infrequently in young pines associated with chronic patches of mortality in stands.

Douglas-Fir in the “Pine Type” Mixture: Root Pathogens and Bark Beetles Share the Spotlight

West of the Continental Divide, root diseases are the dominant influence in Douglas-fir forests, with Douglas-fir beetle outbreaks also important at times. East of the Divide, Douglas-fir beetle takes over the dominant role. In the pine type, patches of fungal root disease are more often small, less

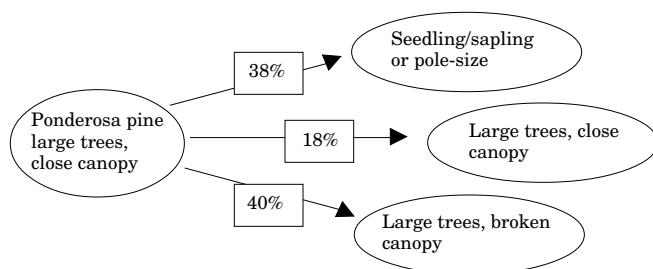


Figure 1—Structure changes of mature ponderosa pine stands in 40 years without the influence of tree harvest or fires. Pathways are largely driven by bark beetles.

than 1 acre in size, but, they can be the largest biomass organisms known to man, and they have the potential to be very old, in excess of 1,500 years (Smith and others 1992). Ponderosa pine is not generally a preferred host for root pathogens (the most notable exception is annosum root disease).

Although the mycelium of root pathogens is mostly underground and insulated from heat and surface changes caused by fires, fire intervals greatly influence the ability of the fungal colonies to grow. Frequent low-intensity fires favor ponderosa pine and open spacing. Both of these conditions will tend to minimize the extent of root pathogens.

When sections of the landscape periodically escape fire for long enough intervals to convert to a majority of Douglas-fir and sufficient stocking for root closure to occur, the root pathogen colonies will slowly increase in biomass and subsequent root disease mortality will increase in extent and intensity.

Root pathogens have probably always played an important role in maintaining ponderosa pine on mixed pine/fir sites by reducing competition from Douglas-fir and grand fir. In the absence of fire or tree harvest, this function was seen to occur in nearly a third of the type over a 40-year period.

So what difference does it make which pathogens or insects are functioning in pine forests? The outcomes of pine beetle activities are very different from those that result from root diseases and Douglas-fir and true fir bark beetles as well (table 7). Among the more significant effects are the tendency for root disease afflicted stands to remain perpetually young as few trees reach old age, and a sustained shift in species composition. Once converted to Douglas-fir and grand fir most stands are expected to remain so even with root diseases and bark beetles killing many of the Douglas-fir and grand fir. From 1935 to 1975, 73 percent of ha of Douglas-fir stands remained Douglas-fir. Only 7 percent of ha converted to ponderosa pine cover type. Relatively few ha can be expected to progress to large-tree, close canopy conditions as well. With each generation of Douglas-fir and grand fir on site, the biomass of root pathogens is likely to

increase, resulting in even shorter life expectancies for Douglas-fir and grand fir.

The longer that sites remain in the pine type with mostly Douglas-fir and grand fir cover, the more extensive and severe the root disease will become. Stand conditions maintained by severe root disease significantly alter the appearance and, probably, many of the functions of forests. Among the differences is the limited production of large-tree elements. Root pathogens kill trees of any age, thus through a lifetime of root disease, stands generally produce relatively few large trees where root disease is severe. Production of few large trees means there are few large snags to provide nesting and roosting sites and, when they fall, they are smaller "large woody debris" that deteriorate more rapidly than larger logs.

There is usually abundant regeneration except in the largest of disease patches where seed-availability can be limiting. The tall canopy is sparse, providing little site protection, and production of merchantable wood volume is low.

Stands tend to develop into mosaics of multistoried tree structures, with few large trees, dense saplings and, depending on the site type, abundant shrubs such as ninebark or mountain maple. As the shrubs age, their quality as wildlife forage declines.

Douglas-fir stands that have less severe root disease become susceptible to outbreaks of Douglas-fir beetle as they reach maturity. These outbreaks are not greatly different from those of mountain pine beetles in pine forests. The larvae are a food source, the large snags are available for cavity nests, the deadfall is fuel for potential fires, and the unburned debris provides soil amendments. Kegley (1999) estimated that about 20 percent of ha of National Forest in Northern Idaho and most of western Montana have become moderately to highly susceptible to significant effects from Douglas-fir beetle outbreaks, up from an estimated 3 percent showing significant effects from 1935 to 1975. Reactions of forest users to Douglas-fir beetle outbreaks are likely to be similar to their reactions to mountain pine beetle outbreaks in pine forests. For example, the Douglas-fir beetle outbreak, which was set off by ice and hail damage in Northern Idaho in 1997, has generated considerable public interest.

Western Larch Forests, Root Pathogens and Bark Beetles Work With Fire to Maintain Balance

Moist sites where western larch cover type was historically important initially had a high proportion of Douglas-fir or grand fir. These mixed stands have some of the greatest root disease effects seen in the Northern Rockies. The habitat types on which larch grows appear to be among the most conducive for root pathogenic fungi (Byler and others 1992). The omnipresent root pathogens tend to remove much of the Douglas-fir and grand fir from the mixed stands, thereby thinning the stands and further favoring the larch. In the past, the combination of root disease, low-intensity ground fires, and mixed severity fires probably worked in concert to maintain larch cover types. Even in the absence of fires, root disease was estimated to cause retention of larch cover type on as much as 25 percent of ha of forest in northern Idaho and western Montana (Hagle 1999). This is

a significant role for root pathogens but still no replacement for fire.

Although the pathogens are nearly always in evidence at the stand (or polygon) level, at any one time most trees will appear outwardly healthy. Large to small groups of dead and dying trees are normally seen within the stand. These represent "hot spots" or clumps of particularly active inoculum, and if the trees are very large, Douglas-fir beetle and fir engraver beetle attacks are common. With time, symptomatic and attacked trees develop in places, that may have gone decades without evidence of infection (van der Kamp 1995; Theis and Nelson 1997).

Fire returns, which are sufficiently frequent to allow western larch to become well-developed as the dominant species in the forest, may serve to reduce fungus biomass somewhat by keeping the size of grand fir and Douglas-fir root systems small, making it difficult for pathogens to maintain biomass. A single generation of Douglas-fir appears to be sufficient to rebuild the fungus biomass. As maturing Douglas-fir are killed by root pathogens and Douglas-fir beetle, canopy openings develop. Seedling Douglas-fir and grand fir will begin growing in the openings. Generations become abbreviated in these openings with young trees succumbing to root disease before or shortly after reaching cone-bearing age. The forest becomes a mosaic of increasingly uneven-aged patches. Since it may take a generation or two before species composition is again shifted mostly away from Douglas-fir and back to western larch (with stand replacement fire), large root disease patches may develop as colonies merge.

When burning occurs, and there is sufficient seed source for larch to regenerate in the stand initiation phase, the large biomass of root pathogens will again play an important role in removing Douglas-fir, and to some extent, grand fir from the stands. The stage is then set for conversion back to western larch for perhaps two or more generations.

In the absence of fire, the species composition in the patches is likely to shift quickly toward Douglas-fir and grand fir. The amount of the site occupied by grand fir is eventually more than that by Douglas-fir because of significantly longer survival of grand fir in the presence of a large root pathogen biomass. Root disease and bark beetles are, as in pine type, unable to perform the functions of fire in these systems. Without fire, there is limited opportunity for larch to regenerate.

The cycle is broken without larch. Root pathogen biomass builds to a point of indefinitely dominating successional dynamics. Large trees become increasingly rare elements and the tallest canopy becomes sparse while the low canopy, that produced by saplings, may be very dense in patches. Fire behavior, forage, and habitat characteristics can be very different from those that were typical of larch forests.

Social Implications of Managing Within the Historic Range of Variability

Wood Utilization—Ponderosa pine was and continues to be preferred species for its clear, straight-grained wood. It is used primarily for boards. The highest-grade lumber produced from old growth trees was and continues to be utilized for applications such as window frames, sash, trim, molding,

siding, furniture, and flooring. A substantial amount of lower-quality ponderosa pine has been utilized for paneling.

As the largest, highest-grade trees have been depleted, utilization standards have changed to accommodate the poorer wood quality of smaller diameter trees with a greater frequency of knots. To achieve clear lengths for many applications, knots are sawn from boards and the resulting clear lengths are joined and glued to produce an artificial clear effect. While this process achieves an appearance of clear wood, the product isn't completely satisfactory. The various strips that are joined in the process will finish differently and lack the durability and aesthetic value of the true clear ponderosa pine board. There continues to be a strong market for the premium grade boards. This material is used by furniture makers and hobby woodworkers alike. One might expect that this market will persist over time. The highly valued, clear ponderosa pine board can only be produced from old growth trees.

Western larch by contrast is not valued for boards, but is very desirable for many other applications. Larch is an excellent material for dimension lumber, plywood, utility poles, sawn beams, laminated beams and even roofing shakes. Early on, after settlement, larch was used extensively for mining timbers. The tight, straight-grained wood produced in older larch is very strong and desirable in support applications. In the current market place, historic lumber of large dimension is commanding very high prices. Recently in the Missoula market area, 12 by 12 sawn larch beams were advertised at \$1/board foot. Applications are being made to produce a variety of chemical products from larch stumps.

Forest product availability and size is affected by the forest composition and structure. As stand density and stems per acre increases, tree size decreases thus reducing the availability of large sawlogs and increasing the availability of small logs and poles. This has resulted in a significant change in sawmill production capability, sometimes requiring a "retooling" of sawmill infrastructure, and in some cases the elimination of forest-related industry in small communities. This has consequences within the economic and social structure of those communities.

Habitat and Forage—The reduction in the use of fire to control tree density and expansion of undesirable species, along with the desire to "control" wildfire, has led to a reduction of meadows and open stands of trees that historically have been available for domestic and wildlife forage (Arno and Gruell 1986). A general increase in stand density and canopy coverage has led to significant declines in all shrubland/grassland cover types that were dispersed throughout almost all coniferous cover types as non-forested openings. This has been observed qualitatively by comparing historical photos of forested landscapes with more recent photos across much of the western United States. The ponderosa pine cover type is a good example to use to understand the connections between HRV, social values, and desired conditions in rangeland settings.

The ponderosa pine cover type and the associated shrubland/grassland cover types (bitterbrush/bunchgrass, sagebrush/grassland, fescue/bunchgrass, and wheatgrass/bunchgrass) occurring as understory and interfacing with the ponderosa pine cover type have experienced sharp declines due to invasion of Douglas-fir and juniper. The

Juniper/sagebrush cover type was documented to have increased by 160 percent and is at ecologically significant high coverages compared to historic levels.

As stand density and canopy coverage have increased from invasion of Douglas-fir and juniper, important shrub/grass cover types, and understory communities have declined in coverage. These declines have led to ecologically significant minimum coverages of the shrub/grass cover types; falling outside of the historic range of variation. Ponderosa pine and the associated shrubland/grassland cover types evolved under frequent, low intensity fire regimes, which have been interrupted in the last 100 years, pushing these cover types outside the historic range of variation.

In some forests, increasing frequencies and severities of defoliation and cone predation by western spruce budworm has slowed the advance of Douglas-fir into adjacent grasslands. Although useful, the effects of western spruce budworm have been too limited in scope to replace the important functions of fires.

Although not yet demonstrated, the loss of large trees and subsequent loss of large snags and logs are likely to be emerging issues as a result of the shift to shorter-lived tree species. Douglas-fir and grand fir have relatively limited abilities to produce the large, hard snags valued as cavity nesting sites.

By understanding the fire disturbance regimes, which resulted in the composition, structure, and pattern of the ponderosa pine cover type and associated shrubland/grassland cover types, land managers can tailor management to mimic these natural disturbance processes and return to coverages within the historic range of variation. This will once again produce the social values associated with these types. If these habitats and ecological processes were maintained within their historic range of variability, the wildlife species that once survived in those situations will once again be able to flourish.

Recreation and Aesthetic Values—Increased stand density along with increased insect and disease activity and the resultant susceptibility to large wildfires has minor effects on recreation opportunities. These effects tend to be very localized and may affect specific areas that people return to each year. Access through the forests becomes more difficult as stand density increases. Because of the large amount of open space in the intermountain West, this has not been a significant factor influencing recreation activities.

Perhaps of greater concern is aesthetic impact of losses of ponderosa pine and western larch. Both species are significant components of the scenery in western Montana and northern Idaho. The western larch cover type in the Intermountain West is 35 percent less than it was 100 years ago. Ponderosa pine cover type is 25 percent less. Stands of large, old ponderosa pine remain in only a few places and although the larch cover type is still present in sufficient numbers to present a spectacular display of fall color, the downward trends in both species is a cause for concern.

Conclusion

This paper has pointed out several significant scientific reasons for managing vegetation within a historic range of

variation. Any decision about manipulation of vegetation, whether within or outside the HRV, ultimately becomes a social decision. As long as humans interact with and utilize forested settings, there will be a need to approach these settings as designed landscapes. Nature could run its course; however, it may not be the course that people desire for it to run. Rene Dubos, author of *So Human an Animal* once wrote, "Nature is like a great river of materials and forces that can be directed in this or that channel by human intervention." As the Forest Service and other land management agencies make decisions about vegetative changes, new landscape patterns will be created affecting many social systems, from recreation settings to sustainable communities. The hope is that these decisions will lead to what Dean Apostol and Nancy Diaz identified in their book *Forest Landscape Analysis and Design* as "a more enlightened, purposeful, and objective development of forested landscapes."

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Developing Desired Future Conditions With the Landscape Management System: A Case Study of the Gotchen Late Successional Reserve

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Abstract—Changing public values have led to federal land management direction like the Northwest Forest Plan with major land allocations for late successional forest habitat. Restoration silviculture is a tool for maintaining optimum habitat despite risk of catastrophic disturbance due to the combined impact of fire, insects and disease. The Gotchen Late Successional Reserve (LSR) in the Gifford Pinchot National Forest provides an example of the issues of southern Washington Cascades LSR management. The Landscape Management System is a computer model applied to the planning for the Gotchen LSR area to assess alternative management actions, understand the effects of these actions on late-successional habitat and other values, and develop appropriate management.

Issues

Public values attached to forests have changed over time, often in response to economic circumstances. Changes in public values in the United States between 1900 and 1950 generated several laws designed to guide national forest management. Subsequent legal challenges over how federal agencies managed forests within the range of the northern spotted owl (*Strix occidentalis*) resulted in the 1994 Northwest Forest Plan (NWFP).

The system of federal land allocation established by the NWFP was designed to meet the dual objectives of protecting species associated with old-growth forest ecosystems and of producing a sustainable supply of timber and non-timber resources. The allocation system includes seven land use categories, one of which is Late Successional Reserves (LSR's)—areas reserved to provide habitat for late-successional species.

In: Barras, Stan J., ed. 2001. Proceedings: National Silvicultural Workshop; 1999 October 5–7; Kalispell, MT. Proc. RMRS-P-00. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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No programmed timber harvest is allowed in LSR's, but "restoration silviculture" is permitted. A distinction is made between silvicultural treatments allowed in LSR's in forests west of the crest of the Cascade mountain range versus those to the east because forest conditions differ. Because of past management practices, such as the suppression of fire, some of the drier, mid-elevation (2,500 to 4,000 feet) forests on the east slopes of the Cascade Mountains have acquired multi-storied, late successional structural characteristics more commonly associated with moist, higher elevation and west-side forests. These drier, mixed-species forests, now multi-storied and with abundant down wood, provide spotted owl habitat but are at an elevated risk from insects, pathogens, and uncharacteristically severe fires. Furthermore, the increased tree density stresses all trees, making them more susceptible to insects and pathogens. Maintaining such late-successional habitat may be inconsistent with natural disturbance regimes, yet is required under current federal law in LSR's in these areas. West of the Cascades, increased urbanization has reduced available spotted owl habitat and, subsequently, increased a demand to provide habitat on eastern Cascades sites where it may not have persisted historically. The Gotchen LSR in the Gifford Pinchot National Forest provides an example of the issues of eastside LSR management.

Site Description

Location

The Gotchen LSR is in the Gifford Pinchot National Forest (GPNF) in southern Washington State. This portion of the GPNF is east of the crest of the Cascade Mountains. The 15,000-acre LSR lies just south of Mt. Adams (T.7N., R.10E.). The northern boundary of the LSR is the Mt. Adams wilderness area, the eastern is the Yakama Indian Reservation, the southern is just inside the Klickitat County line and the western is the White Salmon River (fig. 1).

East of the Cascades, annual precipitation generally decreases on a west-east gradient. In the LSR, this precipitation gradient is modified at the local scale by the 12,307-foot peak of Mt. Adams. One result of this modification is a decline in precipitation from north to south. Annual precipitation at the northern boundary of the LSR is estimated at 90 inches, while at the southern boundary it is just 60 inches

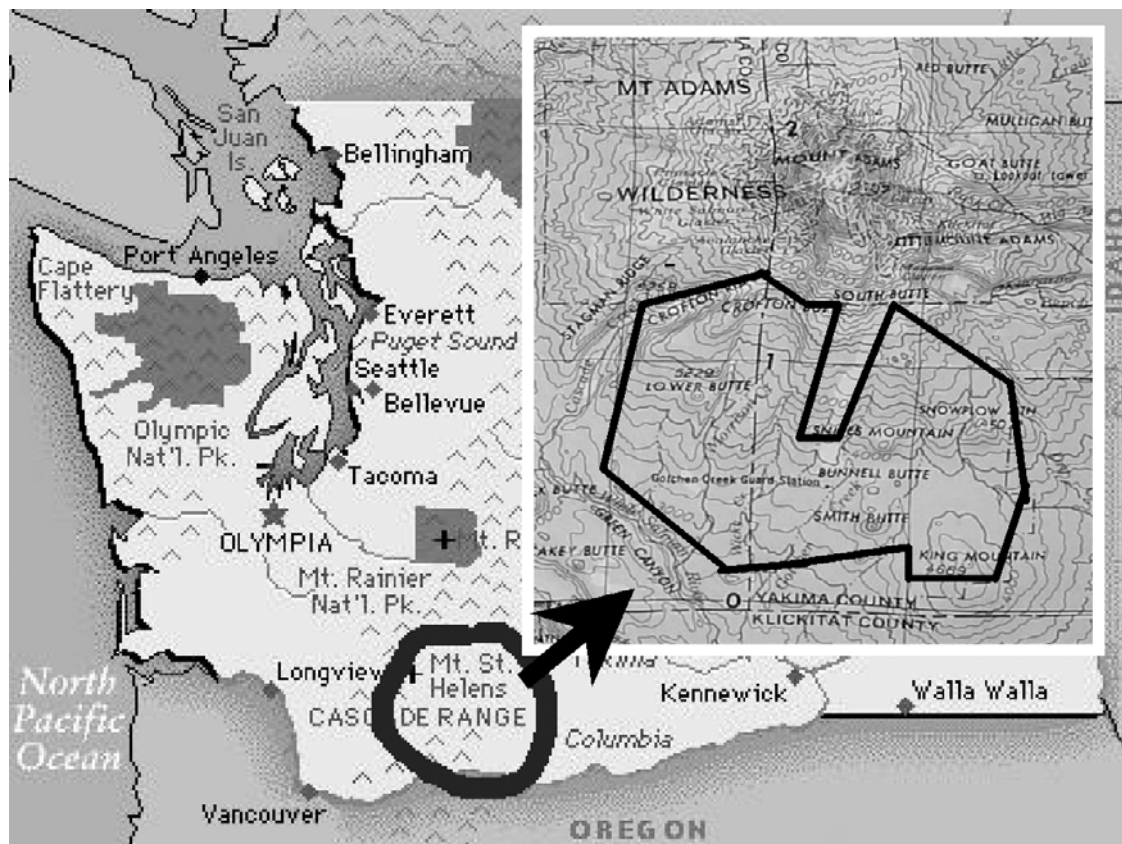


Figure 1—Location of the Gotchen LSR on the Mt. Adams Ranger District of the Gifford Pinchot National Forest.

(Topik 1989). The corresponding change in elevation is from approximately 7,000 to 3,000 feet. On any given site aspect, slope, and elevation influence precipitation. These variables influence the amount of soil moisture at an even smaller scale. Ridgetops and southern exposures, for example, have lower effective moisture than draws and northern exposures. These site characteristics have been implicated in the persistence of late-successional forest refugia in the eastern Cascades (Camp and others 1997).

Flora and Fauna

Effective soil moisture is the key factor regulating the distribution and abundance of vegetation. One method to characterize vegetation is by identifying groups of plants, or associations, that occur consistently within particular environmental conditions. The collection of plant associations that share the same dominant species is termed a “series.”

The majority (86 percent) of the Gotchen LSR is within the grand fir (*Abies grandis*) series, which is comprised locally of 11 plant associations (LSRA 1997). This series has warm, moderate environmental conditions and therefore supports plants from both moister and drier habitats (Lillybridge and others 1995). Grand fir is considered the dominant climax tree species on sites that are too dry for more shade tolerant trees and yet provide enough moisture to enable grand fir to out-compete Douglas-fir. Characteristic drier site species

include ponderosa pine (*Pinus ponderosa*) and beargrass (*Xerophyllum tenax*). More mesic site plants include Douglas-fir (*Pseudotsuga menziesii*), vanillaleaf, western red cedar (*Thuja plicata*). A transitional association between Western hemlock and Pacific Silver fir is *Thuja plicata-Achlys triphylla*, which occurs in shaded, low slope positions near valley bottoms. The northern boundary of the LSR is at approximately 6,000 feet. At this elevation, colder temperatures result in the replacement of the grand fir series with plants in the mountain hemlock-subalpine fir zone (*Tsuga mertensiana-Abies lasiocarpa*).

The variety of plant associations in the Gotchen LSR results in an array of structures suitable for wildlife species associated with early- to late-successional forests. Late succession-associated wildlife species that have been documented in the Gotchen LSR include bald eagle (*Haliaeetus leucocephalus*), northern spotted owl (*Strix occidentalis caurina*), black-backed woodpecker (*Picoides arcticus*), and American marten (*Martes americana*). These species are all either classified as “Threatened,” “Endangered” or “Species of Concern” and are terrestrial, dependent on large-trees (>21 inches d.b.h.), and have either a large (>1,000 acres) or medium (60 to 1,000 acres) home range. Snags and down logs are important structural features used by these species (LSRA 1997). Unfortunately, much of the mid-elevation forest in the Gotchen LSR is comprised of small diameter, shade tolerant grand fir. A gap exists in the 40 to 80-year age

class (fig. 2); therefore future late-successional stands may not develop for years. An active western spruce budworm outbreak, in combination with previous management activities, is generating an accumulation of fuels in the Gotchen LSR. A high-intensity fire could be fatal to the owls. The challenge, therefore, is to provide late-successional habitat while minimizing the risk of a stand replacement fire in the Gotchen LSR.

Objectives

The objective of this study is to test the utility of the Landscape Management System:

- For assessing alternative management actions.
- For understanding the effects of these actions on late-successional habitat and other values.
- For developing, implementing, and monitoring appropriate management (including the possibility of no active management) in the Gotchen LSR.

This paper discusses the preliminary results to date. The application of the Landscape Management System (LMS) to management planning is based on the ecological sciences and on the management science disciplines of systems approaches and decision analysis.

Management Science

Systems Approach

“Systems” approaches keep people from being overwhelmed by complex problems. This is accomplished by dividing problems into groups, by working on each group, and by then addressing interactions among groups. A group can be divided into subgroups, which can be further subdivided. Forest ecosystems, for example, can be grouped, studied, and managed at many levels to address their complexity (Tansley 1935). Management is often focussed at the individual organism level for silvicultural operations (for example, planting, thinning, etc.), the stand level for managing stand structures, and the landscape level for managing landscape values such as between-stand diversity and

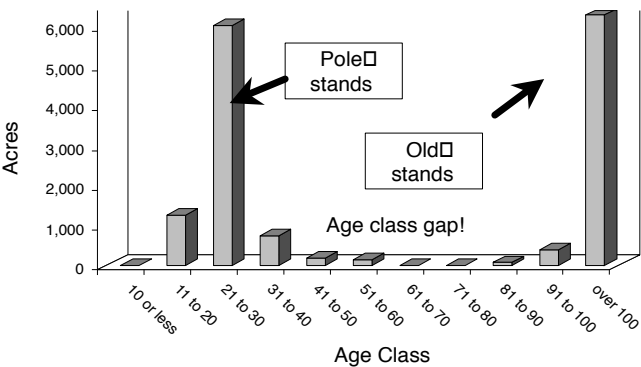


Figure 2—Gotchen Late Successional Reserve Acres by age class.

commodity flows. Coordinating among these levels requires generalizations from one level to the other. Such coordination can create “bottlenecks” in the flow of information among levels. Rapid decisions made at the most localized level possible, with only key information passed on to the next highest level, helps ensure that understanding and managing the system does not bog down and become overwhelmingly complex.

Decision Analysis Approach

Modern concepts in decision analysis involve many aspects of the systems approach (Morgan and Henrion 1990; Oliver and Twery 1999) and have been institutionalized in federal forestry through the Environmental Impact Statement or “E.I.S.” process. The objective of this process is to present the decisionmaker with an array of alternative choices, displaying the effect of each choice on the various possible objectives the decisionmaker may have (fig. 3). The decisionmaker can then understand the tradeoffs among objectives and reveals values by the choice of alternatives and tradeoffs made.

The “rational, iterative approach” is probably most appropriate for forest management (and is included in the E.I.S. process). It entails a series of analytical steps. It is “iterative” for two reasons.

1. Instead of the decisionmaker *a priori* stating and weighting the different objectives for the analysts to achieve, the decisionmaker is presented with an array of alternatives to fit multiple objectives and allowed to choose a management approach after seeing the range of choices and their effects.

2. The decisionmaker is presented with increasing depths of understanding of choices and their effects by developing a “mental model” of the system being developed (Senge 1999). For example, the decisionmaker can first be presented with a simple numerical rank of the effect of each choice on each objective. As the grasp of the choices grows, the decisionmaker can be presented with increasingly deeper explanations of the effects of choices on the landscape, through time, and even at the individual stand level.

The role of the professional in modern decisionmaking is becoming increasingly defined. The professional is responsible

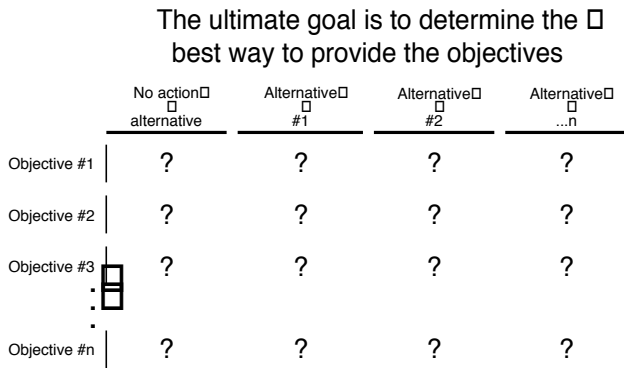


Figure 3. A decision matrix for showing decisionmakers the consequences of alternative management actions using the “rational, iterative” decision analysis process.

(and liable) for giving the best opinion of the consequences of different alternatives. Sometimes, such as within the USDA Forest Service hierarchy, the professional is given decisionmaking authority. In the fields of medicine, land surveying, engineering, and (increasingly) in forestry, the professional is being held accountable for the quality of his analyses; he is expected to present analyses accurate within the reasonable knowledge of the profession. Consequently, professional forest managers and analysts are becoming culpable for misusing or misinterpreting models and other diagnostic criteria, for not using models when they should have, for doing the wrong analysis, and for delaying or avoiding an analysis when one could have been made.

The Landscape Management System

Many tools are available which help forest ecosystem managers with decision analyses and implementation by performing many of the routine, complex, repetitive calculations needed to manage among operation, stand, landscape, and other scales (Oliver and Twery 1999). This paper describes the use of the Landscape Management System (LMS), a PC-based “point and click” interactive system (McCarter and others 1998). LMS allows the manager to import inventory and other stand and landscape information, to “grow” any stand or the entire landscape by sending the inventory data to various computer growth models (for example, FVS and Organon) (Donnelly 1996; Teck and others 1996), to treat stands silviculturally, and to present results. These results may be in terms of inventory; wind, fire, or other hazards; habitat conditions; timber volume; or other factors. The results can be presented as summary tables, graphs, visualizations at the stand and landscape levels (McGaughey 1997), and files exportable to spreadsheet analyses. LMS can be a valuable tool if the strengths as well as the shortcomings of the component analyses are understood.

LMS is a series of about 40 programs written primarily in C++ and Python that link various existing models (for example, Uview, Utools, FVS, and Organon) on a Windows® platform. It is being developed at the Silviculture Laboratory, College of Forest Resources, University of Washington in cooperation with the USDA Forest Service, Pacific Northwest Station. It is available to anyone free of charge, and the model, a users’ manual, and e-mail “help” address is available at: <http://silvae.cfr.washington.edu>.

Methods

To use LMS for preliminary analyses of the Gotchen LSR, district-level stand inventory data were first entered into electronic form. For “legacy” stand exams done prior to 1980 (stand exams dated from 1974 to 1999); a migration program being prepared by the USDA Forest Service Decision Support team in Fort Collins will considerably improve the speed of this important first step. In the absence of this migration program, other conversion programs were written to change the Gotchen LSR data into a form acceptable to LMS. Although good inventory data lead to more accurate analyses and management, the use of LMS can begin with incomplete inventory. This is accomplished by extrapolating inventory among stands of similar ecological

characteristics. Aerial photos can assist in assigning stands to ecologically similar groups. Inventory and other data can be refined systematically during the subsequent management process.

Extrapolation of data can lead to a professional dilemma: is the professional acting more responsibly by using the best available, incomplete science, or by delaying analyses until complete inventory data are available? This dilemma can be partly addressed after the analysis by examining the consequences of the “do nothing” management alternative.

Once the data are loaded into LMS, analyses can be done rapidly. For example, part of the scoping, the development of measurable criteria, and the development and analyses of alternatives (steps one through four, below) was done for a 60-year period by three people in two days. Other aspects, however, require more stand-specific expertise and decisions of local Interdisciplinary Teams. Applications of LMS can follow the “rational, iterative” decision analysis steps described below.

Step 1: Scoping

Local professional and public knowledge and scientific and technical analyses of the area help the scoping process. In addition, stand and landscape visualizations and information on the species composition, elevation, site, aspect, and other factors can be displayed through LMS (fig. 2). The information can be electronically transmitted for rapid distribution among groups in the management hierarchy.

Step 2: Determining the Objectives

The primary objective for managing the Gotchen LSR is to maintain habitat for late-successional species, especially the spotted owl. This objective is assigned from broader hierarchical levels such as laws and policies. In addition, some objectives emerge from local conditions—such as fire safety, since it is perceived that the grand fir stands in the Gotchen LSR are at high risk for fire. Such “emerging objectives” do not need to be pre-approved by the decisionmaker, and thus ignore the effects of alternatives on these objectives. It would be irresponsible, however, for the analyst to overlook a blatant emerging objective.

Step 3: Converting the Objectives to Measurable Criteria

Converting the objectives to measurable criteria requires professional expertise. The LMS program uses forest inventory information to develop certain criteria; for example, to classify stands by structure classes; to classify stands as suitable habitat for different species; to estimate each stand’s wind and fire susceptibility; and to estimate the standing, harvested, and snag and log volumes. These criteria are then used, or further converted and used, as the measurable criteria for the objectives shown in figure 7. Other measurable criteria can also be developed easily in PC spreadsheets using data from LMS.

How well the objectives are met through time under different management alternatives can be projected using

LMS (fig. 4). For higher management levels, a summary value can be calculated for each objective that incorporates the objective and its change through time. In addition, the meaning of each summary value and its previous measurable criteria—its shortcoming and strengths—needs to be communicated clearly to the decisionmaker. This need for the decisionmaker to understand the measurable criteria further emphasizes the importance of the iterative decisionmaking process. It also emphasizes that the analysts need to be unbiased—even disinterested—relative to the objectives and alternatives.

Another professional question arises about the quality of the measurable criteria. The criteria need to be constantly improved and preferably refereed (or at least peer reviewed). In the meantime, the professional will be held accountable for whether the criteria are the “best available science,” whether other criteria are chosen, or whether it is more reliable not to use LMS or other analysis tools. Giving decisionmakers a clear explanation of the measurable criteria and their limitations helps maintain the quality of the professional’s position.

Step 4: Developing Alternatives and Comparison With the Objectives

The Gotchen LSR contains 141 stands. Developing management alternatives that are both realistic and present the range of alternatives would be difficult and time consuming if each stand is considered individually. A stratification or grouping process avoids the “bottleneck” of too many decisions at the landscape level and relies on more accurate, site-specific decisionmaking.

Using information developed during the scoping process, the Gotchen landscape was stratified into six groups of similar site attributes and stand age. The attributes considered were elevation, aspect and slope, which are particularly important indicators of site moisture availability in the eastern Cascades. The groups which were selected as most appropriate for this LSR are: “young” stands, “hot, pole” stands, “cool, pole” stands, “flat, pole” stands, “hot, old” stands, and “flat, old” stands.

Five alternative silviculture pathways were developed for a typical stand in each group (fig. 5). These five pathways included a “no action” alternative plus a range of thinning intensities and schedules. Each alternative pathway was projected for a 60-year planning period for each of the six groups using LMS. The results of all possible pathways were then summarized by decade. Different proportions of each group’s total area could then be assigned to each pathway (fig. 6). An optimization program evaluated the contribution of any set of pathways to a specific objective, as well as effects on other objectives.

A range of alternatives was then developed and displayed as a matrix (fig. 7) for the decisionmaker to choose among. The background information was also readily available through LMS for iterative discussions with the decisionmaker. No decision has been made yet on the Gotchen.

Step 5: Making the Decision

The next step is for the decisionmaker to understand the tradeoffs and to choose an alternative (or request an alternative intermediate between existing ones). The decisionmaker’s values may become apparent by the tradeoffs.

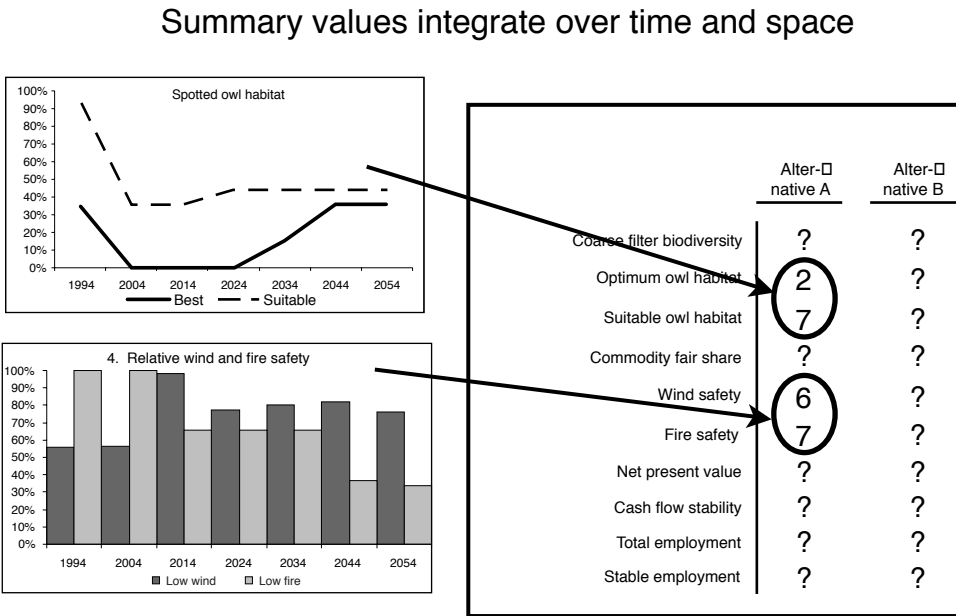


Figure 4—LMS can project the degree to which each objective is realized on each stand and on the forest as a whole with each treatment approach. These values can be integrated across time into a summary value.

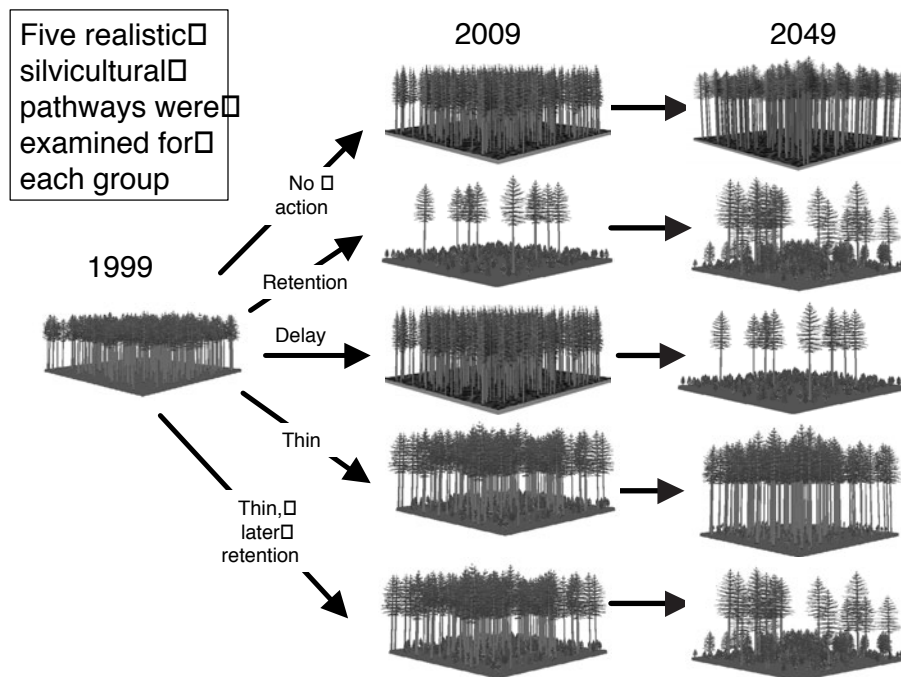


Figure 5—An example of five alternative silvicultural pathways for the “hot, pole” ecological group.

Results of different pathway emphases in a group can be rapidly examined

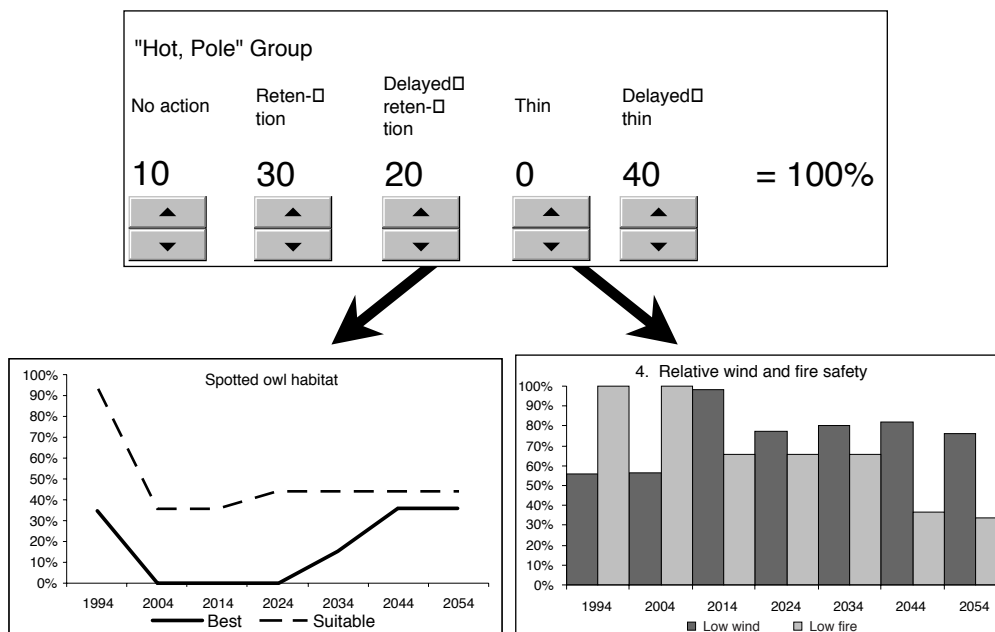


Figure 6—Different proportions of the ecological group's area could be assigned to different pathways and the consequences simulated through LMS.

	No action	Alter- native A	Alter- native B	Alter- native C	Alter- native D
Coarse filter biodiversity	4	5	5	5	5
Optimum owl habitat	0	2	2	2	2
Suitable owl habitat	6	6	6	7	6
Commodity fair share	0	8	8	7	5
Wind safety	9	7	7	7	8
Fire safety	7	9	9	9	9
Net present value	0	2	2	2	0
Cash flow stability	3	9	9	9	10
Total employment	0	7	7	7	5
Stable employment	0	1	1	1	0

Figure 7—The range of alternatives is developed and summary values of the effects on the potential and explicit objectives are displayed in a matrix. After understanding the consequences, the decisionmaker can choose an alternative.

Implementing the Chosen Alternative

Refining the Plan at the Stand Level

The chosen alternative—the proportion of stands in each ecological group to follow each pathway—will be given to

field foresters, who will visit each stand and determine its ability to be treated along each pathway (fig. 8). Some stands—such as those with low height/diameter ratios or low spruce budworm defoliation—may be more suitable for a “no action” alternative than others. These subtleties can best be determined by “on-the-ground” inspection of stands. The best assignment of the proportions of pathways to specific stands can be developed using field-based information combined with landscape projections of LMS.

Treating the Forest as a “Portfolio”

The local forester will then have a complete list of what stands are to be treated, in which way, and what the expected outcomes are for the next planning period. (In this case, it was 10 years, but LMS can also work in 5-year or shorter periods.) The forester can then be opportunistic in treating the stands—as funds, markets, weather, and similar conditions warrant.

Making the Expected Plan Visible

The final assignment of each treatment to each stand can then be projected using LMS to create expected stand and landscape visualizations, charts, and other information. These images and charts can be made publicly available (for example, brochures and electronic postings) so the public and such economic users as tour guides and timber harvesters will know what and where to expect future benefits (fig. 9).

Then, the Field Forester determines which stands
follows each pathway

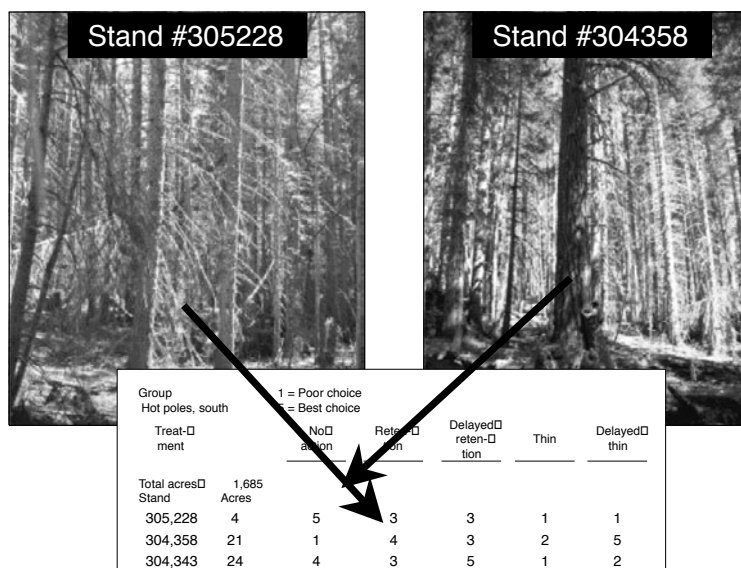
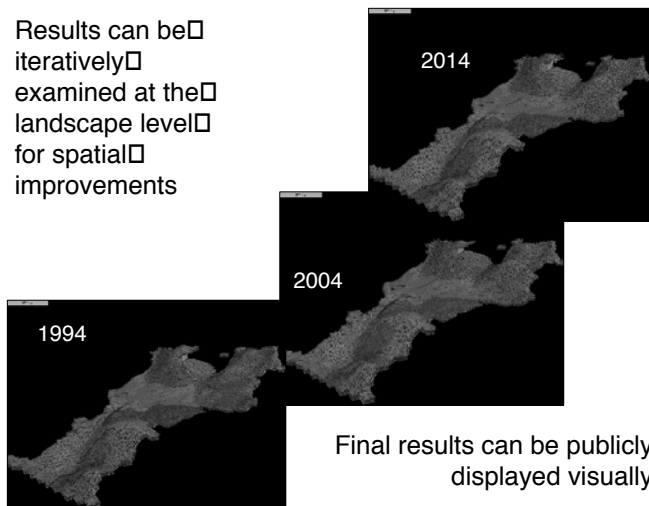


Figure 8—The field forester then decides which stand within a group has greatest ability to be managed along each pathway, eventually summing the acres within each pathway to meet the targeted amount.

Results can be
iteratively
examined at the
landscape level
for spatial
improvements



Final results can be publicly
displayed visually

Figure 9—These stand-specific prescriptions can be fed into LMS and refined to create a landscape plan. Visualization and charts can help make the plan visible to the public and can be used to monitor at various intensities.

Implementing the Silvicultural Operations

The stand-level visualizations have also been found to be helpful to “treatment layout foresters,” timber sale administrators, and loggers because it can provide a visual image of the “before” and “after” expectations of the stands.

Monitoring/Feedback

As the plan is being implemented, monitoring and improvement can be facilitated with the LMS programs. Monitoring at future times can follow a sampling scheme, with all stands cursorily examined and progressively fewer examined in more detail. The visualization component imbedded in LMS allows all stands to be visually monitored quite readily.

At future dates (for example, immediately before and after silvicultural operations and 5 or 10 years in the future), the expected (as projected by the management plan) and the actual (as determined in the field) conditions of different stands could be compared. Such visualizations readily identify gross inconsistencies between expected and observed stand structures.

A sub-sample can be examined in more depth by comparing expected and actual inventories. In addition, the expected areas providing habitats for different animal species can be compared with places where they are actually found.

Where inconsistencies are found between expected and actual future conditions, the causes of the inconsistencies

can be determined and the management (for example, operations, LMS, or errors) can be corrected for the next planning cycle following the well developed “continuous quality improvement” processes (Feigenbaum 1951, 1983).

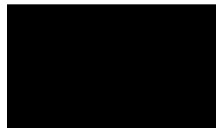
Future Steps

The Gotchen LSR analysis within LMS will be redone using more alternative pathways and refined measurable criteria. If a decision is made, the implementation steps will then be undertaken. The same procedure shown here can be used to coordinate several landscapes on larger scales using the systems approach, decision analysis, and assistance tools (Oliver and others 1999).

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Section IV: Inventory, Monitoring, and Adaptive Management



Preliminary Evaluation of Environmental Variables Affecting Diameter Growth of Individual Hardwoods in the Southern Appalachian Mountains

W. Henry McNab
F. Thomas Lloyd

Abstract—The value of environmental variables as measures of site quality for individual tree growth models was determined for 12 common species of eastern hardwoods in the Southern Appalachian Mountains. Periodic diameter increment was modeled as a function of size, competition and environmental variables for 1,381 trees in even-aged stands of mixed-species. Resulting species models explained from 46 to 78 percent of total variation in diameter increment, of which environment accounted for 3 to 17 percent of the total explained. In similar model formulations where site index replaced environmental variables, it accounted for only 0.01 to 3.6 percent of variation. An important finding was the significant relationship of growing season length and precipitation with diameter increment. Results of testing a selected model with an independent data set indicate that environmental variables are useful as measures of site quality.

Introduction

A primary responsibility of silviculturists is forest management, and growth and yield models help them fulfill this responsibility. Researchers are seeking ways to improve the reliability of these models, increase the use of ecosystem classification and management, and ensure silviculturists have the best possible tools. The research described in this paper is aimed at improving the southern silviculturist's ability to manage forests effectively and efficiently.

Site index, the average total stand height at a particular reference age, is among the most widely used measures of site quality in growth and yield models of forest productivity (Carmean 1975). Although site index is often difficult to determine accurately because the underlying assumptions are seldom satisfied (Beck and Trousdell 1973), it accounts for significant variation in growth models for some species, particularly those that form relatively pure stands such as yellow-poplar (*Liriodendron tulipifera*) (Beck and Della-Bianca 1972). In stands of mixed species, however, site index may be insignificant (Bowling and others 1989; Harrison and others 1986). Replacing site index with environmental

variables in diameter growth models would provide at least four advantages. First, errors associated with its measurement would be overcome (Lloyd and Hafley 1977). Second, an ecological basis for classification of site productivity would be provided (Barnes and others 1982; Reed 1980). Third, the application of models using geographic information systems would be facilitated (Teck and others 1996). Fourth, radial increment might be more sensitive than tree height to variation in site quality (Tryon and others 1957).

Environmental variables already used to quantify site quality for western conifers (Wyckoff 1990) provide the basic model formulations for a national system of growth and yield models that comprise the Forest Vegetation Simulator (Tech and others 1996). Results of recent studies in the Southern Appalachian Mountains indicate that species composition is strongly related to environmental variables, particularly those associated with moisture gradients (McNab 1991). These results also suggest that environmental variables might be used to quantify site quality in growth models of the Southern Appalachian Mountains, where hardwood stands typically consist of multiple species (Beck 1981).

Our primary objective was to determine if environmental variables account for significant variation of periodic diameter growth of individual trees in multispecies hardwood stands in the Southern Appalachian Mountains. A secondary objective was to compare models based on environment with those using site index. The appropriate model formulation, we hypothesized, was the one developed for growth of individual conifers in the Rocky Mountains (Wyckoff 1990). This study is part of an ongoing program of research to model the composition and dynamics of Southern Appalachian forests.

Methods

Study Area and Field Data

Tree growth data were obtained from sites in the Southern Appalachian Mountains in two regional-scale ecological units (Bailey and others 1994)—Blue Ridge Mountains (M221D) and Northern Ridge and Valley (M221A). Sixty-six permanent sample plots ranging from 0.15 to 0.25 acres were established in 1974 (Harrison and others 1986), on productive sites in relatively undisturbed, even-aged stands of multiple hardwood species. Sixty-two of these plots were thinned to favor trees of better quality, higher vigor, and

In: Barras, Stan J., ed. 2001. Proceedings: National Silvicultural Workshop; 1999 October 5-7; Kalispell, MT. Proc. RMRS-P-00. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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desired species. Trees on each plot were numbered, identified by species, and measured for diameter at breast height (d.b.h.). Each tree was remeasured after 5 years to determine periodic d.b.h. increment. Oak (*Quercus* spp.) site index was determined for each plot with the equation developed by Olson (1959) and standardized for all plots by converting it to an equivalent value for white oak (*Q. alba*) using the relationships developed by Doolittle (1958).

Plots were characterized by a number of continuous and discrete variables associated with site quality based on Wykoff's (1990) formulation. We used ecological units because they are similar in concept to the location variable used by Wykoff (1990). Values of summer precipitation and frost-free days, obtained from isopleths (U.S. Department of Agriculture 1941), represented quantitative environmental variables of regional extent. Topographic variables determined on each plot included elevation to nearest 100 ft, aspect to nearest degree, slope gradient to nearest percent, and position on the slope in two classes: (1) lower or (2) middle and upper. The influence of aspect and slope gradient was quantified using the transformations suggested by Stage (1976).

Model Development and Data Analysis

Relationships among individual tree basal area increment and topographic variables were determined using multiple regression to evaluate the formulation (Wykoff 1990) that relates individual tree diameter growth to three components:

Diameter growth = tree size + competition + environment

The dependent variable (diameter growth) was quantified by radial increment and was transformed to the natural logarithm of 5-year periodic change in squared diameter outside bark at breast height ($\ln(\text{dds})$). Variation in diameter at the beginning of the growth interval attributable to size was accounted for by two functions of d.b.h. (also used by Wykoff 1990):

$$\text{Size} = b_0 + b_1 \ln(\text{d.b.h.}) + b_2 \text{d.b.h.}^2$$

where

$\ln(\text{d.b.h.})$ = natural logarithm of initial d.b.h. (inches)
 d.b.h.^2 = initial d.b.h. squared, and
 b_0, b_1, b_2 = regression coefficients

We quantified the effect of competition from neighboring trees on increment with stand basal area at time of thinning:

$$\text{Competition} = b_3 \text{BA}$$

where

BA = plot total stand basal area (ft/acre), and
 b_3 = regression coefficient

Harrison and others (1986) found that stand basal area was the most important influence on periodic annual individual tree basal area increment for all species.

We quantified the influence of site factors on tree growth using the elevation and topographic variables of each plot.

The following formulation is similar to that used by Wykoff (1990):

Environmental effects =

$$b_4 \text{ELE} + b_5 \text{ELE}^2 + b_6 \text{GRA}(\sin(\text{ASP})) + b_7 \text{GRA}(\cos(\text{ASP})) + b_8 \text{GRA} + b_9 \text{GRA}^2 + b_{10} \text{PCP} + b_{11} \text{FFD} + b_{12} \text{SP} + b_{13} \text{EU}$$

where

ELE = elevation (feet)
 ELE^2 = elevation squared
ASP = aspect (degrees)
GRA = slope gradient (percent)
 GRA^2 = slope gradient squared
PCP = precipitation during warm season (inches)
FFD = frost free days (number)
SP = slope position (upper and middle or lower)
EU = ecological unit (M221A or M221D)
 b_4 through b_{11} = regression coefficients.

Models were developed with stepwise multiple regression (SAS Institute Inc. 1985) using backward elimination of insignificant variables to minimize effects of multicollinearity (Zar 1996). The three variables accounting for size and competition ($\ln(\text{d.b.h.})$, d.b.h.^2 , basal area) were forced in the model. Effects of multicollinearity on significance of environmental variables were evaluated using Mallows's C_p statistic (Zar 1996).

Model Validation

The model developed for yellow-poplar was validated with data collected from 3,353 trees on 138, 0.25-acre permanent plots installed throughout the Southern Appalachians in 1961 and remeasured in 1966 to predict growth and yield of yellow-poplar (Beck and Della-Bianca 1972). The model development and validation data sets were similar except that 21 plots (607 trees) of the latter were in central Virginia, beyond the range of the developmental data set. The ranges of diameter growth, size, competition, and environmental site variables in each data set were comparable. The design of the yellow-poplar study was similar to that of the mixed hardwood species. Values of independent variables were calculated for size, competition, and site effects, and the model was solved to obtain predicted $\ln(\text{dds})$. Residuals were plotted against and correlated with d.b.h. and site index to determine model performance over a range of sizes and the adequacy of environmental variables in the model.

Comparison With Site Index

A second set of models used site index to account for variation in diameter growth associated with site quality. Variables accounting for effects of size and competition were not changed:

$$\text{Diameter growth} = b_0 + b_1 \ln(\text{d.b.h.}) + b_2 (\text{d.b.h.}^2) + b_3 (\text{BA}) + b_4 (\text{site index})$$

All variables were forced into the model for this comparison.

Results and Discussion

Model Development

A total of 1,381 trees were sampled and combined into the 12 species and groups of species recognized by Harrison and others (1986) (table 1). Species of magnolia (*Magnolia* sp.) and birch (*Betula* sp.) occurred infrequently and were grouped by genera. A miscellaneous group consisted of nine species present in numbers too few for model development. Hereafter, both species and species groups are referred to as species.

Chestnut oak (*Q. prinus*) and northern red oak (*Q. rubra*) were the best represented in the data set; magnolia and

black locust (*Robinia pseudoacacia*) were least represented. Five species typically occur on middle to lower slopes or in coves and are considered mesophytic: black cherry (*Prunus serotina*), northern red oak, yellow-poplar, magnolia, and birch. Scarlet oak (*Q. coccinea*) and black oak (*Q. velutina*) are considered xerophytic and generally occur on middle to upper slopes and ridges. Red maple (*Acer rubrum*) and white oak are common on both moist and dry sites. Black cherry and northern red oak occur more commonly at higher elevations (>3,000 ft) and white and black oaks are more prevalent at lower elevations (<3,000 ft). Species in this study are common constituents of predominant forest cover types of the Southern Appalachians below about 4,500 ft, especially the types identified by the Society of American Foresters (Eyre 1980) as chestnut oak, white oak-black oak-northern red oak, yellow-poplar-white oak-northern red oak, and sugar maple-beech-yellow birch. Most species sampled are moderately tolerant to intolerant of shade.

Mean values of diameter growth were only slightly greater for mesophytic species than for xerophytic (table 2). Mean d.b.h. was greatest for yellow-poplar and least for birches. Residual stand basal area after thinning ranged from 28.3 to 106.6 ft²/acre and averaged from 58 to 72 ft²/acre. Mean elevation of most species was about 3,300 ft. Slope gradient varied most among the site components: precipitation and frost-free days varied little among species. Graphical examination of plot frequency in relation to aspect indicated that species were represented on sites of all azimuths.

The tree size variables, ln (d.b.h.) and d.b.h.², were consistently highly correlated ($p < 0.0001$) with increment for all species except the miscellaneous group (table 3). The correlation of competition (stand basal area) and diameter growth was variable among species. Elevation was significant ($p < 0.01$) for three species. Aspect was strongly correlated ($p < 0.001$) with growth of only the miscellaneous species. Gradient was strongly correlated ($p < 0.001$) with growth for two species. Precipitation was significantly negatively correlated ($p = 0.01$) with scarlet oak. The number of

Table 1—Common name, scientific name, abbreviation, and number of trees sampled for each species or group of species.

Species	Genus and species	N
Black cherry	<i>Prunus serotina</i> Ehrh.	70
Northern red oak	<i>Quercus rubra</i> L.	214
White oak	<i>Quercus alba</i> L.	151
Yellow-poplar	<i>Liriodendron tulipifera</i> L.	146
Black oak	<i>Quercus velutina</i> Lam.	56
Magnolia ^a	<i>Magnolia</i> spp.	42
Black locust	<i>Robinia pseudoacacia</i> L.	44
Birch ^b	<i>Betula</i> spp.	189
Chestnut oak	<i>Quercus prinus</i> L.	222
Scarlet oak	<i>Quercus coccinea</i> Muenchh.	58
Red maple	<i>Acer rubrum</i> L.	130
Miscellaneous ^c	Various species	59

^aConsisted of Frasers (*M. fraseri* Walt.) and wahoo (*M. acuminata* L.).

^bConsisted of sweet (*B. lenta* L.) and yellow (*B. allegheniensis* Britton).

^cConsisted of basswood (*Tilia heterophylla* Vent.), beech (*Fagus grandifolia* Ehrh.), blackgum (*Nyssa sylvatica* Marsh.), hickory (*Carya* spp.), mountain silverbell (*Halesia monticola* Sarg.), sassafras (*Sassafras albidum* (Nutt.) Nees), sourwood (*Oxydendrum arboreum* (L.) DC.), sugar maple (*A. saccharum* Marsh.), and white ash (*Fraxinus americana* L.).

Table 2—Mean (+/-s.d.^a) individual tree diameter growth (ln(dds)), size (d.b.h.), competition (basal area) and environmental site characteristics by species^b.

Variable	BC	NRO	WO	Y-P	BO	M	BL	B	CO	SO	RM	MISC
Ln(dds)	3.1	2.9	2.4	3.2	2.8	3.0	2.1	2.2	2.4	2.9	2.7	2.2
(in.)	±0.7	±0.6	±0.8	±0.6	±0.6	±0.6	±0.8	±0.7	±0.7	±0.7	±0.6	±0.8
D.b.h.	8.1	9.7	10.2	11.4	11.3	9.9	8.0	6.8	8.5	9.6	8.0	7.1
(in.)	±3.1	±2.9	±2.5	±2.9	±2.1	±3.0	±2.6	±2.1	±2.1	±2.9	±2.1	±3.0
Basal area ^c	61	62	69	69	62	58	67	70	64	59	72	64
(ft ² /ac)	±21	±19	±23	±20	±23	±18	±10	±20	±19	±19	±17	±23
Elevation	4215	3221	2466	3080	2643	3434	3462	3835	3105	2935	3330	3469
(feet)	±386	±667	±346	±711	±411	±630	±455	±732	±671	±475	±668	±748
Gradient	42	38	22	31	34	38	42	40	29	36	30	38
(percent)	±17	±19	±10	±17	±13	±13	±16	±14	±15	±11	±17	±17
Precipitation	29	27	25	26	26	25	28	26	26	26	27	28
(inches)	±2	±3	±2	±3	±3	±2	±2	±3	±3	±3	±4	±3
Frost free	172	177	177	178	180	174	178	169	176	181	171	177
(days)	±5	±8	±7	±7	±4	±9	±6	±9	±9	±5	±10	±5

^as.d. = standard deviation.

^bBC = black cherry, NRO = northern red oak, WO = white oak, Y-P = yellow-poplar, BO = black oak, M = magnolia, BL = black locust, B = birch, CO = chestnut oak, SO = scarlet oak, RM = red maple, MISC = miscellaneous species.

^cBasal area of the stand in which the species occurred.

frost-free days was correlated ($p < 0.001$) with the growth of six species. Among species, black oak growth was not significantly correlated with any environmental variables and black locust was correlated with most variables.

Size and competition variables were forced into parsimonious models for species (table 4). In the presence of other variables, the size variable (d.b.h.²) was significant for only

three species. The competition variable, basal area, accounted for significant variation in all species except magnolia. Other variables included in the best models of species ranged from three to nine variables (including the intercept). More than half of the models for species included either precipitation or growing season length. Multiple correlation coefficients (R^2) for the models ranged from 0.46 for

Table 3—Correlation coefficients of individual tree diameter growth (ln(dds)) with tree size (ln(d.b.h.), d.b.h.²), competition (basal area), and environmental site variables by species^a.

Variable	BC	NRO	WO	Y-P	BO	M	BL	B	CO	SO	RM	MISC
Ln(d.b.h.) (inches)	0.63 ***	0.71 ***	0.69 ***	0.62 ***	0.51 ***	0.57 ***	0.65 ***	0.54 ***	0.50 ***	0.80 ***	0.59 ***	0.38 ***
d.b.h. ² (inches)	0.57 ***	0.69 ***	0.61 ***	0.60 ***	0.49 ***	0.61 ***	0.64 ***	0.48 ***	0.53 ***	0.75 ***	0.53 ***	0.26 *
Basal area (ft ² /ac)	-0.20 *	0.06 ns	-0.47 ***	-0.42 ***	-0.31 **	-0.03 ns	0.03 ns	-0.29 ***	-0.41 ***	-0.06 ns	-0.20 *	-0.07 ns
Elevation (ft)	0.04 ns	-0.07 ns	0.21 **	0.01 ns	0.04 ns	-0.36 **	0.49 ***	-0.04 ns	0.13 *	-0.26 *	0.20 *	-0.10 ns
Sine aspect (degrees)	0.20 *	-0.11 *	0.17 *	0.25 **	0.05 ns	-0.01 ns	-0.40 **	0.14 *	0.05 ns	-0.18 ns	0.16 *	0.40 ***
Cosine aspect (degrees)	-0.24 *	-0.11 *	-0.11 ns	0.02 ns	0.16 ns	0.22 ns	-0.30 *	0.00 ns	-0.15 *	-0.18 ns	-0.13 ns	0.05 ns
Gradient (percent)	0.04 ns	-0.18 **	-0.02 ns	0.38 ***	-0.03 ns	-0.20 ns	0.29 *	0.09 ns	0.29 ***	-0.12 ns	0.11 ns	0.07 ns
Precipitation (inches)	0.28 *	-0.04 ns	0.14 *	0.06 ns	0.06 ns	-0.09 ns	0.03 ns	0.05 ns	0.06 ns	-0.31 **	-0.03 ns	0.13 ns
Frost free days (no)	0.36 ***	0.01 ns	0.24 ***	0.24 ***	0.07 ns	0.29 *	-0.25 *	0.27 ***	0.34 ***	0.13 ns	-0.13 ns	0.42 ***

^aAsterisks under each coefficient indicate level of significance: 1 = 0.1, 2 = 0.01, 3 = <0.001, ns = not significant.

^bBC = black cherry, NRO = northern red oak, WO = white oak, Y-P = yellow-poplar, BO = black oak, M = magnolia, BL = black locust, B = birch, CO = chestnut oak, SO = scarlet oak, RM = red maple, MISC = miscellaneous species.

Table 4—Parsimonious regression models for each species^a with overall multiple correlation coefficient (R^2) and measure of multicollinearity [C_p]. (Asterisks under each species indicate level of significance of the variable^b.) (The first four variables were forced into the models.)

Variable	BC	NRO	WO	Y-P	BO	M	BL	B	CO	SO	RM	MISC
Intercept	**	*	ns	**	*	ns	ns	***	***	**	***	*
Ln(d.b.h.)	***	***	***	**	*	ns	ns	***	***	***	**	***
d.b.h. ²	ns	ns	***	ns	ns	ns	ns	*	ns	ns	ns	*
Basal area	***	***	***	***	*	ns	*	***	***	**	***	*
Elevation	ns	ns	*	ns	ns	ns	ns	ns	ns	*	**	ns
Elevation ²	***	***	*	ns	ns	ns	*	***	ns	*	**	ns
Sine aspect	ns	ns	ns	ns	*	ns	ns	*	***	ns	ns	ns
Cosine aspect	ns	ns	ns	ns	ns	ns	ns	**	*	**	**	ns
Gradient	ns	*	ns	***	*	ns	ns	ns	***	ns	ns	ns
Gradient ²	*	*	ns	ns	*	ns	ns	ns	***	*	**	***
Precipitation	*	ns	*	ns	ns	ns	ns	**	*	**	*	ns
Frost free days	**	ns	ns	***	ns	*	ns	**	ns	ns	*	ns
Eco. unit	ns	ns	ns	ns	ns	*	ns	ns	*	ns	ns	ns
Slope position	ns	*	ns	***	*	ns	ns	ns	*	ns	ns	ns
N in model	8	8	7	7	8	6	5	9	11	9	10	5
C_p	7.1	8.0	0.4	6.9	10.0	2.0	3.9	6.2	7.8	4.5	7.5	1.7
R^2	0.75	0.59	0.67	0.66	0.51	0.49	0.54	0.62	0.60	0.78	0.59	0.46

^aBC = black cherry, NRO = northern red oak, WO = white oak, Y-P = yellow-poplar, BO = black oak, M = magnolia, BL = black locust, B = birch, CO = chestnut oak, SO = scarlet oak, RM = red maple, MISC = miscellaneous species.

^b1 = 0.1, 2 = 0.01, 3 = <0.001, ns = not significant.

the miscellaneous group to 0.78 for scarlet oak. Values of C_p were less than or equal to the number of variables in the model for all species except black oak, indicating that most models are probably adequately precise and have acceptable levels of multicollinearity (Zar 1996).

Figure 1 displays the relative importance of the three types of variables (size, competition, and environmental site effects) in explaining variation in growth by species. Almost 60 percent of the variation was explained for all species; almost 80 percent for scarlet oak. For most species, the effect of tree size accounted for as much variation as competition and environment variables combined. The effect of competition was least important for the magnolias and northern red oak but was very important for black cherry and chestnut oak. Environment variables explained relatively little variation in d.b.h. growth of white oak but accounted for more than 8 percent of variation for other species.

The model developed for yellow-poplar, typical of those for other species, was examined in more detail using an independent data set. The final model for yellow-poplar was based on 146 trees and consisted of seven significant variables (including the intercept). All variables except d.b.h.² were highly significant ($p < 0.01$). Signs of the coefficients were biologically logical for all variables except frost-free days. The negative sign of this variable indicates that radial growth is reduced as the number of frost free days increases. In addition, the simple correlation coefficient was positive, suggesting the presence of multicollinearity.

Residuals of the yellow-poplar regression exhibited no pattern and, except for a single tree (indicated by arrow), were uniformly distributed about the zero reference line (fig. 2). The subject tree grew only 0.2 inches during the 5-year period and was considered for exclusion as an outlier. Trees of similar size and crown class grew an average of 0.6 in. There was no indication of damage, disease, or injury that might explain its slow growth. In subsequent inventories this tree also grew much less than its cohorts on the same plot, which tends to exclude measurement error as the source of variation. Trial omission of this tree improved R^2

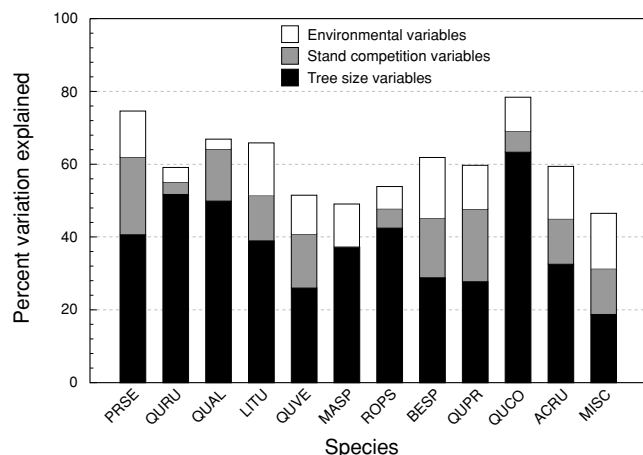


Figure 1—Proportion of total variation explained by variables of size, competition, and environment for the best prediction model for each species.

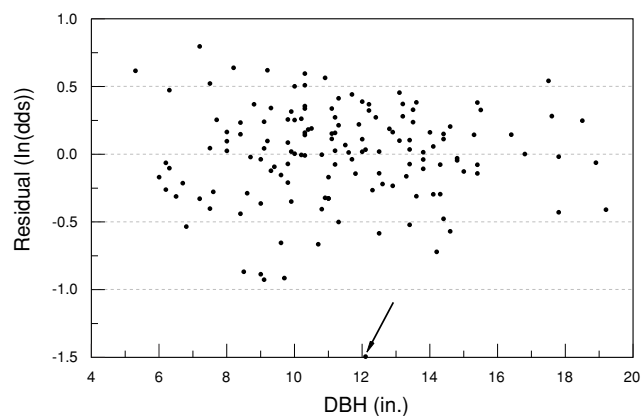


Figure 2—Residuals of the yellow-poplar model developed, using 151 trees. The tree identified by the arrow is explained in the text.

of the final model by 3 percent, but resulted in the same set of significant variables and no change in distribution of residuals. The subject tree was retained in the data set because it probably represented other trees in the validation data set. Larger data sets (for example, Wykoff 1990) probably included a number of trees with less than average diameter increment. The residuals of this model were not correlated with site index ($r = 0.02$, $p < 0.78$).

Comparison With Northern Rocky Mountains Model

Models developed for Southern Appalachian Mountain species were more variable in formulation than those developed for the Northern Rocky Mountains by Wykoff (1990). Similar to western conifers, size and competition significantly affect diameter increment of eastern hardwoods. Elevation was a component in models of all western conifers (Wykoff 1990), but was significant for only three hardwood species (black cherry, northern red oak, and birch), which generally occur at higher elevations. Similarly, aspect and gradient were present in all western conifer models, but were moderately significant ($p < 0.01$) for only half of the eastern hardwood species. Ike and Huppuch (1968) reported that formulation of site quality models for Appalachian hardwoods varied by hardwood species, particularly among species of oaks. Generally, the overall effect of topographic variables was inconsistent for explaining variation of $\ln(\text{dds})$ among species.

The association of individual tree diameter growth with precipitation and length of growing season for several species in our study suggests the importance of broad-scale environmental variables. Tryon and others (1957) reported that diameter growth of yellow-poplar was influenced by precipitation and temperature in West Virginia. Overall lack of significance of the two mapped ecological units suggests that tree growth may be more sensitive to individual environmental components than to combined components. When precipitation and growing season length were removed, ecological unit became significant ($p = 0.03$) only

for scarlet oak. Our results generally agree with those of Wykoff (1990), who found discrete variables were necessary to account for unmeasured regional climatic and geologic effects on tree increment.

Validation of the Yellow-Poplar Model

We tested the yellow-poplar model by predicting 5-year diameter growth of 3,353 trees in a validation data set. The distribution of residuals (fig. 3) was homogeneous and poorly correlated with d.b.h. ($r = -0.03$) although the relationship was significant ($p < 0.05$) because the sample size was large. Residuals were significantly correlated with site index ($r = 0.27$, $p < 0.0001$). The bias in our model suggests that additional variables should be included in the model. Using additional variables associated with competition, Wykoff (1990) found no correlation of residuals with site index in models for Northern Rocky Mountain conifers. Additional factors that may contribute to the bias in our model include: (1) different behavior of yellow-poplar diameter growth in mixed-species stands compared to pure stands; (2) climatic differences during the first 5 years after treatment (1961–1966) of the validation plots compared to that on the developmental plots (1974–1979); and (3) extending the model into central Virginia, beyond its range of applicability.

Comparison With Site Index

Compared to models based on environmental variables, models based on site index performed less satisfactorily (fig. 4). Site index accounted for relatively small proportions of variation in diameter growth for all species (not displayed), from about 3 percent for magnolia and chestnut oak to less than 0.01 percent for northern red and scarlet oaks. For yellow-poplar, site index accounted for 0.2 percent of the variation in diameter increment. The species in which the proportion of variation explained by site index was nearest to that of the model based on environmental variables was white oak, the only species that was not converted to a common basis.

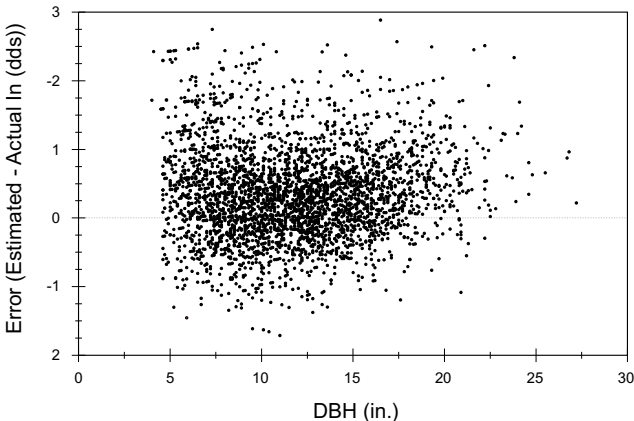


Figure 3—Residuals for the yellow-poplar model validated using an independent data set of 3,353 trees.

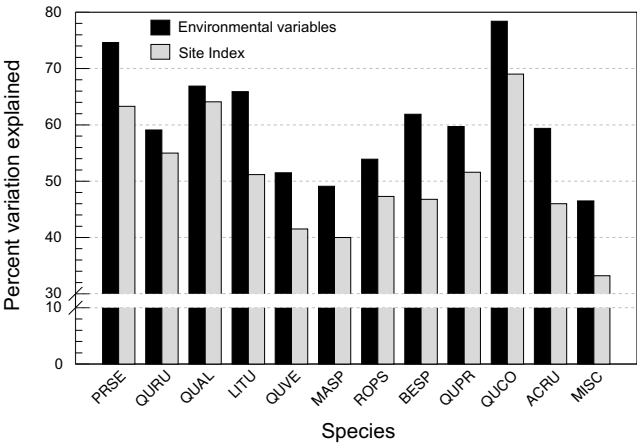


Figure 4—Proportion of total variation in diameter increment explained by models based on environmental variables and site index (size and competition variables included in each model) for the best prediction equation of each species.

Several explanations are possible for the poor performance of site index in the model formulation: (1) conversion of site indexes for all species to that of white oak introduced unknown errors (Lloyd and Hafley 1977); (2) site index relationships are based on prediction equations, which may be biased (Beck and Trousdell 1973); and (3) radial increment might be a more sensitive than height increment to changes in environmental influences (Tryon and others 1957).

Conclusions

Results of this preliminary study suggest that site index can be replaced by environmental variables in growth models of mixed species in the Southern Appalachian Mountains. Our analysis suggested that diameter growth of each species responds individually to environment and that no single environmental variable was of primary importance. The relative importance of two variables on diameter growth—precipitation and length of growing season—should be investigated further. Evaluation of model formulation should continue, and additional competition variables, such as basal area greater than the subject tree and crown ratio, should be included. Our test suggests that the Forest Vegetation Simulator formulation for the Northern Rocky Mountains is applicable to hardwoods in the Southern Appalachians.

Acknowledgments

This manuscript was based on a study designed and established by D. E. Beck and L. Della-Bianca, both retired employees of the USDA Forest Service, Southern Research Station, Bent Creek Experimental Forest, Asheville, NC. We thank Wade C. Harrison, Westvaco Corporation, Summerville, SC, for providing a copy of the data set upon

which his original work was based. G. Miller and J. Guldin reviewed an earlier draft of this manuscript.

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Integrated Inventory and Monitoring

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Abstract—Understanding and inventorying our ecological systems is key to addressing how issues, questions, and management actions will affect the composition, structure, and function of these systems. Taking an ecological systems approach to the inventory and monitoring framework, is one which we feel will allow answers to currently identified management questions and new ones as they develop. More efficient ways to delineate polygons and a more credible method to attribute the polygons from a sample design are needed. Small area estimation such as the k-nearest neighbor or most similar neighbor, currently being evaluated, could be useful in mapping structural characteristic statistical data in a more defensible manner than methods used in the past.

Introduction

Region 1 of the USDA Forest Service includes about 25 million acres in the states of Montana, northern Idaho, North Dakota, and northwest South Dakota. Approximately 8 million acres are classified as suitable forest land, 12 million acres are identified as unsuitable forest land (including wilderness), and 5 million acres is nonforest land (grass and rangeland). The successful and sustainable forest and grassland management depends upon what we know about the land, water and air as well as about the people who reside near or depend upon public lands for their use or enjoyment.

Currently we gather independent data by resource functions, which lead to gaps in information and costly duplication of work. Rather, the focus of this inventory and monitoring system is on coordinating data collection to reduce the overall costs and provide more comprehensive information. Why is inventory important? In moving to consider landscapes as a whole, it is very important to know what exists and where it exists. The inventory will cover the entire land base and, in addition to estimates of timber volumes and land areas, will include information on a full range of vegetation types, as well as data on coarse woody debris, forest health, soil, range, and other relevant items.

A general planning model includes four basic steps; inventory and monitoring, assessments, decisions and implementation. The model is a process that the Forest Service has

generally followed since the conception of forest planning. The same model can be displayed by adding a dimension for scale. Thus the need to define location-specific inventory information for a project decision versus generalized information for a regional decision. Regardless of the decision scale it's important for the information to link between scales; to provide the fine scale detail required for broad-based regional decisions and to set the context and location for implementing regional decisions at a project scale.

The direction for Forest Inventory and Analysis (FIA) is to "...make and keep current a comprehensive inventory and analysis of the present and prospective conditions of and requirements for the renewable resources of the forest and range lands of the United States...." FIA was also directed to "...as part of the Assessment effort... to develop and maintain on a continuing basis a comprehensive and appropriately detailed inventory of all National Forest Systems land and resources" (Forest Service 1992).

The National Forest System (NFS) direction is taken from the ecosystem management principles of health and sustainability as articulated in the Forest Service Natural Resource Agenda. The Northern Region Overview focus is on ecosystem health and recreation is closely tied to the Natural Resource Agenda. Ecosystem health and habitat restoration are the overriding priorities for management. These principles help insure we can meet the needs of the present without compromising the ability of future generations to meet their needs.

This paper addresses what we believe are key components of an ecological systems inventory framework:

- Multiresource inventories that are linked or integrated;
- Multiscale approach that is linked across scales;
- Spatial expression;
- Data attributes that are sensitive to a variety of issues and indicators;
- Ground sampled data linked with mapping;
- Temporal continuity and comparison;
- Multiownership inventories that are coordinated;
- Organizationally executable and affordable.

We explore these components through the challenge of designing an inventory system for a particular part of the ecological system. We have simply called it the "Vegetation" aspect or if using the Holosphere model used on the Sierra Nevada Monitoring Framework, it would be the Biosphere. In this paper, we present the overall design and products for a systematic vegetation inventory. Then we will discuss the particular issues or considerations for each of the components above. At this time, the issues are being addressed through a pilot effort.

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A Vegetation Example

We focus on management surveys here and indicate what Region 1 needs and how the Region will be compatible with the national strategic needs and how project-planning surveys may fit in.

For its management needs the Region wants to define mapped ecosystems, which will vary tremendously in size and which are delineated with a desired accuracy level. These mapped ecosystems need specific information for each hectare in each Forest, but the level of detail may vary between lands classified as forest, range, or wilderness.

Ideally, mapping would be used to delineate cover types (species composition), size and density classes into polygons with 80 percent accuracy. Grouping will be done to achieve meaningful subpopulations for which the desired accuracy is achieved and attributes are assigned. Beyond this, specific information is to be collected by ground sampling for certain sample locations and that information is then used to predict the same type of information for nonsampled locations using small area estimation techniques. It is realized that the predictions will often be quite unreliable and reliable estimates of error are also required. The Region is also committed to providing information for the strategic level needs of the Forest Service so that FIA collects the required strategic level information on a 5-km grid of sample plots located on each National Forest in the Region but only on lands defined as forest.

For both strategic and management purposes the general areas of inventory are (1) timber mensuration, (2) vegetation characterization, (3) presence/absence of selected wildlife species, (4) riparian communities, and (5) presence/absence of sensitive plants.

A special feature of the Region 1 data requirement is that data elements to be collected are taken from information contained in Netweaver, a rigorous exercise by the region to determine information needs.

Multiscale Design

The Forest Service requires statistically valid inventory and monitoring designs for very large scale strategic surveys of vegetation on forest land. These are statewide estimates on a 5 or 10 year cycle documenting the condition of the forest resource and how it has changed. Survey types are (1) strategic scale surveys (national), (2) large-scale surveys (Forest level or below) for forest and nonforest lands called management surveys, and (3) project planning surveys (specific populations where a management practice is or might be applied). The question is can we integrate these types of surveys so that all three types use common information as much as possible? This is critical to the organization for efficiency in sampling, compatibility and comparability of data, and perceived ownership of data.

The FIA inventory employs a nonstratified grid across each state. This does not depend on maps but would result in a small sample size for subdivisions of a forest or smaller subpopulations. In all options below we have assumed that a mandated FIA data collection inventory grid of 5 km which we call the R1 5-km grid. We assume that this also includes

the nonforest lands in the region although FIA does not measure plots there currently.

There appear to be two major options for intensifying the inventory: nonstratified sampling (the existing FIA grid locations or an additional intensification) and stratified sampling. The grid intensification does not provide any cost or sampling efficiency that could be gained with stratified sampling. With stratified sampling we have several design possibilities; fundamentally we want subpopulations of 'like' polygons so they are homogeneous to populate the 'like' nonsampled polygons with good predictability.

Region 1 wants an ecosystem management based inventory and monitoring system. For all options below we visualize screening the locations for possible factors related to rare and endangered species as well as for other issues of interest. This would be a key first step in many project-planning surveys. The neighborhoods of identified locations would then be sampled more intensively in a statistically valid manner that we also have to develop. In some cases purposive sampling will identify special locations not tied in an obvious way to our statistical sample. Those situations would be treated separately. For both these situations very low altitude photography may be a useful supplementary sampling tool.

Mapping

Region 1 has several options to create polygons where a polygon consists of a delineated boundary with attributes that characterize the vegetation for the polygon; those attributes are size class, density and species composition (cover type). Vertical structure is desired but very difficult to develop from remote sensing or aerial photography.

The first step is a mapping phase that will start with satellite imagery and training data to produce a classified pixel map. This basic pixel map is used to aggregate or combine the pixels into an initial vegetation polygon map using an automated process, and then refine the attributes and the boundaries needed with ancillary data such as digital ortho-quads, potential vegetation, Indian resource satellite (IRS 5-meter panchromatic), classified 1 meter data and resource aerial photography. An accuracy assessment will be performed on the polygon map and the results will be documented; users will evaluate the accuracy and determine if it's adequate for the level of analysis being preformed. This map is similar to a "stand" map as traditionally used in forestry but includes the nonforest vegetation also. A National Forest is expected to have polygons or stands with an average size of about 30 acres, with 30,000 to 50,000 total individual polygons. This initial map is considered map one.

The next step, mapping phase II, is aggregating the initial mapped polygons into a map that represents 20 subpopulations (aggregation of similar composition characteristics from map one) with the intention of improving accuracy and providing larger polygons for field sampling. This map two will be used to allocate field sample locations to the 300 subpopulations (21 composition classes, 5 size classes, and 4 density classes). This is for use at the Forest, planning zone, or province level where spatial reference of

composition, structure and pattern is needed for the inventory variables.

A similar map product, map three, is envisioned based on aggregating map product two to define very general vegetation classes. This mapped aggregation would consist of approximately 60 subpopulations for long-term inventory and monitoring and assessments for broad ecological zones or subregions.

The mapping process to create maps one and two will probably be done at a Forest Zone (in other words, a multi-Forest level to take advantage of local experience and knowledge of the ecological system) and to gain acceptance of the maps and ground inventory products at the local levels. All Forests or Zones will follow the same classification format and procedures with Regional Office involvement for quality assurance. Following these procedures will ensure a consistent classification and the ability to create other map products.

As indicated in the introduction, there is a need to identify the inventory with spatial characteristics. The mapping is essential, but recognized as “tenuous” due to the potential changes that could occur in the mapping.

Other Map Efforts

The approach to be used currently centers on the National Ecological Mapping Hierarchy System (ECOMAP) to identify ecological zones for the inventory. ECOMAP is based on biophysical characteristics that only change on geologic time scales. The Sections are based on regional climate, topography, and geologic characteristics. We propose to use the sections to identify the ecological zones for inventory and monitoring. Subsections are based on surface geology, soil great groups, and potential vegetation and land-type associations (LTA's) are based on geologic soils and landform; there appears to be a consistent methodology nationally.

Hydrological units (HUC's) are based on the concept of watersheds with a consistent national framework for level four category units (4th code HUC); about 2,100 exist across the country. Level 5 and 6 HUC's are smaller and without a consistent national framework for definition. HUC's are not always true watersheds and approximately 50 percent of the HUC's are composite watersheds.

It is reasonable to assume that more maps may be desired; for example a recreation use map or a wildlife habitat map. The ECOMAP subsections and landtype associations will be used as a further stratification for inventory and analysis. Hydrologic units will be most useful in the analytical phase and during monitoring.

Statistical Estimation

Sample Designs

Assume a map of vegetation polygon subpopulations. Group these subpopulations into strata of like polygons. Then select a sample of polygons from each subpopulation. Subsample the selected polygons or select a “grid” sample from each subpopulation (which means that the number of sample units from the selected polygons is a random variable

that may be undesirable given that we want to use small area estimation to populate the unsampled polygons in each subpopulation). The advantage is that we focus as much as possible on the smallest subpopulations of interest and assign near-optimal probabilities of selection to units in those subpopulations that are of most interest (this assumes that R1 can decide on putting subpopulations in an order of priorities). The key disadvantages are that sample selection has to wait till the vegetation polygon map exists, the map will change almost continuously and if the map used turns out to be incorrect to a large degree, we may be sampling very differently from expected.

Another issue that may be a disadvantage is that there are certain features of the polygon we would like to map such as structure but it seems unlikely at this time to be able to do so. Hence such features need to be sampled for on the ground, causing difficulties in populating the nonsampled polygons well. With 13 National Forests and 300+ current vegetation classes we have a rough estimate of 500,000 polygons and about 2,000 subpopulations with about 300 polygons per subpopulation with the R1 5-km grid yielding about 1.5 plots per subpopulation (not sure these add up). We are therefore aiming at breaking sample size n into 13 n (F, subpopulations). There are other stratified options that will not be discussed here.

Criteria for Evaluating Design Alternatives

1. Ability to create vegetation polygon map.
2. Ability to make estimates for all critical subpopulations.
3. Comparison of number of strata.
4. Ability to estimate change between two inventory periods.
5. Special designs to accommodate special issues (rare species, etc.).

A pilot test is being implemented as an initial step toward implementation, where the map products are being developed in 1999 for a large area (400,000 acres) of land in the Idaho Panhandle National Forest and assessed for their accuracy. This area was picked for its considerable heterogeneity as well as the willingness of key local people to collaborate. Then in 2000 a large ground sample will be collected in each of the ecosystems to determine whether the objectives can be achieved for the pilot study area.

The Northern Region management inventory (which is likely to be also useful for the strategic survey) would be pilot tested through all phases of data collection, estimation, and analysis. This includes evaluating the ability of managers to make decisions based on the data, model development and testing, and modifications needed prior to full implementation.

To accommodate the strategic needs of the FS and to allow for integration or merger with FIA sampling, the following plot design will be used, a generalization of the FIA plot design. The FIA plot consists of four $\frac{1}{24}$ -acre circular subplots each of which is subsampled by a small $\frac{1}{300}$ -acre circular subplot for regeneration. We plan to use a one-hectare plot subsampled by four circular subplots of about $\frac{1}{4}$ acre centered at the same locations as the four FIA subplots. Transects will be used within the one hectare plot for down

woody material and understory measurements. Further refinement and testing of the plot design will be completed with the pilot test.

Incorporating the existing FIA plot design with the added one-hectare and ¼ acre plots will provide the ability to account for large trees, snags, and other rare occurring characteristics.

Estimation

Much of the estimation theory in this section was adapted from Region 6 written but unpublished directions by permission from John Teply, Program Manager, Region 6 Inventory and Monitoring. We assume that the 4 subplots on the hectare are a random sample of the one-hectare plot for variance estimation. This is required both for classical and bootstrap variance estimation. A nuisance that arises with almost any type plot but certainly with the circular plots used is that parts of the plots will fall outside the population of interest or are inaccessible to sampling either because of difficulty of terrain or in order to reach part of the sample in a practical manner we need to access via private land. Not all landowners will allow access through their land to measure information on NFS land.

To account for the different sizes in actual plot areas by sample locations we decided that the most appropriate estimator to be used in estimating population totals is:

$$\hat{Y}_s = A \left[\sum_{i=1}^n \sum_{j=1}^{m_i} \hat{A}_{ij} Y_{ij} \right] / \left[\sum_{i=1}^n \sum_{j=1}^{m_i} \hat{A}_{ij} \right] \quad (1)$$

where $\hat{Y}_s$ is the estimator for subplot size s , $\hat{A}_{ij}$ and Y_{ij} are the estimated sampled area and value of interest (expanded to a ¼ ha estimate) respectively in subplot j of plot i , n is the number of plots in the sample, and m_i is the number of subplots in the sample for plot i . How the $\hat{A}_{ij}$ and m_i are determined is described in a separate write-up (Max and others 1997). To estimate parameters involving a combination of sizes, we would then have:

$$\hat{Y} = \sum_s \hat{Y}_s \quad (2)$$

with summation over the subplots involved.

The basic rule for measuring plots that either intersect the boundary of the population or are partially inaccessible due to, say hazardous conditions, and adhere to the following basic principles.

1. Decisions concerning whether or not to measure a subplot or what part of a subplot to measure are made independently on each subplot of a PSU, regardless of subplot number, in other words, the PSU center, subplot number 1, is no different than any other subplot center.

2. If a subplot center is either inaccessible or not within the population boundary, then no measurements are taken on this subplot, since the subplot center cannot be established and referenced by standard field methods. In cases where part of the subplot is accessible or within the population boundary, even though the subplot center is inaccessible or outside the population, then this results in a part of the population that is selected to be included in the sample but

is not measured. Hence this is a source of potential bias in the estimation process.

3. If the subplot center is accessible and within the population boundary, then all regular measurements are taken on that part of the plot that is accessible or within the population. The subplot must be mapped, with relevant measurements, in sufficient detail so that the amount of area of the subplot that was actually measured can be calculated accurately. This area provides the information essential for computing the proper area weight for the partially measured subplot.

4. For purposes of making decisions about measurement, a PSU can be thought of as consisting of four distinct and separate, although contiguous, subplots.

Inaccessible PSU's

In this section we address the situation where some, or possibly all, of a PSU is inaccessible. Inaccessibility is usually caused by hazardous conditions, for example the existence of cliffs, that prevent safe access to the area covered by the plot.

A. Subplots where subplot center is inaccessible

i. Entire area of subplot is inaccessible

Follow the basic principle, part (2). The entire subplot is not measured. This lack of measuring a part of the selected sample area is a source of potential bias in estimation.

If the subplot center that is inaccessible is subplot 1, the PSU center, then the location of the PSU must be monumented with respect to a subplot whose center is accessible. This is a deviation from standard field procedure in which the location of the PSU is referenced with respect to the PSU center coincident with the center of subplot 1.

ii. Some area of subplot is inaccessible

Follow the basic principle, part (2). The entire subplot is not measured because the center of the subplot is inaccessible and cannot be established using usual field procedures. This lack of measuring a part of the selected sample area is, again, a source of potential bias in estimation.

If the subplot center that is inaccessible is subplot 1, the PSU center, then the location of the PSU must be monumented with respect to a subplot whose center is accessible. This is a deviation from standard field procedure in which the location of the PSU is referenced with respect to the PSU center, coincident with the center of subplot 1.

B. Subplots where subplot center is accessible

The basic rule is followed, in this case, without exception.

PSU's Intersecting Boundary

In this section we address the situation where a PSU intersects the boundary of the population. The population of interest, defined as simply as possible, is all National Forest System (NFS) land. The situation discussed here is where a

PSU intersects the boundary so that part of the PSU is on NFS land and part on some other ownership. The principles expressed in the basic rule, in this case, are designed to collect as much information as possible while avoiding the necessity of gaining access to the adjoining ownership for establishing subplot centers on the adjacent property.

A. Subplots where center is outside NFS land

i. No area of subplot intersects NFS land

Follow the basic principle, part (2). This subplot is not really part of the population, and there is no potential bias associated with not measuring any part of this subplot.

If the subplot center that is outside the population boundary is subplot 1, the PSU center, then the location of the PSU must be monumented with respect to a subplot whose center is within the population boundary. This is a deviation from standard field procedure in which the location of the PSU is referenced with respect to the PSU center, coincident with the center of subplot 1.

ii. Some subplot area intersects NFS land

Follow the basic principle, part (2). The part of this subplot within the population boundary is really part of the population. To access and measure this part of the subplot requires establishing the subplot center that actually is located on the adjacent property. To avoid gaining access to this adjacent property, we forgo measuring the part of the subplot on NFS land. There is a potential bias associated with not measuring the part of this subplot that is within the population boundary.

If the subplot center that is outside the population boundary is subplot 1, the PSU center, then the location of the PSU must be monumented with respect to a subplot whose center is within the population boundary. This is a deviation from standard field procedure in which the location of the PSU is referenced with respect to the PSU center, coincident with the center of subplot 1.

B. Subplots where center is on NFS land

The basic rule is followed, in this case, without exception.

Variance Estimation

Classical variance estimates can be obtained for $\hat{Y}_s$ using for example equation (5.12) on p.162 in Schreuder and others (1993). Similarly the variance for $\hat{Y}$ can be obtained by summing the variances of the $\hat{Y}_s$ included in the summation in (2) and adding the necessary covariance estimates that can be obtained by suitably modifying eq (5.12) in Schreuder and others (1993).

Based on the discussion in the review of literature, we decided that it was generally better to develop bootstrap-based variance estimates. These yield more reliable confidence intervals for the parameters of interest and can be computed easily even though they are more computer-intensive than traditional variance estimates.

Although there are several more efficient bootstrap variance estimation techniques we will concentrate on the straightforward method at this time since the method should

work over a wide range of situations and is likely to be implemented by numerous users.

To implement the bootstrapping we select n plots at random with replacement from the n plots available. This sample is used to generate bootstrap estimates using equation (1) for the information collected on the one-hectare plot. From each of the n plots selected, four subplots of the four in each plot are selected with replacement. This sample of n plots and 4 subplots is then used to generate estimates for the information collected at these subplots using equation (1) and using equation (2) for linear combinations of information requiring information from various subplots. This constitutes one bootstrap sample. We select such bootstrap. We then generate the following estimates:

$$\bar{Y}(B) = \sum_{i=1}^{n_B} \hat{Y}_i(B) / n_B \quad (3)$$

with bootstrap variance estimator:

$$v\{\hat{Y}(B)\} = \sum_{i=1}^{n_B} \left\{ \hat{Y}_i(B) - \bar{Y}(B) \right\}^2 / (n_B - 1) \quad (4)$$

Generating n_B estimates $\hat{Y}_i(B)$, also generate lower bound $LB_{\alpha/2}\{\hat{Y}(B)\}$ and upper bound $UB_{\alpha/2}\{\hat{Y}(B)\}$, which are those sorted values of $\hat{Y}_i(B), i = 1, \dots, n_B$ such that there are $n_B * \alpha / 2$ below LB and an equal number above UB. We use $\alpha = 0.05$.

Organization and Recommendations

It is clear that there is considerable overlap in the above missions for FIA and NFS-R1, and those need to be worked out in close collaboration between the interested parties involved. The various organizations within the agency involved in inventory and monitoring need to work together to develop a comprehensive, legally and scientifically defensible survey system that is also as cost effective as possible.

It is clear that major organizational changes will have to be made in Region 1. For example: change future remote sensing and GIS roles of local universities to emphasize research, applications assistance and technology transfer to Region, planning zones, and National Forests, rather than production work. Reach out to include other universities, the Remote Sensing Applications Center, and the Regional Remote Sensing Service Team.

The Regional Office role in GIS and remote sensing map development will concentrate on coordination, training, and accountability. The Regional Remote Sensing Service Team should conduct GIS and remote sensing data development at zone centers, especially if the results are expected to serve resource management as well as general planning purposes. Such data should be developed to Regional standards to facilitate Region wide summarization and reporting, and assessment.

Retain flexibility on plot design when possible. For example the Region 1 approach of using a plot that collapses into the FIA plot both in area and transect sampling has considerable promise. But the Region 6 plot design should not be rejected simply because it does not.

Evaluate the gain and losses using the Region 1 potential plot design and the Region 6 plot relative to the FIA plot. Do

this in a scientific publication prior to making the decision to drop those in favor of the FIA plot.

Clearly identify what the FIA grid can and cannot do for NFS management and project planning surveys. This will be addressed too in the Region 1 pilot study.

Remember that the main FIA product is a database and reports based on that for general consumption, whereas NFS needs a database for decisionmaking and long-term assessment. Hence the users and uses of the data are quite different.

Develop statistically valid yet practical project planning surveys if feasible. This may require time and analyses of management survey data before this can be done.

Hire statistical analysts to analyze the strategic and management databases for NFS purposes. That capability is in short supply in NFS currently and is desperately needed. In line with that, identify promising Bayesian methods for decision making for management and project planning in NFS.

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Use of Monitoring and Adaptive Management to Promote Regeneration on the Allegheny National Forest

Lois DeMarco
Susan L. Stout

Abstract—Forest regeneration in the Allegheny Plateau Region of Pennsylvania is a continual challenge due to an overabundance of white-tailed deer (*Odocoileus virginianus* Zimmerman) and the resulting density of interfering plants on the forest floor. Guidelines developed to establish regeneration on the Allegheny National Forest rely on the silvical characteristics of black cherry (*Prunus serotina* Ehrh.). Following these guidelines increased the regeneration success at the stand level, but led to less desirable outcomes at the Forest-level scale. Allegheny National Forest managers undertook a special inventory to verify this observation, based on early monitoring results, and then adopted an adaptive management strategy for each of the main forest types to change regeneration outcomes.

Introduction

The National Forest Management Act of 1976 requires that administrators of National Forests develop and implement a Forest Plan that outlines a vision of how and where sustainable forest management activities may occur. Monitoring data collected as part of the Allegheny National Forest's (ANF) Land and Resource Management Plan aided ANF silviculturists and Northeastern Research Station (NE) scientists in understanding the interactions between stand and forest scales. In this paper we report lessons learned in the last two decades from these interactions of two scales with respect to establishing diverse advance seedling regeneration.

Forest management and silviculture in the Allegheny Plateau Region of northwestern Pennsylvania occur against a backdrop of disturbance and ecological change. Today's forest is vastly different from the presettlement forest. The latter was removed during the railroad logging era that extended from the 1890s through the 1930s (Marquis 1975). The resulting transformation resembles the change observed in some stands subjected only to natural disturbances within the Tionesta Scenic and Research Natural Area on the ANF. Most notably, the proportion of shade-intolerant black cherry increased in Tionesta stands that

were disturbed by 19th century tornadoes and other intensive wind events (C. Nowak, State University of New York, personal communication). Comparable changes in species composition occurred in Allegheny Plateau forests with the removal of the presettlement forest (table 1) (Whitney 1990).

Concurrent with the removal of presettlement forest, and subsequent replacement with early successional forest, Pennsylvania's white-tailed deer herd rebounded after being nearly extirpated at the turn of the century. The deer population took advantage of subsequent optimal habitat conditions and limitations on hunting. The result was considerable damage to forest regeneration and shrub communities by the late 1920s. Figure 1 shows the white-tailed deer population of the Allegheny Plateau throughout this century along with the regional deer density goal set by the Pennsylvania Game Commission (Redding 1995).

Table 1—Change in species composition in the presettlement and second-growth Allegheny Plateau forests, in percent.

Species	Presettlement	Second-growth
Beech (<i>Fagus grandifolia</i> Ehrh.)	44	6
Hemlock (<i>Tsuga canadensis</i> (L.) Carr.)	20	6
Sugar maple (<i>Acer saccharum</i> Marsh.)	5	13
Red maple (<i>Acer rubrum</i> L.)	5	27
White pine (<i>Pinus strobus</i> L.)	5	1
Black cherry	<1	23

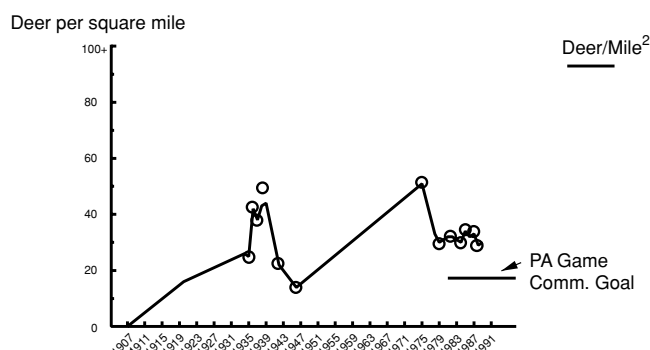


Figure 1—Change in deer density over time in four county region encompassing Allegheny National Forest (after Redding 1995).

In: Barras, Stan J., ed. 2001. Proceedings: National Silvicultural Workshop; 1999 October 5-7; Kalispell, MT. Proc. RMRS-P-00. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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As the region's second-growth forests began to mature in the mid-1960s and early 1970s, deer densities were so high that more than 40 percent of the regeneration harvests were unsuccessful. Deer were responsible for nearly 90 percent of these failures (Marquis 1981). Where deer eliminated seedlings, less preferred or more resilient species filled the growing space. In time, hay-scented and New York ferns (*Dennstaedtia punctilobula* (Michx.) Moore and *Dryopteris noveboracensis* L.), grasses and sedges, striped maple (*Acer pennsylvanicum* L.), and root suckers of American beech created dense shade that interfered with the establishment of seedlings of more preferred tree and shrub species (Horsley 1991).

To overcome an overabundant deer population, scientists emphasized the development of silvicultural techniques that rely on the regeneration characteristics of black cherry. A prolific seeder in this region, black cherry produces significant seed crops annually and bumper crops nearly every other year. Its seed remains viable in the forest floor for 3 to 5 years. Black cherry seedlings are of only moderate preference to white-tailed deer, grow rapidly in high light conditions, and respond dramatically to nitrogen/phosphorous fertilization (Marquis 1990).

Forest managers recognized that the shelterwood sequence was a means of establishing black cherry seedlings as advance regeneration in the northern hardwood, upland hardwood and Allegheny hardwood stands on the ANF (Marquis 1990). They used the herbicides glyphosate and sulfometuron methyl to eliminate interfering plants so that seedlings could become established (Horsley 1991). When abundant seedlings—usually black cherry—were established, overstory removal created light conditions that allowed seedlings to thrive and grow quickly out of the reach of deer. Fertilization and area fencing also were used to help stands regenerate.

The use of these techniques greatly improved the regeneration success rate, in other words, the rate at which fully stocked stands were established following regeneration harvests (USDA Forest Service 1998). They were implemented fully on the ANF beginning in 1980; however, regeneration treatments were concentrated in stands with abundant black cherry seed source.

By 1991, more than a decade after the adoption of the silvicultural guidelines, 10 years after the arrival of the beech bark disease complex, 7 years after the first wave of gypsy moth (*Lymantria dispar* L.) defoliation began, 6 years after a major tornado complex, and 5 years after approval of the ANF's Forest Plan, ANF personnel began to question the effectiveness of treatments and their impacts on stand development processes.

Monitoring

Monitoring and evaluation are important components of the Forest Plan. In cooperation with scientists with the Northeastern Research Station (NE), the ANF staff developed inventory and analysis methods that exceeded Regional standards. Specifically, ANF data included increased detail about species composition and relative heights of regeneration. Because these data were evaluated at both the individual stand and the forest level, ANF personnel were

able to identify larger scale issues and concerns. For example, by aggregating results of annual stocking surveys for individual stands, we determined that black cherry seedlings were dominating the third-growth forest, nearly to the point of creating a monoculture. While this might be acceptable in an individual stand, it poses problems at the forest level.

Monitoring also drew managers' attention to another phenomenon. Because the guidelines were developed to overcome an overabundant deer herd and relied heavily on the regeneration characteristics of black cherry, managers were concentrating regeneration harvests in stands with a black cherry overstory basal area of at least 25 square feet. These stands regenerated black cherry successfully, but rarely regenerated the diversity of all the different overstories that included 25 square feet of black cherry. Monitoring helped managers recognize an important problem in its early stages, but they needed additional data to understand the underlying causes of the problem and its implications for projected Forest Plan outputs and outcomes. That is, monitoring results had implications for delivery of the volume and early successional wildlife habitat expectations included in the Forest Plan. The Forest Leadership Team decided that additional information, over and above what was available through established survey methods, was needed to provide consistent, accurate information on current forest conditions and to confirm the implications suggested by analysis of monitoring data.

In 1992, with support from the NE's Forest Inventory and Analysis (FIA) unit, the ANF conducted an inventory based on a systematic sample of about 320,000 of the ANF's 513,000 acres. This survey spanned the acreage of Management Area 3.0 (MA 3). In this zone, management efforts focus on timber production primarily through the use of even-age management. The 6,000-plot survey was designed

Table 2—Distribution of understory vegetation in Management Area 3 on the Allegheny National Forest, 1992.

Condition	Percent of MA 3 affected
Adequate advanced regeneration	23
Inadequate advanced regeneration	77
Interfering plants	70
No interfering plants	30
Regeneration and interference	15
Regeneration but no interference	8

Table 3—Composition of understory interference in Management Area 3.0, Allegheny National Forest, 1992.

Interference	Percent of MA 3 affected
Fern	46
Grass	21
Woody	21
Laurel	1
Fern and/or grass	57
Any interference	70

Table 4—Overstory and understory species composition in MA 3, Allegheny National Forest, 1992.

Species	Overstory (basal area)	Understory (seedlings)
	----- percent -----	
Black cherry	28	47
Red maple	25	16
Sugar maple	11	1
American beech	9	9
Eastern hemlock	7	<1

to provide current data on understory and overstory conditions.

6,000 Plot Survey Results

The survey data assessed a wide range of forest conditions and laid the ground work for many subsequent analyses. The following are some of the findings.

- Understory composition is dominated by species that interfere with the development and establishment of tree seedlings (tables 2 and 3). Seedlings sufficient in number to count as “adequate advance regeneration” (Marquis and others 1992) are found on only 23 percent of MA 3. Some kind of understory interference is found across 70 percent of MA 3. The understory is dominated by vegetation such as fern, grass, beech suckers and striped maple.
- Species diversity is limited on plots where advance regeneration is adequate. Black cherry seedlings comprise the advance regeneration on 91 percent of the acres on which it was adequate.
- There were significant differences between overstory and understory species composition (table 4).
- Differences between overstory and understory species composition are even more apparent when examined by forest type.
- There is a disproportionate amount of seedling regeneration within the Allegheny hardwood forest type (Allegheny hardwoods account for 29 percent of the acreage, and have 53 percent of the advanced regeneration).

Application of Survey Results

Results of the 6,000 plot survey were first used to support a 1995 analysis of timber harvest capability on the ANF (USDA Forest Service 1995). ANF personnel identified 13 management issues related to natural or anthropogenic disturbance such as a complex of tornadoes in 1985, beech-bark disease, and gypsy moth impacts; the cumulative effects observed through our monitoring; and errors made during analysis for the Forest Plan. Each issue had the potential to change the level of goods and services projected in the Forest Plan. The survey data supported the following conclusions:

- Changes in forest type are likely over time if there are no changes in regeneration practices.

- A better understanding of regeneration requirements for species other than black cherry is needed so that the acreage for potential regeneration harvests can be increased.

A Timber Harvest Capability Report (THCR) incorporated these conclusions in estimates of anticipated harvest levels between 1995 and 2005. The harvest capability was reduced to 53.2 million board feet per year, although the Allowable Sale Quantity of 94 million board feet per year was not changed. This reduction in harvest level acknowledged management limitations in forest types with lower proportions of black cherry. Managers undertook a program of new research and adaptive management to increase harvest capability by gaining a better understanding of regeneration requirements of all species found on the Allegheny Plateau region of northwestern Pennsylvania.

Adaptive Management

The production estimates in the THCR include volume to be produced from stands that will be regenerated using adaptive management. In developing an adaptive management strategy the ANF’s objectives were to obtain full stocking of advance regeneration of a variety of species, appropriate to the forest type of the existing stand, and to make final harvests or selection harvests in stands with adequate stocking of advance regeneration, and achieve full stocking and establishment of a variety of species. On the basis of previous research, the ANF developed separate work plans for the upland hardwood, northern hardwood and oak forest types.

Upland Hardwoods

Following an extensive review of research on Allegheny hardwoods, several modifications to shelterwood sequences were identified for upland hardwood stands, i.e. those in which black cherry is associated with shade-intermediate species. The data suggested that intermediate species, most frequently red maple, but also cucumbertree (*Magnolia acuminata* L.) and black and yellow birch (*Betula lenta* L. and *alleghaniensis* Britt.), established successfully as advance regeneration where both deer browsing and low shade were controlled for 3 to 5 years. The most effective silvicultural technique is a non-commercial shelterwood seed cut to remove shade-tolerant saplings and poles, inside fences where deer damage is severe. These treatments will be followed in 3 to 5 years with a more conventional commercial shelterwood seed cut to add shade-intolerant species to the advance regeneration. A final removal cut will be scheduled 1 to 2 years after the second seed cut. Post-harvest stocking surveys will be needed to monitor the development of seedlings in the third-growth stand. Release treatments that target desirable seedlings might be necessary.

Northern Hardwoods

In other parts of the Northeast, uneven-age silvicultural systems are well matched to the northern hardwood forest

type (Nyland 1996; Leak and others 1987). The ANF had attempted to implement uneven-age prescriptions in a variety of northern hardwood stands from 1988 through 1994. During the summer of 1996, overstory and understory data were collected in these stands to assess the effectiveness of treatments and to determine whether modifications in the use of uneven-age management were needed. Working with NE scientists, ANF foresters learned that the required new age class of seedlings had not developed in most stands. However, where target objectives in stand structure were achieved, particularly by removing sufficient numbers of pole-sized stems, the seedling regeneration was successful (DeMarco and others, in preparation).

On the basis of these results, ANF foresters developed prescription guidelines to limit the application of uneven-age silviculture to situations with a maximum probability of regeneration success, and initiated an administrative study to determine whether the removal of interfering plants in connection with group-selection prescriptions would enhance regeneration.

Oak

Maintaining the oak (*Quercus* spp.) forest type was an issue highlighted in the the Forest Plan. There was little previous regeneration success due to mortality in much of the oak type from successive years of gypsy moth defoliation and severe drought. As a result, there was little basis for developing adaptive management strategies. In 1996, ANF personnel initiated extensive monitoring of the current condition of oak regeneration in stands that were regenerated over the past 20 to 30 years to determine the conditions in which oak seedlings had become established. In addition, historical records were searched to establish a reasonably accurate sketch of preharvest conditions and the sequence of harvest activities. The following was observed in stands with oak seedlings:

- Oak seedlings were found in some areas that experienced major catastrophic disturbance, e.g. tornado and/or tree mortality associated with insect defoliation or wildfire.
- There were varying degrees of success in oak retention as the young stands developed from seedling to sapling size.
- Site factors (slope, aspect, and soil properties) seem to play a greater role in seedling establishment and development in the oak forest type than in Allegheny upland, or northern hardwoods.
- Quality as well as quantity of light plays an important role in the development of seedlings.
- Artificial regeneration can be used to supplement oak stocking, though protection from deer is critical in achieving planting success.
- Frequent post-harvest surveys are needed to determine whether seedling release is necessary.
- Oak stump sprouts are less important in oak regeneration at Allegheny Plateau deer densities than they are in other parts of the oak-hickory forest.

There were several outcomes of this investigation. Along with NE scientists at Parsons, West Virginia, ANF foresters

continued an administrative study on artificial regeneration and tree shelters. Also, with NE personnel at Morgantown, West Virginia, they initiated a study of release treatments in sapling-size stands, and of prescribed burning as a site-preparation technique. Some stands have been identified for shelterwood and release treatments.

Summary and Conclusions

Silviculturists have always been adaptive managers. We observe the outcomes of our treatments and adapt our practices to reflect what we've learned. On the ANF, integrating the formal component of Forest Plan monitoring into this process has improved our silviculture and allowed us to scale up to the forest level in our understanding. We monitored both natural and anthropogenic treatments—silviculture, defoliation and mortality, tornado damage—and learned from each. Because we collected detailed information about variation in pre-treatment conditions and post-treatment outcomes—not just “regeneration success” but *what species, in what relative abundance*, for example—we could recognize cumulative effects and adapt our silvicultural prescriptions accordingly. We saw that landscape scale implementation of stand-level guidelines was leading to a forest-wide change in species composition and changed both our monitoring and our practice. We subdivided our monitoring efforts according to forest type, and tried to learn what conditions and treatments resulted in diversity in the emerging regeneration. We are just starting to use the new practices, and to monitor their results. We expect to continue to learn from our experiences through the Forest Plan Monitoring process.

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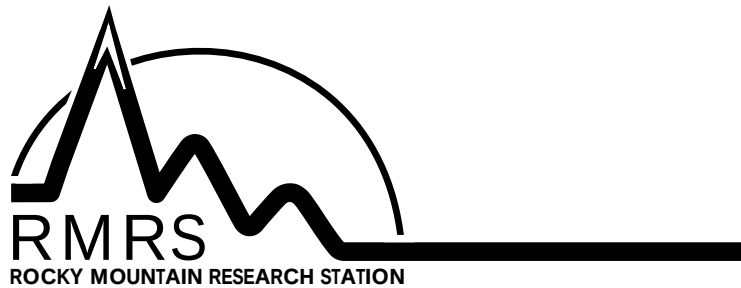
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