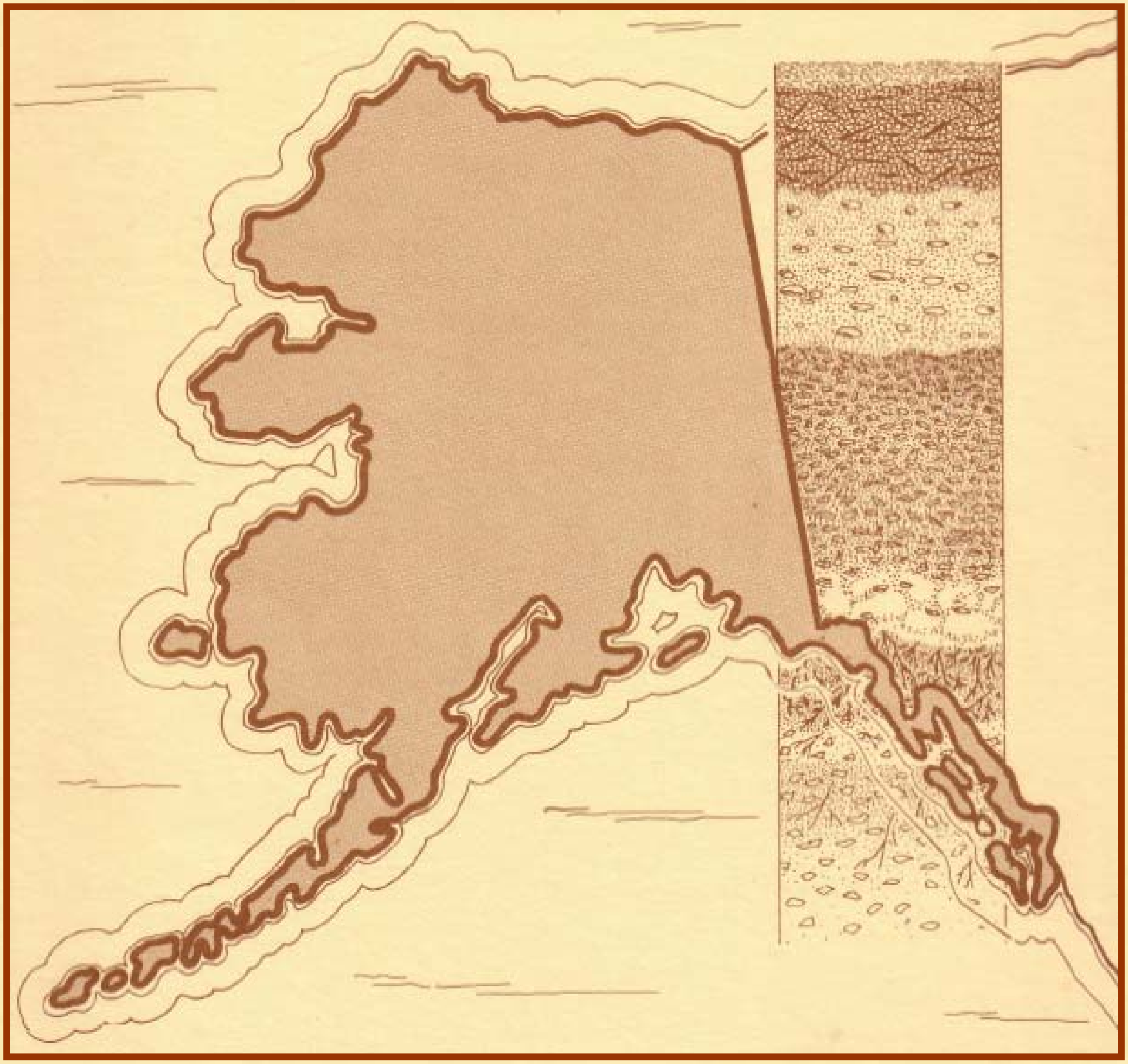
United States
Department of
Agriculture

Forest Service

Pacific Northwest
Research Station

General Technical
Report
PNW-GTR-219

Proceedings of the Alaska Forest Soil Productivity Workshop



PROCEEDINGS OF THE ALASKA FOREST SOIL PRODUCTIVITY WORKSHOP

Anchorage, Alaska
April 28-30, 1987

Charles W. Slaughter and
Tony Gasbarro, Editors

Teri Lawson, Technical Editor

Sponsored by:
Society of American Foresters, Cook Inlet Chapter

Cosponsors:
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Alaska Society of Professional Soil Scientists
Alaska Soil and Water Conservation Board
Tanana Chiefs Conference
University of Alaska Fairbanks
USDA Forest Service, Pacific Northwest Research Station
USDA Soil Conservation Service
USDI Bureau of Land Management

Published by:
U.S. Department of Agriculture, Forest Service
Pacific Northwest Research Station
Portland, Oregon
and
School of Agriculture and Land Resources Management
University of Alaska Fairbanks
Fairbanks, Alaska

General Technical Report PNW-GTR-219
April 1988

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DEDICATION

The workshop was dedicated to the memory of Jim Downs, a friend and colleague killed in a helicopter accident March 6, 1987, while returning from a field assignment.

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INTRODUCTION

Charles W. Slaughter and Anthony F. Gasbarro

The Alaska Forest Soil Productivity Workshop provided an opportunity to enhance cooperation in the development and use of soil-productivity information for forest management in Alaska. The workshop was designed to address. the role of soil information for forest management; assessment, monitoring, and enhancement of soil productivity; and research on productivity of forests and soils.

The environments for forest growth in Alaska are extremely diverse. Forests range over 14° of latitude, from Ketchikan to the Brooks Range at 680 N., and from temperate coastal to subarctic and Arctic permafrost-underlain settings. Management of forests on public and private lands varies from intensive to essentially no management, with virtually no quantitative information available about the resource in some locales. In consequence, this workshop accommodated a broad range of technical and managerial questions. The sponsors and conveners wished to improve direct communication between soil scientists and resource managers, facilitate transfer of new understanding for forest and soil systems from research to application, and identify major information deficiencies.

CHARLES W. SLAUGHTER is principal watershed scientist at the Institute of Northern Forestry, Fairbanks, Alaska. ANTHONY F. GASBARRO is an extension forester at the School of Agriculture and Land Resources Management, University of Alaska, Fairbanks.

Valuable and extensive discussions, stimulated by the formal presentations, occurred during the workshop and after hours. An evening poster session, moderated by Earl Alexander, included three presentations: Podzolization and windthrow: natural fluctuations in long-term productivity and implications for management, by Bernard Bormann; Growth of tamarack in the non-glaciated northern portion of its range, by Trudy Heffernan and E.C. Packee; and Morphology and classification of selected southeast Alaska soils, by H. David Loggy. A final workshop critique was provided in the form of an open panel discussion moderated by John Henley; panelists included Stanley Gessel, Jere Christner, Glen Klock, and Charles Slaughter.

This proceedings includes only submitted papers. These papers have not necessarily been peer-reviewed; technical review was the responsibility of the individual authors. Kelly Wenzlick (Institute of Northern Forestry) and Mayo Earnest (Agricultural and Forestry Experiment Station) provided valuable and timely assistance in preparing manuscripts for publication.

The conveners wish to acknowledge the leading role of the Cook Inlet Chapter, Alaska Society of American Foresters, in initiating and organizing this workshop. We are especially indebted to Tom Ward, Earl Ford, and Chien-Lu Ping for their generous contribution of ideas, time, and enthusiasm. .

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THE ROLE OF THE USDA SOIL CONSERVATION SERVICE IN MONITORING AND ENHANCING LONG-TERM FOREST SOIL PRODUCTIVITY

Burton L. Clifford

ABSTRACT: The USDA Soil Conservation Service has important national responsibilities in monitoring forest soil productivity on private lands. SCS helps enhance forest soil productivity by providing technical assistance through local soil and water conservation districts. District cooperators are assisted in writing a conservation plan and given information on how to conserve and enhance their forest land. SCS is involved in. tree improvement through encouraging the best silvicultural practices, and developing new and improved planting stock at its plant materials centers. Those involved in resource management need to encourage greater management and use of Alaska's privately owned forest lands. We need to be alert to new ideas for enhancing forest productivity.

INTRODUCTION

The mission of the Soil Conservation Service is to provide national leadership in the conservation, development, and productive use of the Nation's soil, water, and related resources. Such leadership encompasses soil, water, plant, and wildlife conservation; small watershed protection, flood prevention; and resource conservation and development.

Integrated in these programs are erosion control, sediment reduction, pollution abatement, land use planning, multiple use, improvement of water quality, and several surveying and monitoring activities related to environmental improvement. All are designed to assure: (i) quality in the natural resource base for sustained use; (ii) quality in the environment to provide attractive, convenient, and satisfying places to live, work and play; and (iii) quality in the standard of living based on community improvement and adequate income so that all Americans may enjoy the benefits of our natural resources. Forests are a renewable resource and SCS is deeply concerned about the conservation and wise use of forest lands.

BURTON L. CLIFFORD is State Conservationist for the U.S.D.A. Soil Conservation Service, Anchorage, Alaska..

MONITORING SOIL PRODUCTIVITY

SCS provides leadership within USDA in the inventory and monitoring of many renewable resources on nonfederal lands. SCS carries out these activities to obtain information on the current status of soil, water, forest, range, and related resources, to evaluate effectiveness of resource programs, to develop mission objectives, and to provide Congress and others with the data required for policy and program development.

Resource data collected by SCS are analyzed and interpreted, and the results are published for public use. The resulting information is particularly valuable for assessing the present resource situation, documenting changes in the resource base, and supporting conservation and land use alternatives.

The Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA) requires the Secretary of Agriculture to periodically assess the Nation's forest and rangeland resources. This assessment includes an inventory of present and potential renewable resources of the Nation. The Soil and Water Resources Conservation Act of 1977 (RCA) directs the Secretary of Agriculture to continually appraise the soil, water, forest, and related resources of the Nation's nonfederal lands. SCS has responsibility for nonfederal lands under these laws; the Forest Service has responsibility for Federal lands. During 1987 SCS will once again conduct a National Resources Inventory to provide the data base for the 1990 Resources Conservation Act appraisal. Every 5 years this process is repeated, providing Congress with a periodic appraisal of the quality and quantity of the Nation's resources, including our forest soil resources. Forestry related information gathered in this national inventory includes basic tree measurements, area of tree cover, by cover type, areas being used for wood production, and use of forest management practices such as timber stand improvement, site preparation and tree planting.

Through the Cooperative Snow Survey program SCS also has responsibility for monitoring the water resources on large areas of forest land in the western states.

ENHANCING FOREST PRODUCTIVITY

SCS assists in maintaining and enhancing the quality of the natural resource base for sustained use of the Nation's 360 million acres of privately owned forest lands. SCS is a service agency, primarily providing soil survey information and conservation planning assistance.

Soil Surveys

When conducting soil surveys forest productivity data are collected and forest-soil interpretations are made, as part of the National Cooperative Soil Survey program. This information is incorporated in technical guides and soil survey reports that support activities conducted by SCS field offices for conservation districts and their cooperators.

Effective use of soil information is the beginning point in planning for a sustained production of forest crops. Forest-soil interpretations, found in soil survey reports, provide information to help the land user make sound decisions for the production of forest crops. This information includes the species of trees to plant, the tree to favor in forest improvement, and the rate of growth that can be expected for the various species of trees growing on individual soils. Forest conservation combines advances in silvicultural information and other technical improvement, with detailed soils information, to make forest lands more productive.

Plant Materials Centers

SCS operates 20 plant materials centers throughout the Nation. The plant materials centers assemble, select, and distribute promising new plants, including trees and shrubs. These plant materials are used for a wide range of conservation purposes, including planting stock for forests and windbreaks.

Conservation Planning

Our program efforts revolve around conservation planning and implementation. We have the opportunity in Alaska to approach resource problems before they occur, through sound planning for safe implementation. This is a special opportunity for Alaskan forests. Preventing soil erosion maintains and enhances forest soil productivity. Little erosion occurs on well-managed forests. Desirable tree species and genotypes can be conserved and reproduced by using silviculturally sound cutting practices and by planting trees. SCS provides technical assistance in these areas through the conservation planning process.

Planning assistance is provided by SCS to landowners who have signed up with the local soil and water conservation districts as district cooperators.

We provide each cooperator with the necessary information and alternatives to make planning decisions. With this assistance the cooperator learns which conservation practices will meet his or her longterm objectives to conserve resource values. Information provided in the conservation plan may include:

- Measures to overcome soil limitations.

- Density (or stocking) and average diameter of the forest as related to the need for adequate growing space.

  Species of trees present or to be planted and the relative desirability of those species for the land user's objectives.

- General condition of the growing stock.

- Need for access roads.

- Other significant factors such as extent and causes of damaging agents (insects, diseases, vertebrates, climatic conditions, permafrost, flooding, etc.), wildlife habitat, watershed values, and recreation and aesthetic potentials.

- Availability of other forestry services, both government and private sector.

Opportunities to receive cost-share reimbursement through the Agricultural Conservation Program is explained as part of the planning process. Forestry practices approved for ACP cost-share in Alaska include tree planting and thinning.

The success of the forestry phase of the SCS conservation program depends on the landowner considering forest land to be a part of the total operating unit. The landowner is encouraged to give wooded areas the same consideration and attention that is given to any other land use. Other values that may be derived from forest management, in addition to timber values, include erosion control, recreation, wildlife habitat, forage production, and environmental enhancement.

In some cases the conservation district cooperator's conservation planning needs for forest land tracts call for a more detailed plan than SCS traditionally develops for wooded lots on agricultural units. SCS will then refer the cooperator to either a service forester with the state division of forestry or to a Forest Service forester in State and Private Forestry. A detailed management plan can then be prepared that will give specific stand prescriptions and begin the process necessary to receive ACP cost-share for, qualifying practices. If this detailed forestry assistance is not available through the state or Forest Service an SCS forester may provide it to a district cooperator.

However, let me emphasize the fact that we think of this as a totally cooperative effort. Before SCS would become involved in the more detailed forest management plans and their implementation it is with the understanding that our sister agencies (state and federal) are unable to provide such assistance. There would be concurrance between myself, the director of State and Private Forestry, and the State Forester that further SCS assistance will be rendered in the interest of the forest resource. Where agreements with the other agencies exist, SCS may provide the following assistance to enhance forest and soil productivity:

- forest land erosion control measures

- location of logging roads

- common insect and disease control methods

- timber stand prescriptions

- limited tree marking

- servicing ACP referrals

Currently in Alaska there is a limited demand for forestry assistance on private lands and the Alaska Division of Forestry has filled this role. It is likely that demand for this kind of assistance will grow, however, and with decreasing budgets, the close cooperation we've had in the past will be even more essential.

In conclusion, let me emphasize my interest in forestry, particularly on private lands. I received my original field office training in southwest Oregon on a conservation district having a major forestry workload, including two 160-acre district demonstration forests. I was well rewarded professionally for the many hours I spent with private landowners in developing and implementing forestry planes on that district as well as the work we were involved with on the demonstration forests.

It was a real disappointment to me when I arrived in Alaska, almost exactly 21 years ago, to learn that forest management was not being applied to private forest lands in the Fairbanks/Delta area. The consensus seemed to be that, forest management simply meant clear cut and hope for some natural regeneration or convert the land to other uses. This land conversion was a real personal concern on the steeper slopes. In most cases soils on south aspects increase in depth below the ridge line, often becoming quite deep at mid-slope. These productive lands are, in my opinion, best suited to commercial forestry but we were unable to convince private landowners of this.

Another potential that interested me was the wood pulp industry. The interior easily produces hardwoods - millions of acres of hardwoods, especially on deep well-drained soils.

What would happen if a short rotation were developed and a management system devised that included fertilization? Remember, Alaska manufactures nitrogen fertilizer. Harvesting methods might include tree shears and feller-bunchers that efficiently harvest trees on a 10-to-20 year rotation. Think of the benefit to wildlife if the harvest was carried out on some type of rotation pattern so wildlife would always have edge and cover.

Because the ground is frozen solid, all of Alaska becomes a road in the winter. While this may seem extreme to some, it does point out the potential for winter timber harvest. Equipment can safely traverse a lot of Alaska under winter condition, giving good access to most potential commercial forest sites. Winter harvest also has the advantage of providing employment for a large segment of the workforce which otherwise faces unemployment at the end of the summer season.

Agricultural parcels that include forestlands need special consideration since the forest resource can complement a farm operation. Longer development periods are needed if forestry is to be practiced, as well as incentives for timber harvest or long term forest management. I have a real concern about logged tracts of land being sold for agriculture. I would much rather see a system whereby a landowner may purchase the standing timber, based on a forest inventory completed after the land sale. The wholesale value could be held against the timber - without interest, until the timber is actually sold or for twenty years, whichever occurs first. At that time, the state would be paid the established value. It is quite probable that landowners would be receptive to better forest management and also probable that many would retain their wood lots for the long term.

It is vital that we, as resource people, seek every opportunity to maximize each resource, especially where we have the opportunity for resources to compliment each other. The real question before us is what can we do as a resource group to blend all renewable resources together into an overall effort that benefits the citizens of our great state both in terms of economics and intangible values. We will only do this through a dedicated team effort. I have related some of my personal beliefs in this discussion in the hope that they may spark some interest or some even better ideas. I want to reassure you that as the State Conservationist, I am vitally interested in our forest resources and in the productivity of our forest soils.

The question remains, how do we get there from here. It is my hope you have a busy, fruitful week.

RESEARCH IN FOREST PRODUCTIVITY WITHIN THE SCHOOL OF AGRICULTURE AND LAND RESOURCES MANAGEMENT, UNIVERSITY OF ALASKA-FAIRBANKS

James V. Drew

ABSTRACT: Research within the School of Agriculture and Land Resources Management, University of Alaska Fairbanks, includes studies directed toward assessing, monitoring, enhancing, and maintaining forest soil productivity. Examples of this research are studies of nutrient dynamics, soil biology, computer simulation models, soil characterization and classification, forest management, and forest growth and yield. The research is supported by state and federal appropriations.

INTRODUCTION

The School of Agriculture and Land Resources Management (SALRM) , University of Alaska Fairbanks (UAF), offers academic programs through its Division of Instruction and Public Service and conducts research at its Agricultural and Forestry Experiment Station. The University of Alaska has had statutory responsibility to provide education and research in agriculture since it opened in 1922 as the Alaska Agricultural College and School of Mines.

Options in agriculture and forestry are included in the instructional curriculum in natural resources management offered by the School of Agriculture and Land Resources Management. A major objective is to teach principles necessary for the successful management of crops, soils, water, livestock, forests, rangeland, and recreational resources. The instructional programs emphasize basic and applied sciences necessary for the management of these renewable resources.

Research in agriculture, forestry, and natural resources is conducted at the Fairbanks and Palmer Research Centers of the Agricultural and Forestry Experiment Station (AFES) as well as at other field locations in Alaska. The objective is to develop new information to (1) increase the efficiency of production systems for food and wood products; (2) improve processing and marketing of Alaska's food and wood products; (3) improve resource inventories and land-use planning for agriculture and forestry; and (4) develop resource management for improving the quality of life, including revegetation procedures, pollution control, landscaping and home gardening, and outdoor recreation. This information is provided to user groups through AFES publications as well as through SALRM instructional program and the Cooperative Extension program of the University.

A number of research projects at AFES are directed toward assessing, monitoring, enhancing, and maintaining forest soil productivity. These projects include studies by our Forest Soils Laboratory as well as research in soil biology, computer simulation models, soil characterization and classification, forest management, and forest growth and yield. Much of this work is done in

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cooperation with the Institute of Northern Forestry, U.S. Forest Service, which is located at UAF.

RESEARCH AREAS

Nutrient Dynamics in Forest Soils

The principal objective of research conducted by the AFES Forest Soils Laboratory is to evaluate the importance of physical, chemical, and biological controls of soil fertility in the productivity of forest ecosystems in interior Alaska. Results of this work have shown that topography, through slope and aspect, mediates the physical, chemical, and biological control of ecosystem processes.

The management of taiga forests involves the use of these physical and chemical controls of soil biological activity and resource supply in managing tree growth. For example, forest harvesting raises soil temperature and improves the supply of mineral nitrogen for plant use. Burning of the forest floor also raises soil temperature and immediately improves the supply of important plant nutrients through organic matter combustion with the result that tree seedling growth is dramatically increased in the first year or so following fire.

Research results on the physical, chemical, and biological control of ecosystem processes are helping to predict the consequences of management on factors which control forest productivity. These predictions are being evaluated in postharvest and postburn ecosystems. Recent results of this research have been published as articles in the scientific literature, as chapters in symposium proceedings, as a special issue of the Canadian Journal of Forest Research, and as a book providing a synthesis of the structure and function of Alaskan taiga forests.

Forest Biology

In 1983, the Rosie Creek fire near Fairbanks burned 8,600 acres including a portion of the Bonanza Creek Experimental Forest. The burned area has afforded a unique opportunity for study of postfire responses in an interior Alaska forest. Studies have included nineteen investigators working on seventeen research projects in three topic areas.

Studies at or near completion include: empirical wood yield recovery, wood-inhabiting beetles and borers and their woodpecker predators, and a predictive model of tree survival. Levels-of-growing-stock plantations were established to assess the long term effects of stand density on productivity. Site preparation trials and provenance trials were also established. Continuing studies are covering microenvironment monitoring, nutrient cycling, revegetation and shrub biomass, and phosphorus availability. The early results of the Rosie Creek fire research project have been published by the Agricultural and Forestry Experiment Station.

Computer Simulation Models

An ecosystem-based model for forest management, growth, and yield (FORCYTE-10) is being used to investigate the effects of intensive management of taiga white spruce on future site productivity in interior Alaska. Management simulations produced with the model indicate that intensified management may increase site productivity and that a portion of the increase may result from the addition of nitrogen to the soil by alder that invades clearcut sites. In both whole-tree and stems-only harvesting, symbiotic nitrogen fixation is important in maintaining ecosystem productivity. The importance of maintaining a pool of easily mineralized nitrogen on the site after clearcutting was indicated by comparing whole-tree harvesting to a stem-only harvest. Results of this research will be published in scientific journal articles.

Soil Characterization and Classification

Soil characterization studies are underway in southeastern, southcentral, and southwestern Alaska to improve the classification of Andisols, soils often influenced by the deposition of volcanic ash. These studies are in cooperation with the USDA Soil Conservation Service, Forest Service, and Tokoku University in Japan. Analysis of a number of Andisols from Alaska indicated low bulk densities, high phosphorus retentions, and high contents of amorphous aluminum or pyroclastic material. These properties are important in relation to the productivity of forest stands associated with Andisols. The results of this research will be published by AFES.

Forest Management

In 1986, a cooperative project involving the U.S. Forest Service, the Alaska Power Authority, and AFES was initiated to determine the sustainable volume of wood chips that could be produced on selected lands in the Tanana Valley for use in combination with coal for generating electricity in industrial power plants. The sustainable volume of harvest available from these lands was determined to be thirteen times the maximum consumption of chips by one power plant burning a mixture of 15 percent chips and 85 percent coal. Test burns in boilers used for electrical generation in Fairbanks indicated that wood chips could replace up to 15 percent of the coal without causing a significant reduction of boiler capacity. The final report of the study will be available through the Alaska Power Authority.

In addition, research in silvics is emphasizing the selection of tree species best suited to specific site in interior Alaska; this information is critical for effective forest management. For example, initial results indicate that tamarack and other species of larch may have higher rates of productivity on specific sites than other northern forest species.

Forest Growth and Yield

Information on growth and yield is essential for the management of tree species and is being developed for forest stands in interior and southcentral Alaska. Immature white spruce trees have been found with impressive diameters; e.g., one 42-year-old tree had a breast height diameter of 16 inches and a 77-year-old tree had a breast height diameter of 19 inches. These findings demonstrate that certain sites in the northern forests of Alaska are capable of forest growth comparable to other circumpolar countries that have significant forest industries.

Current research is aimed at developing and improving growth and yield data for a number of native tree species in interior and southeastern Alaska. Data on the growth of forest stands are also being determined in Research Natural Areas designated in interior and coastal Alaska. Results will be published by AFES.

Northern Forest Silviculture and Management

Since the late 1970s, SALRM has sponsored an annual international workshop on forest regeneration at high latitudes. Emphasis on forest regeneration resulted from a poll of forest scientists and managers in northern countries to identify significant problems in the management of northern forests. Workshop meetings and associated -field studies have been held annually in various northern countries.

In 1985, the workshop was given full Working _arty status by the International Union of Forest Research Organizations (IUFRO) and was assigned the title "Northern Forest Silviculture and Management."

The ninth meeting of this group was held in northern Finland in 1987 and included participants from the United States, Canada, Norway, Sweden, Finland, Russia, and the People's Republic of China. Proceedings of each of the workshops have been published cooperatively by the School of Agriculture and Land Resources Management and the Pacific Northwest Research Station, U.S. Forest Service. These publications provide a compendium of information on forest silviculture and management at high latitudes.

RESEARCH SUPPORT

These studies are examples of research at AFES that is related to forest and soil productivity. The work is supported by appropriations for research at UAF from the Alaska State Legislature, from Federal appropriations to the USDA authorized by the Hatch and McIntire-Stennis Acts, from competitive grants from the National Science Foundation, and from other grants and contracts including funds from the U.S. Forest Service.

The year 1987 marks the 100th anniversary of the Hatch Act which established the national system of state agricultural experiment stations in Land-Grant universities, and the 25th anniversary of the McIntire-Stennis Act which provides funds for cooperative forestry research. These acts provided hallmark legislation for the base support of research within the various states and led to research results of substantial importance to agriculture and forestry.

THE ALASKA DEPARTMENT OF NATURAL RESOURCES AND SOIL PRODUCTIVITY

Craig Olson

ABSTRACT: The basic soil related policies of the Alaska Department of Natural Resources are presented. The principles by which land development and use are permitted and land use plans are implemented are discussed. A rationale for such policies: and principles is presented. And finally, the planned activities and research to achieve stated soil management goals and objectives are listed.

The Alaska Department of Natural Resources (DNR) is concerned about soil productivity. The climate of much of Alaska is such that land is but marginally useful for producing food and fiber. Soils are generally young or cold and poorly developed. We therefore need to husband our soil resources so that they can help support Alaskans and their lifestyles. In this paper I will discuss what the DNR's policies are concerning soil management, some of the rationale for such management, and our objectives of these polices.

The basic soil related policy of the DNR when permitting land use or when implementing land use plans is to minimize loss of soil productivity to the extent feasible and prudent, and secondarily, to enhance soil productivity where possible. By this we mean that when permitting some kinds of development, such as building construction, we recognize that it reduces the biological productivity of the site; yet, we also recognize that, building construction and other land clearing is basically, beneficial to Alaskans. Our aim then is to keep land clearing to the minimum to achieve the development objectives, so that as much land as possible can be retained in a productive condition for future food and fiber production or as wildlife habitat.

The Alaska Legislature passed the Forest Resources and Practices Act in 1978. This Act was primarily concerned with protecting water quality, but it accomplished protection of soil productivity at the same time. The Act and subsequent regulations were designed to protect against soil erosion and thus protect against the loss of soil productivity. In addition there is the provision for reforestation, again ensuring site productivity. This Act governs forest practices on both private, borough, and State owned lands and is a key to the maintenance of soil productivity on these lands for future generations.

Since statehood, the State of Alaska has received approximately 83 million acres of its 105 million acre entitlement from the federal government, and though the Alaska Department of Natural Resources is the custodian of these lands, to dispose or retain, much of this land manages itself with little or no intervention by the DNR. Since the DNR attempts to control wildland fires, in a de facto sense the Department manages the land and also soil productivity. Similarly, the Alaska Department of Fish and Game manages the hunting of ungulates which also, in a de facto sense, is management of forage and soil productivity, and it is hunters in combination

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with predators and natural factors that really affect herd number and forage use. So the DNR in reality only actively manages or controls use of land and soil near populated lands and development nodes or less than ten percent of the area it is responsible for. Actually, the total acreage of State land either harvested for timber or sold and subsequently cleared for housing or agriculture since statehood is probably less than a half million acres.

To date we have disposed of approximately 450,000 acres, 300,000 for settlement and 150,000 for agriculture, and we have sold and harvested timber from less than 200,000 acres.

The USDA Forest Service completed a statewide resource inventory in 1967 that indicated that Alaska had about 28 million acres of commercial forest land (CFL) or land capable of producing 20 cubic feet of useable wood per acre per year. A more recent study indicates that the State owns about 10 million acres of this CFL. The level of site or soil productivity on this land is such that the land might be manageable for successive crops provided it is accessible. And though recent analysis indicates that there is somewhat less acreage of CFL than previously estimated, the State does have a large holding of productive land.

Much of the other 90-100 million acres of State owned land might be brought into production or made productive with site manipulation or use of exotic species. Since criteria for whether a piece of ground is CFL or not is based on measurement of growth of existing species in the existing soil, many soil types or situations may prove to be much more productive with some site modification or for alternate species.

To date the State and Federal Governments have cooperated on gathering soil information. The thrust of both State and federal agencies thus far has been to establish baseline information, that is, to determine the productivity along with other site characteristics by way of soil surveys. As part of some of these surveys tree growth data were collected and then later site indices were calculated for the native species on each soil series.

With so little development and use activity one might ask, "Why even bother with gathering this information?" The answer is that we can expect with great certainty that there will be increased demand for lower productivity lands. This has been the trend worldwide almost since the dawn of man. We are currently in an economic and growth slow-down, but we can certainly expect that even within 20 years much more of Alaska will be called upon to produce food and fiber products to meet the demand of the world's burgeoning population. The green revolution has truly been amazing over the past few decades with countries such as China and India feeding themselves, when only 20 years ago severe famine was predicted for these regions. But, as part of this green revolution, marginal lands were brought into production with the use of fertilizers and irrigation. Also, a tremendous acreage of forests was cleared to make room for this expanded agriculture. This kind of growth is not sustainable and it is clear that grave mistakes can be made with respect to overuse of the soil as has happened in the sub-Saharan region of Africa. Right now one can argue that Alaska has expansive resources and that a little loss of soil productivity doesn't matter. One can further argue that the expense of maintaining or restoring site productivity far exceeds the benefit if we discount the cost into the future. Yet, loss of soil productivity is a loss of State capital, capital that will undoubtedly be needed in the future. If it weren't for oil the Middle East would be bankrupt as the region was exploited and the soil over used for centuries.

We, as land managers, can affect soil productivity. It is the biological, physical, chemical, thermal, hydrological, climatic, and spectral properties of the soil that determine its productivity and all of these aspects can be manipulated by man to some extent. As we manage our soil resources, we must keep in mind the effect on all these factors and that any physical manipulation of the soil affects more than one of these factors. Within the DNR there are individuals who have experience and training in the assessment of land use activity impacts on soil productivity. However, we rely to a large extent on organizations such as the SCS, the University, and the 1,000 or so cooperators in the Soil and Water Conservation District program to provide input into the State's planned land development projects.

As certain Divisions in the DNR, such as Land & Water Management and Mining, go about permitting land use they keep in mind the basic. objective of maintaining soil productivity. As Divisions within the Department, such as Forestry and Agriculture, manage the land they look to enhance soil productivity. We have several planned activities to achieve those objectives. First, we plan to determine the productivity of soil types for all suitable species including exotics. Second, we plan to determine where we can enhance productivity through site manipulation. Third, we plan to establish the feasibility of "reclaiming" peat bogs through draining and extraction. Fourth, we plan to determine where fertilization can be effective. And fifth, we plan to establish which species or provenances do best on which soil.

It will cost a lot to achieve these objectives, money that we don't really have. But, it is just this kind of information that will enable us to increase our capital wealth and help us get through economic slumps such as the one we're in. So, it is workshops like this one combined with close agency cooperation, innovative thinking and determination that will be needed to accomplish our objectives. We'll need to begin on lands close to or accessible to existing communities and work our way to the more remote areas. It is an enormous job but one that promises to pay good dividends.

The DNR is dedicated to maintaining and enhancing soil productivity so that Alaskans of the future will have at least what we have today and we're dedicated to working with other research agencies, land management agencies, and public land users to ensure soil protection.

THE BUREAU OF LAND MANAGEMENT IN ALASKA

Russell E. Hanson

ABSTRACT: The Bureau of Land Management (BLM), once the primary land managing agency in Alaska, is now only one of a number of large land managers in Alaska. The remaining forest land base is widely scattered and currently provides for local subsistence uses of forest products. Currently the BLM seeks to: 1) Determine the acreage and volumes of its remaining forest lands and, 2) Manage those lands so basic values such as soil productivity, water quality, and site potential are not impaired.

Prior to 1960 the Bureau of Land Management (BLM) was the custodian of most of the land in Alaska. This 309,000,000 acre land monopoly was broken only by the Chugach and Tongass National Forests, the then Mt. McKinley National Park, and some military and private holdings. As a result of various pieces of legislation this acreage has declined to the point where it has been estimated that the BLM will ultimately manage approximately 70,000,000 acres of land in Alaska. For those not familiar with recent Alaska land transfer activities, a short review will follow, with some emphasis on how BLM forest lands were affected.

The first piece of legislation effecting major changes in land ownership patterns was the Alaska Statehood Act of 1959. Under this act, the State of Alaska was allowed to select 104,000,000 acres of public domain over a period of 25 years. While this process is still ongoing, the state tended to select lands close to cities and towns, lands with mineral potential, and forest lands. An example of the latter was the selection of the Bonanza Creek Forest near Fairbanks. As a matter of fact, the Statehood Act probably had the most profound effect on BLM forest land ownership, since the state had a considerable interest in acquiring forest land and did so early in their selection process.

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The next major piece of legislation that affected the BLM lands in Alaska was the Alaska Native Claims Settlement Act of 1971 (ANCSA). Native villages and corporations were given the right to select approximately 44,000,000 acres of land under the provisions of ANCSA. Another provision of this Act, Section 17, D-2, allowed for the selection from the public domain (BLM) of up to 80,000,000 acres of "national interest" lands for inclusion in a conservation system. The ANCSA selection priorities tended to repeat the state's. Lands were selected on or adjacent to native villages and for mineral potential. Since most of the villages were along rivers, selections included substantial acreages of forest land.

Finally the D-2 legislation, Alaska National Interest Land Conservation Act of 1980 (ANILCA), emerged from Congress with nearly 100,000,000 acres added to various agencies. ANILCA, while transferring huge acreages out of BLM, probably did not change its remaining forest land base substantially. Much of the ANILCA lands are in wetland areas or mountainous terrain, and not forest land, or at least commercial forest land.

How much commercial forest land will the BLM in Alaska ultimately have? Currently there is no inventory of acreages or volumes that can answer that question. A project has been started that will identify acreages by broad forest types, ie. white spruce, black spruce, and mixed hardwoods/brush. Whatever the results of the inventory, it can be assumed that only a small fraction of the BLM's remaining land base will be in commercial forests.

In general, the remaining BLM forest lands with commercial potential will be white spruce stands located in or near river bottoms. The current BLM forestry program is primarily free use permits to qualified residents for such purposes as firewood and, increasingly, house logs. This type of disposal is required by the subsistence portion of ANILCA and, while small in size, is a controlling factor in forest management activities.

The BLM also occasionally has a commercial timber sale. The latest sale, for 250,000 board feet, was sold for salvage of insect infected and killed spruce. Commercial timber sales in the near future will be increasingly difficult due to:

1) Requirement that all sales must recover the government's costs,

2) Decreased markets for softwood products and,

3) Limited access to remote timber stands.

The BLM's primary interest in soil productivity in Alaska will be mainly in two areas of concern. First, with a limited forest land base we will, at a minimum, want to maintain the current productivity of our forest lands. This would include providing fire protection for our commercial forest lands and protection of soil from erosion and large scale disturbance. Secondly, the BLM will attempt to minimize soil disturbance caused by logging, especially in the alluvial soils. Such protection will be provided through limitations on equipment and prescribing the season for logging, ie. winter logging.

One problem that arises in achieving the least disturbance of forest soils is that we may provide less than optimal conditions for white spruce reproduction. Clearcutting and extensive summer yarding may provide maximum light conditions and mineral soil required for white spruce regeneration, while BLM may require partial cutting and winter logging.

The BLM's forestry program in Alaska will continue to be one of custodial, as opposed to intensive, management in the foreseeable future.

FOREST SOIL PRODUCTIVITY RESEARCH IN ALASKA GOALS AND OBJECTIVES OF THE USDA FOREST SERVICE, PACIFIC NORTHWEST RESEARCH STATION

D.N. Swanston, C.T. Dyrness, V.J. LaBau

ABSTRACT: Serious soil productivity problems are faced by forest managers in interior and coastal Alaska. The most pressing of these problems are related to a lack of knowledge on nutrient-cycling dynamics, soil-formation and drainage processes, and site variability within the hyper humid, cool, maritime forests and the interior subarctic forests of the State.

PRODUCTIVITY PROBLEMS OF FOREST SOILS

Coastal Alaska

Energy input into the hemlock-spruce forest ecosystems of coastal Alaska is temperature dependent and decreases northward as does soil productivity. Because temperatures are lower than those found further south, rates of decomposition and chemical weathering are slowed. Soil development is restricted and substantial quantities of raw organic material accumulate in the forest floor. Generation, storage, and release of nutrients are low under these conditions; site potential is therefore also low.

High rainfall, frequent fall storms, and restricted soil drainage exert a strong influence on microsite variability and subsequent soil productivity. Indications are that the extensive peatland development in southeastern Alaska is related to formation of impermeable layers in the soil. Storm winds, combined with restricted drainage above these shallow, impermeable horizons, produce frequent windthrow and associated mound-and-pit topography. The mounds may create sites of improved soil productivity as the result of better drainage and higher soil temperatures.

Interior Alaska

In interior Alaska, forest soil productivity is temperature dependent and subject to rapid changes from fire and flooding. Probably the most significant productivity problems come from low temperatures. The cold climate of central Alaska causes extremely slow decomposition of organic matter; essential nutrients are thus often tied up in unavailable forms, and forest growth tends to be nutrient limited.

Nutrient limitations are not the only constraints on forest soil productivity in central Alaska.

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Frequent fires on uplands and flooding of river-bottom sites cause local changes in soil temperature and soil drainage. On some sites, especially on southern aspects, insufficient supplies of soil moisture may limit tree growth.

In the subarctic, older stands comprised of late successional species (for example, old-growth white spruce [*Picea glauca* (Moench) Voss] or black spruce [*P. mariana* (Mill.)B.S.P.]) are often supported by extremely cold soils, possibly dominated by permafrost.

SOIL PRODUCTIVITY RESEARCH

The Pacific Northwest Research Station, through its three regionally oriented forestry research facilities (the Forestry Sciences Laboratory at Juneau, the Institute of Northern Forestry at Fairbanks, and the Forestry Sciences Laboratory at Anchorage), is addressing these problems through basic and applied research aimed toward the better understanding of how to manage and increase timber productivity in these diverse climatic and silvicultural environments.

Forestry Sciences Laboratory, Juneau

Intensive research on forest soils productivity has begun only recently in coastal Alaska forests; this research is the responsibility of the Forestry Sciences Laboratory in Juneau. Since the late 1970's research has been accomplished both internally by timber and watershed research personnel and through cooperative research with forestry and soils departments at Oregon State University and the University of Washington. Emphasis was initially placed on correlating soil and site potential, and forest community types at various successional stages. More recently, work has begun on important aspects of soil origin and the influences of soil-forming processes on drainage and nutrient availability. Current research activities are concentrated in three areas: (1) nutrient distribution and dynamics, (2) soil formation and drainage, and (3) microsite variability.

Nutrient distribution and dynamics--Knowledge is limited on the successional dynamics of nutrients and the nutrient requirements of overstory and understory species common to hemlock-spruce ecosystems of coastal Alaska. Research has only recently begun to address the cool, wet site conditions that are conducive to the slow decomposition of organic material. Essential nutrients are often tied up in unavailable forms, and forest growth tends to be nutrient limited. Studies are underway to determine the distribution of nutrient elements among ecosystem components, nutrient mobility, and rates of nitrogen fixation in relation to litter cover. All these study elements are needed to establish baseline information for evaluating the effects of future clearcut harvesting on short-term nutrient dynamics.

Soil information and drainage--The supply of available nutrients in coastal Alaska forest soils is controlled by rate of organic matter decomposition, geochemical weathering, and the drainage characteristics of the soil. Peatland vegetation is common in the hyperhumid, cool, maritime climate of southeastern Alaska. The questions of how peat is formed and which factors control succession toward peatland vegetation are not yet satisfactorily answered. New information suggests that podzolization of soils in the region commonly results in dense spodic horizons at shallow depth that impede soil drainage and may be responsible for widespread paludification. Additional evidence suggests that windthrow may be an important natural mechanism that can reverse this paludification process and improve local site productivity. When trees rooted in mineral soil are windthrown, the impermeable horizons are disturbed and large windthrow mounds are formed. These factors improve drainage and decomposition over time and help improve establishment and productivity of forest trees.

The emphasis of research is currently on assessing differences in soil fertility and development between disturbed and undisturbed sites.

Microsite variability --Because of the shallow rooting depths of coastal hemlock-spruce forests, windthrow is common and causes mineral soil to mound; this process is believed to playa critical role in maintaining optimum drainage and soil temperatures. Theoretically, raised microsites have improved drainage, and seedlings growing on raised terrain have a competitive advantage over plants established on adjacent lower, wetter terrain. Improved drainage and higher soil temperatures also speed up decomposition of the organic matter. Geochemical weathering should be enhanced, and mounds with a mineral substrate may be better growing sites because of increased nutrients. Microsite work so far has shown that impermeable layers are not reformed in the upturned soil of windthrow mounds, apparently because of the lack of a seasonal anaerobic water table.

Mound and pit topography, especially on some of the poorer forest soils, can have profound effects on forest growth. Frequency, size, type, and age of mound may be highly correlated with timber yields. The present hypothesis is that high-site stands have large mineral mounds; medium-site stands have less frequent, mostly organic mounds, and low-site stands are usually unmounded. Research is underway to test this hypothesis.

Institute of Northern Forestry, Fairbanks

Intensive research on forest soil in interior Alaska spans the past 20 years. Work has been carried out by personnel at the Institute of Northern Forestry in Fairbanks, working jointly with Dr. Keith Van Cleve of the Forest Soils Laboratory, University of Alaska. The research comes under four major headings: (1) the effect of forest-management activities on soil productivity, (2) the effect of fire on soil productivity, (3) nutrient cycling in upland forest ecosystems, and (4) nutrient cycling on floodplains and terraces along major rivers.

The effect of forest management activities on soil productivity--Although some work has been accomplished on soil productivity, much remains to be done. As a result of limited forest management activities, most of the stand treatments have been imposed by the researchers themselves. Treatments have included fertilization, thinning, clearcut and shelterwood harvesting, and a variety of site treatments ranging from mechanical scarification to broadcast slash burning. Treated forest types are white spruce, aspen (Populus tremuloids), and birch (Batula papyrifera). Responses to these management activities that have been measured include tree growth rate, level of available nutrients (especially nitrogen), and soil temperature.

Dramatic improvement in supplies of available nitrogen have been shown to result from clearcut harvesting of white spruce. Indications are that this improvement is the direct result of elevated soil temperatures, which lead to increased rates of nitrogen mineralization. It has also been found that fertilization of young white spruce is more effective in conjunction with thinning, which improves both the temperature and moisture regimes of the site. These results indicate that the forest manager can ease nutrient limitations by stand manipulation and harvesting. How much of the released nutrient supply is taken up by competing vegetation and how much by the new generation of trees still needs to be addressed.

The effect of fire on soil productivity--Recurring wildfires are an important part of the interior Alaska forest environment. Fire-return intervals range from about 200 years to only 30 years on the driest uplands. Researchers have long been interested in the effects these fires have on available soil nutrients, both immediately after the fire and in the long term. Early efforts to study the soil effects of fire were concentrated on the black spruce forest type. The approach was largely by laboratory analysis of soil samples collected in burned and unburned locations. But in 1983, the Rosie Creek Fire burned a substantial part of Bonanza Creek Experimental Forest; researchers are now able to study the effects of fire in additional forest types (white spruce, aspen, and birch). Besides soil analyses, evaluation of soil productivity has included pot and field bioassays, study of decomposition rates, examination of soil solution chemistry, and measurement of nutrient uptake by early successional vegetation.

In general, study results have shown that the effect of fires has been to improve soil productivity, despite lower levels of some elements. Additional research is needed to determine what effects repeated fires at short intervals have on long-term soil productivity.

Nutrient cycling in upland forest ecosystems--An intensive, multidisciplinary study of the structure and function of upland forest ecosystems was conducted from 1975 to 1981. The general approach was to intensively study a black spruce/permafrost ecosystem and then compare the functional characteristics of the black spruce stands with other, more productive forest types (white spruce, aspen, birch, and balsam poplar [Populus balsamifera L.]). As part of this study, productivity, nutrient budgets, and turnover rates were determined for all major interior Alaska forest types.

Results of the study indicated that forest floor and mineral soil temperatures largely control the development and productivity of upland forest ecosystems in interior Alaska.

Nutrient cycling on floodplains and terraces along major rivers--Research on soil-vegetation relations on interior Alaska floodplains has been underway for two decades. Emphasis has been on studying the soil changes that accompany advancing succession from early willow (Salix sp.), to alder, through balsam poplar, and eventually to mature stands of white spruce. Some early work involved the effects of alder on nitrogen in these alluvial soils. Changes in levels of other soil nutrients over the span of successional stages also have been documented. Scientists are currently examining relations between successional stages and soil chemistry under a 3-year grant from the National Science Foundation. Salt crusts developing on newly deposited alluvial surfaces are of special interest in this study, and one objective is to determine the effects of the salt crust on plant growth and species composition in the earliest stages of succession.

Forestry Sciences Laboratory, Anchorage

The recently established Alaska Forest Inventory and Analysis research project, with its office in Anchorage, is responsible for collecting forest and range land statistics for Alaska. The scope of data collection is multiresource and involves several agencies. Data on soils are collected to identify soil and site variables that may help to predict site productivity. Data and information are needed for other natural-resource inventory-data users, such as the USDA Soil Conservation Service and the State of Alaska Department of Natural Resources. Cooperative agreements with several of these users include collection of soils data and information on established field plots.

The sampling design currently being used is oriented to vegetation assessment at four scales of sampling: (1) LANDSAT, (2) high-altitude photography (1:60,000 scale, color infrared), (3) low-altitude photography (1:5,000 scale, color infrared), and (4) ground plot measurements. Soils data are collected only at the ground level, but efforts are underway to correlate the ground information with estimates of vegetation production from photo analyses at the other scales.

The Tanana River basin multiresource inventory was completed in 1984; it covered 34 million acres. The soil data collected included profiles from pits dug in over 150 vegetation mapping units on 78 groundplots scattered around the basin. In addition, the Soil Conservation Service did extensive soil reconnaissance mapping along with the field inventories.

The southeastern Alaska inventory was completed in 1986; it covered about 25 million acres. The same sample design was used. The USDA Forest Service, Alaska Region, Lands and Resources staff helped collect soil data, and the USDA Soil Conservation Service reviewed the soil classifications. Soil profiles were described in about 180 vegetation mapping units on 58 ground plots scattered throughout southeastern Alaska.

The data from these inventories are currently being processed and analyzed to determine what physical and geomorphic characteristics might be correlated with production of biomass, timber, and possibly with browse production and wildlife habitat.

Preliminary results of the Tanana River basin study should be available in late 1987 or early 1988. Results for southeastern Alaska will follow about a year later.

FUTURE DIRECTIONS FOR RESEARCH

The most urgent need in forestry in Alaska is for information on long-term changes is soil productivity in relation to soil-moisture regime, soil-temperature regime, and landscape position. We need to trace in detail the course of soil fertility on sites after fires, floods, windthrow and harvesting. We need to document differences in soil productivity with changes in microsite. He need to determine rates of nutrient availability and uptake for all types of vegetation in each successional stage. What is the role of competing vegetation in determining site productivity? What is the effect of natural scarification by windthrow on site productivity? Are changes in soil moisture interacting with soil nutrients an influence on soil productivity? These questions are best answered by long-term, detailed measurements on a variety of permanent plots that include the major forest types and successional stages.

ALASKA DEPARTMENT OF NATURAL RESOURCES SOIL AND WATER CONSERVATION PROGRAM

Keith R. Quintavell

ABSTRACT: The farm_ forest, and grazing land of the state is a basic asset of the state. It is the purpose of Alaska's soil and water conservation law to provide for the orderly development of land, for guiding settlement, and for conserving soil and water resources.

INTRODUCTION

The Alaska Soil and Water Conservation Board (ASWCB), with its associated local soil and water conservation districts (SWCDs), is a key organization in the development of Alaska's grazing, forest, agricultural, and settlement land resources through soil and water conservation. The ASWCB, with five members representing five geographic regions of Alaska, is appointed by the Governor, and is established pursuant to Alaska's soil and water conservation law. In addition to the responsibility for administering the state's soil and water conservation law, the ASWCB is one level of hierarchy above the local soil and water conservation districts, and acts in an advisory capacity to them (fig. 1).

The nine local soil and water conservation districts are governmental organizations established for purposes similar to those of the ASWCB, but from a local perspective (fig. 2). Each district has five supervisors who are duly elected to represent the "land users" within their district (with over one thousand "land users" being represented by soil and water conservation district supervisors throughout the state). A "land user," as defined by statute, is a person who is a producer of renewable resources, including farming and forestry.

BACKGROUND

The history of conservation districts in the United States is closely allied with the creation of the Soil Conservation Service (SCS) in the "Dust Bowl" era of the 1 930 's . The primary purpose of the SCS was to help farmers and ranchers manage their land to minimize soil erosion and maximize soil productivity.

In order to deliver SCS services locally, the idea of conservation districts was conceived. These districts, governed by locally elected boards, were to develop and carry out local resource conservation programs with technical help from the SCS. A "Standard Act" was proposed, in which formation and operation of conservation districts were outlined, and from which states could develop their own legislation.

The legislature of the Territory of Alaska adopted a modified version of the "Standard Act" in 1947. It created the Alaska Soil Conservation District, covering the whole state (586,000 square miles), and the three member Soil Conservation Board as its governing body. It also

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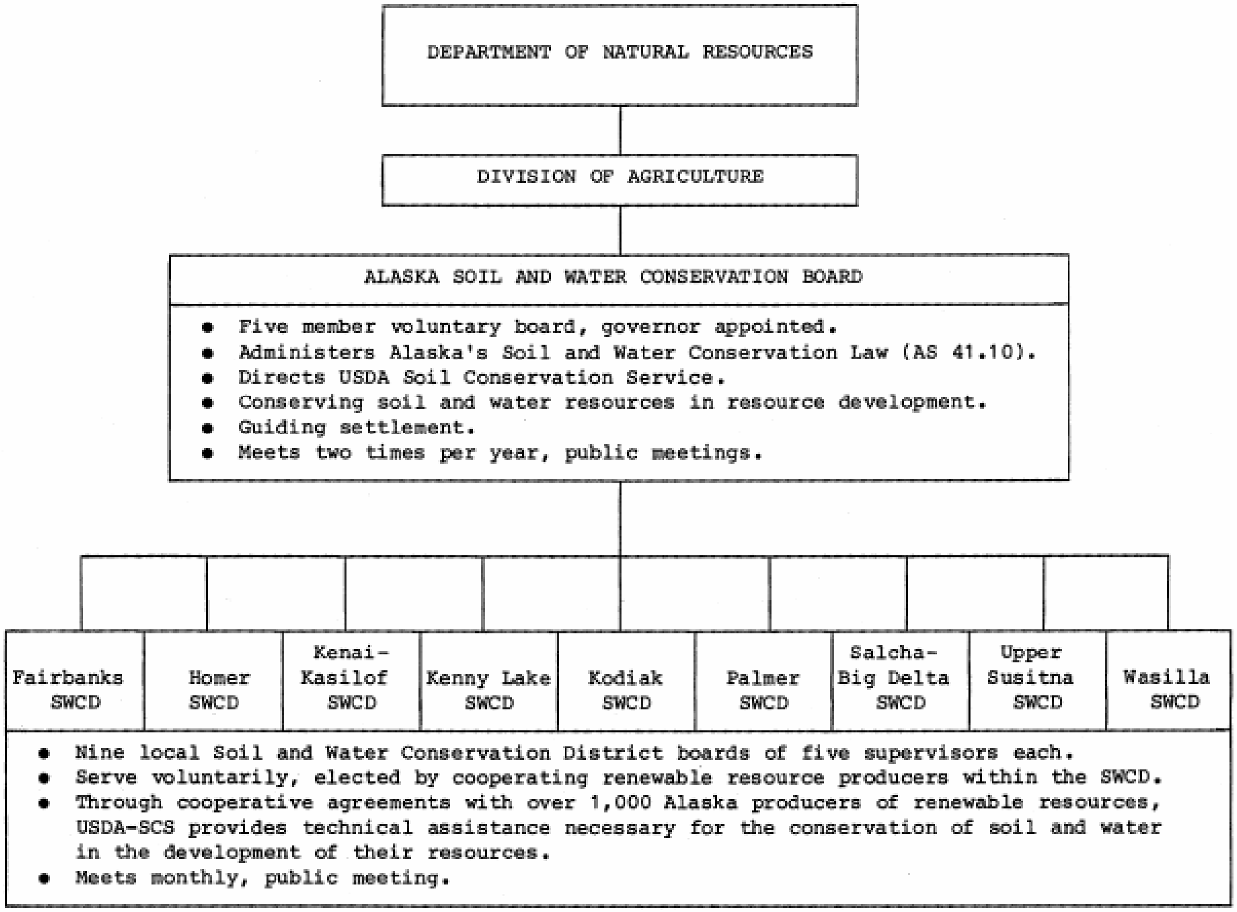

Figure 1.-- Organization of the Alaska Soil and Water Conservation Program.

authorized the creation of local sub-districts of the Alaska Soil Conservation District, and the installment of five member boards of supervisors to act as the local governing bodies of each sub-district.

In 1983 the legislature amended the Soil Conservation District Law. It added water to the terms Alaska Soil and Water Conservation Board and Soil and Water Conservation District. It changed Soil Conservation subdistricts into Soil and Water Conservation Districts, and increased the members of the Alaska Soil and Water Conservation Board from three to five.

There are currently ten soil and water conservation districts in Alaska, and the tenth encompasses the area of the state which is not located within the boundaries of a local soil and water conservation district. The tenth district, the "Alaska Soil and Water Conservation District", is governed by the Alaska Soil and Water Conservation Board.

FUNCTION

As legal subdivisions of the state, SWCDs are empowered to develop and carry out natural resource conservation programs which affect their districts. The Commissioner of the Department of Natural Resources has delegated to SWCD supervisors the powers spelled out in the Soil and Water Conservation District Law. They are:

Surveys and investigations.--To conduct land capability surveys and investigations of areas and of soil conservation and erosion control, including necessary preventative and control measures; to publish the results of such surveys and investigations, and to disseminate information concerning the results of such surveys and investigations to prospective settlers and the general public. (This includes all resource interests, land use planners, borough and city planning departments, and those with other conservation concerns.)

Soil and water conservation and erosion control.-To carry out measures for soil conservation and erosion control within the SWCD, including but not limited to engineering operations, methods of cultivation, the growing of vegetation, and changes in use of land, with the consent and cooperation of the land occupier or agency having jurisdiction thereof.

Guidance and assistance of settlers.--To make technical guidance and other assistance available

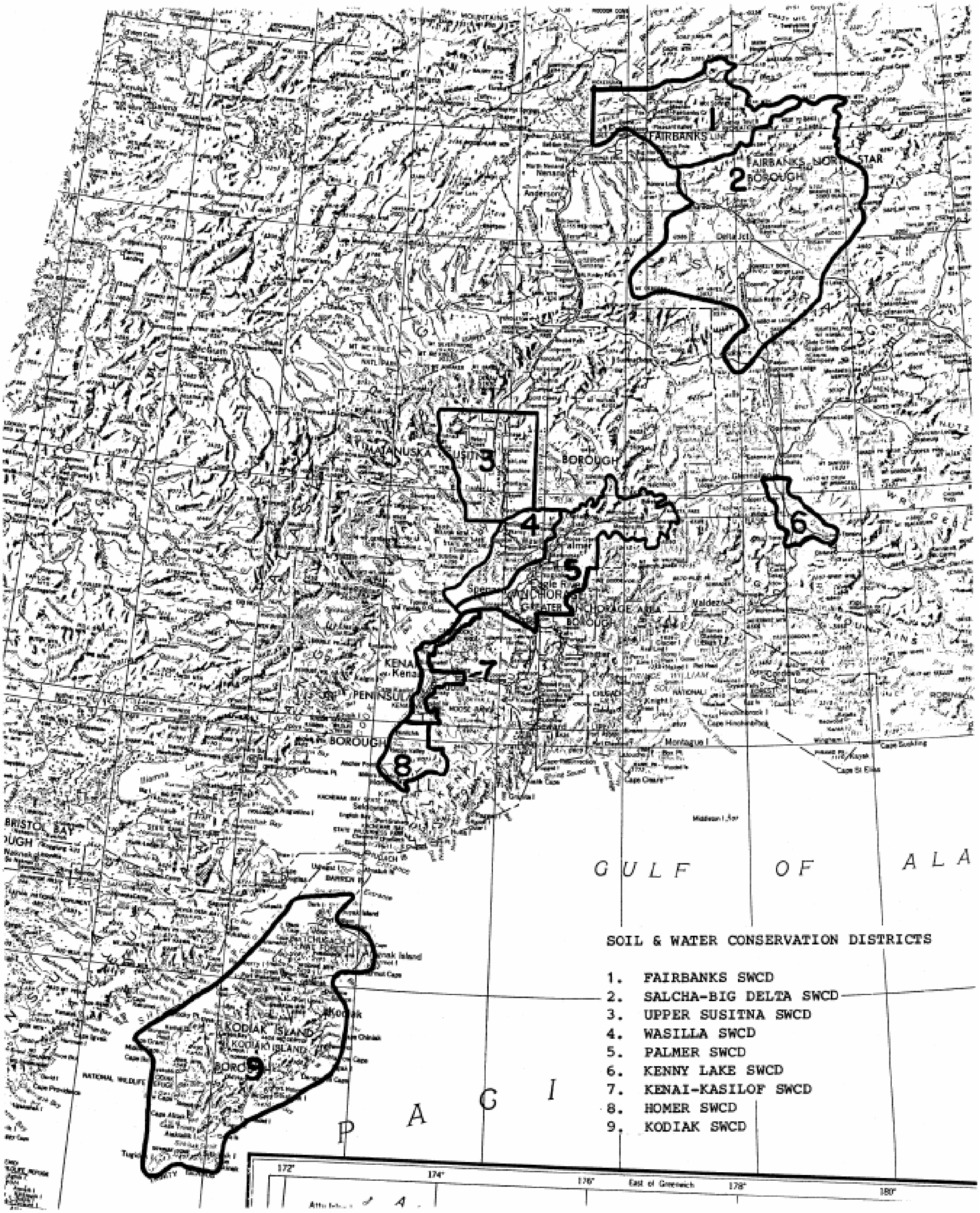

Figure 2.--Boundaries of the nine local soil and the water conservation districts in Alaska. The area of the state located outside these nine districts the "Alaska District," and is governed by the Alaska soil and Soil and Water Conservation Board.

to settlers of new land, so as to assure the development of such land in a manner that will permit it to be used in accordance with its capabilities, and treated in accordance with its needs.

Cooperation with occupants or agencies.—- To cooperate with, furnish assistance to, and enter into agreements with, any occupier of and or agency, governmental or otherwise, within the SWCD, subject to such conditions as the SWCD governing body may deem necessary to advance the purposes of the law.

Acceptance of contributions.--To accept contributions in money, services, materials, equipment, or otherwise, from the United States or any of its agencies, from any agency of the State, and from any other source, for use in carrying out the purposes of the law.

ACTIVITIES

Following are some examples of activities of the ASWCB and SWCDs in carrying out their powers under state law for conserving soil and water.

- Guide USDA, SCS in their delivery of services to Alaskans, including monitoring of municipal water supplies, flood and avalanche conditions, inventorying wetlands, forest, and rangelands, and assessing soils and hydrology.
- Prepare proposals and receive grants from the Environmental Protection Agency to study ways to maintain quality of water resources in association with development activities at Point MacKenzie and Delta Junction.
- Work with Alaska Department of Environmental Conservation to develop Alaska's Water Quality Management Plan for Agriculture as required by federal law.
- Review soil and water conservation plans for all cooperating land users around the state.
- Prioritize soil and range survey needs before purchase by the state.

Additionally, examples of the ASWCB and SWCDs in carrying out their powers under state law for guiding settlement and the orderly development of land are:

- Drafted legislation which was enacted as the "Right-to-Farm" Law, and the "Grazing Preserve" Law.
- Revised state agricultural land patent language for better acceptance by financial lending institutions.
- Drafted administrative regulations to allow the Delta barley farms to be divided into smaller farms.
- Review and comment and DNR land plans and disposals.
- The preparation of a report for the legislature indentifying the remaining State-owned natural rangelands, and recommending legislative protection similar to of state forest designation.

ASWCB & SWCD RELATIONSHIP WITH FOREST LAND USERS

To provide for the orderly development of land and to control soil erosion and water degradation, it is necessary to get technical assistance to the land users. As a separate entity somewhere between government agencies and private landowners, SWCDs are in a unique position to accomplish this.

While SWCDs have primarily obtained assistance for agricultural and grazing land users, the SWCDs' relationship with forest land users should not be much different. The process is already in place. The SWCDs can obtain technical assistance from SCS and other agencies for forest land users just as easily as agricultural and grazing land users.

SWCDs have supported the postion of service forester in the past, and while there is no one by that title, some SWCDs currently have memorandums of understanding with the Alaska Division of Forestry which make such assistance available to land users within the SWCDs.

Maintaining soil productivity and water quality through erosion control in the development of forest resources is a concern of SWCDs. In fact, DNR departmental order #120 requires review of all forest management plans by SWCDs.

Another area in which SWCDs and the forest industry can cooperate is in plant materials and evaluation. Four SWCDs, with a fifth in the planning stages, maintain plant material demonstration and evaluation sites. These sites are in different areas of the state, representing different climatic conditions. Through memorandums of understanding with forest agencies, the SWCDs could also evaluate commercial and ornamental tree species along with their grain and grasses.

A Brief History of Tanana Chiefs Conference, Inc. and Post Logging Soil Erosion on Clear Cut Sites

John C. Maisch

ABSTRACT: A brief history of Tanana Chiefs Conference. Inc. is presented, covering early historical development and important events in the formation of the corporation. An overview of the forestry program, with observations on post-logging erosion and corrective treatments on clearcut sites in Interior Alaska, along with objectives for maintaining site productivity are also presented.

Tanana Chiefs Conference, Inc. (TCC) is an Interior Alaskan organization with a unique history. Its origin can be described by a word from the Athabascan language, spoken by Native people long before Interior rivers, this country or its states had their current names. The word is NU-CHA-LA-WOY-A, which when translated from the spoken language means "where the two rivers meet". These two rivers are the Tanana and Yukon and at their confluence is the traditional meeting site of the Athabascan peoples of the Interior. Today, the village of Tanana is located near this site.

Shortly after spring breakup on the rivers each year, the chiefs of the different villages of the Yukon and Tanana valley regions would meet. The purposes of these meetings were to settle important problems in trade, hunting and to plan ahead for the winter and their peoples needs. The chiefs elected a regional chief to serve as their leader and spokesperson; Chief Andrew Isaac of Dot Lake currently serves in this capacity.

A more formal development of the corporation took place in the early 1960/s when the controversy over land rights became an important issue. Many young Native leaders became involved and Al Ketzler, Sr. helped organize a meeting of 32 villages at Tanana in June 1962. As a result of this meeting, the Tanana Chiefs Conference was incorporated.

The main goal of Tanana Chiefs Conference Inc. (TCC) was to protect the land and the culture of Native people of the Interior and to promote a settlement with the United States government over land issues. TCC and other tribal organizations in the state formed the Alaska Federation of Natives to help each other accomplish its goals. All this work resulted in the Alaska Native Claims and Settlement Act of 1971 which set up 12 regions, authorized the transfer of about 40 million acres of

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land and a cash settlement of nearly $1 billion. The bill states that "a management system of corporation entities be established by region and the rest of the land and money be divided between village corporations." Tanana Chiefs Conference, Inc. is the largest of these geographic regions, encompassing most of Interior Alaska. Approximately 43 villages are members of TCC. In time these villages incorporated Doyon, Limited as the profit corporation for their region.

Tanana Chiefs Conference, Inc. became the non-profit corporation for the Doyon region. With the passage of the 1973 Indian Self-Determination and Education Act, it became a state and federal contractor for programs in the region. The company grew from five employees in 1973 to several hundred In 1985. Under its administrative divisions TCC provides a multitude of services with Health Services, Finance and Administration and Subregional Services being the three main administrative branches. The Forestry Program is part of the Community and Natural Resources Division which is located within the Subregional Services Branch.

The main objective of the forestry program has been timber inventory of village land selections In the region (fig. 1). The program staff is small in number, relative to the area of responsibility, which is about four million acres. The main goal of the timber inventory program is to collect baseline data about the forest

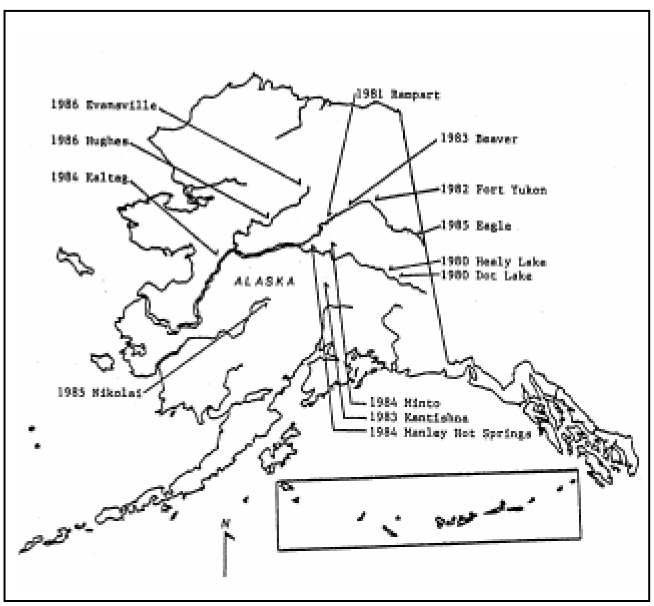

Figure 1.--Location of Tanana Chiefs Conference, Inc. forest inventory projects.

resources. At present little is known about these resources in terms of volume, species composition, spatial distribution, or quality.

A basic inventory begins with the purchase of aerial photography and initial vegetation type interpretation and mapping. This preliminary mapping is then ground truthed by a reconnaissance of the project area. Final vegetation Interpretation is then completed for the entire project area and preliminary acreage figures are estimated for forest vegetation types. From this data Inventory, plots are proportionately allocated and about 60 to 65 stands are then randomly sampled on the ground. The inventory method used for this sampling is the variable plot method with 10 plots taken in each stand selected. Information on tree height, diameter, defect, age, growth and other stand data is recorded for later computer processing.

Upon completion of a project, the village receives a set of vegetation type maps at the scale of two inches to a mile, and an inventory report. This report provides information on volume estimates and acreage by species and size class, annual allowable cut and other important forest statistics.

Forest inventory is not the only aspect of forest management with which the program is concerned. Technical assistance for regeneration surveys, reforestation projects, timber sale layout and numerous other special projects requested by a village or corporation are among the assigned duties of the program. There is a close cooperation with the Bureau of Indian Affairs Forestry Program in Alaska and resources are often shared to accomplish projects.

In 1985 the TCC forestry program became involved in a soil stabilization project initiated by the Toghotthele Corporation of Nenana. Severe post-logging soil erosion had been a problem on several logging units located on corporation lands and as a result Toghotthele Corporation approached the Agricultural Stabilization and Conservation Service in Fairbanks for assistance. Funding for a portion of the project was provided by the Agricultural Conservation Program which Is administered by this agency. Under this program an annual cost share funding of $3,500 is available per person or organization for soil stabilization work.

The logging units range in size from 20 to over 200 acres with about 4,200 acres having been cut over a period of 12

Figure 2.--First spring runoff and resulting soil erosion on a logging deck.

Figure 3.--Soil erosion along the main haul road in the old state units.

years, beginning In 1969 and ending in 1981 (Putman 1986, Zufelt 1984). Of the 39 separate logging units, 24 units were logged while under State jurisdiction and the remaining 15 units were cut by Fibrex and Shipping, Inc. under contract with Toghotthele Corporation. Approximately 26 million board feet Scribner of white spruce (Picea glauca) sawtimber were removed from these sales with about 16 million board feet being exported to Japan (Leach 1983).

Areas with the worst erosion problems are located in the older State sales and units have been prioritized for stabilization work as funds become available. Most of the erosion problems are a result of poor logging practices, such as improper road design and placement, landings larger than necessary and placed across natural drainages and skidding techniques that often used drainage bottoms as skid trails. This has resulted in some spectacular erosion trenches, pits and soil flows (fig. 2 and 3). In some areas trenches as deep as 15 feet can be found and many of the original logging roads are unusable. The more recently logged units, administered by the Toghotthele Corporation, also exhibit many of the same problems, but have not developed to an equal degree of severity.

Since 1979 several site rehabilitation projects have taken place on these lands and have included slash cleanup and disposal, site scarification work to improve natural regeneration, and the planting of 22,000 white spruce seedlings. During the summers of 1983 and 1984, a comprehensive regeneration survey was made of a] I these lands to determine which units were still in need of rehabilitation work and to assess work completed. It was determined that many units still had serious soil erosion problems and deficient white spruce stocking, so specific projects were initiated to help solve these problems.

The first of these projects was begun in 1984 and consisted of a series of grade stabilization structures that were installed in a severely eroded drainage. The design of the structures was provided by the Soil Conservation Service and ten of these structures were installed (fig. 4). Logs used in the project were salvaged from slash piles and the Toghothelle Corporation provided the work crew for installation.

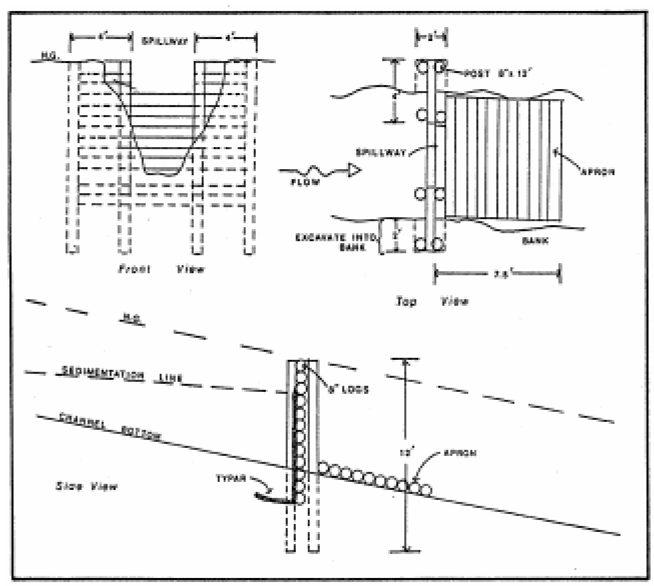

Figure 4.--Soil stabilization structures as designed by the Soil Conservation Service. Redrafted with slight modifications by Tanana Chiefs Conference, Inc., 1987.

The results after two years of use are mixed_ but some useful observations have been made concerning improvement of the structures. After the second year's spring runoff several of the structures were beginning to show signs of erosion under their bottom logs, even though these were excavated 2 feet below grade. Apparently, enough water was flowing between and under the structures' lower logs to further erode soil from around them and the expected siltation did not take place. On other structures located in the same drainage, proper siltation was occuring and some new vegetation was already established on these sites.

As a result of these observations it was suggested that Typar or another similar water-permeable fiber cloth be installed on the upper side of. the structures. This cloth will trap and hold the soil while still allowing water to flow through the material. This material is often used in logging road construction to prevent road surfacing gravel from compacting into the soil In wet areas. Once this site Is stabilized white spruce seedlings will be planted in the drainage.

Many of the log decks In the area also required stabilization. In 1986 a project was begun in logging units 1, 2, 3, and 6. A total of 10 log decks and portions of several logging spur roads were shaped and graded with a small caterpillar tractor and then broadcast seeded. Recommendations for seeding and fertilization rates were obtained from a University of Alaska Cooperative Extension Service publication and from the Soil Conservation Service. Each deck was seeded with a Smooth Brome Manchar_Grass (Bromus inermis cultivar manchu) at the rate of 16 pounds per acre. This was followed by a treatment of fertilizer at a rate of 60 pounds nitrogen, 100 pounds potassium and 50 pounds phosphorus per acre. Initial results look very promising and a vigorous crop of grass was established on most of the sites after the first growing season. These log decks and spur roads will be inspected in the spring of 1987 to assess spring runoff effects on the sites. These areas will also be planted with white spruce once they are stabilized.

In general some good progress has been made in the rehabilitation of these areas_ but further work will be required to bring these sites back to their full potential for tree growth. The TCC forestry program has no specific written goals or objectives to follow In maintaining site productivity, but would follow the Forest Resources and Practices Regulations used by the state of Alaska as the basic guidelines for protecting site productivity. Additionally, in contacts with the villages and corporations served by the program, foresters encourage the use of proper forest management practices and offer remedial advice for projects with problems. As more forest development takes place on Native lands, this aspect of forest management will become more important. The job will be to educate and communicate proper management techniques before projects are initiated so problems can be avoided.

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SOIL PRODUCTIVITY - WHAT IS IT?

Glen O. Klock, Ph.D., CPSS

ABSTRACT: Forest soil productivity is the ability of a site's soil to support and produce biomass where the maximum potential production is a function of both extrinsic and intrinsic site factor. Maintenance of long-term productivity in the forest ecosystems of Alaska requires a full understanding of the role and response of these intrinsic site factors to forest management.

One of the primary responsibilities of resource managers in Alaska is to maintain the land's productivity capacity. Management of the diverse soil resource within this region is an important key to maintaining or perhaps improving this productivity capacity. The objective of this conference is to examine present interactions between man's management activities and the forest soil resource to determine possible effects on the long-term productivity. Workshops and conferences on the effects of forest management on the long-term productivity have been held in other regions of the United States (i.e. Balmer 1978, and Ballard and Gessel 1983). This first forest soil productivity conference in Alaska, however, will 'provide anew insight into forest soil management opportunities and constraints in both the interior and coastal areas where environmental factors are perhaps more critical than elsewhere in the United States.

It is the objective of this presentation to set the stage for the workshop's technical contributions by defining the concept of soil productivity and providing a framework for coordinating research and technology transfer in this area. At a recent conference in Corvallis, Oregon" titled "Maintaining the Long-Term Productivity of Pacific Northwest Forest Ecosystems," well-known research ecologist Dr. Jerry Franklin pointed out that "Long-term productivity is more than soil nutrition!" He further stated that "Long-term productivity is maintaining resilience in forest ecosystems and landscapes by maintaining forest complexity and diversity." While Dr. Franklin emphasizes that ecological diversity should be the cornerstone of the management of our forest ecosystems, we must focus in this workshop on the ability of soil systems within these ecosystems to absorb change created by forest management without loss of productivity.

If we are to focus on soils as a key factor in maintaining long-term productivity and it is not "soil nutrition" as stated by Dr. Franklin, then what is it? Many definitions exist, but I will define forest soil productivity as the ability of a site's soil to support and produce biomass where the maximum potential production is a function of both extrinsic and intrinsic site factors. Extrinsic factors are those over which the ecosystem has no marked influence and include soil parent material, topography, and regional climate. Intrinsic factors are those influenced by the presence of the ecosystem and processes occurring within the ecosystem. Intrinsic site factors include a range of soil-form processes including water, nutrient, and carbon cycling.

More often, it is the modification of the intrinsic soil factors of soil moisture, aeration, and nutrient availability by forest operational activities and the consequent change in net primary biomass production that is of concern to forest land managers. Whether the modification is significant enough to affect current and/or long-term

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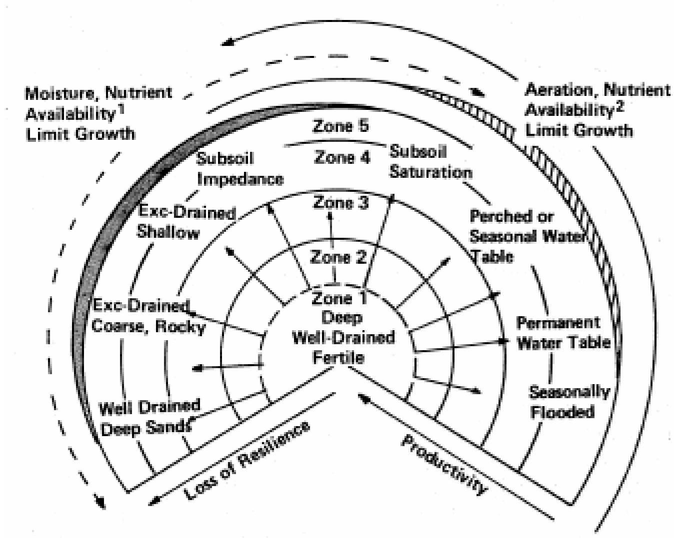
future site productivity is highly dependent upon (1) the type and magnitude of the activity, (2) the time of the activity both seasonally and the stage of stand development, and (3) the productivity resilience or sensitivity of the soils being affected (Klock 1983). In the excellent technical presentations to follow in this workshop one should note how each of the researchers relate their work to the intrinsic factors that influence forest soil productivity.

Participants in this workshop may not be familiar with the term "soil productivity resilience" which was first used in soil science literature in 1983 (Klock 1983). The productivity resilience of forest soil is the ability of a particular forest soil to resist significant changes in its moisture, aeration, and nutrient availability characteristics that will affect the site's productivity capacity. In recent years ecologists have referred to the resilience of natural ecosystems as the degree, manner, and rate of restoration of initial structure and function in an ecosystem following disturbance (Holling 1973, Westman 1978). Resilience as an ecological characteristic reflects ultimately the nature and complexity of many processes within an ecosystem. Because soils are a major component of all forest ecosystems, any evaluation of the effects of forest soil management on site productivity must be based on a study of soil characteristics controlling soil productivity resilience. As forest management can have both positive and negative impacts on productivity, evaluation of soil productivity resilience will assist in quantifying both the degree of "opportunity for" and the "irreversibility of" commitment of ecological resources.

Stone (1978) initially introduced and graphically displayed the affects of intrinsic site factors on forest productivity. Later Klock (1983) I modified the great arc as shown in figure 1 to include the role of nutrient availability. Maybe the great arc' should be further modified to reflect the factors of temperature and/or permanent frost encountered in interior Alaska. The arc is stratified by zones 1 through 5 which reflect zones of forest soil resilience created by intrinsic soil factor limitations. Obviously zone 5 has the greatest limitations and soils falling within this zone are often the most sensitive to forest management activities. Because of climate and topography Alaskan soils frequently fall in zone 5. Therefore, considerable attention must be given to the possible impacts on the Alaskan soil resource and its intrinsic site factors by forest management activities. Many excellent scientific papers on these soil factors and their relationship to forest productivity in Alaska have been prepared by Dyrness, van Cleye, Viereck and others.

Research on management effects on intrinsic site factors has frequently utilized the case study approach. Often it has focused on narrow, specific questions. Nutrient cycling studies, for example, often are directed towards finding the impacts of possible clearcutting on streamwater



1/Lack of mineral retention sites as well as minimum soil solution retention, subject to leaching losses.

2/Creates soil reducing condition making some nutrients rather unavailable while others in quantities possibly toxic to forest vegetatlion.

Figure 1.--A spectrum of soil moisture soil aeration nutrient availability and site productivity gradients. "Ideal" soil characteristics for maximum site productivity prevail at the center. Most forest soils fall along radial transitions, soil productivity resilience zones 1-5, towards various extremes at the rim. Severity of soil productivity resilience factors varies around the circumference as well as radially.

quality rather than the effects of nutrient losses on soil productivity. Similarly, forest residue treatment studies such as slash burning have looked at changes in soil properties and nutrient losses and have led to broad assumptions about the possible effects on soil productivity.

Studies of forest productivity, on the other hand, often lack the systematic approach needed to relate productivity to measurable site characteristics. Certainly, normal or empirical yield tables relate the production of forest products to stand age and site index. While information of this type is necessary for product yields, it has severe limitations for use in productivity studies. Site index cannot be reliably determined on a clearcut. Where species conversion is practiced, site index for an existing species mayor may not represent an equivalent site index for its replacement. Although work has been done to minimize these problems (Steinbrenner 1979), such techniques are, however, species specific, fail to deal with the dynamic nature of forest ecosystems, and are based on observations of past rather than future productivity (Grier et al 1987).

Another problem with site productivity studies is that they are primarily concerned with wood yield rather than total productivity- There mayor may not be a close correlation between the two values. Researchers primarily with an ecological focus have used measurement of net primary production (NPP) as a tool to define site productivity. These studies, however, often reflect scientific rather than management interest. Although NPP varies with stand age, measurements of NPP on mature stands may give some idea of the potential productivity of a given site. It is interesting to note that a Picea mariana (Mill.) stand in Alaska was measured to have biomass of 118 t/ha, not too unsimilar to stands of other conifer species in the United States (DeAngelis 1981). The NPP, however, is only a small fraction, 2.1 t/ha/yr, of conifer stands with similar biomass. Other research in Alaska (van Cleve, 1971) has shown a somewhat higher NPP of 10.8 t/ha/yr, but a lower total biomass, 43 t/ha, in Alnus incana (L.) stands. One must keep in mind, however, that a larger percentage of the plant's energy goes into producing and supporting belowground biomass on a low quality site, which was not measured in the Alaskan studies.

Another area of soil productivity research is the use of modeling. While these models appear to provide the most useful information to predict potential impacts of management over several future crop rotations, further research will be needed to validate their predictions. Yarie will discuss at this workshop some of the modeling approaches now available to analyze soil productivity

Researchers often find it difficult to evaluate the effects of forest management practices on forest productivity. In turn, forest managers find it difficult to interpret research results and put this information into useful economic forest management guidelines. Workshops such as this are extremely useful for this needed technology transfer. While researchers address specific issues, the forest manager should be sensitive to trends indicated by the results of many researchers. For example, the research of many scientists indicates that soil compaction, most frequently by ground skidding operations, leads to reduced timber volume growth. Thus, the forest manager must be operationally sensitive to soils that are easily compacted. Other kinds of generalities can be drawn about the relationship between forest management activities and site productivity including residue treatments, herbicide applications, fertilization, road construction, and site preparation.

Forest managers are cautioned about implementing practices developed as a result of research in other regions. The continuing clearcut issue is a good example. Here in Alaska there is one soil management issue where research in the Pacific Northwest could be particularly misleading. A general recommendation in the Pacific Northwest is to protect the forest floor and soil organic matter to maintain forest productivity in future crops. Because of differences in temperature regimes between the Pacific Northwest and Alaska, similar treatment of the organic layer may bring contrasting productivity results. Here soil temperature may be more critical with nutrient availability being secondary, particularly in regeneration stands (van Cleve et al 1983).

SUMMARY

Maintaining forest soil productivity is more than understanding soil nutrition. Besides preserving the necessary complexity and diversity, maintenance of site productivity requires a full understanding of the role and response of intrinsic site factors to forest management. Forest management can control the time and magnitude of the impact of their activities on the soil resource. In turn, soils have varying levels of resilience to these management activities. Where a forest management practice may be acceptable without irreversible impact on one soil type it may have serious limitations to future productivity on another soil type. An understanding by researchers and forest managers of a soil's resilience or sensitivity to management activities is essential to maintaining the long-term productivity of both interior and coastal forest ecosystems in Alaska.

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ASSESSING SOIL PROPERTIES WHICH LIMIT FOREST PRODUCTIVITY

S. P. Gessel, D. W. Cole, and H. N. Chappell

ABSTRACT: Alaska has a wide diversity of forest growing conditions and the soil is only one factor in the forest productivity equation. Assessing the role of the soil necessitates control of the other factors, or quantitative data on their contribution to productivity. As this is not available we reviewed general site relationships in order to recognize the limitations of this assessment. The effect of the past extensive fires in interior Alaska is an additional uncertainty. Specific research on soil-productivity relationships of Alaskan forests is reviewed, as well as pertinent research from similar environments. Soil factors which seem to playa dominant role in Alaskan forest productivity include:

temperature, especially low temperatures; moisture, especially excess, but possible deficiencies in the interior; depth and texture; biology, especially factors affecting turnover rates and elemental supply; essential elements, mainly nitrogen but also phosphorus and perhaps others.

Many uncertainties exist with respect to specific relationships. Soil processes which determine the state of these critical soil properties need to be studied in order to understand the role of the soil in Alaskan forest productivity. More complete information is certainly needed in order to manipulate the properties to either increase productivity or prevent reductions.

INTRODUCTION

There is no good documentation of when man first made observations on the relationship between soils and forest trees, but certainly these preceded much scientifically organized information on either soils or forestry. One of the early comments is found in White's Natural History of Selbourne (Williams et al. 1936) written about 1750: "Though these two forests are only parted by a narrow range of enclosures, yet no two soils can be more different; for the Holt consists of a good strong loam, of a mirey nature, carrying a good turf, and abounding with oaks that grow to be large timber; while the Wolmer is nothing but a hungry, sandy, barren waste."

This kind of information found practical application in the quest for good agricultural land by pioneers involved in forest removal throughout the world. For example, the early settlers in Australia soon discovered the superiority of soils on basaltic intrusions into poor sandstone formations and the differences in the forests on these soils. The same experience could be repeated for settlements across the world.

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RELATIONSHIP OF PRODUCTIVITY TO SOIL AND OTHER FACTORS

The modern interest in forest soils was largely stimulated by the necessity for more information about forest productivity. Coile (1952) and other researchers achieved a large amount of success by exploring and developing relationships between soils and site or forest productivity. The application was generally toward identification and classification but also had use in management. Coile's work and that of others has resulted in a large number of specific relationships between soil properties and site.

A great amount of information has been generated on the general subject of soil-forest productivity relationships since these early observations. Carmean (1975) provided a good review of soil-site studies in the United States up to that time and recognized the limitations of applying results from one area to others. Stone (1978) also reviewed the history of soil-site studies and pointed out that the number peaked in the 1960's and has fallen off since. He identified the limitations of assuming that soil moisture was the principal factor in yield and that moisture could be predicted from average soil moisture regimes. Many other workers have recognized the necessity to develop soil-productivity relationships for specific forest areas. Examples include work by Steinbrenner (1981) who found different relationships for recently transported soil materials than for older residual soils in Washington and Oregon.

We utilize these examples to illustrate the fact that soil-productivity assessments are not necessarily interchangeable from one area to another. Forest tree species differ widely in their ability to utilize soil resources under different climatic regimes, and all factors affecting productivity must be considered in making assessments. The restrictions are clearly identified if one uses Jenny's (1941) soil formation relationship and extends it to forest productivity as has been done by several authors, including Chertov et al.(1977) and Gessel (1967). The soil forming equation is:

$$S = f\text{ (climate, age, parent material, topography, organisms)}$$

This states that soil properties are determined by the independent factors on the right side of the equation.

We can write a similar relationship for forest productivity as:

$$\text{Productivity} = f\text{ (climate, age, topography, organisms, soil)}$$

This states that if we wish to identify the contributions of soil to site or productivity, then we must separate or hold constant the contributions of climate, time or age, topography, and the various organisms in the forest, including man.

IDENTIFYING SOIL PROPERTIES CONTROLLING PRODUCTIVITY

Having identified the contribution of other environmental factors to productivity we now turn our attention to the soil. We begin by considering what the soil must ideally provide for trees. These include:

1. An appropriate medium for roots to develop in and perform the anchorage and psysiological functions necessary for stable long term growth, which implies an adequate oxygen supply.
2. An adequate water supply, hut not excess.
3. All the essential elements for tree growth in the form and amount needed throughout the life of the tree.
4. A habitat which selects for organisms which benefit the tree as opposed to those detrimental to the tree.

There are, of course, many processes which go on in the soil relative to these functions which determine the adequacy of the soil to serve its role. We will not deal with these processes in detail as many will be evaluated in other portions of this program. We will categorize soil properties which determine whether the soil can supply these essentials.

Soil Properties Affecting Forest Productivity

Physical.--Physical properties determine the total quantity of soil available for root growth and the ability of the soil to store and supply items essential to plant growth. Other things being equal, soils of greater volume available for roots provide a better overall medium and also a better supply of water and nutrients. Soil properties which reduce total volume such as shallow depth to a restrictive layer or high gravel or stone content also reduce productivity. Some of the physical properties which affect productivity are rather easily changed by forest operations while others are more permanent in quantitative value. Examples of the more permanent -are texture and gravel content while those subject to modification involve density, porosity, water and air permeability. Although we generally think of soil depth as a more permanent feature, this can also be changed by erosion or operation of equipment which moves soil. Soil temperature characteristics, frequently considered to be more permanent, can also be changed rather readily through ground cover modification or soil color. Reduced or accelerated drainage can also readily modify many of the soil's important water characteristics.

Assessment of relationships between soil physical properties and site or productivity has been much more successful than for the other properties. Therefore, a large number of specific relationships between such factors as soil depth, depth to B horizon, gravel content, clay content, or available water have been reported (Carmean, 1975) for some forest areas or environments. We therefore have a reasonable basis for estimating what a change in some of these properties may do to productivity in these forests.

Chemical.--This array of properties has many relationships to tree growth and productivity. Basically, they determine the ability of the soil to supply elements essential for tree growth at the right time and in the correct amounts. Productivity can be reduced as much by excess of certain elements as by deficiencies of them. The ability of the soil to supply the necessary elements, or the tree to extract them from the soil, is complicated by many processes in the soil and plant and the adaptive ability of trees, including association with"" other organisms. For example, there is a difference between total and available amounts of most elements in the soil. As a result, development of simplified relationships between soil chemical properties and forest productivity' has generally not been successful despite the fact that some strong relationships do exist, as for example, "excess magnesium in serpentine soils. We also find that physical properties which limit productivity may further reduce chemical properties which also limit productivity. For example, very high stone content could dilute nitrogen or other essential elements to the extent that they become limiting.

The most common problem forest trees have with chemical properties of forest soils is either excess or deficiencies of elements. In either case the problem can be intense enough to cause failure of the forest. However, it is more commonly evident in reduced growth and general poor health of the forest. Modification of the soil system to improve the supply of essential elements is usually easier than improvement of physical properties or removal of excess amounts. Generally two kinds of conditions exist with respect to deficient-elemental supply and forests. One is an almost absolute deficiency of an element as found in some New Zealand soils (Will 1978) or Australian forest areas (Stoate 1950). The other pertains to a low level of supply which reduces productivity below what is expected from the status of other site factors. Research has demonstrated' the technical, economic, and operational feasibility of improving productivity by correcting these kinds of deficiencies.' A particular example is nitrogen in Washington and Oregon forest soils (Gessel et al. 1983) but there are numerous other examples across the world'. Reports and publications of the Regional Forest Nutrition Research Project at the University of Washington are available for further details.

We also have evidence that many forest areas can also suffer from an excess of certain elements such as aluminum, hydrogen, or even calcium. The very low productivity of some soils originating from limestone is well known in forestry and defies easy correction (Mandzak 1986). Relatively high aluminum and hydrogen is common to most forests soils, but in excessive amounts those ions cause both direct and indirect effects, but with large species differences (Ryan et al. 1986a, b). "These excesses may be inherent in the forest soil system or they may be induced from the outside, as from atmospheric deposition.

Although fire can change many properties of forest soils we chose to say a few words under this discussion of chemical properties. Fire has been a major influence on forest soils in interior Alaska (Lutz 1956). The nature of the influence }is still debatable because the exact relationship between fire and elemental supply is unknown for many forest soils. Whether fire is beneficial or detrimental certainly depends on the elemental status before the fire and the severity of the burn. Because of these variables we find reports on the effect which vary from very serious loss of productivity to great improvement as in the "ash-bed effect" in Australia. The improvement is attributed to greater phosphorus supply under areas where piled-up debris has been burned (Humphreys et al. 1965). Reports of reduced productivity frequently attribute this to reduced nitrogen supply as a result of loss to the atmosphere. Many forest soils have excess carbon in relationship to nitrogen and this can be changed by fire. The role of fire in Alaskan forest soil productivity needs further work.

Biological.--Forest soil is the habitat for a host of different organisms. Some of the processes these organisms carry on as part of their life cycle are very important to the functioning of the soil as a medium for forest growth. We know something about some of the organisms but for most we have very little information. We therefore do not have simple relationships between soil biology and forest productivity and we don't have simplified methods to assess these.

We can argue that a soil which provides a better habitat for organisms also provides a better habitat for tree roots. Some studies have shown better productivity to be associated with higher numbers of certain kinds of organisms such as earthworms. The contribution of mycorrhizae to forest productivity is well known. The role of organisms in the nitrogen cycle, especially fixation and release from organic matter by decomposition processes, is reasonably well understood. However, not all soil organisms are beneficial to the growth of forest trees. Many are responsible for reduced growth and ultimate destruction, such as the various root destroying_, fungi. Therefore the practical application of soil biological information to productivity assessment is not easy. We have identified certain organisms as beneficial or detrimental but the methods to do this do not permit quick field evaluation and direct application to productivity assessment.

Soil Factors which May Limit Forest Productivity in Alaska

This then brings us to the specific case of assessing soil factors which may limit forest productivity in Alaska. It does not take much knowledge of Alaska or review of forestry in the state to realize that generalizing the assessment for the whole of Alaska has many hazards. Alaska is a very large state with a wide array of soils and vegetation. Fortunately a number of workers have summarized the important features of the vegetation and in some areas the soils. These include the works of Viereck (1966, 1970), Viereck and Dyrness (1980), Stephens (1969), Stephens, et al. (19.68, 1969), Van Cleve and Dyrness (1980), and Harris and Farr (1974). We use only the features of these contributions which aid the task of identifying soil properties which determine forest productivity. Alaska has been the setting for numerous investigations of soil and plant development. The many areas of very young soils resulting from ice recession, flood plain deposits, or volcanic depositions present opportunities for such studies. Examples of these are the works of Taylor (1933), Crocker and Major (1955), Ugolini (1968), Ugolini et al. (1979), and Lawrence (1958). These have all contributed useful information on properties of Alaskan forest soils.

From these studies we can draw a very general summary of forests, soils, and environmental conditions affecting forests in Alaska. Two distinct forest areas exist, those of the southeast and those of the interior. Both forest areas, along with similar forests in Canada, have had some soil-site investigations. Although the forests differ in regard to general climate, species, topography, and soils they are both influenced by climatic features which cause them to be different in relationship to soil-forest interactions from those of the lower 48 states. The overriding feature is the cold temperature regimes, coupled in many areas with excess water. However the relatively dry climate of interior Alaska may mean that water deficiency can occur on some soils. The extensive fire history of the interior region soils must also be considered.

We look, therefore, for generalities regarding soils and forest productivity to the studies which have been done in Alaska and other northern latitudes of the world. Although somewhat dated, the book by Tamm (1950) does establish the general characteristics of northern coniferous forest soils, including those in Alaska.

From these general and specific studies we believe that Alaskan forest soil-forest productivity interactions are dominated by three features:

1. cold temperature regimes.
2. excessive moisture supply in many soils, but possible deficiencies in some interior area soils.
3. effects of fire on interior soils.

The cold temperatures and excessive moisture act to bring about changes in the chemical and biological functioning of the soil system, and especially under certain soil physical regimes. Low temperatures generally mean slow rates of both biological and chemical activity. Excess water, with poor aeration, can further reduce those rates, resulting in storage of detritus material rather than turnover. In the extreme. cases we find permafrost conditions or peat bogs. This does not mean that all Alaskan forests end up as permafrost or peat bogs, but it does mean . that soil and vegetative cover conditions which accentuate the development of the permafrost may be important in productivity considerations. It also means that relatively small changes in factors which influence temperature regimes or drainage exert considerably more influence over the final productivity than in environments with great temperature or moisture amplitudes.

From these considerations we would expect important soil properties which affect productivity in Alaskan forests to be those which relate to:

1. soil temperature
2. soil drainage
3. biological turnover rates,
4. element supply, especially nitrogen and nitrogen/carbon relationships, and possibly phosphorus.

To complete the assessment we now review those soil-site investigations which have been made in Alaska, supplemented with some from similar northern latitude areas.

Stephens et ale (1968) and Stephens et al. (1969) reporting on Tongass National Forest soils, observed that soil moisture was ample for tree growth and that soil moisture tensions high enough to significantly reduce tree growth have not been recorded in southeastern Alaska. They further found that soil temperatures were low and maybe restrictive. Most of the mature forest mineral soils have similar properties regardless of parent material, but the organic layers do differ. For site index relationships they found that the deep, freely drained soils were the best sites with an index of 150 at 100 years. Soils less than 10 inches deep have reduced site, even with free drainage, while soils of only 0-2 inches of mineral material fall to an index of 90 (Table 1). Predominance of either coarse fragments or volcanic ash in the mineral portion results in a site drop to 130. Somewhat reduced drainage and poor drainage cause a reduction to 120 and 70 site index. Poorly drained soils are the most extensive ecosystem in southeastern Alaska. These normally have 3 inches to 1 foot of forest floor over peat and a shallow mineral soil to an impeded layer.

These authors go on to say that organic matter furnishes most of the elemental supply for forests and that slow decomposition from a combination of low temperatures and excess water causes elemental deficiencies and reduced growth. There is a large quantity of nitrogen in Alaskan ecosystems but less than a fraction of 1 percent is released each year causing nitrogen to limit growth in many situations. Amounts of organic matter and nitrogen for some of the ecosystems are given in Table 2. Stephens et al. (1968) also found almost a direct relationship between nitrogen content of the surface organic layer and site index (Figure 1). However they did not find a good relationship between site index and what

Table 1.--Common Forest Ecosystems in Southeastern Alaska (after Stephens et al. 1969).

Symbol	Description	Site Index (100 years)
F_1	Freely drained - at least 10" deep	150
F_2	Freely drained - less than 10" deep	118
F_2R	Freely drained - 0-2" into rock	90
F_3	Freely drained - 0-10" coarse texture	130
F_4	Somewhat poorly drained	120
F_5	Poorly drained soils	73
M_1	Sphagnum muskeg	-
M_2	Sedge slope muskeg	-
A_1	Alpine heath	-

Table 2.--organic Matter, Total Nitrogen and Site for some Southeastern Alaskan Soils (kgs/ha).

	Forest Floor		Mineral Soil		Total Soil		Site
Ecosystem	O.M.	N.	O.M.	N.	O.M.	N.	Index
F_1	300,627	4,258	336,000	7,893	606,752	11,585	150
F_2	194,075	9,106					118
F_2R	408,446	3,592			408,446	3,592	90
F_3	394,083	3,042	439,802	6,720	821,905	9,762	130
F_4	405,275	4,378		3,286		7,261	120
F_5	266,836	2,928	(not rooted below F.F.)				73
M_1					1,188,300		
M_2					1,406,500		
A_1					437,856	11,016	

they thought should be warmer locations in Southeast Alaska.

Van Cleve et al. (1980) report on studies of nutrient cycling in the interior Alaskan flood plain forests. They concluded that process functioning was very important on the sites studied. Those processes which resulted in reduced soil temperatures and subsequently nitrogen availability controlled growth rates. Biological processes replace physical as most important in the flood plain forests but this differs with the successional stage. In the early stage, the physical properties of water relations and chemicals related to salt at the soil surface, control development. At mid-succession biological processes which affect nitrogen supply became more controlling. There are from 300 gms/m^2 to 500 gms/m^2 of nitrogen in the soil system. At the mature forest stage moss layers develop and soil temperatures decline. Even though nitrogen supply is up to 600 gms/m^2 there may not be enough available.

Harris et al. (1974), in their review of southeastern Alaskan forest ecosystems also stress the lowering of soil temperatures with increased age of the forest and resulting decrease in decomposition rates, accumulation of forest floor and moss, and decrease in nitrogen availability. They cite data of Gregory and of Chandler which show between 224,000 to 440,000 kgs/ha of organic matter in the forest floor and 20 cm. of mineral soil after 250 years of accumulation.

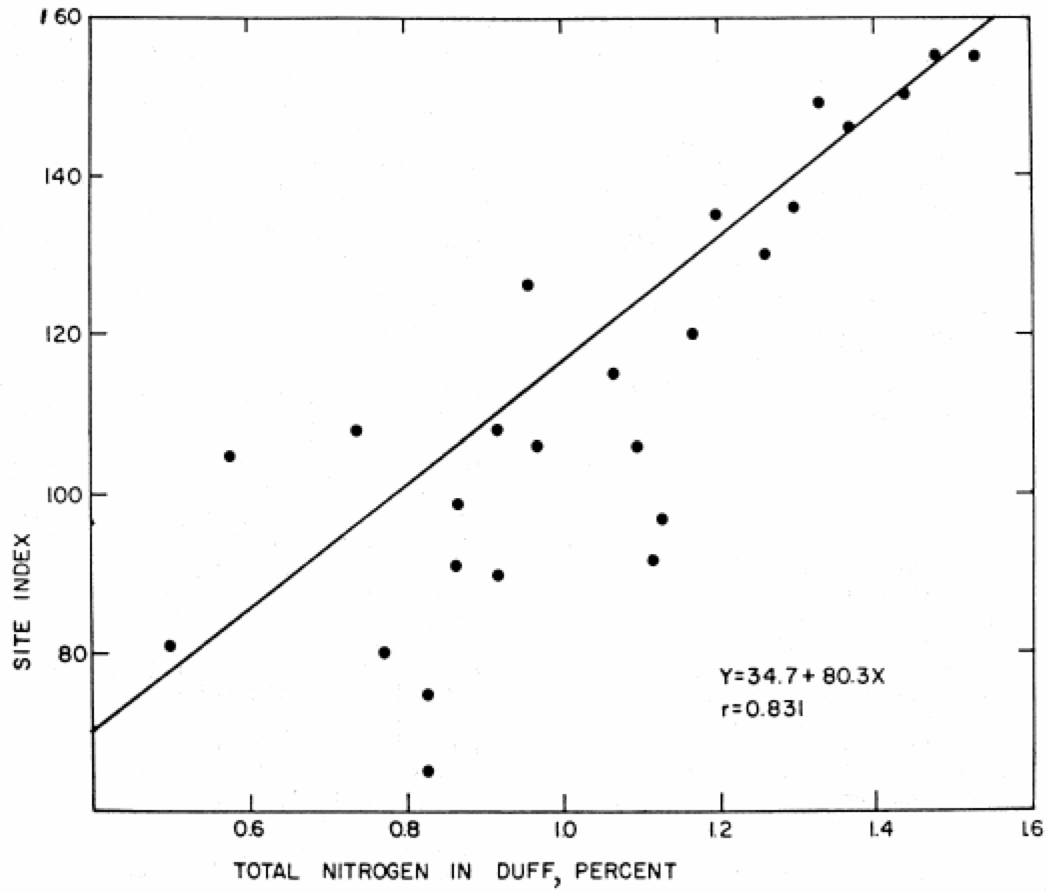

Figure 1.--Relation between total nitrogen in duff and site for southeastern Alaska (after Stephens et al. 1968).

Stephens et al. (1968) reported a general deficiency of nitrogen in soils of southeastern Alaska and also that foliar analysis of trees showed the same. They found no relationship between site index and elements other than nitrogen for the sites studied. They did determine, based on a study of 106 Sitka spruce plots, that site index was 20 feet less for stands on blowdown areas compared to burned and thought this was related to lower soil temperatures.

Stevens(1963) reported on the relationship between soils and vegetation in the Hollis area. Vegetation type was related to soil series from low to high elevations but he gave no quantitative data on soils or site. Godman and Gregory (1953) did find that soil_ with better drainage and deeper mineral soils were better sites in Southeastern Alaska. Ford et al. (1986) reported better sites corresponded to soils with greater depths, higher organic matter, and better drainage.

Weetman (1980) -recognized the importance of low temperatures and raw humus accumulation throughout the Boreal forests of Canada and the problems inherent in the management of forests with these raw humus layers.

Other studies in cold forest areas outside of Alaska include those of Payandeh (1980) who used 500 plots in Spruce-fir forests of northern Ontario. He found poor correlation between soil properties and site index over the range of environmental factors he was dealing with. He concluded that the productivity relationship was too complex to be expressed in a simple equation.

Crampton (1977) using data from 975 sites in the Peace River white spruce forests with relatively low rainfall (16 in) found somewhat impeded drainage improved site. In this case he used MAI as the productivity measure with results as follows:

Free drainage	48 ft^3 A/yr.
Impeded drainage	58 ft^3 A/yr.
Poor drainage	21 ft^3 A/yr.

Chertov et al. (1977) examined models of forest soil productivity relationship for Boreal forests of Russia. They first reviewed the development of models and looked at the most likely soil properties which would be related to productivity. These were:

1. soil water regimes
2. stable properties of the soil and parent material such as texture, depth

3. dynamic properties of the topsoil reflecting the effective fertility of the system.

Using 470 sample plots in the cool, wet areas of the Soviet Union and height as the expression of site they concluded that three soil categories showed promise for site assessment.

1. thickness of the forest floor and peat layers as an expression of the water regime.
2. texture of the A and C horizons as a measure of stable properties.
3. total nitrogen multiplied by the exchangeable bases in the forest floor and peat layers as a measure of fertility.

DISCUSSION

Attempts to critically assess soil properties which determine forest productivity in an area as large and diverse as Alaska may not meet with immediate success. However when other environmental factors which relate to forest productivity are also considered the possibility of success is increased. The assessment process is a very useful exercise because:

1. even partial identification of soil properties which determine productivity gives us a much better understanding of local sites.
2. identification of the most important soil properties in each ecosystem provides a basis for better management.
3. assessment of soil properties affecting forest productivity provides a basis for improvement action.
4. identification and understanding of the relationship of soil properties to forest productivity provides a basis for monitoring these to detect changes which may increase or decrease future productivity.

CONCLUSIONS

Those soil properties which seem to have distinctive and controlling functions in Alaskan forest ecosystem productivity, and therefore merit more attention include:

1. Soil temperature relationships.
2. Soil moisture relationships, especially excess moisture. However in some ecosystems a low water supply may be important.
3. Soil depth and texture as these affect water, drainage, and nutrients.
4. Soil biology, especially processes related to decomposition, elemental turnover, and release in available forms.
5. Available soil nitrogen supply, and perhaps other elements, as phosphorus.

We will be interested in how those authors dealing with more specific relationships between soil properties and site in Alaska agree or disagree with our assessment. Certainly the processes which determine the state of these soil properties need to be understood in order to assess the true role of the soil in forest productivity in Alaska. The effect of the extensive fires which annually burn large tracts of interior Alaska must also be more thoroughly understood. Large amounts of nitrogen and carbon are returned to the atmosphere in these fires and many soil processes are changed as well as temperate regimes.

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CORRELATION OF FOREST GROWTH AND YIELD
WITH
SOIL CHARACTERISTICS

Edmond C. Packee

ABSTRACT: Correlation of forest productivity with soil characteristics depends upon good information on both sides of the equation. Existing site index curves for Alaskan northern species are discussed. Total variability in the dependent variable (site index) attributed to soil characteristics in northern environments is oftentimes low.

INTRODUCTION

Forest site quality can be defined quite simply as the ability of forest land to grow trees (Carmean 1975). More specifically, in terms of timber management, site quality is "the timber production potential of a site for a particular species or forest type" (Clutter et al. 1983). Site quality is the sum _f all environmental factors impacting the site: climate, topography, soil, species, and time. The accurate assessment of site quality is an important task for forest managers since yield and often response to silvicultural treatments depends upon the productive potential of the site, site quality.

The only precise method to determine site quality for a specific piece of the landscape is to grow a "fully stocked" stand of the desired species on the site for a designated period of time. Indeed, most European yield tables are based on the measurement of the actual volumes produced and these are correlated with a site characteristic, commonly height; Assmann (1970) states that "today, an almost subconscious identification of height quality class with a definite total crop yield predominates." Where actual stand productivity data are lacking, indirect methods of site quality estimation must be employed.

Clutter et al. (1983) recognize three basic direct approaches to site quality estimation:

- from historical yield records,
- based on stand volume data,
- based on stand height data;

and three indirect approaches to estimation:

- from overstory interspecies relationships,
- from lesser vegetation characteristics,
- from topographic, climatic, and edaphic factors.

Although volume is the ultimate measure of site productivity, there are practical problems in using volume directly (Assmann 1970; Carmean 1975). Franz von Baur in 1881 "saw in the mean height of the stand the 'most exact and only accurate guide not only to the evaluation of a reasonably stocked and normally-grown stand but also its quality class'" (Assmann 1970). The use of height growth, since height growth is closely associated with volume growth in normally stocked stands; as an index of site quality was strongly advocated by research foresters in the United States shortly thereafter (Carmean 1975). Today, site index based on height growth is the commonly accepted method for estimating site quality in North America and northern Europe (Hagglund 1981). It

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is also the standard used for indirect methods of site quality estimation (Carmean 1975).

Volume, as a comparative measure of site productivity, is most frustrating since tree diameter is strongly associated with stand stocking characteristics. Table 1, abstracted from Stiell (1976), illustrates the effect of stand density on volume in a 50-year-old white spruce stand. This illustrates the practical problem; bear in mind that tables can be constructed that take into account stand density, but that such tables require additional measurements for stand density. Stand density can affect tree height growth. However, it is generally accepted that there is a broad range of sand densities which do not significantly affect height growth, but that extreme densities (grossly overstocked and understocked) do affect height growth and this varies with species. Hence, the preference for site index as the parameter for quantitatively assessing site quality. However, when using site index to compare the productivity of tree species, remember it is on "index" only and that the volume yield is what must be compared.

Table 1. Yield table for 50-year-old unmanaged, high survival white spruce plantations (Site $Index_{50}$ Class = 60) at Petawawa Experiment Station, Ontario (from Stiell 1976).

Planted Spacing ft.	Planted Stems/ acre	Current Stems/ acre	Mean DBH in.	Basal Area $ft.^2$/acre	Total Volume $ft.^3$/acre
4 x 4	2723	1680	4.8	308	3942
5 x 5	1742	1250	5.2	187	3560
6 x 6	1210	980	5.7	172	3273
7 x 7	889	790	6.1	160	3037
8 x 8	681	650	6.5	149	2840
10 x 10	436	436	7.4	128	2470

SITE INDEX

Site index, which is based on height and age measurements of free-growing, dominant or dominant and codominant trees, has several distinct, advantages including: relative ease of use, accuracy and low cost of field measurements, and value for comparative purposes even when adequate yield information is lacking (Carmean 1975). There are three major drawbacks to the use of site index:

- Effect of stand characteristics on height growth,
- Accuracy of the site index equations/curves,
- Lack of suitable trees for measurement.

Carmean (1975) summarized stand and tree conditions that affect site index. Empirical data for many species indicate that height of the tallest trees is still the best descriptor (Hägglund 1981; Carmean 1975). Site index estimates based on the height of dominants are considered to be less affected by stand density, to be less subject to sampling error, and to have less sampling variation than estimates based on dominants and codominants (Hagglund 1981; Carmean 1975); hence, sample tree selection must be clearly described to avoid overestimation or underestimation of site index. Genetic variation in height growth is not considered to cause significant problems in small areas (Carmean 1975), except for two situations:

- clonal stands typical of the northern forest hardwoods (balsam poplar, quaking aspen, western black cottonwood) which can exhibit great differences in growth potential between clones;
- stands in which the genetic material has been manipulated (either positively through a tree improvement program or negatively through high-grading).

The accuracy of site index curves is important to their usefulness. Site index curves intended only for identifying broad classes of site quality should not be considered adequate for intensive forest management purposes (Carmean 1975); furthermore, the use of such site index curves as the dependent variable in indirect approaches to site quality estimation may produce good correlations which in reality are nonsense.

Site index curves for Alaskan species have not been adequately tested with independent data. The only published site index curves for tamarack were developed by Gevorkiantz (1957) for the Lake States and they are anamorphic. Preliminary testing of these curves with limited Alaskan data indicate the curves are non-applicable to Alaskan stands. White spruce site index curves developed by Farr (1965) for Alaska have not been independently tested; however, when compared with curves developed elsewhere (Ontario--Stiell 1976 and Alberta--Heger 1971) (Figure 1), the difference in curve shapes suggests strongly that the Alaskan curves need testing. Zasada (personal communication) plotted height-over-age curves for a limited number of white spruce trees 100 to 300 years old from Willow Island and found a distinct shape for each of the three sites sampled; these data further support the need for the testing of the published site index curves.

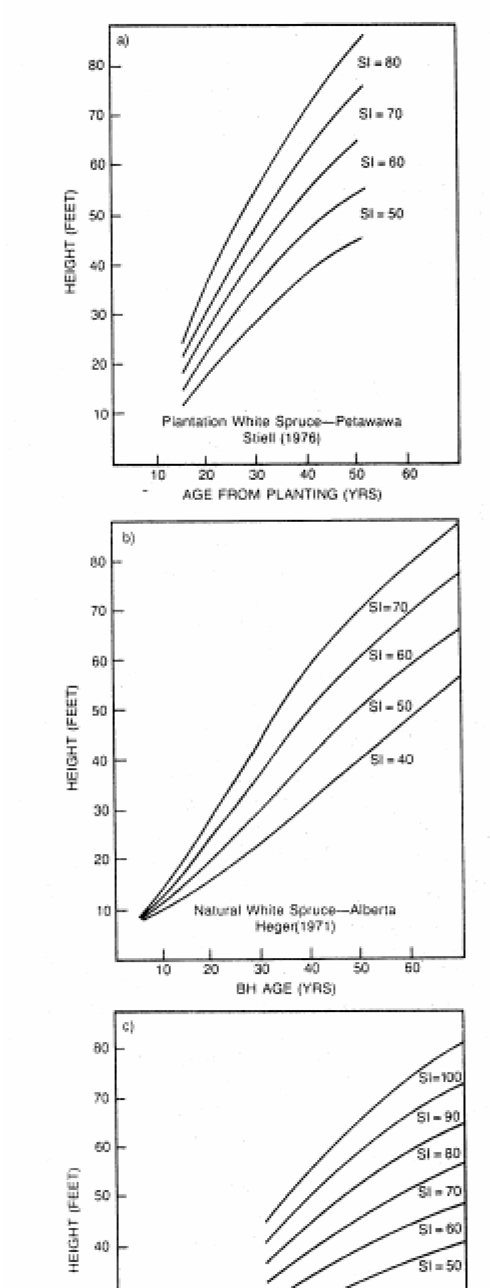

Figure 1. Comparison of site-index curves for white spruce in a) Ontario (Stiell 1976), b) Alberta (Neger 1971) and c) Alaska (Farr 1965).

Because of the inability to construct reliable polymorphic height-over-age curves, site index curves for paper birch in Alaska were constructed using the guide curve technique (Gregory and Haack 1964). Carmean (1979) compared these anamorphic curves with polymorphic site index curves developed in the Lake States and found them to be quite different. Previously (1978) he found for the northern hardwood species different height-over-age curve patterns for different levels of site quality. Spurr (1952) questions the validity of anamorphic site index curves on the basis that the inherent assumptions are usually not true. Hence the paper birch site index curves are not only suspect, but most likely inadequate for quantitative purposes. Gregory and Haack (1964) also sampled 43 aspen trees from a maximum of 39 stands located throughout the interior of Alaska; the resulting site index curves were compared with the Lake States' polymorphic site index curves of Carmean (1978) and were found to be quite similar in shape (Carmean 1979). Carmean (1979) is concerned with his sample size for aspen, 42 trees, and states that the pattern of height growth is not well expressed because of the limited data and hence recommends additional stem analyses. This is also a concern in Alaska where the range of aspen greatly exceeds the area of northern Wisconsin and upper Michigan.

Furthermore, even if the site index equations/curves are valid and sufficiently accurate, regional differences due to climate might exist. Page and van Nostrand (1971) demonstrate this quite clearly for black spruce in eastern Canada (Figure 2) where they compare the site index curves developed for the more maritime province of Newfoundland with the curves for eastern and central Canada (Heger and Lowry 1971).

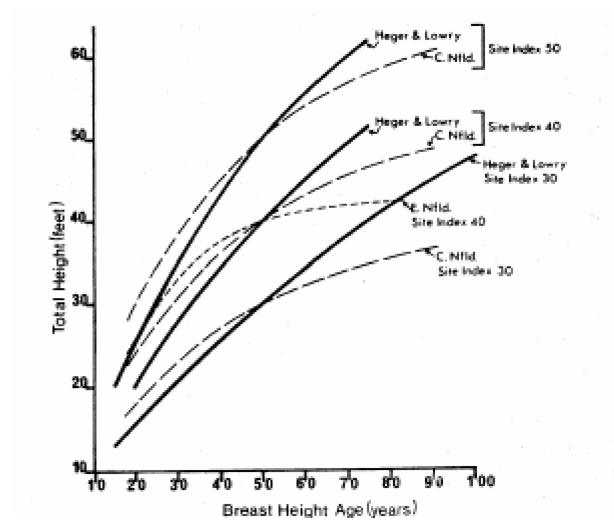

Figure 2. Comparison of site index curves for black spruce in central and eastern Newfoundland and "standard" curves of Heger and Lowry. (1971) (from Page and van Nostrand 1971).

For these four species, the site index curves must be questioned as to their suitability for quantitative analyses. They are suitable for qualitative comparisons of site quality, e.g., high, good, fair, low (Carmean 1975). Site index curves for the other northern forest tree species native to Alaska are either lacking or require obvious testing for Alaskan adaptaton. Since there is the question regarding the suitability for quantification uses, the question must be raised, "Should we attempt to quantify site index as a function of site variables before the site index curves are validated?"

SOIL-SITE CORRELATIONS

Before specifically> discussing soil-site correlation, the use or purpose of soil-site correlation equations must be considered. From an operational point-of-view,. direct measures using the standing trees are the most practical in terms of efficiency. To use soil characteristics to estimate site index or site quality when standing trees are not there or are in such poor condition that they cannot be used for site index determination, indirect methods of site quality determination are necessary.

When using indirect methods of site index determination along the west coast from southern Oregon to the northern tip of the Queen Charlotte Islands, I always used the rule "Keep it simple." Frankly, soil-site correlation equations are typically anything but simple!

Where trees were lacking, I preferred comparing it to assess the site by comparing it with similar sites with trees on them. This is the "naive model approach" (Jaffe and Spirer 1987) in which I predict the site index based on something similar existing nearby--and it works quite well. Is it so outrageous to expect a brush field on an old burn on one ridge to have approximately the same site index as a similar site on the next ridge?

I also use understory vegetation such as the habitat type approach of Daubenmire and Daubenmire (1968) and refined by Pfister et al. (1977). Failing these, I use potential climax vegetation (based on stumps and/or that naive model approach), landforms (based on Fulton's 1974 classification), aspect and slope, mineral soil texture (controlling horizons), and drainage class to select the most productive species for the site and to get an idea of site quality. Albeit, accuracy is suffering, but in most cases, I can make the correct silvicultural decision (Packee 1976). On the British Columbia coast, I should point out that there is a wide range of site index with the site index ranging from less than 60 to over 140 feet for Douglas-fir and slightly less for western hemlock. This is not the case in the northern forest of Alaska where site indices over 100 feet are relatively rare.

To make a realistic silvicultural decision does not require great precision in the data. A ball park figure is often more than "adequate. How much will precise estimates of site index help us today in interior and southcentral Alaska to practice better silviculture when minimal silviculture is the best that is being practiced?

The research point-of-view presents a totally different picture. Understanding how ecosystems function may require far more precise data and a way to assess what and how soil variables affect productivity. Quantification of ecosystem controls and processes requires good soil-site correlation equations. There are considerable gaps in our knowledge about site quality, and soil-site correlation equations will help up to better understand the ecosystems we are trying to manage.

The two most serious problems that we face in developing realistic and meaningful soil-site correlation equations in the northern forest region of Alaska are: 1) the inadequacies of the site index curves and associated yield information and 2) the difficulty in ensuring that the range of site variation is adequately sampled. The first of these was partially addressed earlier in this paper. The second can be addressed by considering the magnitude of the forested region of interior and southcentral Alaska and the nature of the stands and sites within the region. By limiting the area, results have limited application; but, the study is now practicable. Payandeh (1986) did this for two relatively small areas in northern Ontario in his search for the soil factors most strongly influencing site quality for black spruce on peatlands and spruce-fir; in the latter stands the site index range was approximately 15 feet.

The narrow range of site indices suggests relatively uniform environments. Carmean (1975) comments, "Some of the more successful soil-site studies have been made in study areas where the site index (50-year index age) may range 40 to 50 feet. In contrast, less success occurs where the total range of site index is perhaps only 20 to 25 feet." In interior and southcentral Alaska, the range of site conditions suitable for growing economically viable stands is quite narrow for a species and controlling factors appear "to be more often related to soil temperature than drainage (there are exceptions, but they are obvious).

Payandeh (1986) used multiple linear regression analysis and dummy variables to predict site index. For the spruce-fir forest type, five site factors and lesser vegetation combined accounted for only 22 percent of the variability in site index. Soil moisture regime and iron concentration accounted for an additional 2 percent of the variability in site index. Soil moisture regime and iron concentration accounted for an additional 2 percent. For the black spruce on peatland, peat depth and lesser vegetation accounted for 12 percent of the total variability in site index; the inclusion of peat pH, nutrient concentration and percent moisture content accounted for an additional 5 percent of the variability. In both cases, considerably greater amounts of the variability were explained by height, age, and other tree characteristics.

Payandeh concludes:

> "Results indicate poor correlation between site index and soil factors and lesser vegetation. Consequently, predictive equations based on these variables are of limited use. Many climatic and environmental factors other than soil factors and vegetation affect site productivity and plant growth. In addition, relationships between. site productivity and soil factors and vegetation are far too complex

and highly variable to be expressed or explained by simplistic relationships. Therefore, soil factors chosen for 'prime site' identification, such as texture, stone content, moisture regime and depth, may be poor predictors of site quality."

This brings me back to my earlier statement: "Keep it simple." We have to avoid spurious correlations. Because things are associated or correlated does not mean a causal relationship. Dow Chemical scientists used a highly sophisticated stepwise multiple regression procedure and explained 99.9969 percent of the variability; to achieve this near perfect correlation after some trial runs, they replaced the real values for the variables with numbers randomly drawn from a hat (Jaffe and Spirer 1987). We must be careful not to respond to the latest mathematical tools and computer programs in search of the lurking variable(s). We must avoid "overfitting" the model and' thus creating partial relationships which may be nonsense.

However, I do not want to leave the impression that soil-site correlation equations won't work in the northern forest._ Hägglund and Lundmark (1977) developed soil-site correlation equations for Scots pine and Norway spruce in Sweden. They were extremely careful in selecting the sample stands; 80 percent of their data were discarded because of their stringent requirements. Their selected data set consisted of 3,117 plots on mineral soils and 268 plots on peatlands. Because of the low number of plots on the peatlands which created "special" problems, the equations were developed only for the mineral soil plots. Of the mineral soil plots, 1,624 were Scots pine and 1,493 were Norway spruce.

Hägglund and Lundmark (1977) state, "The accuracy of the prediction [of site index] with site properties is considerably lower then (sic) when using site index curves." Nevertheless, "where methods using properties of the existing stand cannot be applied," they believe their equations give a realistic estimate of site index. The multiple correlation coefficient of their equation for Scots pine is 0.70 and 0.82 for Norway spruce.

AN ALTERNATIVE

An alternative to soil-site equations is to relate site quality to the soil unit. Such an approach is presented by Edmons et al_ (1986) for soils in southwestern Virginia and is closely tied to soil classification and survey procedures. This may not be as esoteric as the latest mathematical tools and computer programs and may require considerably more effort; but the end results may be a more practical tool for the northern forests of Alaska. Not only can site quality be correlated with the soil unit, but appropriate silvicultural prescriptions and the potential response to treatments can be identified as well. This type of information *ill benefit the operational forester immediately and will be used.

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TECHNICAL ASPECTS
OF THE
WASHINGTON FOREST LAND GRADING PROGRAM

Lyn R. Townsend

ABSTRACT: The inherent forest productivity and behavior of soil mapping units on the private forest lands of Washington were determined during the Forest Land Grading Program (FLGP) from 1975-80. The authority for the FLGP was established by the state legislature for purposes of forest land taxation. Technical aspects of the program included premapping reconnaissance, field mapping using aerial photography and ground truthing, and soil sampling for later laboratory analysis and classification. Legal aspects of the program required more intenstive and uniform determination of forest site quality and operability than that collected in other soil surveys in the United States at that time

INTRODUCTION

The inherent productivity of a site for growing trees is of great importance to the land manager faced with investment responsibilities. Stocking control, fertilization, tree planting versus natural regeneration, brush control and other activities accelerate usable wood fiber growth. But, are all sites equal in the response the land manager can expect? Will one activity always be more lucrative than another? Could some sites experience a negative impact? Are trafficability and road building costs the same for sites that appear surficially the same? These questions and others establish the need for a way to assess sites that can be relied on to predict growth as well as other important site responses.

One way to consistently assess sites is a forest soil survey. In recent years, this method has been gaining recognition as the preferred method for site assessment and multiple-use interpretations. Modern forest soil surveying integrates geologic data, landscape or landform mapping, habitat typing, elevation-aspect-climate relationships, and, of course, the edaphic properties of sites into a scientific and uniform system of describing tracts of land on the earth's surface for interpretive purposes.

A case, in point, of the use of soil survey to make interpretations for forestry needs is the Forest Land Grading Program conducted in the State of Washington from 1975 to 1980. This large-scale effort served as a critical evalua-

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tion and, later, as a testimonial of the practicality and accuracy of soil surveying.

PURPOSE AND AUTHORITY FOR THE FOREST LAND GRADING PROGRAM

The basic purpose of the FLGP was to fulfill the requirements specified in Washington's House Bill Number 1184, Section 4:

> " The department of natural resources, in consultation with the Department of Revenue and other appropriate representatives of government agencies and landowners, shall design and implement a program to determine which privately owned land is forest land as defined by the Revised Code of Washington (RCW) 84.33.100 and as classified under chapter 84.28 RCW and to have such forest land graded by the department of natural resources in conformance with factors that may affect the nurture and continued production of forests at each site such as but not limited to species variability, characteristics of forest soils, climate variability, topography and access. The program shall include field work to obtain data which are necessary or useful in determining such grades and identifying which land is devoted to or suitable for growing and harvesting timber. "

In other words, the state forestry agency, the Department of Natural Resources (DNR), was charged to "grade" forest land in terms of productivity and operability for purposes of tax assessment of such lands. The more productive a piece of ground and the easier it was to work it with equipment, the more the landowner paid in annual property taxes. Because soil surveying was the method of choice to carry out this ambitious statewide program on private forest lands, National Cooperative Soil Survey Standards called for other interpretations in addition to productivity and operability.

DEVELOPMENT OF A PROCEDURES HANDBOOK AND COMPATIBILITY WITH NATIONAL COOPERATIVE SOIL SURVEY STANDARDS

To gain consistency in a multi-discipline project that would ultimately accomplish the mapping and vegetative and physical analysis of over 15 million acres, certain procedures, references, etc. had to be defined. The FLGP Procedures Handbook (1978) was designed to achieve this and was completed about 2 years after the first acres had been "graded" and mapped. Why the time lag? At first, the procedures established by the U.S. Soil Conservation Service (SCS) concerning forest-soil correlation were thought to be comprehensive enough to preclude the need for more documentation (Forestry Staff 1980). But, as with most programs at an individual state level, unique situations and variations in interpreting instructions cropped up almost daily. SCS documentation had been adequate for modern soil surveying of forest land because of the cadre of SCS foresters and soil specialists that directed programs at regional, state and local levels. However, a more lasting set of written instructions was needed for this fast-paced major endeavor. The procedures were needed not only for uniformity, but later as an explanation of what was done. The result -- the Forest Land Grading Procedures Handbook by the State of Washington's Department of Natural Resources.

The handbook listed and explained the complete operational procedures that were unique to the data requirements of the FLGP. Interestingly, the National Cooperative Soil Survey (NCSS) documentation (Soil Survey Staff 1975, 1984) that covered primarily the mapping of soils (on any kind of land) was detailed enough to guide that aspect of the program. Thus, the procedures handbook was "a supplement to the Revised Soil Survey Manual", thereby insuring that National Cooperative Soil Survey standards would be met.

PREMAPPING ACTIVITIES, FIELD MAPPING, AND SAMPLING SOILS

Premapping

Premapping activities included obtaining and preparation of stereoscopic aerial photography, securing reference and background material (such as previous soil survey reports, geology maps, and vegetative and climatic data), scheduling and conducting an initial field reconnaissance, and designing soil mapping units. Although these activities are typical for any soil survey, designing soil map units would turn out to be one of the most crucial steps taken by DNR to meet their land grading responsibilities. Also, soil surveys published by Weyerhaeuser and Crown Zellerbach companies and others turned out to be very helpful where vast acreages of forest had been cut, and trees of measureable age were unavailable.

Field Mapping

The first step in field mapping was to develop a tentative mapping legend consisting of soil bodies that were observed and designed during premapping. Such soil bodies or units were predicted, to result in differing levels of productivity, operability or both. An initial field review conducted by higher level soil specialists and foresters would either group or subdivide units based on practicability in mapping and interpretation.

The day-to-day routine of field mapping consisted of:

1. Soil specialists (mappers) travelling all available access roads examining road cuts and hiking into undisturbed sites; or be transported to remote areas by helicopter.

2. Soil mappers and foresters working together to decide soil taxonomy family and series. differentia based on indicator forest vegetation.

3. Tentative soil unit delineations based on stereoscopic recognition on aerial photographs of macro-features such as sloper forest types, and landforms.

4. Final delineations of soil and complete identification on each "field sheet" (aerial photo) .

5. Written documentation of vegetation, physiccal attributes, forest operations and productivity of each map unit.

6. Training of new soil specialists that continuously joined the 10 field-based mapping parties.

Sampling Soils

A continuous process from beginning to end of a field survey is soil sampling. This had particular importance for complying with NCSS standards. During the program, a minimum of 2 quarts was needed for bulk samples, for tray display, correlation, and laboratory analysis. Collections were made from the entire geographic range within a project and among projects for a particular taxonomic unit. Standard USDA soils forms were used to document the samples and their in situ appearance and behavior. Various analyses were conducted in the laboratory, e.g.; percent base saturation and pH, liquid limits, characterization tests for spodic horizons, particle-size determination, Atterburg limits, plasticity index.

The main purpose of soil sampling was for accurate placement of a soil unit into Soil Taxonomy (Soil Survey Staff 1975), the classification used in the United States.

SOIL-FORESTRY PRODUCTIVITY MEASUREMENTS.

After soil map units had been designed, mapped and delineated on aerial photography, the potential productivity or site index of each unit was established. This was done by direct measure ments of trees rather than site-estimating equations based on soil-climatic variables. Deliberation by the FLGP Advisory Committee and supporting experts thought that direct measurements identified in the field and documented on field sheets were more defensible and easier to explain to landowners and the public.

Soil-Site Plot Identification

Soil-site plots were considered benchmarks on the landscape. The USDA "Wood-5" (Forestry Staff 1980) or the FLGP Forestry Field Data Sheets (Forest Land Grading Staff 1978) were used to record the legal description and on-the-ground directions should the plot be revisited. The location of the plot was also marked with a "T" for tree information on the emulsion side of the field sheet. If additional designations were requested by the landowner, they were so marked. Individual site trees were flagged or tagged by cards to assist in later quality control.

Species Selection

The selection of the appropriate species to measure productivity on a soil was based on documented observations as to its extent, and discussion between foresters, soil specialists and others. Further documentation was added if the soil map unit happened to be in a transitional location between species. Typically, in western Washington, Douglas-fir was selected as the indicator species in the lowlands; western hemlock in the coastal regions; and red alder for poorly drained soils. In eastern Washington, Douglas-fir was used for the intermediate elevations; ponderosa pine for lower elevations; and western larch for certain other areas.

Site and Yield Table Selection

At the outset, all available site and yield publications were analyzed for applicability to Washington conditions. Because several of the reference documents were multi-state based, e.g., McArdle's (1961) coastal Douglas-fir and Barnes I (1962) western hemlock 100-year curves local site curves and yield tables were used (Chambers 1978; King 1966; Wiley 1978). Existing documents for red alder (Worthington 1960), inland Douglas-fir (Meyer 1961),ponderosa pine (Meyer 1961) and western larch (Schmidt 1976) were used in lieu of anything available locally.

The procedure for measuring site index was essentially the same for all species:

1. An approximately 1/10- to 1/2-acre stand was located on contiguous soil pedons falling within the taxonomic range of the soil unit.

2. Ten or more trees with the largest diameter-at-breast-height (dbh) were observed for normal external growth indicators, i.e., no basal or bole scars, absence of large limbs ("wolf" trees) and double tops, full crowns, and, depending on the particular site table, a dominant or codominant structural position.

3. Five trees of the ten were selected for site measurement. Height, dbh to the nearest 1/10-inch, and age were determined for each tree. Age was determined by increment borings with at least two cores showing the actual pith.

4. Additional site data were collected including stand basal area which was used in eastern Washington to calibrate growth estimates of actual versus "normal" stands.

5. Average height and average age of trees from a single stand determined the site index for the specific location and soil unit.

Mapping units that were less than 2,000 acres in extent in a project area required at least one plot per 500 acres, and a minimum of 5 plots were needed for larger map units.

Statistical analysis of the plots for a soil unit consisted of computing the coefficient of variation (CV) and standard error of the mean (SEM) at one standard deviation. A CV of less than 8 percent indicated that measured soil pedons were reacting consistently, and further subdivision of the soil unit into phases was unwarranted. An SEM of less than 2.5 indicated that additional plots (above the required 5) were unnecessary. A maximum sample of 10 plots was set, however, if the SEM standard was not met. On soils lacking suitable stands for site index measurement, data from similar taxonomic units within the project area were used and then fully documented.

Once site index was established for a mapping unit, the corresponding mean annual increment (MAI) was computed (cubic feet/acre/year at age 50 for western Washington; age 100 for eastern Washington). Again, the MAI was adjusted by the percentage of measured basal area versus the "normal" basal area in published tables. MAI's were further grouped into 9 productivity classes to simplify the later task of land valuation for tax purposes.

Determination of Operability Classes

Four classes were established to "grade" the operability of each soil mapping unit:

Class 1 (Favorable) -- Includes mapping units consisting of stable soils that slope less than 30 percent, and forest operations do not significantly impact soil productivity and soil erosion. Forest operations, such as roading and logging, are carried out with minimal limitations.

Class 2" (Average) -- Mapping units that comprise this class include stable soils that slope less than 30 percent, but on which significant soil erosion, compaction, and displacement may occur as a result of forest operations.

Class 3 (Difficult) -- Includes units which have one or more of the following characteristics: (1) stable soils that slope between 30 and 65 percent; (2) units that slope between 0 and 65 percent, but display evidence that rapid mass movement may occur as a direct result of forest operations.

Class 4 (Extreme) -- All mapping units that slope more than 65 percent.

Individual members of survey crews and supporting, visiting specialists shared responsibility for uniform classification of all soil units into operability classes. Development of within-project criteria and correlation was the task of local specialists; between-project consistency was assigned to the state-level staff.

CORRELATION AND DISPLAY OF FOREST PRODUCTIVITY, OPERABILITY AND OTHER INTERPRETATIONS FOR A SOIL MAPPING UNIT'

What did all this field, office and laboratory work that spanned 5 years accomplish? The bottom line was a Productivity/Operability overlay (fig. 1) that graphically documented indicator species, site index, operability class, and acres for each mapping unit delineation. This was the basic document used by local tax assessors to begin the new tax system based on land "grades".

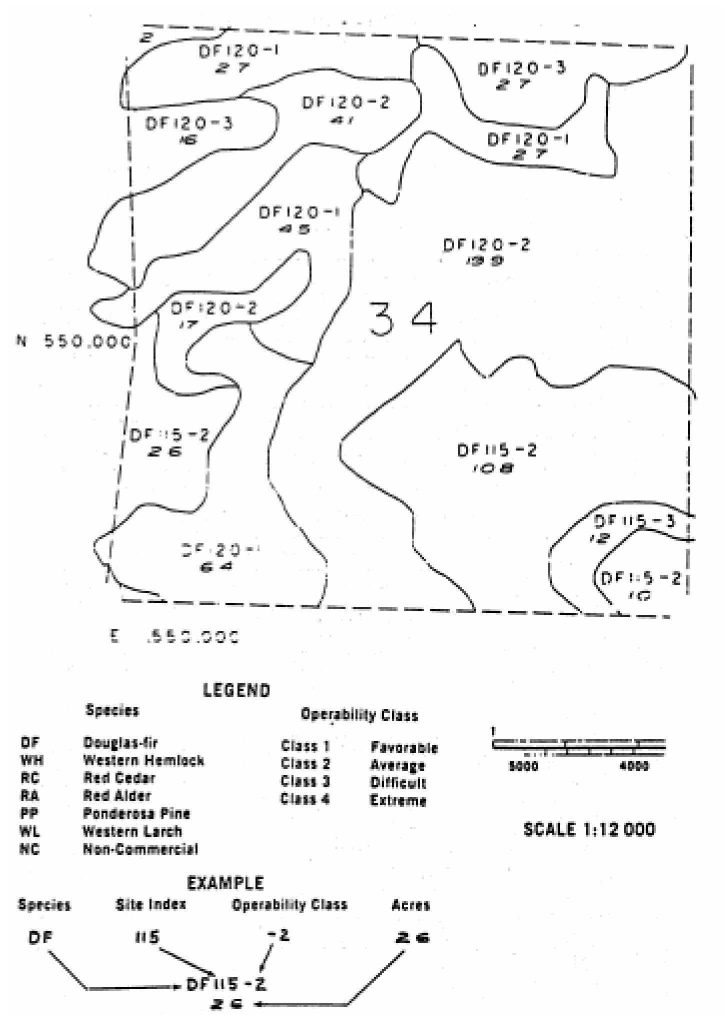
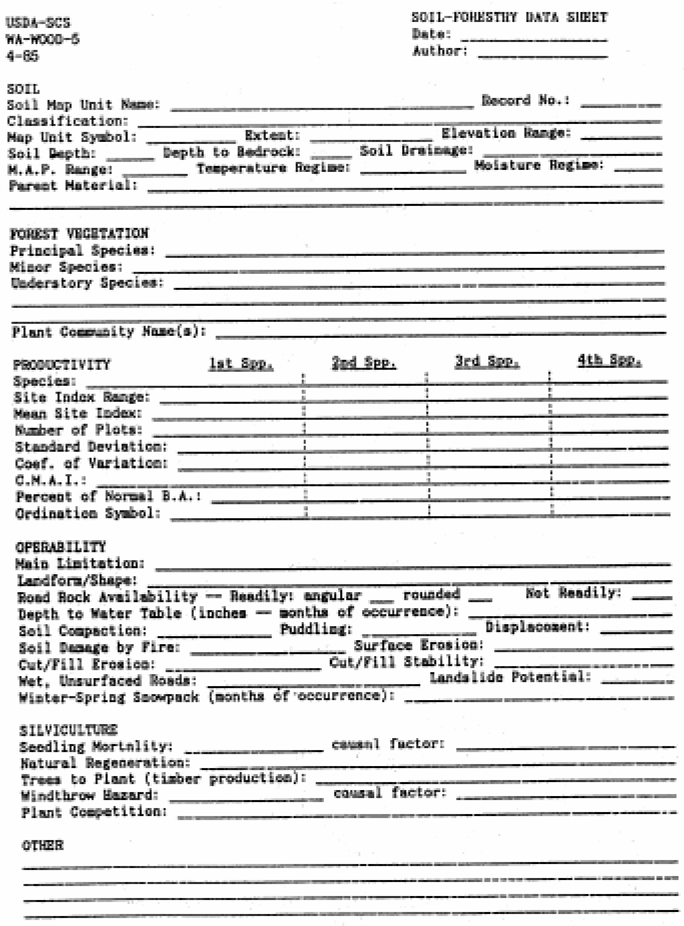


Figure 1.--The Forest Land Grading Program PRODUCTIVITY/OPERABILITY Overlay.

Four items on a map might seem a too-simple product of the numerous staff years and resources invested in the FLGP by DNR, SCS and associated organizations. The vast documentation, observations and knowledge amassed by the many specialists were a great wealth to land managers needing more detailed information on map unit behavior. Fortunately, near the end of the FLGP in 1980, some innovative approaches to packaging this information was pursued.

The SCS went through a series of report formats over a 3 to 4 year period for displaying soil properties and interpretations important to forest management. Of course, other interpretations for urban, agriculture, etc., were published in standard soil survey reports. These standard survey reports also contain some of the basic forestry information for general use. However, the more detailed approach to information display evolved into the SCS's Soil-Forestry Data Sheet (fig. 2). Data and interpretations for each soil map unit consist of soil features, forest vegetation, operability, silviculture and other items unique to that unit (Forestry Staff, 1982). The DNR was also experimenting with technology transfer for their foresters, and developed a very similar information display.


USDA-SCS
WA-WOOD-5
4-85

SOIL-FORESTRY DATA SHEET
Date:
Author:

SOIL
Soil Map Unit Name: Record No.:
Classification:
Map Unit Symbol: Extent: Elevation Range:
Soil Depth: Depth to Bedrock: Soil Drainage:
M.A.P. Range: Temperature Regime: Moisture Regime:
Parent Material:

FOREST VEGETATION
Principal Species:
Minor Species:
Understory Species:

Plant Community Name(s):

PRODUCTIVITY	1st Spp.	2nd Spp.	3rd Spp.	4th Spp.
Species:				
Site Index Range:				
Mean Site Index:				
Number of Plots:				
Standard Deviation:				
Coef. of Variation:				
C.M.A.I.:				
Percent of Normal B.A.:				
Ordination Symbol:				

OPERABILITY
Main Limitation:
Landform/Shape:
Road Rock Availability -- Readily: angular ___ rounded ___ Not Readily:
Depth to Water Table (inches -- months of occurrence):
Soil Compaction: Puddling: Displacement:
Soil Damage by Fire: Surface Erosion:
Cut/Fill Erosion: Cut/Fill Stability:
Wet, Unsurfaced Roads: Landslide Potential:
Winter-Spring Snowpack (months of occurrence):

SILVICULTURE
Seedling Mortality: causal factor:
Natural Regeneration:
Trees to Plant (timber production):
Windthrow Hazard: causal factor:
Plant Competition:

OTHER

Figure 2.--The Soil Conservation Service Soil-Forestry Data Sheet for information display.

QUALITY CONTROL

Quality control for both soil mapping and collecting forestry data were stringent and taken seriously by all in the FLGP. Not only did the Procedures Handbook spell out methods and intensities of quality control, but NCSS-SCS standards of long-standing dictated initial, progress and final reviews, correlations and corrective actions.

spot checking of forest site quality specifically required a remeasurement of 5 percent of the site index plots within a project area. Remeasurement plots were randomly selected. If any deficiencies were noted, corrective actions were immediately begun.

SUMMARY

The FLGP, with all of its excellent organization and program control, was essentially a series of concurrent NCSS soil surveys on forest land. The main differences that separated the FLGP experience with other soil survey efforts on forest land at the time were:

* A very specific product was identified by a major soil survey user group, i.e., the Washington State Legislature. This product guided the program.

* Detailed procedures concerning forest site determination and operability classes were formulated, with strict requirements and quality control on sampling intensities and map unit behavior documentation.

* Active integration of geologic data, landscape/landform information, and forest habitat typing into soil map unit design and interpretations.

* A soils-oriented federal agency and a forestry-oriented state agency joined forces; that resulted in an emphasis on soils mapping and accurate, quality forestry correlation and interpretation. (Note: Many other federal, state and private organizations participated at a lesser level in the FLGP.)

The technical aspects of the FLGP offer some excellent and important possibilities for other regions needing to know more about the inherent productivity of their forest land, and how a tract of land will behave before they harvest or improve it. Indeed, the benefits of some of the FLGP techniques are already being felt in southeast Alaska. (Lalich, 1984).

As the inventory and demand for the vast aboveground, renewable, natural resources of Alaska develops, consideration of the foundation... the soil, becomes more and more important.

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SITE QUALITY, FOREST GROWTH, AND SOIL-SITE STUDIES IN THE FORESTS OF COASTAL ALASKA

Wilbur A. Farr and Earl W. Ford

ABSTRACT: Cooperative studies in coastal Alaska designed to obtain Information on site quality, forest growth, and soil-site relationships are described.

INTRODUCTION

Several studies are underway, especially in southeast Alaska, to estimate productivity of forest lands and to develop predictive measures ,of future stand development given a variety of management strategies. These studies are designed to develop height growth and site index equations, evaluate the effects of thinning on stand development, and determine relations between site index and soil properties. Soil-site relations are especially needed because over 92 percent of the commercial forest land in coastal Alaska is occupied by stands of old-growth timber. Current estimates of future productivity for these lands are limited and untested.

This paper describes some of the studies and the progress that has been made on them.

THE COASTAL FORESTS

The forests of coastal Alaska are part of the temperate western hemlock (Tsuga heterophylla (Raf.) Sarg.)-Sitka spruce (Picea sitchensis (Bong. (Carr.) rain forest that extends along the Pacific coast from near Coos Bay, Oregon, north and west to the Alaska Peninsula, a distance of about 1,800 miles. Compared to most of the vast interior of Alaska, the southern coast is cooler in summer, warmer in winter, and has more precipitation (Farr and Hard 1987). Climate is relatively uniform especially near sea level and changes in mean site productivity with latitude are predictable for the type as a whole. Site index of Sitka spruce decreases northward at the rate of about 2.6 feet per degree of latitude (Farr and Harris 1979).

The most extensive stands of western hemlock and Sitka spruce occur in southeast Alaska where the type occupies about 11.2 million acres, about 6.6 million acres of which is classified as commercial forest land. In Alaska, the type generally consists of virgin stands of western hemlock and Sitka spruce with small percentages of western redcedar (Thuja plicata Donn ex D. Don) and Alaska cedar (Chamaecyparis nootkatensis) (D. Don) Spach). About 400,000 acres of commercial forest land have been harvested in southeast Alaska since 1900, and 10,000-17,000 acres are now harvested annually. All logging is by clearcutting.

Although mean site index decreases with latitude, many environmental factors contribute to local site differences, including soil parent material, soil development, nutrient status, drainage, precipitation, slope, aspect, and elevation. Some soils are very youthful, only recently exposed by glacial retreat; others are 5,000-10,000 years old. Compared to most areas of the world, the soils of coastal Alaska are youthful, and productivity is highly variable within and between stands.

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SITE QUALITY

Site index is the unit of measure used to assess site quality of the coastal forests. It is based on the height of the taller trees in a stand at stand age 50 to 100 years. Until recently, Taylor's (1934) proportional site index curves for hemlock and spruce were used. They were based on mean height of dominant and codominant trees at stand age 100 years. Similar curves developed by Meyer (1937) and Barnes (1962) were also used for the hemlock-spruce forest type as a whole. All are proportional curves, developed from a central guide curve. More recent curves are polymorphic, developed from measurements from felled trees.

Newer site index and height growth equations were prepared for western hemlock in Oregon and Washington (Wiley 1978) and for hemlock and spruce in southeast Alaska (Farr 1984). Cooperative efforts with the State of Alaska have also resulted in provisional site index and height growth curves for hemlock and spruce on the Haines State Forest[1], and for Sitka spruce on the proposed Yakataga State Forest.[2] Stem analysis data from Sitka spruce have also been collected from even-aged, stands in Prince William Sound,[3] and relationships have been developed between site index and latitude and temperature for the hemlock-spruce forest type (Farr and Harris 1979, 1983).

All newer site index and height growth equations for coastal Alaska were developed from data, collected below 300 feet in elevation. This was not intentional, but resulted from a general lack of suitable even-aged stands at higher elevations. Although relatively little, is known about site productivity of hemlock and spruce at upper elevations, an increasing percentage of the harvest is taking place there and efforts to collect stem-analysis data at higher elevations will continue over the next several years as suitable even-aged stands are located.

[1] Wilbur A. Farr. Provisional site index and height growth curves for unmanaged stands of western hemlock and Sitka spruce on the Haines State Forest at Haines, Alaska. On file, Forestry Sciences Laboratory, Juneau, AK, 36 p.; 1985.

[2] Wilbur A. Farr. Provisional site index and height growth curves for unmanaged stands of western hemlock and Sitka spruce on the proposed Yakutaga State Forest at Icy Bay, Alaska. On file, Forestry Science_ Laboratory, Juneau, AK, 27 p.; 1985.

[3] Thomas J. Sheehy and Wilbur A. Farr. A cooperative study. The development of soils-site information for the Chugach National Forest. Study plan on file at Forestry Sciences Laboratory, Juneau, AK, 7 p.; 1975.

Little is also known about the growth rates of western redcedar and Alaska cedar in coastal Alaska or elsewhere in their natural range along the north Pacific coast. A current study to develop taper equations for the cedars in southeast Alaska may provide some information on comparative growth rates of these species.[4]

Hemlock and spruce are usually found in mixed stands in coastal Alaska, although pure stands of spruce do occur on highly disturbed sites and in valley bottoms. Extensive pure stands of Sitka spruce are also found on Afognak, Shuyak, and Kodiak Islands. Pure, or nearly pure, stands of hemlock often become established on poor sites or where abundant regeneration is present at the time the overstory is removed or destroyed.

When Taylor (1934) sampled even-aged stands in southeast Alaska in the late 1920's and early 1930's, he generally found a mixture of hemlock, spruce, and, in the southern areas of the forest, western redcedar. Rarely did he find pure stands. His analysis of height-diameter curves for the species led him to believe that site index should be based on mean height of both hemlock and spruce. On his plots, he estimated mean height of dominant and codominant trees of each species, then averaged the mean height of each species to estimate mean stand height. More recently, Farr (1984) found that mean breast-high age of hemlock in even-aged stands averages about 5 years older than mean breast-high age of spruce. Seldom are ages the same for both species because most dominant hemlock are from advanced regeneration. Shape of the site index curves also differs for the two species, especially for lower site classes beyond age 50 years. For these reasons, new site index and height growth curves were developed for each species, and we recommend that site index of each species be separately estimated.

In even-aged stands, site index of Sitka spruce is usually. higher than for western hemlock, especially on the higher sites. This difference may mean that land managers will want to favor spruce on the higher sites to maximize yields. Much additional work will be needed, however, to study how various mixtures of hemlock, spruce, and cedar affect stand development, yields, and estimates of future economic returns over the full range of sites.

COOPERATIVE STAND-DENSITY STUDY

Regeneration after clearcutting is excellent on all but a few sites in coastal Alaska and, once established, growth rates of hemlock and spruce are relatively high. New stands contain several thousand stems per acre, and crown closure begins to take place by age 15 to 20 years. Crown

[4] DeMars, Donald M. Volume equations for old-growth western redcedar and Alaska cedar in southeast Alaska. Study plan on file at Forestry Sciences Laboratory, Juneau, AK., 8 p.; 1984.

closure approaches 100 percent by 25 to 30 years of age and remains so for 100 years or more.

In the mid-1970's, a long-term cooperative study was started to measure the effects of stand density on growth and development of even-aged stands of hemlock and spruce in southeast Alaska.[5] Since then, 278 1-acre plots have been installed on Federal, State, and private lands in southeast Alaska, and more are being added each year. Plots range in age from 10 to 100 years and include sites commonly found on productive forest land (table 1). The objectives are to study the long-term effects of combinations of species and densities on stand development and growth. Results are being used to develop managed-stand simulators, and they will also provide managers with a range of intensive management options for even-aged stands.

The stand-density plots are remeasured at 2-year intervals_to obtain detailed growth and mortality data. Computer data bases and programs are used to store and process the remeasurement data. Recently, we have been using this permanent-plot data base to develop growth coefficients for SEAPROG, a southeast Alaska variant of PROGNOSIS (Wykoff and others 1982, Stage 1973). SEAPROG is a detailed, individual-tree, distance-independent growth model; a test version is now available at the Federal computer center at Ft. Collins, Colorado.

Future work will include a detailed analysis of the permanent-plot data base and of its shortcomings, and installation of more plots covering sites, ages, soil types, and plant associations not now represented. Data from stands growing on poor sites are especially lacking because stands of old-growth timber are seldom harvested on lands of poor site quality. Most plots are located on high site lands (table 1).

Plots representing a wider range of densities after thinning are also being installed. Precommercial spacings were at 8, 12, and 16 feet. Recently we included 20-foot spacings and, in one case, spacings up to 27 feet.

[5] Wilbur A. Farr. The effects of stand density upon growth and yield of hemlock-spruce stands in coastal Alaska. Revised study plan. Study on file, Forestry Sciences Laboratory, Juneau, AK, 24 p.; 1976.

Table 1--Distribution of stand-density plots by site index of Sitka spruce and age, southeast Alaska

Age at breast height	Site index (50 years)			
	<61	61-75	76-90	>91
Years	- - - - - - - -	Feet	- - - - - - - -	
1- 20	3	9	59	81
21- 40	3		15	43
41- 60	6	3	18	28
61- 80		1		1
81-100	5	2	1	

COOPERATIVE SOIL-SITE STUDY

In 1980, the Forest Service expanded its site-quality research in coastal Alaska to include a cooperative soil-site index study.[6]

Objectives of the soil-site study are to determine if meaningful soil-site relationships can be determined for the major soil types represented on commercial forest land in southeast Alaska and to develop estimates of mean site index and variance for each soil series, family, or group of soil series.

Collection of data for this study has been underway for several years, and is continuing. Soil profile descriptions and horizon samples have been collected by Forest Service soil scientists from representative pedons on most site quality and stand-density plots in coastal Alaska. The process has been slow, accomplished along with other duties, mostly as time is available.

A single pedon was described and sampled on each site-index plot or group of stand-density plots, unless the plots contained more than one distinct soil series. If more than one soil series occurred on a plot or group of plots, a map was drawn showing the location of series boundaries, and a pit was dug to represent each series.

Most physical properties of each pedon were determined in the field, including soil drainage, soil depth, slope, aspect, and elevation. Chemical and mechanical analyses were performed at approved laboratories. At the beginning of the study in 1978, a few of the soil samples were sent to Oregon State University for analysis. Between 1980 and 1984, samples were sent to the Univerisity of Idaho for analysis; since 1984, samples have been analyzed at the USDA laboratory at Lincoln, Nebraska.

[6] Earl W. Ford, Wilbur A. Farr, and Roy Sidle. Development of productivity ratings for stands of old-growth western hemlock and Sitka spruce in southeastern Alaska based on soil-site factors. Study plan on file, Forestry Science Laboratory, Juneau, AK, 12 p.; 1983.

Data for each pedon are stored in the Federal computer center in Ft. Collins, Colorado. The data base is still far from complete, and much error checking still needs to be done.

Analysis

Analysis of the soil-site data base will take time; even then, _t will only serve as a beginning to our understanding of how well physical and chemical soil properties are correlated with forest productivity in the coastal forests. A total of 291 pedons have been sampled so far--113 on site-index plots and 178 on stand-density plots (table 2). Number of plots decreases with increasing latitude, consistent with the cutting history. Several soil orders, series, and drainage classes are represented (tables 3 and 4), and some plots have more than one soil. Many pedons have been classified only to family because they have not been classified to series. Requirements are that at least 10 representative pedons of a potential series must be described and at least 2000 acres of the type must be identified before a potential series can be officially classified to series.

Spodosols are well represented; relatively few entisols, inceptisols, and histosols have been sampled (table 3). Most samples come from well-drained or moderately well-drained soils. Relatively few pedons were sampled on poorly drained soils (table 4), which may prove to be a weakness of the data in later analyses

The entire data base will soon be compiled, edited, and ready for analysis. Analysis will include identification of subsets of variables for correlation and regression analysis, groups of soil variables thought to represent functional relationships with site index, and key variables to look at in more detail in future studies. Correlation and regression analyses will be performed to help identify soil variables, singularly and in combination, that can be used to predict site index. Preliminary field studies will also be conducted this summer to measure soil variability and extent of Bh development on a stand basis for a subset of site-index and stand-density plots.

Another goal is to provide reliable estimates of mean site index for each of the important soil series or groups of series found on commercial forest land in southeast Alaska. This will require considerable additional sampling because about 50 soil series have been identified on commercial forest land and only 25 series have been sampled on the site-index and stand-density plots, in many cases only once or twice.

Soil scientists in the region have made estimates of mean site index for each series; some are given in table 5. The estimates are clearly not uniform from area to area, however, probably because of insufficient data. Improving on most of these estimates will be difficult until much more data are collected.

Table 2--Distribution of plots by area and study, coastal Alaska

Area	Study: Site index	Study: Stand density
	- - - Number - - -	
Prince William Sound	25	
Chatham	30	34
Stikine	15	103
Ketchikan	43	141
	113	278

In a preliminary analysis of a portion of the data base, we looked at relations of site index of Sitka spruce to four soil variables commonly used to classify soils--soil depth, soil drainage class, organic carbon content, and coarse fragment content (Ford and Farr, in this volume). Data from 116 plots, for which complete data were available, were used. Results of the analysis differed from those of Stephens and others (1968), in that in our analysis site index was not correlated with soil depth and drainage. We found site index to be highly variable and significantly correlated only with coarse fragment content. More information is needed to adequately test for soil drainage. The analysis suggested that considerably more analyses will be needed, plus the collection of additional field data before reliable soil-site relationships are fully understood.

CONCLUSIONS

Studies are underway in coastal Alaska that will eventually provide land managers with some tools necessary to reliably estimate future productivity and yields from managed even-aged stands of western hemlock and Sitka spruce. These are long-term studies requiring the installation of a large number of permanent and temporary plots covering a wide range of site, ages, species composition, and densities.

Studies that develop height growth and site index equations are also important as they provide the means for estimating site index and height growth of even-aged stands. Problems that concern estimation of future productivity of land currently occupied by stands of old-growth timber are equally important.

An understanding of soil properties in the coastal environment, of how these properties changes with time, and how they are related to the growth and development of even-aged stands is critical to future management of the coastal forests.

Table 3--Distribution of plots by area, soil order, and soil series, coastal Alaska

Area	Plots	Soil order: Entisols	Spodosols	Inceptisols	Histosols	Soil series
	Number	Percentage				Number
Prince William Sound	25	21	21	50	7	UNNAMED
Chatham	64	4	79	6	10	13
Stikine	118	0	63	2	11	13
Ketchikan	184	1	81	7	12	18

Approximate number of soil series on commercial forest land in southeast Alaska = 50

Number of soils sampled = 25

Table 4--Percentage of plots by area and drainage class, coastal Alaska[1/]

Area	Drainage class: EWD	WD	MWD	SPD	PD	VPD
	Percent					
Prince William Sound	1	63	13	13	6	
Chatham		35	38	21	4	2
Stikine		79	7	5	7	
Ketchikan		85	7	1	6	1

1/ EWD = excessively well drained; WD = well drained; MWD = moderately well drained; SPD = somewhat poorly drained; PD = poorly drained; VPD = very poorly drained.

Table 5--Provisional estimates of site index of Sitka spruce by area for selected soils in southeast Alaska

Soil group	Soil series	Area: Chatham	Stikine	Ketchikan
		Site index, 50 years		
	SPODOSOLS			
Humic Cryorthods	Karta	100	100	100
Humic Cryorthods	Kupreanof	100	100	100
Humic Lithic Cryorthods	Mosman	80		55
Humic Lithic Cryorthods	Tolstoi	95	100	100
Typic Cryaquods	Wadleigh	60	80	80
Lithic Cryaquods	St. Nicholas	60	80	80
Sideric Cryaquods	Sloduc	55	80	
	HISTOSOLS			
Typic Cryofolists	Annahootz	100		
Lithic Cryofolists	McGilvery	80	60	65
Lithic Cryosaprists	Kaikli	55	50	60
Terric Cryosaprists	Maybeso	55	50	50
	INCEPTISOLS			
Histic Cryaquepts	Hofstad	60		80
	ENTISOLS			
Typic Cryofluvents	Tonowek	100	100	100

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MORPHOLOGY AND CLASSIFICATION OF SELECTED SOUTHEAST ALASKA FORESTED SOILS

W. David Loggy

ABSTRACT: The morphology and classification of forested soils on the Tongass National Forest are being accomplished through a National Cooperative Soil Survey.

INTRODUCTION

The soils of the forest of Southeast Alaska are being inventoried by the Tongass National Forest as a cooperating federal agency of the National Cooperative Soil Survey (NCSS). The initial soil survey work on the Ketchikan Management Area of the Tongass National Forest began in 1961. There was a brief interlude starting in 1970 and soil survey was started again in 1978 on the remaining unsurveyed forest land. Except for Wilderness areas, the soil survey will be completed on the land base of the Ketchikan Management Area in September of 1987.

Soil survey information on soil morphological, physical, and chemical properties, and soil spatial distribution is needed to determine soil suitabilities for forest planning, management area analysis, project planning and initiating, and monitoring. The soil survey efforts in all the management areas of the Tongass National Forest are providing this information. The characteristics of some of the typical forest soils of the Ketchikan Soil Survey Area are presented here.

KUPREANOF SERIES

- Loamy skeletal, mixed Humic Cryorthod

- 0 horizons	5 to 13 cm. thick.
- E horizon	0 to 13 cm. thick.
- Bhs horizons	13 to 100 cm. thick.

- Gravelly silt loam surface texture. 35 to 50 percent' gravel in the particle size control section.

- Less than 15 percent base saturation.

- Formed from colluvium materials on mountain-slopes.

- Site index 150 - 100 year base.

- Greater than 40,000 hectares.

TOLSTOI SERIES

- Loamy-skeletal, mixed humic Lithic Cryorthod.

- 0 horizons	10 to 20 cm. thick.
- E horizon	1 to 5 cm. thick.
- Bhs horizons	33 to 38 cm. thick.

- Very fine sandy loam surface textures.
- 35 to 80 percent gravel in the particle size control section.

- Less than 5 percent base saturation.

- Formed from colluvium on mountainslopes.

- Site index 150 - 100 year base.

- Greater than 40,000 hectares.

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WADLEIGH SERIES

- Loamy-skeletal, mixed Typic Cryaquod.

- 0 horizons 10 to 25 cm. thick.
- E horizon 0 to 10 cm. thick.
- Bhs horizons 18 to 70 cm. thick.
- Over compact glacial till.

- Very gravelly silt loam surface texture. 30 to 70 percent gravel in the particle size control section.
- Less than 15 percent base saturation.

  Formed from till on moraines, drumlins, mountainslopes and hillslopes.

- Site index 120 - 100 year base.

- Greater than 40,000 hectares.

MCGILVERY SERIES

- Dysic Lithic Cryofolist

- 0 horizons 28 to 50 cm. thick.
- 2c horizons 0 to 10 cm. thick.

- Typically fibric with less than 20 percent mineral content.

- Sodium pyrophosphate color 10YR 8/3.

- Formed from conifer litter on mountainslopes.

- Site index of 90 - 100 year base.

- Greater than 40,000 hectares.

MAYBESO SERIES

- Loamy-skeletal, mixed, Euic Terric Cryosaprist.

- 0 horizons 53 to 102 cm. thick.
- Over compact glacial till.

- 40 to 80 percent gravel in the till.

- Sodium pyrophosphate color 10YR 4/3.

- Occurs on footslopes and toeslopes of valley sides.

  Site index 70 - 100 year base.

- Greater than 40,000 Hectares.

KINA SERIES

- Dysic Lithic Cryohemist.

- 0 horizon 152 cm. thick.

- Sodium pyrophosphate color 10YR 7/3.

- Between drumlins and on valley floors and benches of mountainslopes.

- Supports non-forested "muskeg" vegetation.

- Greater than 40,000 hectares.

STRATEGY AND TACTICS FOR MONITORING LONG-TERM SITE PRODUCTIVITY

Richard E. Miller and John W. Hazard

ABSTRACT: Monitoring is required of all Federal agencies. We discuss concepts for monitoring the capacity of forest sites to produce wood in this and future generations. The general plan for monitoring long-term site productivity should integrate all levels of sampling productivity and other types of monitoring or surveys. An integrated plan should satisfy numerous monitoring objectives at least cost.

INTRODUCTION

Monitoring is required of all federal agencies by regulations developed after passage of the National Environmental Policy Act of 1969 (NEPA). This monitoring by Federal agencies is to determine if their stated objectives, requirements, and standards are being achieved. For example, the 1976 National Forest Management Act (NFMA; P.L. 94-586) directs the U.S.D.A. Forest Service to provide goods and services, and to maintain other values, such as quality of water and soil and diversity of wildlife and plants.

A specified objective of NFMA is to maintain and improve the capacity of forest sites to produce wood products in consistent and sustained amounts. To monitor the attainment of this key objective, the Forest Service must be able to quantify how stands of trees are responding to forest practices in this and in future centuries. We believe that designing and implementing reliable, cost-effective monitoring systems to do this monitoring will require extraordinary effort. Effective monitoring involves statistical sampling and thus requires a sampling plan; without a formal and technically valid plan, no assurance can be given that monitoring objectives will be attained.

In this presentation, we describe types of monitoring that are currently being considered by the Forest Service, discuss some advantages and disadvantages of measuring tree growth as direct evidence of the effects of forestry practices on site productivity compared to measuring change in soil or other site factors as indirect evidence, and suggest some necessary items in the design of cost-effective monitoring systems.

MONITORING AND FOREST PLANS

The word "monitor" is derived from the Latin verb monere, to warn. Monitor can be accomplished by observing, detecting, or recording an operation or condition. On National Forests, monitoring is a means of measuring management outputs and effects; thus, monitoring provides the basis for evaluating management practices relative to acceptable environmental standards and production goals (Fig. 1).

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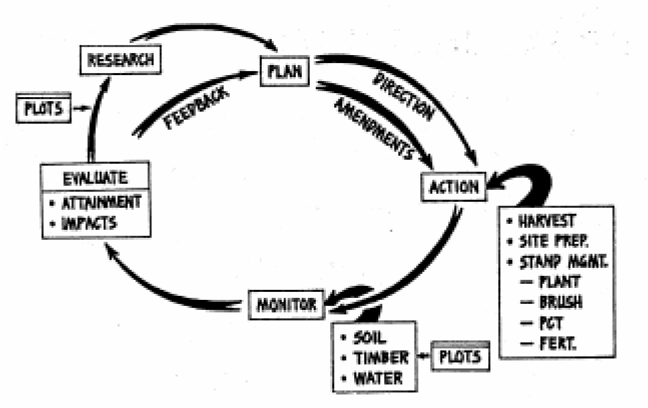

Figure 1.--Monitoring and evaluation in the Forest Plan as perceived from the National Forest Management Act (1976)

Research needs identified during monitoring and evaluation must be considered in formulating research programs and plans.[1/] Repeated cycles of this monitoring-evaluation-feedback process are intended to provide accountability and continuous improvement of methods and performance in the National Forests so that national and regional objectives and requirements are achieved (Table 1).

Several types of monitoring are being considered by the Forest Service; these include monitoring for implementation, effectiveness, and validation (Table 1). Implementation monitoring will quantify the amount of work actually accomplished so that it can be compared with the amount of work planned. Examples include the number of acres treated or wood volumes harvested. Effectiveness monitoring attempts to quantify the effects or the results of projects or activities. For example, was the timber harvest accomplished without exceeding the acceptable standards for water quality or, soil disturbance or what were the gains in growth of fertilized or thinned stands? Validation monitoring provides a check on current standards or predictions. Examples include:, are our current standards for acceptable soil loss or soil compaction sufficient to maintain the inherent capacity of the soil to produce wood or forage? Are the current standards for suspended sediments or stream temperature adequate to maintain fish populations?, Are current

Table 1--The Federal hierarchy and monitoring[1/]

Level	Action (example)
National:	Set goals, policies, and regulations
Congress; Exec., W.O.	(Prevent substantial and permanent impairment of land productivity.)
Regional:	
Regional Office National Forest (BLM State Office) (BLM District)	Define objectives, standards and guidelines, and minimum requirements (Keep erosion within soil T-factors to maintain soil productivity.)
Local:	
Ranger District	Meet the above directives when conducting projects or activities
(BLM Area)	Monitor project <u>implementation</u> (Was work accomplished as planned?) Monitor project <u>effectiveness</u> (Was erosion rate within T-factors?) Monitor <u>validity of standards</u> (Are T-factors sufficient to maintain productivity?) Monitor <u>validity of predictions</u> (Are current predictions of forest growth valid?)

1/ Adapted from: Unpublished Administrative Report, 1986, "Monitoring Framework to Meet FLMP Requirements", authors unspecified. U.S. Department of Agriculture, Forest Service, Watershed and Air Management, P.O. Box 2417, Washington, DC 20013.

1/ Federal Register, Vol. 47 (No. 190, 9-30-1982) National Forest System Land and, Resource Management Planning. Department of Agriculture, Forest Services. 36 CFR Part 219. Paragraph 219.28.

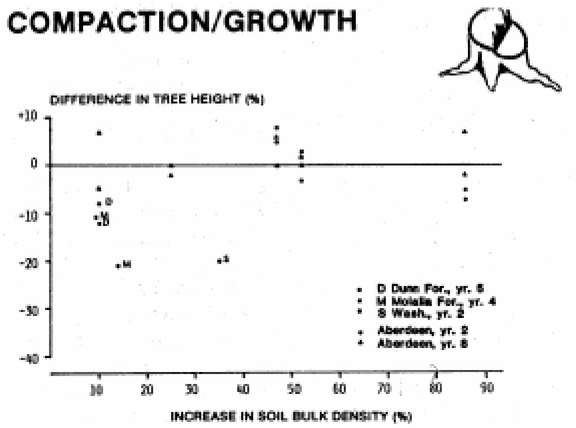

Figure 2 - Differences in height of Douglas-fir hemlock seedlings on compacted skidroads and harvested-only portions of clear-cut areas is western Washington and Oregon.

predictions of yield gains from genetic improvement or silvicultural practices supported by growth of local stands? If properly planned and implemented, these three general types of monitoring should provide short-term an_ long-term information to alert the Forest Service about the current and future capacity of forest sites to produce wood and to maintain soil and water quality.

WHAT TO MEASURE

To know the effects of timber harvest and forestry practices on long-term wood, production (sustained site productivity), we must measure tree growth and volume yields on a sample of permanent plots at sites that have been subjected to harvest and various practices. In the absence of this direct evidence, we are forced to substitute indirect evidence, for example by measuring effects of harvest or forestry practices on soil properties, such as the amount of exposed, eroded, displaced, or compacted soil. Although using soil properties as standards provides a first approximation for guiding current operations, we need to check the validity of these standards. Generalizations such as soil compaction reduces tree growth," may not always apply. Figure 2 shows that sapling growth on compacted skid trails was equal to growth on, adjacent, non-compacted areas at three clearcuts near Aberdeen, WA.[2/] These regional investigations show that compaction decreased height growth at' some but not all locations. The effect of slash burning on stand volume growth in the Douglas-fir region also varies among study locations (Fig. 3).[2/]

In short, the effects of a given forest practice on tree growth (site productivity) may differ

[2/] Unpublished data on file at the Forestry Sciences Lab, Olympia, WA.

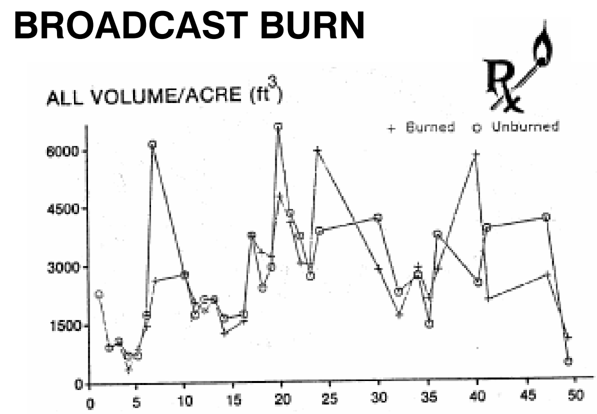

Figure 3.--Cumulative volume yields of Douglas-fir and associated species in 34- to 39-year-old stands on adjacent burned and unburned areas at *30* locations in the Cascade Range of western Washington and Oregon.

among sites and among operators, and depend on when the effect is measured. These sources of variation mean that the consequences of forest practices cannot be reliably generalized, management prescriptions must fit the local situation, and long-term, tree growth information is needed to set standards and to validate assumed standards based on initial effect on soil properties. This validation process will also increase our understanding of causes and effects.

Clearly, forest yields must be monitored over the long term, so we can interpret the significance of short-term gains or losses that we observe in seedling or sapling growth. , May we assume, for example, that a 25% decrease in seedling height will be retained in the current or in future rotations? If not, how do we justify expenditures to avoid or to correct assumed negative effects of harvesting activities?

We shall continue to operate with uncertainty or skepticism until we establish and maintain plots at selected locations to document long-term effects of forest practices and region-wide environmental changes. We should recognize, however, that permanent plots are a major, long-term commitment of resources--of time, people, and funding. Therefore, permanent plots should be established only as part of a carefully planned process. Finally, technical controls will be needed to ensure adequate planning, review, and adherence to procedural standards.[3/]

[3/]Unpublished Administrative Report, 1986, Report of Task Force on Permanent Plot Standards," by Robert O. Curtis, Leader, and other Task Force Members. U. S. Department of Agriculture, Forest. Service, Forestry Sciences Laboratory, 3625 - 93rd Avenue S. W., Olympia, WA 98502."

DESIGNING A COST-EFFECTIVE, QUANTITATIVE MONITORING PLAN

A valid, cost-effective monitoring plan will assure that the monitoring will generate the required information with specified reliability and at minimum cost; designing such a plan, however, can be complex and costly. In the following sections of our paper, we discuss some necessary items in the design of cost-effective monitoring plans that will provide reliable, quantitative data.

Step 1: Define the Objectives

Defining objectives is the first step in developing a monitoring plan; the following must be specified:

- Information requirements;
- Uses to be made of results;
- Scopes of inference (defining populations);
- Estimates required to satisfy needed information;
- Precision requirements; and
- Cost and other physical constraints.

These objectives are the foundation of monitoring designs. All objectives may not be answered by a single design. If more than one design is .required, the individual designs should be compatible and integrated into the general monitoring plan. This integration ensures that all objectives are met at least cost. Monitoring activities can also be coordinated with other management surveys that relate to forest productivity. For example, regeneration surveys, managed-stand surveys, and soil vegetation, insect, or disease surveys may be incorporated into the general monitoring plan to reduce total cost further and to expand the data base for evaluation.

<u>Information requirements, uses, and scope</u>.--<u>A</u> monitoring system involves many items of information at various levels of reliability and resolution (specific through general). The information needs should be organized within scopes of inference and uses of results (Table 1). For example, information may be needed to:

- Check implementation of a Forest Plan;
- Quantify the effectiveness of a practice to meet standards or expectations; or
- Validate or calibrate current predictions or standards.

The scope of inference defines the geographic or descriptive boundaries within which sampling (monitoring) will be controlled and within which the inferences of the data analysis will apply. For example, sampling and inferences could be restricted geographically to a specific clearcut, watershed, District, or Forest. Alternatively, the scope could be based on descriptive strata such as forest type, geological or soil strata, or plant association. A well-defined scope (population) assures that the sample can be properly drawn and can possess the desired statistical properties for valid inferences.

Administrative scopes of inference may be Ranger Districts, Forests, or Regions; sampling units would be drawn from the specified population or scope. Sampling for a District-wide inference about some activity has a more narrow scope than sampling for a Forest-wide inference related to the Forest Plan. Regional scopes of inference are appropriate for validating regional standards and predictions. Scopes of inference, however, can be "interpenetrating." This means that a population with a broad scope of inference, such as a Forest, can consist of subpopulations, such as Districts. Thus, samples drawn within Districts are interpenetrating samples of the Forest sample; these District samples can be used to develop statistically sound Forest, and hence, Regional estimates.

<u>Estimates and precision required.--Estimates</u> of desired information are developed from samples. For example, the variable of interest could be volume growth per acre, soil bulk density, or percentage of exposed mineral soil. Precision is an index of reliability of the sample estimate. An estimate of variance is required to plan sample size--that is, the number of observations that will be needed to provide an estimate with this expected precision. The precision or reliability of an estimate can be increased by increasing sample size.

From a national perspective, the Forest Service is directed by the NFMA to "prevent substantial and permanent impairment in land productivity." This directive implies that "substantial and permanent" must be defined before a sampling system can be designed that will detect that amount of change in site productivity. If our purpose of monitoring is to detect change or difference in tree growth or in a soil property after a forestry operation, or to determine if specified standards of change have been exceeded, we must first set the amount of change or difference that our monitoring system should detect. We then design a sampling system that will provide an estimate of this change with the desired precision. For example, if current standards are that 20% or less of a harvested area may be adversely affected, then the necessary number of samples can be calculated to determine if this standard has been exceeded. Note that detecting small differences or changes substantially increases the required sample size (and thus, cost and time).

Measuring tree growth can be "effectiveness" monitoring, "validation" monitoring, or both. To monitor the effectiveness of a treatment such as thinning or the effect of soil disturbance on tree growth, we must measure growth on both treated and suitable untreated (control) areas. The difference in growth on treated and untreated areas is an estimate of response or treatment effects--that is, effectiveness monitoring. Moreover, these data can also be used to validate predictions of tree growth or response used by timber management planners or by soil scientists who predict tree response from changes in soil properties.

Alternatively, if growth is not measured on suitable untreated areas, the effect of treatment or impact of a potentially soil-degrading practice can not be isolated. Instead, this monitoring can provide an estimate of growth after treatment that can be compared to predicted growth--that is, validation monitoring.

Cost and other constraints.--Costs or other constraints may dictate sample size or sampling methods. Statistical theory indicates that costs of detecting change in tree growth or in a soil property will increase with increasing variability in the sample population. Research experience in detecting change in growth of coast Douglas-fir stands after N fertilization can indicate the costs of monitoring the effectiveness of operational treatments or monitoring the validity of growth projections based on research models. This research experience suggests that monitoring volume growth per acre will be financially feasible only on a limited number of locations and practices. Moreover, the types and quality of measurements taken in effectiveness and validation monitoring should be compatible with those used in treatment response studies (research plots).[4/] This means that monitoring should provide reliable per-acre estimates of growth, mortality, ingrowth, and removals.

Statistical theory also shows that the cost of detecting a change in tree growth or in a soil property will increase markedly as smaller changes are to be detected. Thus, the cost of detecting a 15% change in tree growth or in soil porosity will be more than double that of detecting a 30% change.

Step 2: Integrate the Monitoring Systems

Attempts should be made to integrate all levels of monitoring. This integration can reduce the total cost below that of the combined costs of several independent monitoring systems.

A monitoring plan clearly involves many sampling situations. The information requirements will possess different scopes of inference, different indices of reliability, and different cost requirements. The key is to make sampling designs compatible; first, so that information for more than one objective can be collected at common locations and second, so that estimates can be combined among samples without complicating the interpretation. An efficient design should satisfy monitoring objectives at least cost. Design efficiency is expressed as a combination of sampling costs and precision. The user may need a sampling design that provides a desired precision at minimum cost or maximum precision at a fixed cost. The information known about the populations before sampling will affect design efficiency and complexity. If patterns of variability are known, then stratification may be used to improve efficiency or reduce costs. To a limited extent, the complexity of the design can be tailored to the comprehension of the personnel who will conduct and maintain the design.

Given the need for a certain kind of information, however, the design must provide reliable information. Once information falls below some threshold of reliability, it becomes useless. Thus monitoring, like research, presents limited potential for compromise.

Step 3: Procedural Details

After a monitoring design is chosen, additional items must be specified and subsequently followed. A list of these items follows, but further details exceed the intent of this presentation:

Sampling rules: the detailed steps for drawing the sample;
Definition of sampling units: optimum plot size, shape, or line length;
Estimation on procedures: the algebraic expressions for developing estimates and standard errors;
Computation procedures for estimating sample sizes to meet the desired precision; Field instructions; and
Computation instructions: computer programs for summarizing the data.

SUMMARY AND CONCLUSIONS

- Carefully designed and integrated systems are needed to monitor the effects of harvesting, forest practices, and regional environmental changes on various components of forest ecosystems.

- To know the effects of timber harvest and forest practices on long-term wood production, we must measure volume growth on permanent plots in a sampling of stands. Measuring changes in soil characteristics or other substitutes can provide indirect evidence--when these substitutes are shown toare shown to be reliable predictors of long-term tree growth.

[4/] Unpublished Administrative Report, 1986, "Report of Task Force on Permanent Plot Standards," by Robert O. Curtis, Leader, and other Task Force Members. U.S. Department of Agriculture, Forest Service, Forestry Sciences Laboratory, 3625 - 93rd Avenue S.W., Olympia, WA 98502.

- Quantitative monitoring involves statistical sampling. Without a formal and valid sampling plan, no assurance can be given that the monitoring effort will generate the required information with specified reliability.

- Data collected on suitable monitoring or survey plots can be used both to supplement research data used in growth and yield simulations and to validate or calibrate regional simulations for more local situations.

- The general plan for monitoring long-term site productivity should integrate all levels of sampling and other types of monitoring or surveys as appropriate. An integrated plan should satisfy numerous monitoring objectives at least cost.

SOIL PRODUCTIVITY PROTECTION AND IMPROVEMENT: OBJECTIVES, POLICY, AND STANDARDS IN THE PACIFIC NORTHWEST REGION OF THE FOREST SERVICE.

Robert T. Meurisse

ABSTRACT: Legislation and prudent management require protection and improvement of the soil resource. USDA Forest Service, Pacific Northwest Region, has established a soil productivity protection policy based on reported research for management practices affecting potential productivity. Emphasis is on potential for altering three state variables of soil moisture, nutrients and aeration. Key features of the policy are requirements for: (1) analysis of potential for soil damage when planning and implementing projects; (2) appropriate mitigating and/or rehabilitation measures; and (3) monitoring against established standards and objectives. The policy has been effective in reducing soil damage by compaction, displacement, puddling, and severe burning. It also has encouraged state-of the-art practices to meet specified standards.

INTRODUCTION

Soil has long been recognized by land managers as being the basic resource affecting present and future ability to produce vegetation or plant biomass. Also, it is the medium through which water is received and transmitted. Condition of the soil is critical to the provision of both favorable water flows of high quality and vigorous plant growth.

Recently, legislators have felt the need to enact laws containing language for "protecting the soil" while managing National Forest renewable resources. The Multiple Use Sustained Yield Act of 1960: requires that we "manage all the various renewable surface resources of the National Forests..... without impairment of the productivity of the land." The National Forest Management Act of 1976 placed increase_ emphasis on the concern for the protection and improvement of the soil resource. Nowhere in the legislation or research literature were there meaningful standards, procedures, or objectives to assess whether the intent of maintaining productivity was being met. Also, nowhere was there a concise, common, working definition of soil (site) productivity.

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SOIL PRODUCTIVITY DEFINITION AND WORKING MODEL

In order to better understand the rationale for our Regional policy and standards, it is important to define soil productivity and provide a working model. The Soil Science Society of America (1975) defines soil productivity as: "The capacity of a soil in its normal environment) for producing a specified plant or sequence of plants under a specified system of management." A slight modification of this definition is in the Forest Service Manual

(FSM-2521.05). It is "The inherent capacity of a soil for supporting growth of specified plants, communities, or sequence of plant communities." In either case, emphasis is on the capacity to produce plants.

Productivity is governed by the magnitude and rates of change of several state variables. The magnitudes and dynamics vary in space and time, are interactive among themselves, and are affected by management practices both locally and globally. Thus, our standards and policy are designed to reflect these state variables and they can be quantified to assess changes through monitoring. The basis for our policy and standards is contained in the model: P = f (SM.SN.SA. L·H·V), where P = Productivity as a measure of carbon fixation. Useful measures may be Net Primary Productivity (NPP), volume increment or biomass increment/area/time.

SM is available soil moisture, SN is available soil nutrients, SA is soil aeration, L is light (quality and quantity) H is heat and V is vegetation (species a genetic trait).

Site capacity factors (state variables) most easily affected by management activities are soil moisture, nutrients, aeration and vegetation. Light and heat are relatively stable, but may have global implications. Vegetation can be altered by changing species to meet specific objectives and by altering genetic makeup. However, genetic response is dependent upon available moisture, nutrients, and aeration. Productivity can increase, decrease, or remain unchanged depending on how the state variables are changed. Of particular concern in our soil productivity protection policy is moisture, nutrients, and aeration.

SOME PROCESS-PRACTICE INTERACTIONS: A BASIS FOR POLICY AND STANDARDS

Much has been written about the extent, processes, and effects of compaction, puddling and displacement in the Pacific Northwest (Dyrness 1965; Swanston and Dyrness 1973; Froehlich 1974; 1979; Froehlich and McNabb 1984). Traditional ground skidding, slash disposal by piling and mechanical site preparation commonly compacts, puddles and displaces soil on 20 to more than 50 percent of harvest units for a single harvest/reforestation entry. Effects on tree growth vary by soil conditions, but usually result in decreases (Froehlich 1974; Wert and Thomas 1981; Froehlich and McNabb 1984). Compaction and puddling reduce available soil moisture, decrease aeration and may affect nutrient availability. Reduced aeration may have secondary effects on productivity due to increased potential for diseases and insects due to plant stress. Displacement removes nutrients and may decrease moisture supply because of reduced infiltration and storage capacity. Fire, especially of long duration and high intensity, may significantly reduce nutrient supplies by volatilization and accelerated erosion (Wells et. Al. 1979). Loss of nutrients also results from tree removals (Bigger and Cole 1983; Johnson 1983).

Cultural practices such as soil tillage can restore or improve moisture availability and aeration in compacted or puddled soils and in soils with natural restrictive layers (Froehlich and McNabb 1984). Nutrient supplies can be maintained and increased, particularly on low fertility sites, by careful management of live and dead woody biomass. For example, significant quantities of nitrogen can be added by fixation with alder and ceanothus species (Binkley, 1983; Binkley and Husted 1983). Decaying woody biomass is important for N-fixation by mycorrhizae, moisture conservation, as well as survival, growth and distribution of conifer seedlings (Larsen, Harvey and Jurgensen 1980). Gessel and Atkinson (1983) discussed the importance of fertilizers in sustaining productivity of Douglas-fir forests.

Erosion by mass wasting is an extremely important component of maintaining healthy forest ecosystems on many forests in the Pacific Northwest. The extent of stability problems is described by Burroughs (1985). Sidle (1985) describes factors influencing slope stability and Brown (1985) describes damage by landslides to the forest environment. Finally, it is important to recognize that different soils have widely varying capacities for sustaining productivity depending on their unique properties. Klock (1983) has discussed a concept by which sensitivity of soils to silvicultural activities can be described. He has described five productivity resilience zones based on intrinsic properties. Thus, management prescriptions need to be adapted to specific soil types with understanding of their intrinsic properties.

It is within the framework of the model previously described and supported by the foregoing discussion that the Pacific Northwest Region of the Forest Service has developed its policy on soil productivity protection and _improvement and upon which it is administered.

OBJECTIVES AND POLICY

The three principal objectives we have established for managing under principles of multiple use and sustained yield without permanent impairment of land productivity, and improving soil productivity when appropriate, are as follows:

1. Plan and conduct land management activities so that reductions of soil productivity potential caused by detrimental compaction, displacement, puddling, and severe burning are minimized. Nutrient capital on forest and rangelands is to be maintained at acceptable levels.

2. Plan and conduct land management activities so that soil loss from accelerated surface erosion and mass wasting, caused by these activities, will not result in an unacceptable reduction in soil productivity and water quality.

3. The Pacific Northwest Region, and Forests within it, will have realistic, measurable soil protection standards and guidelines, which can be monitored and which are in accord with and supportive of land management objectives.

The policy contains three major features. It requires: (1) analysis of potential of soil for damage; (2) appropriate mitigating and/or rehabilitation measures where necessary; and (3) monitoring against standards and objectives. Specifically, "Environmental Assessments and Environmental Impact Statements will address the potential of affected soils for compaction, puddling, displacement, surface erosion, and damage by severe burning," through an interdisciplinary team process. For mass wasting, the policy is broader than soil productivity *per se*. It reflects the greater potential for off-site damage from landslides. Thus, it requires the interdisciplinary team process to evaluate projects for significant soil loss and/or sedimentation hazards to lives and property, or damage to downstream values. Then appropriate mitigation and/or rehabilitation measures will be planned as needed to meet soil management and water quality objectives.

A key part of the policy is that "monitoring activities will be planned and conducted to determine whether soil productivity protection objectives and standards have been met and whether they are realistic." Also, "periodic management reviews will be scheduled to determine whether soil management objectives are being achieved." It then becomes the responsibility of land managers to evaluate the trade-offs and select appropriately designed projects to meet stewardship responsibilities.

STANDARDS

Management activities create various degrees of soil disturbance. Good land stewardship minimizes significant adverse impacts on soils. In order for managers to know how well they are doing, Regional numerical standards provide broad limits of acceptability. Specific forests may choose to set narrower limits with appropriate justification.

The general standard for compaction, displacement, puddling, and severely burned is that "a minimum of 80 percent of an activity area should be left in a condition of acceptable productivity potential for trees and other managed vegetation following land management activities." An activity area is the, total area for which a ground impacting activity is planned and that is a feasible unit for sampling and evaluating.

Standards for detrimental compaction, puddling, and displacement, and severely burned are as follows:

(1) Detrimental Compaction. Compaction of soil increases soil bulk density and decreases porosity as a result of the application of mechanical forces such as weight and vibration. Detrimental compaction is that beyond the limits described. Because of the unique physical properties and management problems of volcanic ash and pumice soils, a different criterion for determining detrimental compaction has been established for them.

(a) Volcanic Ash/Pumice Soils. An increase in soil bulk density of 20 percent or more over the undisturbed level.

(b) Other Soils. An increase in soil bulk density of 15 percent or more over the undisturbed level, a macropore space reduction of 50 percent or more, and/or a reduction below the 15 percent level as measured by an air permeameter.

(2) Detrimental Puddling. Soil puddling is a physical change in soil properties due to shearing forces that destroy soil structure and reduce porosity. Detrimental puddling can be observed as vehicle tracks when soil is molded and when depth of rutting has reached 6 inches or more.

(3) Detrimental Displacement. Soil displacement is the removal and horizontal movement of soil from one place to another by mechanical forces such as a blade. Detrimental displacement is the removal of more than 50 percent of the topsoil or humus enriched Al and/or AC horizons from an area of 100 square feet or more which is at least 5 feet in width.
Mixing of surface soil layers by disc-plow operations, or removal of surface soil layers by hand scalping are not considered as detrimental displacement.

(4) Severely Burned. Soils are considered to be severely burned when the top layer of mineral soil has been significantly changed in color, usually to red, and the next one-half inch blackened from organic matter charring by heat conducted through the top layer.

Erosion is categorized as surface or mass wasting. For surface erosion, standards are in terms of minimum percent effective ground cover, which is defined as:

All living or dead herbaceous or woody materials and rock fragments greater than three-fourths of an inch in diameter in contact with the ground surface. Includes tree or shrub seedlings, grass, forbs, litter, chips, etc.

(1) Surface Erosion. Surface erosion is the detachment and transport of individual soil particles by wind, water, or gravity. Surface erosion can occur as the loss of soil in a fairly uniform layer across the land surface or in many small rills.

To stay within acceptable levels of soil loss and meet soil management objectives, the minimum percent effective ground cover following cessation of any soil disturbing activity should be as follows:

	Minimum Percent Effec. Ground Cover	
Erosion Hazard Class	1st yr.	2nd, yr.
Low (Very slight-slight)	20-30	30-40
Med. (Moderate)	30-45	40-60
High (Severe)	45-60	60-75
Very High (Very Severe)	60-75	75-90

(2) Soil Mass Wasting. Soil mass wasting is the detachment and movement of soil or surface mantle material. Some landslides fail in a single mass or single event and move downslope to cause debris slides and avalanches. Other landslides detach and move slowly downslope, over a period of years. Both these types represent end members of landslide generated impacts. Mass wasting events are classified based on their morphology, water content, type of material involved, and rate of movement. Landslides are discrete land surface units. Therefore, each potential mass wasting event must be evaluated independently of others in a project area. Calculations of percentage area in landslides alone do not provide a meaningful assessment. Potential for further movement, impacts on productivity, and effects on other resources must also be evaluated.

SOIL MONITORING

In order to evaluate effectiveness of standards and practices to meet soil management objectives, a monitoring procedure has been developed and is used in the Pacific Northwest Region. It is described by Hazard and Geist (1984) and Howes, Hazard, and Geist (1983). The procedures are a system of line transects, with random orientation from grid intersections. This system is flexible and assures good distribution in an activity area. It permits visual observations, physical samples such as soil cores or nuclear gauges for bulk density, or samples for chemical and fertility analysis in an activity area. These procedures have been used for a variety of projects including clearcut harvest and site preparation, bare soil conditions from broadcast burning in harvest units, and in commercial thinning with a feller buncher.

POLICY EVALUATION--FINDINGS AND CONCLUSIONS

During 1985, a field evaluation of the policy was conducted on three National Forests in northeast Oregon. One of the requirements was that the review team visit sites where data were available from previous monitoring projects using procedures similar to those used by Howe's, Hazard and Gist (1983). The area is dominated by volcanic ash soils and vegetation is mostly overstocked stands of ponderosa pine, lodgepole pine and mixed conifer.

Some of the key findings are as follows:

1. Where ground skidding and tractor piling of residues is the common practice, 15 to 30 percent of the activity area is damaged (exceeds standards). This is reduced from previous levels of 20 to more than 50 percent.

2. State-of-the-art management practices generally can be accomplished in accordance with soil management objectives without excessive costs. The policy has been a major factor in encouraging practices designed to maintain or improve site productivity.

3. In most cases, effective ground cover standards can be met with clearcutting and broadcast burning on slopes up to 45 percent.

Some of the major conclusions are:

1. The Pacific Northwest Regional Soil Productivity Protection Policy is a reasonable and prudent one for ensuring long-term productivity potential is maintained or enhanced.

2. Conditions such as very heavy timber volumes and fuel loads, repeated harvest entries, uneven terrain, and others, may require special innovative techniques and careful sale administration to protect soil resource potentials.

3. Use of designated skid trails, piling of fuel concentrations and/or prescribed burning in clearcuts, shelterwoods, and partial overstory removals are common practices in the Region.

4. Managers are accepting larger amounts of residue than a few years ago. It reduces soil compaction and displacement and residues provide shading for seedlings, moisture conservation and future sources of organic matter.

5. Soil tillage with winged subsoilers is increasing throughout the Region. On sites of low quality, it may not be warranted until regeneration harvest occurs.

6. Quantitative soil monitoring is costly but necessary to answer certain specific questions about effect of practices on soil conditions. It is critical to have carefully defined monitoring objectives and to monitor key projects.

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MONITORING SOIL PHYSICAL CONDITIONS ON A NATIONAL FOREST IN EASTERN OREGON: A CASE STUDY

Timothy E. Sullivan

ABSTRACT: Guidelines developed by the Pacific Northwest Region, USDA Forest Service, were used to monitor the impact of tractor logging and machine piling on soils in 24 timber sale units on the Malheur National Forest between 1981 and 1985_ The sampling system used provided a statistically sound evaluation of the impacts of these practices on the soil resource. Compaction was the primary detrimental soil condition measured. Machine piling and the cumulative effects of multiple harvest entries were major contributors to the detrimental compaction that occurred.

INTRODUCTION

An intensive soil monitoring program was initiated on the Malheur National Forest in 1981 to determine if tractor logging and machine piling were resulting in excessive soil resource damage-; Forest managers and resource specialists in the Blue Mountains of Southeast Washington and Northeast Oregon (Malheur, Wallowa-Whitman, Umatilla, and Ochoco National Forests) were concerned that excessive soil resource damage was occurring where these management practices were being prescribed.

Machine piling was a particular concern. For some years prior to the early 1980's, machine piling was being used to achieve a "total cleanup" of the logging slash. Units that had been machine piled typically looked like open parks, totally devoid of any slash. It was the impact of the extensive machine piling on the soil resource that was a particular concern of the Forest managers and resource specialists.

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Twenty-four units, covering a variety of soil types, timber types, and silvicultural prescriptions, were monitored between 1981 and 1985. Monitoring was conducted according to the procedure described in "Guidelines for Sampling Some Physical Conditions of Surface Soils" (Howes, Hazard, and Geist, 1983). The guidelines were first issued in May 1981 as "Interim Guidelines for Sampling Soil Resource Condition;" They were revised and reissued in July 1983.

OBJECTIVES

The objective of the monitoring program was to determine if the Regional Soil Protection Standards (USDA, Forest Service 2520,2-4 R-6 Supplement 45 Sept. 1983) were being met on selected timber sales. Policy requires that Monitoring activities will be planned and conducted to determine. whether soil productivity protection objectives and standards have been met and are realistic." The objectives of this paper are to (1) Present an overview of the Regional monitoring system, and (2) Present the results of 5 years of intensive soil monitoring on the Malheur National Forest.

REGIONAL STANDARDS

Region 6 soil protection standards were first issued in June 1979 as R-6 Supplement 38 (Forest Service Manual 2520,2-3, R-6 Supplement 38);' While being somewhat subjective, they were intended to be observable and/or easily measurable by field people. They were based on the best research available at the time; It was intended that they would be modified as new information became available.

the standards were revised in July 1983. The Supplement was reissued as Supplement 45 (Forest Service Manual, 2_4, R-6 Supplement 45). The results reported here are in terms of the 1983 revision

The standards state that total acreage of all detrimental soil conditions, including the permanent transportation system, should not exceed 20 percent of a unit. Detrimental soil conditions are defined as follows:

Detrimental Compaction - A 20 percent increase in bulk density above the undisturbed level on "volcanic ash and pumice" soils. A 15 percent increase in bulk density above the undisturbed level on all "other" soils.

Detrimental Puddling- Molding and rutting of the soil to a depth of 6 inches or more.

Detrimental Displacement- The removal of more than 50 percent of the A1 or AC horizons from an *area* of 100 square feet or *more.* The displaced area must be at least 5 feet wide.

Severely Burned- A soil where the top layer of mineral soil has been significantly changed in color, usually to red, and the next 1/2 inch blackened from organic matter charring by heat conducted through the top layer.

Surface Erosion- Surface erosion is defined as the detachment and transport of individual soil particles by wind, water, or gravity. It can occur as the loss of soil in a fairly uniform layer across the land surface or in many small rills. Because it is difficult to measure erosion directly, it was decided to use effective groundcover as the measure to prevent unacceptable erosion. A minimum percent effective groundcover is specified for 2 years following disturbance for the Erosion Hazard Classes listed in the Soil Resource Inventory for the Malheur National Forest.

Effective groundcover includes all living and dead herbaceous and woody materials, and rock fragments greater than three-fourths of an inch in diameter, in contact with the ground.

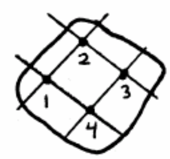
	Required Minimum Percent Effective Groundcover	
Erosion Hazard Class	1st Year	2nd Year
Low	20-30	30-40
Moderate	30-45	40-60
High	45-60	60-75
Very High	60-75	75-100

MONITORING PROCEDURE

The monitoring procedure provides a statistically sound sampling system that can be used to evaluate a variety of management impacts and soil conditions at a point in time or to measure changes over time.

The system is a line transect method that randomly orients a predetermined number of transects in a unit. The starting points are systematically located by placing a square grid over a map of the unit (fig. 1). The grid intersections are the starting points of the transects. The dimensions of the grid are determined by the size of the unit and the desired sample size. Once located, each transect is assigned a random azimuth that will be used to layout the line in the field.

Transect lengths can be any convenient length as long as the measured distances are converted to percentages. All of the transects used in this report are 100 feet in length.



Transect	Azimuth
1	59°
2	257°
3	103°
4	338°

Figure 1.--Locating transect starting points with a systematic square grid.

Each transect was laid out with a 100-foot tape and a compass in the field. The tape was stretched between two wooden stakes. The surface condition along the transect was then categorized and recorded into one of nine visual classes set up by the Forest (table 1). The visual classes are: (1) Undisturbed, (2) Skid Trails, (3) Slash, (4) Miscellaneous, (5) Roads, (6) Landings, (7) Displacement, (8) Puddled, and (9) Eroded.

Visual classes 5-9 each meet at least one of the definitions of detrimental soil conditions. Any length recorded in one of these was automatically considered damaged. Visual classes 1-4 were not automatically considered damaged; only the portion of these visual classes determined to be detrimentally compacted by bulk density measurements was counted as damaged.

The Average Percent Detrimental Impact (APDI) for a transect was calculated by adding the length of each transect in visual classes 5-9 tc the portion of visual classes 1-4 determined to be detrimentally compacted. The APDI for each unit was calculated by averaging the APDI's of all the transects.

The visual classes are used to subjectively quantify different kinds of disturbances. Managers and resource specialists often want to know how much of a unit is in skid trails or landings, etc. The nine classes presented here are ones- that were important to the managers on the Malheur Forest. They can be changed to meet any management situation.

Compaction was measured by taking core samples at regular intervals along the transects and comparing the bulk densities to the mean undisturbed density for the unit. The undisturbed density was determined from typically 30-40 core samples taken in undisturbed areas within or immediately adjacent to the unit on the same soil type. Core samples were taken from a depth of 4-6 inches.

The recommended sampling interval was changed from 5 to 10 feet in-1983 after a sensitivity analysis showed that there was no practical difference in results (table 2).

STATISTICAL METHODS

Test of Significance

A simple "t test" is used to determine if the APDI measured on a unit exceeds the Regional standard of 20 percent.

If $t \geq L\ t_{80\%,n-1}$, then the Regional standard has been exceeded.

$$t = \frac{p.. - 20}{\sqrt{\frac{s^2}{n}}} \quad \text{where,}$$

p.. = Average Percent Detrimental Impact
20 = Regional Standard
s^2 = Variance among transects
n = Sample Size

$t_{80\%,n-1}$ = One-tailed t value at, 80 percent probability level

Sample size (n) refers to the number of transects used to sample a unit. The calculated sample size (N) is the means used to determine if the desired level of precision has been met. Nan n values are presented in table 3. The formula for calculating N is:

$$N = \frac{t^2 s^2}{(p.. - 20)^2} \quad \text{where,}$$

N = Calculated sample size
t = One-tailed t value (80%)
s^2 = Variance among transects
p.. = Average Percent Detrimental Impact
20 = Regional standard

The desired level of precision is 80 percent. It was chosen to reflect the needs and intensity of management on the Malheur National Forest. It was not intended to be a "research" level investigation.

The large N values for Frosty 2, Clear Lunch After, and North side reflect the closeness of the AUDI to the Regional standard. As the APDI approaches the standard, the larger the sample size required to maintain the desired level of precision. The management decisions involved do not normally justify spending the time or funds to measure that many transects.

Monitoring was initiated in 1981 using a sample size of 5 and 10 transects. These results were, determined to be less than sufficient because of the large confidence intervals (fig. 2). The sample size was increased in 1982 to 15 transects on the pre-logging units and 30 transects on the post-logging units to increase the reliability of the results. Reliability is increased as the confidence interval (CI) on the APDI is decreased (fig. 2). The average width of the CI decreased from ± 22 in 1981 to ± 7 percent in 1982.

The 1982 results were scrutinized for practicality by the Forest Management Team. After considering the costs and the risks involved, it was decided that a sample size of between 15 and 20 transects would provide sufficiently reliable results. The average CI for the units monitored since 1982 increased slightly from ± 7 to ± 10 percent, more than sufficient for the management of the Forest.

DESCRIPTION OF UNITS

Twenty different cutting units were sampled between 1981 and 1985. Three of the units were sampled more than once for a total of 24 units monitored. Two units (Seagull and Mosquito 4) were sampled twice. One unit (Clear Lunch) was sampled three times.

Table 1—Percentage of the units in visual categories

	Undisturbed (1)	Skid Trails (2)	Slash (3)	Misc. (4)	Roads (5)	Landings (6)	Displacement (7)	Puddled (8)	Eroded (9)
Black Snag	38	6	7	46	3	0	0	0	0
3 Cabin	18	13	9	50	0	6	4	0	0
Deer 16	2	11	7	78	2	0	0	0	0
Deer 17	2	4	2	82	5	5	0	0	0
Mosquito 3	0	2	10	75	0	6	7	0	0
Mosquito 4	0	5	9	78	4	0	0	0	4
Mosquito 4 Repeat	7	6	32	45	3	2	1	0	4
Meadow 4	0	3	85	0	3	8	1	0	0
Meadow 5	0	3	97	0	0	0	0	0	0
Frosty 1	27	9	64	0	0	0	0	0	0
Frosty 2	3	13	80	0	3	0	1	0	0
John Day	0	0	91	0	4	3	2	0	0
Clear Lunch Before	89	4	0	7	0	0	0	0	0
Clear Lunch After	20	9	66	0	0	5	0	0	0
Clear Lunch Repeat	4	7	4	84	0	1	0	0	0
Steagall Before	89	1	0	7	3	0	0	0	0
Steagall After	24	7	60	0	5	2	2	0	0
China Thin	0	8	27	65	0	0	0	0	0
Quick Salvage	68	26	0	6	0	0	0	0	0
Wet	32	22	3	43	0	0	0	0	0
Cow 11	2	0	0	98	0	0	0	0	0
Cow 13	8	0	90	2	0	0	0	0	0
Northside	45	10	0	35	0	10	0	0	0
Scalp	29	26	2	43	0	0	0	0	0
Average:	21	8	31	35	1	2	1	0	1

Seagull was sampled before and after the current logging (identified as Steagall Before and Steagall After) to determine the impact of this entry. The unit had been logged before. Mosquito 4 was sampled twice after logging (identified as Mosquito 4 and Mosquito 4 Repeat) to see if similar results could be obtained. Clear Lunch was sampled before logging (Clear Lunch Before) to estimate the amount of naturally occurring detrimental soil condition, and twice after (Clear Lunch After and Clear Lunch Repeat) to see if similar results could be obtained.

Clear Lunch Before occurred in an. area that had never been entered before. The results from this unit provide an estimate of the baseline soil condition; i.e., the amount of naturally occurring detrimental soil condition.

Soil Types - Fifteen units occurred on volcanic ash soils, seven units on "other" soils', and two units on mixed ash and "other" soils.

Table 2--Results of sampling interval sensitivity analysis

		APDI[1] and 90% CI[2]	
Unit	Sampling Interval (feet)	Before	After
Steagall	5	16 ± 8	30 ± 8
	10	15 ± 8	29 ± 9
China Thin	5	---	13 ± 5
	10	---	14 ± 7
Clear Lunch	5	1 ± 1	18 ± 8
	10	1 ± 1	19 ± 10

1/ APDI = Average Percent Detrimental Impact
2/ CI = Confidence Interval

Table 3--The actual sample size (n) and the calculated sample size (N) at the 80 percent probability level

Unit	n	N	Unit	n	N
Black Snag	13	3	Clear Lunch Before	13	1
3 Cabin	15	4	Clear Lunch After	29	219
Deer 16	16	3	Clear Lunch Repeat	29	7
Deer 17	17	8	Steagall Before	15	14
Mosquito 3	23	1	Steagall After	32	5
Mosquito 4	18	1	China Thin	27	5
Mosquito 4 Repeat	20	6	Quick Salvage	5	4
Meadow 4	29	2	Wet	10	1
Meadow 5	17	5	Cow 11	5	3
Frosty 1	14	17	Cow 13	5	1
Frosty 2	24	66	Northside	10	75
John Day	15	2	Scalp	10	2

Cumulative Effect - Nine units occurred in stands that had been previously logged and machine piled. The results from these units reflect the cumulative effect of this entry and all previous entries.

Silvicultural Prescriptions - Fourteen units were regeneration cuts, six units were overstory removals, one unit (Quick Salvage) was a salvage harvest, and one unit (China Thin) was a :commercial thinning harvest. Steagall Before evaluates the impact of a partial cut that occurred in the past. Clear Lunch Before did not evaluate a silvicultural prescription as there had been no previous entry.

Timber Types - Seven of the units occurred in ponderosa pine, seven in lodgepole pine, and ten of the units in mixed conifer stands.

Table 4 lists the total acres, acres sampled, soil type, previous logging history, silvicultural prescription, and the species composition. Where total acres exceeded 50, a representative 10-acre. subsample was monitored. There was not time or the funds available to sample all of the acres in the bigger units.

Table 5 lists the dates the units were logged and piled, and the equipment used.

RESULTS

The test of significance is presented in Table 6. Figure 2 displays the Average Percent Detrimental Impact (APDI) and the 90 percent Confidence Intervals.

Fifteen of the 24 units monitored exceeded the Regional standard of 20 percent. Another five units (20 in all) were very near the standard with more than 15 percent of their area detrimentally impacted.

Clear Lunch Before, with no prior management activity, was less than 1 percent detrimentally impacted. The two units monitored before and after the current logging (Clear Lunch and Steagall) showed an increase in detrimental impact of 17 and 14 percent, respectively. Clear Lunch went from less than 1 percent of the unit detrimentally impacted to 18 percent. Steagall went from 16 to 30 percent.

Results By Soil Types - Eight of the fourteen logged units that occurred on volcanic ash soils, five of the seven units that occurred on "other" soils, and both units that occurred on mixed soils exceeded the Regional standard.

Results By Previous Activity (Cumulative effect) - Seven of the nine units that had been previously logged exceeded the Regional standard. Eight of the fourteen logged units that had no prior activity exceeded the standard.

Results by Silvicultural Prescription - Nine of the fourteen logged regen units, five of the six overstory removal units, and the salvage unit exceeded the Regional standard. Neither the commercial thinning nor the older partial cut (Steagall Before) exceeded the standard.

Results by Timber Types - Five of the seven types in ponderosa pine, four of the seven units in lodgepole pine, and six of the nine logged units occurring in mixed conifer stands exceeded the Regional standard.

Detrimental compaction was by far the most significant kind of detrimental soil condition monitored. It comprised 95 percent of the total detrimental condition encountered.

Table 7 presents cost information for eight units monitored in 1982 and 1983.

Table 4--Description of unit

	Acres	Acres Sampled	Soil Type	Prior Activity	Silvicultural Prescription	Species
Black Snag	80	10	Other	Yes	Final Removal	Ponderosa Pine
3 Cabin	147	10	Other	Yes	Final Removal	Ponderosa Pine
Deer 16	35	35	Mixed	Yes	Final Removal	Mixed Conifer
Deer 17	36	36	Other	Yes	Final Removal	Ponderosa Pine
Mosquito 3	27	27	Ash	No	Regeneration Cut	Mixed Conifer
Mosquito 4	27	27	Mixed	No	Regeneration Cut	Mixed Conifer
Mosquito 4 Repeat	27	27	Ash	No	Regeneration Cut	Mixed Conifer
Meadow 4	10	10	Ash	No	Regeneration Cut	Lodgepole Pine
Meadow 5	6	6	Ash	No	Regeneration Cut	Lodgepole Pine
Frosty 1	15	15	Ash	No	Regeneration Cut	Lodgepole Pine
Frosty 2	11	11	Ash	No	Regeneration Cut	Lodgepole Pine
John Day	10	10	Ash	No	Regeneration Cut	Mixed Conifer
Clear Lunch Before	18	18	Ash	No	Regeneration Cut	Mixed Conifer
Clear Lunch After	18	18	Ash	No	Regeneration Cut	Mixed Conifer
Clear Lunch Repeat	18	18	Ash	No	Regeneration Cut	Mixed Conifer
Steagall Before	33	33	Other	Yes	Regeneration Cut	Lodgepole Pine
Steagall After	33	33	Other	Yes	Regeneration Cut	Lodgepole Pine
China Thin	170	10	Other	Yes	Commercial Thin	Ponderosa Pine
Quick Salvage	45	45	Ash	Yes	Salvage	Ponderosa Pine
Wet	512	10	Ash	Yes	Final Removal	Ponderosa Pine
Cow 11	10	10	Ash	No	Regeneration Cut	Lodgepole Pine
Cow 13	14	14	Ash	No	Regeneration Cut	Mixed Conifer
Northside	264	10	Ash	No	Regeneration Cut	Mixed Conifer
Scalp	293	10	Other	Yes	Final Removal	Ponderosa Pine

Table 5--Dates units were logged and piled, and the equipment used

Unit	Logged	Piled	Skidding Equipment
Black Snag	Feb. '85	May '85	Logging - D6, Piling - D3
3 Cabin	1976	1981	Piled w/ D6 Cat
Deer 16	July '83	July '85	D6C Cat, 518 Skidder, 966C
Deer 17	July '83	June '85	D6C Cat, 518 Skidder, 966C
Mosquito 3	Aug. '82	Nov. '82	D7 Cat, 518 Skidder, Intern. 100
Mosquito 4	Aug. '82	Nov. '82	D7 Cat, 518 Skidder, Intern. 100
Meadow 4	Oct. '79	Mar. '80	D6 Cat, 518 Skidders
Meadow 5	Oct. '79	Mar. '80	D6 Cat, 518 Skidders
Frosty 1	---------------------------	No Record	--------------------------
Frosty 2	---------------------------	No Record	--------------------------
John Day	---------------------------	No Record	--------------------------
Clear Lunch	July '82	July '82	Nissan N45, 518 Skidder
Steagall	Feb. '82	July '82	Feller-Buncher, D6D Cat, 518 Skidder
China Thin	------ All Year ------		D6 Cat or smaller, 518 Skidder
Quick Salvage	---------------------------	No Record	--------------------------
Wet	Nov. '80	Dec. '80	Cats, 518 Skidder
Cow 11	Fall '79	Spr. '80	D6 Cat
Cow 13	Spr. '78	Fall '78	Feller-Buncher, 518 Skidder, FMC
Northside	Fall.'79	Sum. '82	D6 Cat, 518 Skidders
Scalp	Feb. '81	Spr. ,81	D6 Cat, 518 Skidders

Table 6.--Test of significance

Unit	APDI	$t > t_{80\%,n-1}$	Unit	APDI	$t > t_{80\%,n-1}$
Black Snag	37 ± 14	Yes	Clear Lunch Before	1 ± 1	No
3 Cabin	33 ± 14	Yes	Clear Lunch After	18 ± 8	No
Deer 16	33 ± 10	Yes	Clear Lunch Repeat	14 ± 6	No
Deer 17	31 ± 15	Yes	Steagall Before	16 ± 9	No
Mosquito 3	52 ± 11	Yes	Steagall After	30 ± 8	Yes
Mosquito 4	39 ± 8	Yes	China Thin	13 ± 5	No
Mosquito 4 Repeat	28 ± 9	Yes	Quick Salvage	39 ± 35	Yes
Meadow 4	41 ± 9	Yes	Wet	10 ± 4	No
Meadow 5	30 ± 10	Yes	Cow 11	46 ± 30	Yes
Frosty 1	17 ± 6	No	Cow 13	70 ± 28	Yes
Frosty 2	19 ± 4	No	Northside	17 ± 18	No
John Day	33 ± 8	Yes	Scalp	44 ± 17	Yes

Table 7.--Cost information for eight units monitored in 1982 and 1983

Units	Transects	Costs	Acres	Acre
Steagall After	35	$2,555	33	$ 77
China Thin	27	$2,155	10	$216
Clear Lunch After	32	$2,572	18	$143
Meadow 4	33	$1,803	10	$180
Meadow 5	20	$1,551	6	$259
Frosty 1	17	$1,236	15	$ 82
Frosty 2	27	$2,015	11	$183
John Day	18	$1,151	10	$115

DISCUSSION

The monitoring results confirmed the suspicions of land managers and resource specialists. Machine piling and the cumulative effect of multiple entries typically resulted in excessive soil compaction.

The Forest has taken the following action to correct the situation:

- Fuel management direction has been clarified to reduce the overall extent of slash disposal. It is no longer expected that, all slash will be treated. Acceptable fuel profiles for fire protection are represented by Fuel Model 11 as described by Hal Anderson (1982).

- Skid trail impact is maintained at acceptable levels by the use of designated skid trails approved prior to felling. They are considered part of the permanent transportation system in that they will be used again. Skid trails are routinely waterbarred for erosion protection but are seldom scarified.

- Restoration of units exceeding the standards will be completed at the first opportunity. On low quality sites, it may not be warranted until regeneration harvest occurs. The Forest is presently locating several sites to evaluate the effectiveness of the winged subsoiler for alleviating compaction.

The sampling procedure worked very well for. monitoring cutting units to determine if they were within the limits of the Regional Soil Protection Standards. One unit (China Thin) appeared to be more compacted than the results showed. The problem was that the unit itself and the surrounding area had been so extensively impacted from past management activity that good, undisturbed bulk densities could not be found. The densities used to compute mean undisturbed density for the unit were probably high, which would result in an underestimate of total soil compaction.

The guidelines proved to be easy to use, adaptable to a variety of situations and conditions, and defensible.

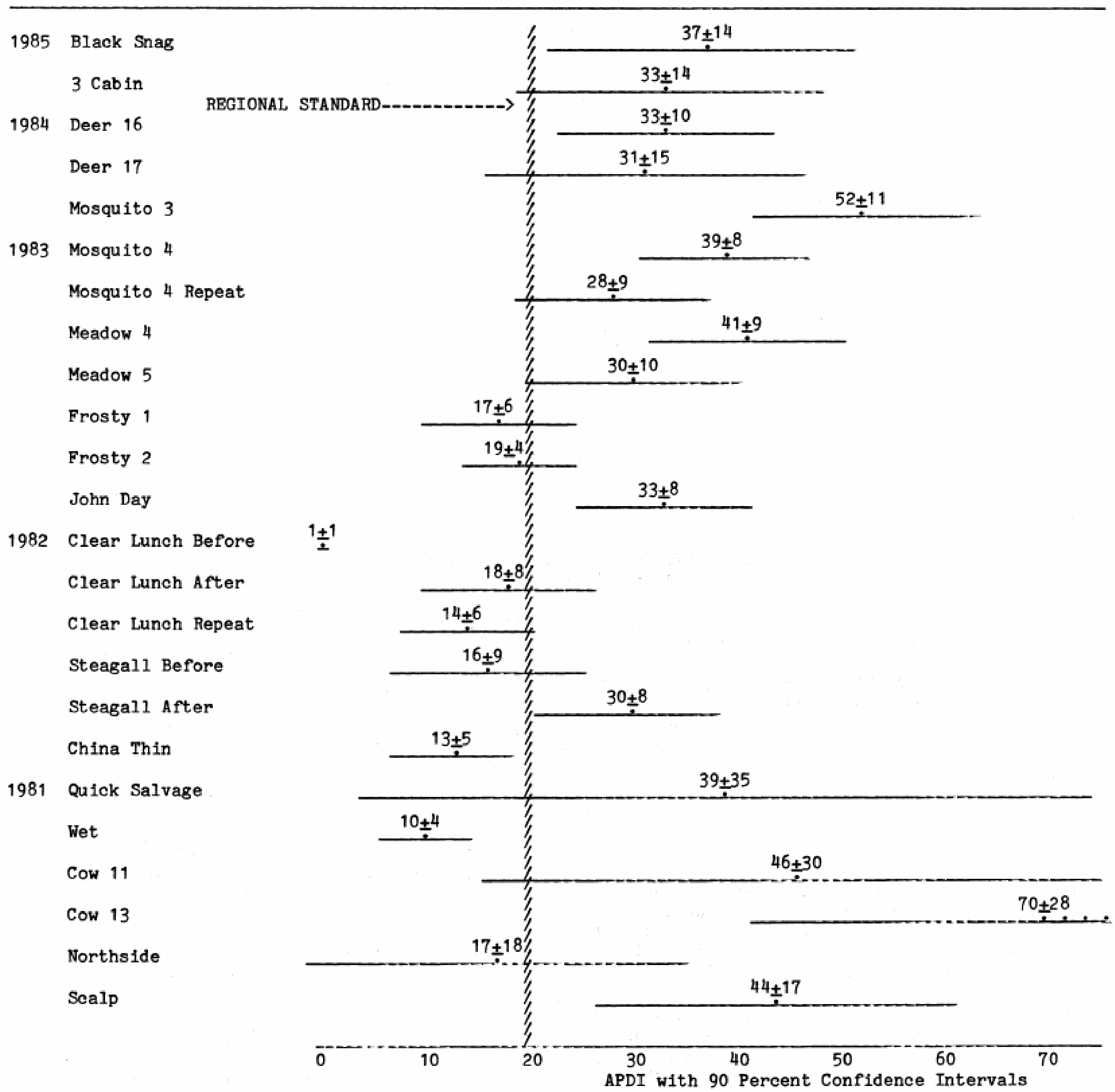


Figure 2--Average Percent Detrimental Impact (APDI) with 90 Percent Confidence Intervals.

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ESTIMATION OF SITE INDEX IN FOREST INVENTORIES OF COASTAL ALASKA--AND OTHER CONFESSIONS

George L. Rogers

ABSTRACT: Forest inventory designs and procedures used in coastal Alaska are discussed and questions are raised which require users to look underneath the processed results in order to understand which information may need to be qualified or adjusted. Some suggestions for improvement are offered.

INTRODUCTION

When Earl Ford invited me to present a paper for this workshop I accepted thinking I could simply describe in 10 minutes or less how site index (SI) information is collected in timber inventories in coastal Alaska.

When I sat down to write, however, I recalled from my experience with forest inventories that users rarely dig into design or data collection. techniques enough to know which parts of the output need to be qualified or adjusted for specific uses.

It has been stated that the definition of an economist is one who can pronounce SUPPLY AND DEMAND and _hat a forester is one who can pronounce GROWTH AND YIELD. It follows, I suppose, that a soil scientist is one who can pronounce CATION EXCHANGE CAPACITY AND BULK DENSITY. Regardless of the concepts or terms a specialist is required to pronounce, he/she can do justice to them only if there is understanding, in some detail, of the design and techniques used to collect and process the basic data used to describe them.

My objectives in this paper, therefore, are to: 1) review the purpose of timber inventories, 2) give a brief description of the most recent (1978-1985) timber inventory designs used on the five inventory units of the Tongass and Chugach National Forests with specific reference to methods of collecting SI data, 3) compare results with a previous inventory, and 4) make a few suggestions for improving future inventories. I am afraid this will take more than 10 minutes" even though I have no R^2 values to give out and promise not to list the names of all the soil series, associations, and complexes in coastal Alaska.

PURPOSE OF TIMBER INVENTORIES

Three classic questions a timber inventory should be designed to answer are: 1) How much? (area and

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volume by species, size, damage, age, and site class, etc.) 2) What, is the rate of change over time? (the same classes) 3) Where is it? (how the various classes are, distributed geographically) Estimates of SI and associated potential productivity have always been included, but they are becoming more important as a basis not only for comparing potential timber values with values of competing resources, but also to provide a credible basis for projecting yields and allowable cuts. Answers to these questions are necessary to perform reliably the functions of forest planning. Information from forest inventory is aggregated, disaggregated, analyzed, and used by foresters, economists, biologists, soil scientists, and other specialists. Other uses include "feeding" and improving our growth model and as "first cut" information far project planning until better, more site-specific information is available. The Resources Planning Act [1/] also requires these answers.

TIMBER INVENTORY DESIGNS AND PROCEDURES

Our most recent inventory cycle (1978-1985) used three different designs. All included soil-based estimates of SI because over 90 percent of the forest land in coastal Alaska is occupied by stands of old-growth timber that are not suitable for direct estimates of SI based an total height and age.

The 1978 Chugach inventory (Kenai and Prince William Sound units) used a double sampling design based on 25,000 one-acre photo interpreted (PI) points drawn from 100 percent photo coverage for area estimates. Two hundred and sixty-three one-acre, 10-variable point ground plots were randomly drawn from PI points classified as forest land capable of producing at least 20 cubic feet per acre per year in fully stacked stands at culmination of mean annual increment (C.M.A.I.). Site index was based an the soil ecosystem, classification method developed by Stephens and others in 1969 [2/], extended to. the Chugach, National Forest. The extension, although applied to the entire forest, was actually applicable only to the western part of the Prince William Sound unit where immature soils predominate. Estimates of SI for much of the forest were, therefore, probably underestimated. We are currently lacking information to. check or make refinements in the estimates of SI.

Regardless of probable errors due to improper application of soil-site relationships on the Chugach National Forest, the system itself is based an easily recognized field characteristics such as depth and color of mineral soil, relative drainage, depth to water table, and the ability to distinguish between organic and mineral soils as well as between mature and immature sails. The field procedure includes looking over a one-acre plat, predicting its SI and then digging a pit to, a depth of 24 inches, or to bedrock. If the keyed soil has a tabulated SI that differs greatly from predicted SI, additional pits are dug to determine if additional soil types are present. A soil classification is recorded for each of the 10 points, and SI for the plot as a whole is based on the soil type found at the greatest number of points--not a mean SI for all 10 points. The same inventory design and method of determining SI was used far previous inventories of the Tongass National Forest. The inventory design (not map-based) does not provide much in the way of in-place information beyond the block level (blocks may be 100,000 acres or more). The Chugach National Forest now has a 100 percent timber type map which, although the inventory sample was not drawn from the mapped strata, could provide a link to the inventory far in-place information needs. Experience with the soil ecosystem method for estimating SI has shown a high degree of repeatability among individuals after only one or two. days of training.

The 1982 Chatham Area timber inventory was a stand exam type of in-place inventory. Fifty-five primary sampling units were drawn with probability proportional to. size (PPS) from the total list of 316 units, averaging 18,000 acres. Within each primary sampling unit a secondary sampling unit, about 250 acres in size, was randomly located and systematically sampled with variable plots at an intensitity of one plot per five acres. Site index was estimated from a separate soil survey of the same 250 acre units, but the delineated soil taxonomic units did not coincide with the timber type map polygons. Therefore, each timber plot carried a SI based an the mapped sail unit within which it fell. Site index, in other words, was an average far a particular soil unit and was not determined specifically far each timber plot or stand. Accumulated totals might be similar if sampling intensities were the same. However, several things happened which raised questions. They were: 1) the soil map (actually a monoural photo tracing) that was produced for the timber inventory had a resolution of 20 acres compared to five acres far the timber map, 2) soil units were sampled at varying intensities depending an the judgement of the individual sail specialists, and 3) About five percent of the timber plots could not be assigned a reliable estimate of SI because of distortion in the soil photo tracing when overlayed an the timber type map. So we are unsure how precise the SI estimates are.

The 1984 Stikine Area.and 1985 Ketchikan Area timber inventories utilized a 100 percent timber type map. Variable five-point plots were used, covering abaut five acres. The plot sample was systematically drawn by means of a grid overlay with a random start. This resulted in proportional allocation of the sample to. all strata within the forest land--even if not mapped. This of course cannot happen if there are more strata than samples. If we were only interested in existing

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[1/] The Resources Planning Act (PL 93-378) of 1974.

[2/] F. R. Stephens, C. R. Gass, R. F. Billings, and D. E. Poulson. Soils and associated ecosystems of the Tongass. USDA Forest Service Alaska Region, draft report, June 1969.

volume we could have sampled more efficiently using optimum allocation. Proportional allocation, however, gave a better distribution of plots across all strata than would optimum allocation, and we believe better correlation of timber values with other resources and conditions and offered an easier link with future timber and nontimber inventories.

For the first time in coastal Alaska, soil specialists were a part of the timber inventory crew. Soil pits were dug, described, and classified at each point of each plot in unmapped soils and in highly variable mapped soils. This left about 30 percent of the locations which the specialist did not visit. At these location the crew dug pits and recorded soil depth and color, indicator plant species, whether mineral or organic, etc. The soil specialist then made an office determination of whether to accept or modify the classification recorded on the soil map. We consider this the best method to date for estimating SI.

One aspect of the field procedure needs review. Pit location at each point was subjective, left up to the soil specialist. Each pit was to be located to best represent average SI around a point, but it had to be within the range of trees tallied by a 40 basal area factor prism, and could not be within the 1/294-_acre fixed plot at point center as we did not want to disturb the fixed plot-- the source of all data on non-tree vegetation and trees less than five inches in diameter at breast height. All point locations were permanently located but pit locations were not documented.

The original intent was to establish a pit 10-12 feet due north of each point. It soon became apparent that many such pit locations would fall on rock outcrops, in heavy brush, or on atypical microsites. This would not be a problem with a large number of samples, but it could be with a relatively small sample based on a sampling error of plus or minus 10 percent per billion cubic feet at one standard deviation. After discussions with Forest soil scientists and consideration of available funds and people, it was decided to vary pit location based on experience and judgement of the soil specialists.

COMPARISON OF RESULTS WITH PREVIOUS INVENTORIES

The only information available to compare with previous results is from the Stikine Area of the Tongass National Forest (table 1).

There appears to be little difference in means in table 1, but they should be used with caution because they are based on c lass midpoints. Also, SI in the 1984 inventory was based on the tallest spruce (Stephens and others [3/]) converted to

Table 1--National site productivity class, site index, and percent of capable forest land by inventory year for two forest inventories on the Stikine Area, Tongass National Forest

Productivity Class	Productivity Range	Site index[1/] Mean	Site index[1/] Range	Capable Forest Land[2/] 1972	Capable Forest Land[2/] 1984
	cf/a/y[3/]	-----Feet-----		---Percent---	
1	225+		162+	--	--
2	165-224	148.0	134-161	--	--
3	120-164	122.5	111-133	29	41
4	85-119	102.0	93-110	56	34
5	50- 84	82.5	72- 92	15	17
6	20- 49	61.0	50- 71	--	7
7	< 20	45.0	< 50	--	2
			Mean site index=	105.0	104.1

Taylor's (1934) SI curves for comparison. These are preliminary estimates. Final productivity estimates for the 1984 inventory will be available after conversion to Farr's (1984) base age 50 year site index curves. Along with the conversion, new SI ranges will be established to reflect CMAI of material 5.0 inches and larger, rather than 7.0 inches and larger noted in the table. No samples of SI greater than 133 occured in either inventory. No samples below 72 in 1972 might be explained as a result of clustering effects inherent with random sampling as compared with more even distribution associated with systematic sampling. Or it may be a result of independent PI efforts at classifying productivity classes greater than or less than 20 cubic feet per acre per year.

An extension of the above table for 1984 to include land mapped as not capable of producing 20 cubic feet per acre per year would show that about 55 percent of the 968,000 acres have a SI greater than 50 and, therefore, are capable of producing more than 20 cubic feet per acre per year--actually about 40. This points out a problem which is often overlooked; that is, potential productivity , unless otherwise stated, assumes

[3/]F. R. Stephens, C. R. Gass, R. F. Billings, and D. E. Paulson. Soils and associated ecosystems of the Tongass. USDA Forest Service Alaska Region, draft report, June 1969.

[1/] Based on mean height of dominant and codominate western hemlock and Sitka spruce at a total stand age of 100 years. In this example, the SI ranges established to match the productivity class ranges were developed from a mean annual increment table (Taylor-1934) for material seven inches and larger in diameter at breast height and six inch inside bark top diameter.

[2/] Land capable of producing at least 20 cubic feet per acre per year.

[3/] Cubic feet/acre/year.

full stockability. We know that stockability is limited in some stands and that the condition is most prevalent in areas classed as incapable of producing 20 cubic feet per acre per year. The apparent error in map classification, then, may not be as bad as it first appears, but we have not developed adequate methodology to adjust for the potential productivity implied by a measure of SI.

FUTURE IMPROVEMENTS

I have pointed out or implied a number of inventory design and/or procedural problems associated with estimates of SI and productivity of forest soils. Before "fixing" all of these on our way to perfection, we should answer a question central to the realms of inventory information and forest planning. What is really needed or required with respect to map scale and degree of resolution and precision of attributes--not to mention common mapping units? This has been discussed for a long time but not fully resolved, with the possible exception of map scale. Maybe we cannot get there from here, or maybe we need an economist who, can not only pronounce SUPPLY AND DEMAND, but also can help analyze the costs/risks of making wrong decisions based on inventory information.

In any case, there would appear to be several opportunities for improvement in inventory design and definitions, such as:

1) The 20 cubic feet per acre per year lower limit for capable forest land is somewhat of an artifact. Land suitable for timber production now requires consideration of all forest land regardless of estimated productivity. Our recent inventories on the Tongass National Forest included sampling of all forest land, but more work is needed to validate the classifications on the lower sites.

2) Sample size in timber inventories has been based on total volume and current growth. If the precision of estimates of potential productivity is important, then we need to determine if adequate samples are taken to estimate mean SI.

3) Site index estimates for the Chugach National Forest need to be checked and probably improved. There may be enough data existing to do this, such as from stand exams, etc.

4) Intuition tells us that the procedures recently used to estimate SI on the Stikine Area and Ketchikan Area inventories are better than using the older soil ecosystem method. However, enough doubt is raised from table 1 that a similar but more thorough analysis should be done for the Chatham and Ketchikan Areas. If no appreciable gains are achieved by the current method then perhaps the soil ecosystem method should be updated and used because it is less expensive to apply. Regardless of the method used in the future, pit locations on permanent plots should be documentated so they can be relocated and checked at the next visit--probably 10-15 years in the future.

5) A fixed plot could be used to reduce bias associated with SI and stockability estimates. For example, a quarter-acre circular plot around each sample point could be segmented and considered accordingly to assess variation and obtain an average value for each. Development of a defensible methodology could be interesting and challenging. Some of the problems to be worked out are: a) Should a portion of a plot that is not stockable carry a SI of zero? This is different than a portion of a plot which is stockable but not fully stockable. b) Should a rock outcrop covering a fourth of the plot and with enough trees present to call it at least minimumly stocked, be considered stocked? A SI can be measured directly here if the trees are of suitable ages, etc., but what should we require for establishment period? Would we classify the same outcrop non-stockable or 50 percent stockable if no trees were present? c) How large would a non-stocked or partially-stockable portion of the plot need to be to require an adjustment from full stockabiity?

6) With Geographic Information Systems on the horizon, there may be an opportunity to improve our estimates of SI, especially on the Chatham Area, by combining the soil and timber maps to reduce or eliminate the need to expand information from the ground plots.

Finally, as we continue to improve our methodology we should remember that an inventory is a description or assessment of the resource at a point in time. Adjustment of it to some future time will be easy if future influences remain the same as those of the past. Eventually we will need to deal with change such as those due to climate, acid rain, and ozone, and how they may affect forest soil productivity.

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AN APPROACH TO SOIL PRODUCTIVITY ASSESSMENT IN SOUTHEAST ALASKA

Willem W. S. van Hees

ABSTRACT: Efforts to relate timber site productivity to site characteristics often revolve around procedures equating site index to various soil characteristics. An alternative to this approach is presented that uses volume equations developed for individual trees on different forest ecosystem soils and compares the results for statistically significant differences. These unique equations are suitable for quantifying differences in site productivity.

INTRODUCTION

In southeastern Alaska, as elsewhere, quantification of vegetative productivity, usually timber, as a function of soil and site characteristics has been a subject of great interest to research scientists. Such knowledge is critical to resource managers for long-range planning.

Examining the relation between vegetative productivity and soil characteristics consumes substantial research time and money but has been justified by the reasonable assumption that soil characteristics are among the most important site characteristics affecting production.

The most common measure of timber site productivity is site index--the height of dominant or codominant trees at some chosen index age. (Note that the term is "site index," not soil productivity index.") Typically, a scientist will relate site index (SI) directly to soil characteristics (SC) through regression analysis (SI = f(SC)).

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SOIL PRODUCTIVITY VERSUS SITE INDEX

Site index is, in some ways, an inexact quantity to use in regression analysis. Determining site index at a given location involves tree height and age which are then used in a site index table or in a site index equation. These tables and equations were likely developed through regression analyses. Thus, any regression analysis using a dependent variable (such as SI) established through a previous regression analysis is incorporating variability inherent in the first analysis and increasing the "fuzz factor" of the current analysis.

Zahner (1957) attemped to relate site index to soil characteristics. Although his coefficients of multiple correlation were good, he noted that site index is elusive because it is changeable; it can be altered by genetic character of the trees, weather cycles, and impacts from animals and insects.

Measurement of site index is often subjective with respect to selection of the dominant or codominant tree(s). Is the particular tree selected really representative of site capacity for potential productivity? That is difficult to answer; and in development of site index equations, a scientist strives to observe many trees on many sites so that the average tree selected for site index measurements is representative of that site.

Baker and Broadfoot (1979) address subjectivity. They note that it is difficult to objectively select and quantify measurable soil characteristics that consistently reflect potential tree growth. They developed a method that predicts site index within 5 feet of measured site index 95 percent of the time if all soil-site factors are correctly evaluated. To do this, they looked at four major soil factors with 23 subdivisions and rated each subdivision as "best," "medium," or "poor" based on the potential contribution to tree growth. This requires a high degree of familiarity with the species and site combinations used to adequately identify, a priori, what constitutes the best and worst levels of each soil property. This is not realistic for areas where little is known about such relations, such as in southeastern Alaska.

Subjectivity of site index estimation must be kept in mind when a researcher works in old-growth stands. Coile and Schumacher (1953) note that measuring site quality (through site index estimates) requires a known relation between the total tree heights and ages of dominant or codominant trees in well-stocked, even-aged stands and that this approach to site quality measurement is inappropriate on lands not supporting stands of such ages and stocking distributions. Much of the timberland in southeastern Alaska contains old-growth stands. These stands are often not well stocked (even on poor sites, a managed stand 150 years old should produce about 8,000 cubic feet per acre (Taylor 1934); the average old-growth stand in southeastern Alaska ,has less than 6,000 cubic feet per acre (van Hees in press)and is not even-aged. Estimating site index on such sites is difficult.

A final thought on using specific soil characteristics as independent variables in, regression analysis is the contribution a given soil characteristic makes to growth or productivity of a specific vegetative species. Even. though a regression analysis can be performed for each combination of species and soil characteristic a scientist wishes to examine, a given soil characteristic may be., important to the health and productivity of one species but not to another. This complicates decisions on selecting soil variables to measure for multiple silvicultural objectives and for integrated resource inventories.

THE ALTERNATIVE

In simple terms, site, productivity means "How much can the site produce over a given time span?" The particular item on the site that does the actual producing is the tree. Other than site index (which accounts for height growth), a commonly used measure of tree production is tree volume growth or, more directly, tree basal area growth coupled with height growth. Volume growth (Vg) can be expressed as annual, periodic, or cumulative growth--whichever suits your needs.

Good functional forms already exist to express the type of volume growth you are interested in. The forms are often reciprocal or exponential functions and have been useful to many foresters (Spurr 1952).

Expression of site productivity (tree growth) as a functional relation between site index and soil characteristics seems round about. Tree growth rate, for example, at a given point is more directly a function of tree diameter than of soil characteristics. Over the life of the tree, the soil will have an effect on growth; a growth equation will express that effect through the magnitude of predicted growth values. So, develop a number of growth equations for each species on soil A, then do the same for each species on soil B. After these sets of equations have been developed, test them to see if they are unique. If the equations are unique, you can then comment about the productivity differences between soils. If the equations are not significantly different from each other, combine the data, develop a combined equation, and recognize that neither soil is likely better than the other for timber productivity of the tree species in question.

AN EXAMPLE,

A study I recently completed (van Hees in preparation) is an example of such an approach to soil productivity assessment. Periodic annual cubic-foot volume growth percent was equated to tree diameter at breast height and percent of live-tree stocking on the site. Inclusion of live-tree stocking addressed the influence stand density has on tree growth. Regression analysis was performed for five tree species on seven forest ecosystem soils. The tree species were Alaska-cedar (*Chamaecyparis nootkatensis* (D. Don) Spach), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.), Sitka spruce (*Picea sitchensis* (Bong.) Carr.), and western redcedar (*Thuja plicata* Donn ex D. Don). The forest ecosystem soil classification is the one developed by Stephens and others (1969) for the Tongass National Forest, Alaska; it groups standard U. S. Department of Agriculture Soil Conservation Service soil series classifications into broader ecosystem categories based mainly on elevation, soil drainage, and soil depth. Further refinement was based on similarities ,in soil texture, development, and structure. See table 1 for a brief description of the ecosystem soils used in this study.

Regression equations were initially developed for each tree species and soil combination having more than 30 observations. F-tests were performed on all equations within a particular ecosystem category, followed by tests on equations between categories. With the exception of Alaska-cedar, mountain hemlock, and western hemlock on F2r soils, and Alaska-cedar and western hemlock on F5 soils, all equations within and between ecosystems were significantly different from each other. For the exceptions, data were combined and new equations developed.

Table 1--General characteristics of some southeastern Alaska forest ecosystem soils.

FOREST ECOSYSTEM 1/	DRAINAGE	DEPTH	TEXTURE
F1	Well drained	Greater than 10 inches mineral soil over bedrock	Sandy loam to silt loam
F2	Freely drained	Less than 12 inches, shallow to bedrock	Peat over gravelly loam
F2r	Well drained	Duff over gravel bedrock	Undecomposed litter over gravelly silt loam
F4	Somewhat poor	Greater than 30 inches generally	Sandy loam to silt loam to gravelly silt loam
F5	Poor	Greater than 24 inches to slowly permeable deposit	Black muck mucky peat
F6	Somewhat poor	Shallow to bedrock	Stony
f1	Well drained	Greater than 36 inches	Silt loam to very fine sandy loam

1/ F indicates ecosystems with mature soils
f indicates ecosystems with relatively fast rates of soil development.
Source: Stephens and others (1969).

A set of tree volume growth rate equations by forest ecosystem soil and tree species were developed. Of 19 equations, 1 (mountain hemlock on F6 soils) fit the data very well (r^2 greater than 0.90), 11 of them fit moderately well (r^2 between 0.70 and 0.89), and 7 fit poorly (r^2 between 0.60 and 0.69); equations for mountain hemlock on F2 and Sitka spruce on F2r soils fit most poorly. I can now say, with varying degrees of confidence, that a given species planted on a given soil will grow at a certain rate (see table 2 for specific growth rates). Given an existing condition, expected growth rates of a healthy tree can also be predicted.

Because most of the equations were significantly different from each other and none tested the same in the between-soils tests, it was apparent that there are differences in productive capabilities of the soils and that the soil classification system used distinguished among the productive capabilities of the various sites.

SUMMARY

The approach to soil productivity I've described maintains ease of application, development, and implementation. It does not, however, identify the soil characteristic(s) most critical to site productivity. It may not always be necessary or even desirable to know the specific soil characteristic but, rather, the relative and quantitative differences between soil productivity levels.

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Table 2--Percent average annual growth rate by diameter at breast height, forest ecosystem soil, and tree species, *for* southeast Alaska.

FOREST ECOSYSTEM SOIL AND SPECIES	DIAMETER AT BREAST HEIGHT (INCHES) 6	8	10	12	14	16	18	20
				---PERCENT---				
F1								
SITKA SPRUCE	13.25	7.64	5.05	3.64	2.79	2.24	1.86	1.59
WESTERN HEMLOCK	14.78	8.27	5.26	3.62	2.63	1.99	1.56	1.24
F2								
ALASKA-CEDAR	4.92	2.26	1.03	0.37	-0.03	-0.29	-0.47	-0.60
SITKA SPRUCE	5.31	3.59	2.67	2.11	1.72	1.45	1.25	1.09
WESTERN REDCEDAR	5.19	3.73	2.86	2.27	1.85	1.54	1.30	1.10
WESTERN HEMLOCK	10.99	6.10	3.83	2.61	1.86	1.38	1.05	0.82
MOUNTAIN HEMLOCK	20.57	11.05	6.65	4.26	2.81	1.88	1.23	0.78
F4								
ALASKA-CEDAR	7.57	4.80	3.34	2.46	1.87	1.45	1.13	0.89
SITKA SPRUCE	6.32	3.66	2.43	1.76	1.36	1.09	0.92	0.79
WESTERN REDCEDAR	5.71	4.13	3.18	2.55	2.10	1.76	1.49	1.28
WESTERN HEMLOCK	8.43	4.72	3.01	2.08	1.52	1.16	0.91	0.72
MOUNTAIN HEMLOCK	13.02	6.86	4.01	2.47	1.53	0.93	0.51	0.22
F5								
ALASKA-CEDAR AND WESTERN HEMLOCK	4.89	2.73	1.73	1.19	0.86	0.64	0.50	0.39
SITKA SPRUCE	3.29	2.08	1.53	1.22	1.05	0.92	0.85	0.79
MOUNTAIN HEMLOCK	2.53	1.45	0.94	0.67	0.51	0.40	0.32	0.27
F6								
MOUNTAIN HEMLOCK	10.85	6.01	3.76	2.55	1.81	1.33	1.01	0.77
F2r								
ALASKA-CEDAR, WESTERN HEMLOCK, AND MOUNTAIN HEMLOCK	5.13	2.87	1.83	1.26	0.92	0.70	0.54	0.43
SITKA SPRUCE	5.72	3.32	2.22	1.61	1.25	1.01	0.85	0.74
f1								
SITKA SPRUCE	9.72	7.44	6.07	5.16	4.50	4.01	3.63	3.33

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PRELIMINARY ANALYSIS OF FOUR SOIL VARIABLES AND THEIR RELATION TO SITE INDEX OF SITKA SPRUCE IN SOUTHEAST ALASKA

Earl W. Ford, Wilbur A. Farr, and Chien Lu-Ping

ABSTRACT: A soil-site study is underway in the western hemlock (*Tsuga heterophylla* (Raf.) Sarg.)-Sitka spruce (*Picea sitchensis* (Bong.) Carr.) forest type of southeast Alaska to determine if soil properties are related to site index. If so, prediction equations will be developed so that land managers can estimate the future productivity of forested lands currently occupied by stands of old-growth timber. In this preliminary analysis of four variables commonly used to classify forest soils--depth of mineral soil, drainage class, organic carbon content, and coarse fragment content--soil drainage and coarse fragment content were found to be significantly related ($p < 0.05$) to site index.

INTRODUCTION

The western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) - Sitka spruce (*Picea sitchensis* (Bong.) Carr.) forest type occupies about 11.2 million acres of forest land in southeast Alaska, of which about 6.6 million acres is classified as commercial forest land. About 400,000 acres of the type have been harvested over the past 70 years by clearcut logging. Much of the remaining 93 percent consists of old, uneven-aged stands.

Several pieces of legislation directly affect the management of timber and soil resources on the Tongass National Forest: one requires that the Forest Service manage timber as a renewable resource without impairment of the long-term productivity of the land; another requires that a certain amount of timber be available for the long term.

The Multiple Use Sustained Yield Act (1960) was passed by the U.S. Congress on June 12,1960. This act requires the Forest Service to manage "all the various renewable surface resources of the national forests so that they are utilized in the combination that will best meet the needs of the American people." The act also requires the Forest Service to achieve and maintain "in perpetuity a high-level annual or regular periodic output of the various renewable resources of the national forests without impairment to the productivity of the land."

Passed on December 2,1980, by the U.S. Congress, was the Alaska National Interest Lands Conservation Act (1980), which requires the Forest Service to "maintain the timber supply from the Tongass National Forest to dependent industry at a rate of four billion five hundred million foot board measure per decade."

Timber inventories of the Tongass National Forest confirm that the forest has the standing volume; to meet the harvest mandate. The inventories,

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however, measure total volume on the forest today, which is mostly old-growth timber. The inventories do not estimate potential yields from even-aged stands growing on the same lands. To accomplish this with precision requires reliable estimates of future site productivity for lands now occupied by stands of old growth. Current estimates of future growth potential after harvest of the old growth are limited and untested.

Site index, the measure used to assess site quality of the coastal forests (Farr 1984), is based on the mean height of the taller spruce or hemlock in even-aged stands at 50 years of age at breast height. With the exception of about 400,000 acres of .even-aged stands, the forest of coastal Alaska are old growth. Trees in old-growth stands usually are not free to grow throughout their life, so they should not be used to estimate site index.

A study by Stephens and others (1968) indicated that site index can be estimated from soil depth and drainage; the conclusion was based on 92 plots, all in stands; originating after fire or logging. Data from stands after blowdown were not included because the authors estimated that site index is reduced by about 20 feet in such stands. The authors identified seven soil groups based on soil depth and drainage, and estimated mean site index and standard deviation for each group. Their mean site index values were then applied in the ecosystem classification system for the Tongass National Forest.[1] This classification system has drawn support as well as criticism among foresters and soil scientists. When National Cooperative Soil Survey standards were implemented for National Forest inventories in Alaska in 1980, the ecosystem classification system was mostly discontinued. All soil surveys on National Forests in Alaska are now conducted in accordance with standard procedures from Soil Taxonomy (Soil Survey Staff 1975).

In 1980, a study was initiated to develop productivity ratings for old-growth stands in southeast Alaska based on soil-site factors.[2] The objectives are to test for actual relations of site index to soil properties for the major soil types represented on commercial forest land in southeast Alaska and to estimate mean site index and variance for each important soil series or association of series. Detailed data have been collected on 291 plots, and a soil-site data base has been developed. Analysis of information in this data base will allow for enhancement and tests of validation of previous work.

The purpose of this paper is to examine the relation of site index of Sitka spruce to four common soil classification factors--depth of mineral soil, soil drainage, organic carbon content, and coarse fragment content.

METHODS

Soil and site-index information was collected on 291 plots on the Tongass National Forest (fig. 1). All plots were below 500 feet in elevation. No data was collected from higher elevations because of the cutting history on the forest.

The predominant soil on each plot was classified to series, based on Soil Taxonomy (Soil Survey Staff 1975). Where the soil series was not known, the soil was classified to family. In a few cases a taxadjunct or variant was used. Soil boundaries were delineated where more than one soil was found on a plot, and a pit was dug to represent each soil. Soil samples were taken from each pit and a sample of each horizon of a pedon was sent to the National Soil Survey_ Laboratory at Lincoln, Nebraska, for chemical and mechanical analyses. All descriptive information for each plot along with the laboratory data is being stored at the Federal computer center in Fort Collins, Colorado.

In this study, 116 of the 291 plots were used for analysis because complete information was available for them in the data base. The plots were grouped, by depth of mineral soil, drainage class, organic carbon content, and coarse fragment content. Classes for these variables are defined in table 1.

Significant differences in mean site index. between classes were tested by one-way analysis of variance.

RESULTS

Four soil orders were identified and sampled on the Tongass National Forest--Spodosols, Histisols, Entisols, and Inceptisols. Spodosols were most common; relatively few Histosols, Entisols, and Inceptisols were sampled.

A one-way analysis of variance was first run to test the null hypothesis -that mean site index of Sitka spruce is the same for all classes of depth of mineral soil. The hypothesis was accepted ($F = 0.80$; table 2). Mean site index was clearly similar for all classes, and the range in site index within classes was wide.

Results were similar when the data were grouped into the depth classes used by Stephens and others (page 3, 1968) for well-drained and moderately well-drained pedons ($F = 0.50$, table 3). This analysis showed no relation between site index of Sitka spruce and depth of mineral soil, contrary to the results obtained by

[1] F. R. Stephens, C. R. Gass, R. F. Billings, and D. E. Paulson. Soils and associated ecosystems of the Tongass. USDA Forest Service Alaska Region, draft report, June 1969.

[2] Earl W. Ford, Wilbur A. Farr, and Roy Sidle. Development of productivity ratings for stands of old-growth western hemlock and Sitka spruce in southeastern Alaska based on soil-site factors. Study plan on file, Forestry Science Laboratory, Juneau, Ak., 12 p.1983.

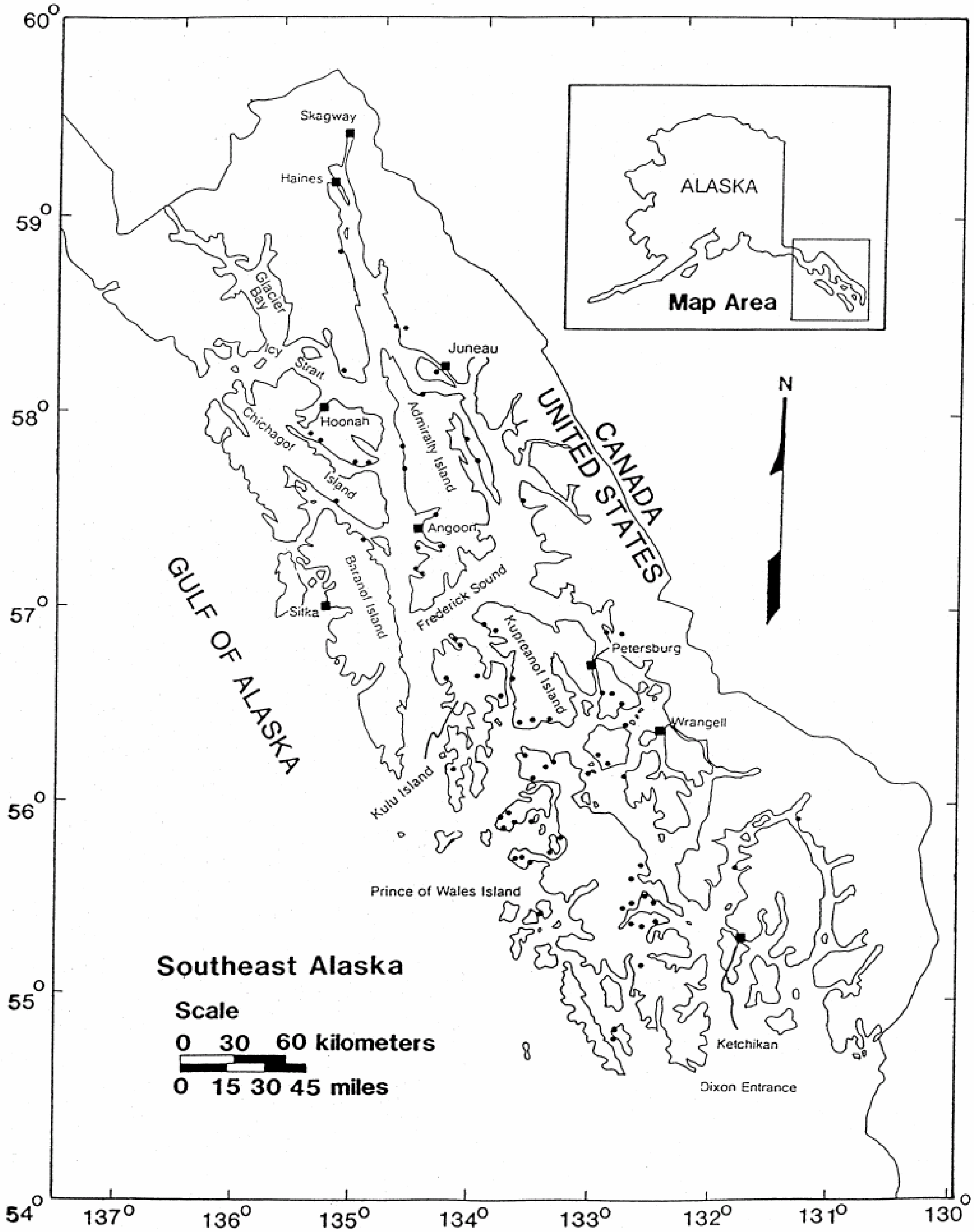

Figure 1.--Distribution of soil-site index plots in southeast Alaska.

Table 1--Definitions of depth of mineral soil, drainage, organic carbon, and coarse fragment classes.

DEPTH OF MINERAL SOIL

1 - <10 inches deep

2 - 10-20 inches deep

3 - >20 inches deep

DRAINAGE

1 - Moderately well and well drained

2 - Somewhat poorly drained

3 - Poorly drained

4 - Very poorly drained

COARSE FRAGMENTS, VOLUME

1 - Skeletal: more than 35 percent rock fragment in the control section

2 - Nonskeletal: less than 35 percent rock fragment in the control section

ORGANIC CARBON CONTENT

Spodosols (well drained)

1 - More than 6 percent organic carbon in the upper 10 cm of the spodic horizon and more than 20 inches deep (Humic Cryorthods)

2 - 1.2-6 percent organic carbon in upper 10 cm of spodic horizon (Typic Cryorthods)

3 - More than 6 percent organic carbon on a weighted average in upper 30 cm of spodic horizon and a free iron-to-carbon ratio of 6 or more. (Typic and Lithic Cryohumods)

4 - More than 6 percent organic carbon in upper 10 cm of spodic horizon and soil less than 20 inches deep (Humic Lithic Cryorthods)

Spodosols (poorly drained)

5 - Poorly drained with a free iron-to-carbon ratio greater than 0.2 (Sideric Cryaquods)

6 - Poorly drained with 1.2-6 percent organic carbon in spodic horizon and a free iron-to-carbon ratio of less than 0.2 (Typic Cryaquods)

Other soils (moderately well and well drained)

7 - Other moderately well and well drained soils (Cryofolists, Cryothents, Cryumbrebts)

Other soils (poorly drained)

8 - Other poorly drained soils (Histosols)

Table 2--Mean, minimum, maximum, and standard error for site index of Sitka spruce by depth of mineral soil, southeast Alaska. [1]

Depth of mineral soil	Obser-vations	Site index (50 years)			
		Mean	Min	Max	Standard error
Inches	Number	Feet			
<10	13	96	48	119	5.47
10-20	16	91	67	119	3.72
>20	87	97	42	123	1.88

[1] No groups were significantly different at the 0.05 level of probability.

Table 3--Mean, minimum, maximum, and standard error for site index of Sitka spruce by depth of mineral soil for well-drained and moderately well-drained soils, southeast Alaska.[1]

Depth of mineral soil	Obser-vations	Site index (50 years)			
		Mean	Min	Max	Standard error
Inches	Number	Feet			
<2	7	90	48	107	8.46
2-10	6	101	77	119	6.40
>10	103	97	42	123	1.62

[1] No groups were significantly different at the 0.05 level of probability.

Table 4--Mean, minimum, maximum, and standard error for site index of Sitka spruce by soil drainage class, southeast Alaska.[1]

Soil drainage class[2]	Obser-vations	Site index (50 years) Mean	Min	Max	Standard error
	Number	Feet			
WD & MWD	96	98	42	123	1.73
SPD	9	91	73	116	4.33
PD	6	82	56	120	5.57
VPD	2	74	48	101	26.16

[1] No groups were significantly different at the 0.05 level of probability.

[2] WD = well drained; MWD = moderately well drained;

SPD = somewhat poorly drained; PD = poorly drained;

VPD = very poorly drained.

Table 5--Mean, minimum, maximum, and standard error for site index of Sitka spruce by soil coarse fragment class, southeast Alaska.[1]

Coarse fragment class	Obser-vations	Site index (50 years) Mean	Min	Max	Standard error
	Number	Feet			
Skeletal	57	92	42	123	2.51
Nonskeletal	59	100	48	123	1.95

[1] The two classes were significantly different at the 0.05 level of probability.

Table 6--Mean, minimum, maximum, and standard error for site index of Sitka spruce by organic carbon group, southeast Alaska.[1]

Organic carbon content group	Obser-vations	Site index (50 years) Mean	Min	Max	Standard error
	Number	Feet			
1 Humic Cryorthods	43	97	54	123	2.74
2 Typic Cryorthods	16	100	42	120	5.25
3 All Cryohumods	9	100	78	117	4.79
4 Humic Lithic Cryorthods	9	88	67	107	4.79
5 Sideric Cryaquods	5	105	83	120	8.00
6 Typic Cryaquods	6	79	56	91	5.12
7 Other well-drained and moderately well-drained soils	18	100	72	119	2.92
8 Other poorly drained and very poorly drained soils	10	90	48	107	5.60

[1] No groups were significantly different at the 0.05 level of probability.

Stephens and others (1968). Relatively few plots were on very shallow soils (0 to 10 inches deep) in our study, however. Additionally, no attempt was made to stratify the sample based on other factors, such as classification or depth of organic matter above the mineral soil; these factors could have masked the importance of soil depth.

A one-way analysis of variance was also run on soil drainage classes. This test showed that mean site index was significantly related to soil drainage (F = 2.76, table 4). The decline in mean site index with decreased drainage is evident, but the considerable range in estimated site index within each drainage class is unexplained.

The data were also divided into two classes based on coarse fragment content. An analysis of variance showed a significant difference in mean site index of Sitka spruce between the coarse fragment classes at the 5-percent level of probability (F = 5.344, table 5).

The significant difference between skeletal and nonskeletal classes may be because nonskeletal soils tend be more highly weathered with more available nutrients. Nonskeletal soils also have greater volume of soil material available for root growth and nutrition than do skeletal soils.

Organic carbon content of the spodic horizon is used in the classification of Spodosols. The Spodosols are grouped into six classes in table 1. Other well-drained and moderately well-drained soils were placed in a seventh class and the other poorly drained soils (histosols) into an eighth class. An analysis of variance showed a borderline significant difference in mean site index of Sitka spruce among the eight classes (F = 2.080, table 6).

Some values in table 6 are of considerable interest. The Sideric Cryaquods, for example, have a mean site index of 105 for spruce, the highest of any class. Why these somewhat poorly drained soils have such a high mean value is hard to explain. Are these soils truly somewhat poorly drained, or are they saturated with freely moving water, and actually moderately well drained? If they are somewhat poorly drained then why is their mean site index some 26 units higher than for other similarly drained Spodosols--the Typic Cryaquods?

Obviously, much is yet to be learned about these soils and how soil variables are related to site index.

CONCLUSION

Preliminary results suggest that soil taxonomic factors alone may not be reliable predictors of site index. A larger data set, however, may show that site index can be reliably predicted from some combination of soil drainage, coarse fragment class, and physical and chemical properties.

Site productivity based on soil drainage and coarse fragment content alone would result in broad land divisions of limited utility for land-management planning because soil drainage is only used in soil classification at the higher strata of the classification system, namely in suborders or subgroups. Coarse fragments are used to differentiate soils to family.

Alone, these two factors are not sufficient to allow land managers to make the detailed assessments or land allocations necessary to meet congressional mandates for managing the Tongass National Forest. A more detailed analysis of physical and chemical variables is needed.

To meet land-management planning requirements of the National Forest Management Act, soil surveys. are being conducted at medium intensity and soils are being mapped to series. We believe that reliable estimates of site index can eventually be made at the series level, although much more field sampling will be required.

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EFFECT OF PODZOLIZATION ON SOIL FERTILITY

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ABSTRACT: The process of podzolization preferentially occurs in cool to cold humid climates dominated by conifers or heath species. Spodosols and Podzols occupy 4.3% of the soils of the world or 0.56 billion hectares (Foth and Schafer. 1980). Most of the well drained soils of British Columbia and SE Alaska are affected by the process of podzolization. The purpose of this extended abstract is to show how podzolization influences the movement and distribution of nutrients and non-nutrient elements in a forest soil.

At the present time there is still debate about the mechanism of podzollzation and currently two major contrasting theories exist. The fulvate theory (Duchaufour. 1982) involves the chelation of Fe and Al by mobile fulvic acid. produced in the litter, and the transport and arrest of these complexes at the Bhs/Bs interface. Subsequent decomposition of the organic ligand frees the Fe and Al allowing them to migrate into the Bs where they precipitate or. as in the case of AI, interact with silica to form non-crystalline substances. Farmer's theory (Farmer, 1982) invokes the formation of soluble aluminosillcate positivly charged sols (proto-imogolite) in the E horizon and their migration in the B where they become arrested and form the Bs horizon. Fulvic acid. uncomplexed by metals, migrates from the forest floor and is precipitated on the imogolite surfaces forming the Bhs horizon.

I have proposed a third theory that explains more fully the process of podzolization and the formation of imogolite or other noncrystalline substances in the Bs horizon (Ugolini and Dahlgren, 1987). This theory involves the formation of carbonic acid (H2CO3) by the reaction of H2O with CO2 produced by organic matter decomposition, and root and microbial respiration. Carbonic acid is the weathering agent that attacks the minerals liberating bases and silica and leaving an Al-rich residue. Imogolite and other noncrystalline substances: are synthesized in situ as silica combines with the Al released by H2CO3 weathering. Concomitant with these processes fulvic acid synthesis occurs In the forest floor. Fulvic acid forms organo-metal complexes with the Fe and Al in the E horizon. The resulting complexes migrate in the profile until arrested when Interacting with the noncrystalline substances previously formed. This theory conceives, therefore. two chemical compartments: in the upper. the major proton donor is the fulvic acid that lowers the pH, prevents the

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dissociation of H_2CO_3, attacks the minerals. complexes the Fe and Al and other metals and moves them into the Bs where these metal-organo-complexes are arrested. The arrest of these complexes is induced by the presence of noncrystalline substances and causes the formation of the Bhs horizon. Carbonic acid dominates the lower compartment, now able to dissociate because it is no longer depressed by the acidity of the fulvic acid arrested at the Bhs/Bs interface. Carbonic acid weathers the minerals and provides the conjugate base, the bicarbonate. for ion transport. This theory is based on the data collected over ten years of research on the Spodosols of Findley Lake, a small basin in the central Cascades. Washington. In addition these data were corroborated by investigations in Alaska in both the boreal and the coastal rain forests and subalpine forest of NE Japan.

At the Inception of these studies it was decided that the composition and interpretation of the soil solution collected in situ would represent the most direct way to assess the contemporaneity of soil forming processes. Soil solution was obtained by the use of tension lysimeters placed beneath genetic horizons and maintained at 10kPa. The mechanisms of transport and the Interaction between the migrating soil solution and the surficial physical-chemical properties of the solid phase are key for the understanding of soil processes and the distribution and availability of nutrients and non-nutrient elements.

Critical in understanding of migration and distribution of elements is the role played by the biota, in this case the dominant species of the high elevations of the Cascades. At Findley Lake recent work by Vogt and others (Vogt et al. 1987a, b) and Dahlgren (Dahlgren 1987) has shown that 98.3% of the annual increment of Al goes into the belowground biomass whereas only 1.7% in the above- ground biomass. It is therefore clear that both the <u>Abies amabilis</u> and the <u>Tsuga mertenslana</u> significantly contribute to the redistribution of Al In the ecosystem. There is also a close relationship between the Al present in the roots and levels of inorganic Al in the different soil horizons (Vogt et al. 1987a). Roots growing in the Bhs horizon have higher Al concentrations in their tissues than those growing in the forest floor and E horizons. Aluminum distribution in the root system corresponds to the level of this element in the soil solution; the higher the Al concentration in the soil solution the higher; is the Al content in the roots (Dahlgren. 1987). Because of the high root turnover In these sub alpine ecosystems. Vogt and others (Vogt et al. 1987a), speculated that the uptake and accumulation of Al in the roots may be deleterious to their tissues causing root mortality. The large investment of photosynthates for the annual replenishment of dead roots is the price that these species pay for growing in this AL-dominated ecosystem (Vogt et al 1987a, b). On the other hand these conifers have developed an ecologically competitive advantage over other non-Al-tolerant species.

Let's consider now the role of podzolization in terms of nutrient distribution and availability. In the upper compartment, O. E. and Bhs horizons, the pH is low (3.8 to 4.3) and with the exception of the organic horizons where the Ca and Mg dominates the exchangeable cations, Al prevails in E and Bhs. At Findley Lake, in these horizons both the Ca and Mg represent only 8%, while Al occupies 92% of the exchangeable sites. Total nitrogen is high in the forest floor with values of 1.5 to 1.8%, but decreases to low values in the E (0.08%) and in the Bhs (0.58%). Total P is concentrated in the forest floor (0.15%) and it acquires value less than 0.01% in the rest of the profile. (Dahlgren, 1984). Because of the strong leaching regimen imposed by the fulvic acid in the upper soil compartment nutrient cations such as Ca. Mg and K are readily leached and arrested in the Bhs. Nutrient supply to plants comes from the release of ions in the forest floor where 60% of the fine roots are found.

In the lower compartment, Bs, BC and C, carbonic acid is the major proton donor and the pH is in the vicinity of 5.0. In this, mineral compartment Al dominates the exchangeable complex whereas only a small fraction is occupied by Ca and Mg. Total N ranges between 0.14 and 0.17% while total P is less than 0.01%. Weathering and ions transport in this compartment are due to carbonic acid and the conjugate base bicarbonate, in addition to sulfate and chloride.

Vegetation is directly and indirectly. responsible not only for the distribution and mobility of ions in the soil but also for the existence of the two chemical compartments. Both Abies amabllis and <u>Tsuga mertensiana</u> are responsible for driving the pedological processes by providing organic acids, either derived from root exudates or indirectly via decomposition of their litter. Fulvic acids and other organic chelators that originate from decomposition or plant exudates are water soluble and capable of forming inner sphere complexes with Al and Fe. Consequently both metals are depleted from the upper soil compartment where fulvic acid prevails. Root and microbial respiration. on the other hand, are responsible for the production of CO_2 that upon reacting with water produces carbonic acid - H_2CO_3. Bicarbonate, a conjugate base of carbonic acid. a weaker acid than fulvic acid (pKa H_2CO_3 = 6.3 vs. pKa fulvic acid = 4.5), is not capable of forming a soluble inner sphere complex with polyvalent metals (AI, and Fe). Therefore, Al and Fe tend to accumulate In the compartment where carbonic acid prevails. The Al may react with silica forming noncrystalline substances (allophane/imogolite) whereas the Fe may form the mineral ferrihydrite. The chemical behavior of the two proton donors -- fulvic and carbonic acids, explains the absence of imogolite and allophane in the upper soil compartment, E and Bhs horizons where the fulvic acid dominates, and their presence in the lower compartment, Bs, BC and C horizons where the carbonic acid prevails (Ugolini and Dahlgren, 1987).

The physical and chemical properties of allophane/imogolite play an enormous role in pedogenesis and ecosystem processes. Specifically they are involved in 1) providing an effective sink for AI, thus preventing the escape of these ions into the ground water and surface water flows; 2) providing an effective pH buffering mechanism by absorbing both H^+ and OH^-; 3) displaying variable charged surfaces capable of exhibiting both cation and anion exchange capacity; 4) displaying anion adsorption capable of non-specifically and specifically adsorbing Cl. SO_4, F and PO_4; 5) retaining heavy metals in order of decreasing affinity Pb>Cu>Zn>Co, Cd; 6) arresting mobile organic acids and preventing their migration into the ground water and 7) providing the precursor minerals for the synthesis of layer silicates.

In conclusion, podzolization occurs as a close association between pedogenic and biotic processes; these processes occur in a cool to cold hyperhumid climate. This climate is responsible for the low rate of organic matter decomposition and the incomplete organic litter breakdown that leads to the formation of fulvic acid. The strong percolating regimen and the presence of fulvic acid within the upper soil horizons promote a dissolution of minerals with release of plant nutrients and mobilization of Fe and Al as soluble metal-organo complexes. The migration from the surface and the arrest of these complexes in the Bhs and Bs horizon create an effective retention of the metals and nutrients within the solum. Recent research in SE Alaska has shown that P also migrates from the surface and it is arrested in the Bhs horizon (Spaltenstein, personal communication, 1987) In a Spodosol, therefore, one can distinguish two major nutrient pools: one in the forest floor and one in the Bhs horizons. The release of nutrients from the forest floor is a function of the rate of decomposition that in the Pacific silver fir ecosystem is 2 to 3 times less than in the Douglas-fir region (Edmonds, 1980). In the Bhs horizon the release of nutrients is also, in part. a function of the decomposition of the ligand and dissolution of precipitates e.g. Al_phosphates. In both situations the release is considerably slow. The prevailing consensus that spodosols are not very fertile soils is supported by our recent studies.

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MODELING APPROACHES TO THE ANALYSIS OF SITE PRODUCTIVITY

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ABSTRACT

Site productivity can be measured relatively easily by accessing the change in the quantity of biomass or volume of the desired product over any time period. This measurement could yield a direct estimate of past productivity on a particular site. The accuracy of a prediction of future production based on measurements of past production has to be judged on the basis of the similarity of past site characteristics to current or future conditions. Growth and yield tables have to be used with these restrictions in mind.

One solution to the problem is to develop response surfaces (regression equations) of the effects of growth-controlling variables on productivity. A multiple regression type of model could be used to predict growth based on a combination of environmental parameters averaged over the growing season or some other selected time period. As an example, a water balance model (Spittlehouse and Black 1981) was calibrated for a white spruce, stand in interior Alaska based on data collected by Van Cleve (personal communication) and reported in Van Cleve and Zasada (1976). The model is:

$$dW/dt = P-E-D-R$$

where dW is the change in soil water content over time period dt, p is precipitation, E is evapotranspiration, D is drainage, and R is runoff. The driving variable for the model is net solar radiation. Site characteristics required are root zone depth, soil water retention characteristics, and rainfall interception coefficients. This model was able to predict the seasonal change in soil water content for a calibrated site on a daily basis. A soil water deficit could also be estimated on a daily basis. The soil water deficit was defined to be the difference between maximum potential evapotranspiration under nonlimiting conditions and the estimated actual evapotranspiration for the day. These values'could then be su_ood over the growing season to yield a seasonal soil water deficit. This was done for the four years of the study reported by Van Cleve and Zasada (1976). The seasonal soil water deficit was then related to the average basal area growth per tree. The resulting equation had an r^2 of 0.79 indicating a high degree of control of basal area growth due to moisture availability during the time period of the study.

The model just described is relatively simple and can be programmed using a spreadsheet program on a desktop computer. This model also only considered moisture. If moisture was not limiting growth in these stands the correlation coefficient between growth and soil water deficit should have been much lower or very lo\v soil water deficits would have been calculated. In that case it would have been necessary to use a more comprehensive set of environmental factors (i.e. temperature, moisture, nutrients, etc.) which in some cases may be linked to the specific vegetation growing on the site. For example, the nutrient quality of litterfall can be related to the type of species growing on the site and litterfall quality has been related to nutrient availability for tree growth. There are several examples of more comprehensive ecosystem type models; FORCYTE, STAND, and LINKAGES are three.

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As an example of the type of analysis that can be accomplished with a larger ecosystem model, LINKAGES was calibrated for upland white spruce sites in interior Alaska. The model adequately represented the expected successional sequence from aspen to mature white spruce over a 300 year time period. The model was then programmed to allow the inclusion of various management scenario's. The four management scenario's used by Yarie (1986) were run and the results indicated that as a result of intensifying forest management we can expect a degradation in site quality (i.e. a decreased harvest in successive rotation). The decrease appeared to be related to a decrease in site forest floor biomass and available nitrogen.

The results of large ecosystem models have to be considered to be a hypothesis of effects of modeled activities. The model has allowed us to predict far into the future (200-1000 years). The next step after we have these predictions is to establish long term studies that can be used to monitor key variables. If these variables respond as the model predicts over a 10 to 50 year time period then our long term prediction may, to some extent, be validated.

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WHITE SPRUCE SITE INDEX IN THE KANTISHNA AND COPPER RIVER AREAS OF INTERIOR ALASKA

Darrell R. Kautz

ABSTRACT: In conjunction with soil surveys in Alaska, the Soil Conservation Service estimates soil-site index as a measure of forest soil productivity. Results indicate that white spruce site indices are higher for most soils in the Kantishna area than in the Copper River area.

INTRODUCTION

Soils of Interior Alaska vary tremendously in their natural potential to grow trees. At one extreme are poorly drained soils underlain by shallow permafrost which support only stunted, widely spaced black spruce (*Picea mariana* (Mill) B.S.P.). At the other are well drained soils without permafrost on which grow tall, well stocked stands of white spruce (*Picea glauca* (Moench) Voss) and paper birch (*Betula papyrifera* Marsh.). Of greater interest to forest planners, managers, and users, particularly those concerned with the production of timber and other wood products, are the less apparent, smaller magnitude differences in the potential productivity of the more productive forest soils. Many forest planning and management decisions are based, in part, on potential productivity. Soils of high productivity can be given the most intensive management while those of lower productivity can be managed with a minimum input of labor and capital (Soil Conservation Service 1980).

Site index, defined as the height growth of dominant and codominant trees at a specified age, provides a measure by which forest planners and managers can interpret the relative productivity of forest soils. Site index also can be used for entering volume tables or as an independent variable in growth and yield prediction models (Bell and others 1984). In conjunction with the USDA Soil Conservation Service soil survey program in Alaska, trees of all major species on all major forest soils are routinely measured in order to estimate site index.

White spruce, the most productive conifer and major commercial species of interior Alaska, grows across a wide range of soil and site conditions. This species grows best on well drained soils on south-facing hill slopes, stream terraces, and flood plains where trees occasionally exceeds 100 feet (30m) in height and 20 inches (50 cm) in diameter. In Alaska, white spruce is used for house logs; milled into dimension lumber; used for posts, poles, and timbers and burned for firewood.

The purpose of this paper is to report estimated white spruce site index for forest soils in the Kantishna and Copper River soil survey areas of interior Alaska.

DESCRIPTION OF THE SURVEY AREAS

Both the Kantishna and Copper River soil survey areas (fig. 1) are in the taiga Forest ecosystem of interior Alaska. The

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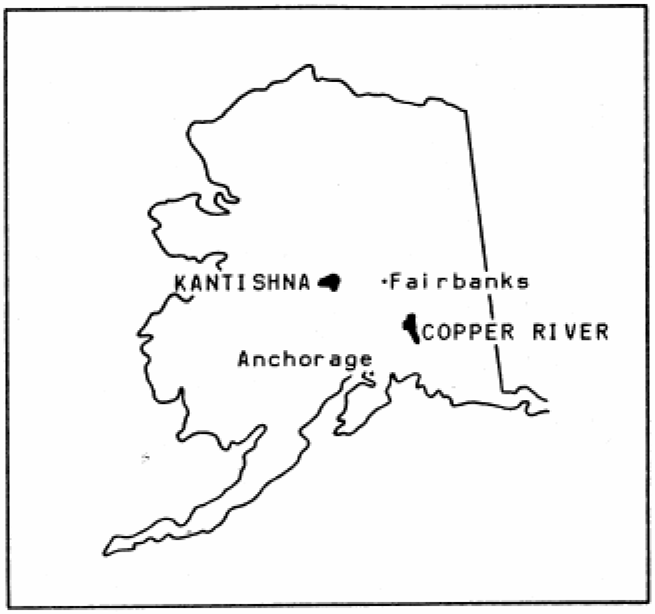

Figure 1.--Location of the Kantishna and Copper River Soils survey areas, Alaska.

taiga consists of a mosaic of forest types and includes pure and mixed stands of white spruce, black spruce, paper birch, quaking aspen (Populus tremuloids Michx.), and balsam popular (Populus balsamifera L.). Vegetation patterns are largely the result of variations in topographic and edaphic conditions and post-fire forest succession.

The climate of interior Alaska is characterized by long cold winters and short warm summers. Temperatures range from -50 degrees F (-45 degrees C) or less in winter to occasionally over 90 degrees F (32 degrees C) in summer. Mean annual air temperature is approximately 26 degrees F (-3 degrees C). Mean annual soil temperature at a depth of 20 inches (50 cm) in many interior soils ranges from 30 to 34, degrees F (-1 to 1 degree C)_ Both the Kantishna and Copper River areas lie within the zone of discontinuous permafrost (Pewe 1969). Mean annual precipitation ranges from about 9 to 16 inches (22.9 to 40.6 cm), of which 50 percent or more usually falls as rain between April and September (Allen 1983). Although the growing season is short with occasional freezing temperatures, conditions for the growth of trees are favorable during the long summer days.

Kantishna Soil Survey Area

The Kantishna area is located in the central interior of Alaska, approximately 100 miles (160 km) west of Fairbanks (fig. 1). The area extends from the Kantishna River west to the Cosna River and from the Tanna River south for approximately 20 to 30 miles (32 to 48 km). Elevations range from about 250 feet (76 m) along the Tanana River to over 2100 feet (640 m) at the top of Mooseheart Mountain. The survey area consists primarily of an extensive outwash plain composed of sandy and sandy-skeletal glaciofluvial deposits. Much of the outwash is mantled with a thick layer of eolian sands which are formed into longitudinal and rosette patterned, stabilized dunes. Resistant bedrock hills, of which Mooseheart Mountain is the most prominent, protrude above the outwash and dunes in a few places. The entire area of outwash, sand dunes, and hills is mantled with a layer of silty loess of varying thickness. Other features include wide meandering flood plains along the Kantishna and other major rivers.

A detailed description of the survey area, associated soils, and factors of soil formation is found in the Soil Survey of the Kantishna Area, Alaska (Olszewski, in preparation).

Copper River Soil Survey Area

The Copper River area is located in southcentral Alaska approximately 150 miles (240 km) east of Anchorage (fig. 1). The area extends from the village of Gakona southeast for 5 to 20 miles (8 to 32 km) on each side of the Copper River to the town of Chitina. Elevations range from about 600 feet (183 km) at the confluence of the Copper and Chi tin a Rivers to slightly over 2400 feet (732 m) southwest of Glennallen. A broad, nearly level terrace composed of clayey lacustrine deposits is the most extensive feature in the survey area. Along the Copper and other major rivers, a step sequence of stream terraces formed as the river downcut through the lacustrine terrace. Other features include wide, braided flood plains along the rivers, scattered morainal and resistant bedrock hills, extensive till plains, and other glacial landforms.

A detailed description of the survey area, associated soils, and factors of soil formation is found in the Soil Survey of the Copper River Area, Alaska (Clark and Kautz, in preparation).

SOIL-SITE INDEX CORRELATION

Policies and procedures used by the Soil Conservation Service for conducting soil-site index correlations are described in detail in the National Forestry Manual (Soil Conservation Service 1980). For soil surveys in Alaska, soil-site index data are collected during the course of daily soil survey field operations. Field crews consist of a soil scientist and a forester or trained range conservationist or

Table 1--Estimated white spruce site index (index age 100 years) for productive forest soils in the Kantishna and Copper River areas of interior Alaska.

	Number of Stands Sampled	Site Index\1		
		Avg	STD	CV
Kantishna area	22	91	16.7	18
Koyukuk silt loam	8	102	9.6	9
Nenana silt loam	4	101	10.9	11
Zitziana silt loam	3	86	13.7	16
Beales silt loam	7	74	13.3	18
Copper River area	61	70	9.7	14
Copper River silt loam, lacustrine substratum	6	77	8.2	11
Gulkana silt loam	14	74	10.6	14
Klawasi silt loam, lacustrine substratum	5	72	9.8	14
Klutina very fine sandy loam	7	70	8.7	13
Mendeltna silt loam, lacustrine substratum	3	69	8.6	12
Nizina very fine sandy loam	5	69	7.3	11
Pippin silt loam	5	69	11.2	16
Tolsona silt loam, till substratum	5	65	13.9	22
Copper River silt loam, silty substratum	5	64	5.9	9
Copper River silt loam, till substratum	6	64	5.3	8

1/ Average in feet; calculated for each sample stand based on Farr (1967). STD = standard deviation. CV = coefficient of variation.

biological technician. In most areas, crews can anticipate the occurrence of suitable stands of trees and associated soils for sampling using photo interpretation and by observing the landscape while flying or driving to and from the field. Daily fieldwork and route of travel are planned accordingly. This approach minimizes the need to dedicate personnel or field time exclusively for the collection of soil-site index data.

Stands selected for sampling Include both pure stands of white spruce as well as mixed stands of spruce and hardwoods. Only moderately well stocked, even-aged stands are sampled. The desired minimum sample size is 5 stands on each productive forest soil. During most soil surveys, which continue for 2 or more years, 2 or more soils occasionally are correlated into a single soil while others may be split into separate soils. By the time the survey is completed, the sample for some soils usually consists of more than 5 stands and for other soils 15 fewer than 5. For soils of minor extent or soils extensively impacted by wild fires, finding 5 suitable stands to sample is not always possible or practical.

Within each sample stand, an area representative of overall stand conditions and approximately one-quarter acre in size is selected for sampling. Before site trees are measured, the soil scientist determines that the soil throughout the sample area is representative of the soil body on which the stand is growing. The soil scientist describes a soil profile near the center of the sample area and classifies it to the series level (Soil Survey Staff 1975).

Breast height age and diameter and total height of 5 or 6 dominant or codominant trees between about 50 and 180 years old are measured in each sample stand. All site tree, soil profile, and related site data are entered into an automated data base for storage and analysis. White spruce site index is calculated for each stand using the equation given in Farr (1967). Average site index, sample variation, and sample size are reported in the final soil survey report.

RESULTS AND DISCUSSION

Average white spruce site index for the Kantishna area is 91 feet (27.7 m) compared to an average of 70 feet (21.3 m) for the Copper River are a (table. 1). Farr (1967) reported average site indices of 84 feet (25.6 m) for the Tanana River uplands between Fairbanks and Nenana and 62 feet (18.9 m) for the Copper River plateau.

To a large degree, the more rapid growth of white spruce and higher average site index In the Kantishna area can be attributed to the lower elevation of the area and a more favorable growing season. Twenty-one of 22 sample stands in the Kantishna area were less than 750 feet (229 m) in elevation. In the Copper River area, 53 of 61 sample stands were between 750 and 1500 feet (229 and 457 m) elevation, while all of the others *were* above 1500 feet (457 m). Climatic data from points in and near each area indicate that the growing season in the Kantishna area is both longer and warmer than in the Copper River area. The Kantishna area also receives slightly more summer precipitation (Allen 1983).

In both the Kantishna and Copper River areas, root distributions observed in excavated soil pits and on windthrown trees indicate that most white spruce roots occur within the surface 20 to 30 inches (50 to 76 cm) of soil. In both areas, this surface rooting zone consists partly to entirely of silty loess. In the Kantishna area the loess contains substantial amounts of mica while the Copper River area loess is of mixed mineralogy. To determine if any physical or chemical differences between these loess types could account for differences in white spruce site index, laboratory data for soil samples from each area were compared. Characteristics compared included bulk density, available water capacity, cation exchange capacity, organic carbon, total nitrogen, and soil react ion (pH). Except for more acidic soil reaction (lower pH) for loess from the Kantishna area, no other differences were apparent. Presumably, differences in environment due to elevation outweigh any minor differences in the physical and chemical characteristics of the rooting zone.

Within each survey area, white spruce average site index varies considerably between soil types (table 1). In the Kantishna area, the most extensive and productive forest soils occur on well drained, stabilized sand dunes. Soils on the dunes are classified and differentiated primarily on the basis of the thickness of the silty loess layer above the sandy substratum. On the average, site index increases as the thickness of the loess cap increases. Associated with increasing loess thickness is an increase in the available water capacity of the primary rooting zone. Average site index is highest on Koyukuk and Nenana soils. Koyukuk sorla have greater than 40 inches (101 cm) of loess and Nenana soils have 20 to 40 Inches (50 to 101 cm). The next highest site index is on Zitziana soils, which have 10 to 20 inches (25 to 50 cm) of loess. Beales soils, with less than 10 inches (25 cm) of loess, have the lowest average site Index (table 1).

Unlike many places in Alaska, flood plains in the Kantishna area do not have extensive areas of well drained, productive forest soils. Instead, most soils have shallow permafrost and are very poorly drained or ponded. Where productive forest soils do occur, they tend to be restricted to narrow stringers on the crests and backslopes of levees next to the river channel. Trees on these soils were not sampled for site index.

Productive forest soils in the Copper River area occur on a variety of landforms with an equal variety of parent materials. Productive forest soils are found on lacustrine terraces, stream terraces, flood plains, and various glacial landforms. Compared to the Kantishna area, average white spruce site index in the Copper River area apparently does not vary much between soils (table 1). Further, higher site Indices are not associated with any obvious or consistent soil properties except for the presence of free carbonates in the substratum. Copper River lacustrine Substratum and Klawasi lacustrine substratum soils both have clayey substrata with strong coarse granular structure. Mendeltna lacustrine substratum soils have dense, clay loam substrata with poorly developed structure. Gulkana, Klutina, Nizina, and Pippin soils have sandy to sandy-skeletal substrata. Allof these, soils have free carbonates present in the substratum.

Slightly lower site indices are found on soils which lack free carbonates in the substratum. Talsona till substratum and Copper River till substratum soils have dense, loarny glacial till substrata. Copper River silty substratum soils are formed in deep, structureless silt loam loess.

A few soils on steep hill slopes in the southern portion of the Copper River area were not sampled for site index even though they supported productive forest growth. This portion of the survey area had not been impacted by recent wild fires and most white spruce were greater than 200 to 250 years old. Cores from a number of sample trees showed periods of suppressed growth and signs of advanced heart rot.

In both the Kantishna and Copper River areas, variation in estimated site index between sample stands is considerable for most soils (table 1). Much of the observed variation undoubtedly reflects the natural spatial variability in soil productivity. Soil productivity is influenced by a complex variety of interrelated soil, site and other environmental factors that vary widely and independently across the landscape. The cumulative effects of such factors do not necessarily coincide with artificial limits and categories associated with soil series. Some variation also can be attributed to differences in stand histories of the individual sample stands which result in different rates of tree growth independent of soil and site potential. Stand characteristics that impact tree growth include genetic potential of trees, density of trees, competition with other vegetation, climatic conditions during the course of stand development, and the occurrence of disease and insect pests.

CONCLUSIONS

Factors that affect potential soil productivity and site index include climate, biological potential of trees, associated organisms, topography, and soil physical and chemical properties. All of these factors vary to varying degrees between the Kantishna and Copper River areas; however, the higher productivity of the Kantishna area can be attributed largely to a more favorable growing season associated with lower elevations.

Within each area, differences in soil-site indices can be associated with observable soil physical and chemical properties, regardless of whether actual processes and cause-effect relationships are known or understood. Further, these soil properties can be displayed on soils maps and interpretative maps for forest planning and management purposes. Depending on the level of Planning and management activities anticipated, soil classification and mapping to phases of soil series, based on such factors as aspect, slope position, and elevation can be accomplished to minimize variation and increase the reliability of site index estimates. However, the intensity of observation and documentation necessary to support soil phase breaks for interior Alaska may not be practical or cost effective.

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VEGETATION PRODUCTIVITY AND SOIL FERTILITY IN POST-FIRE SECONDARY SUCCESSION IN INTERIOR ALASKA

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ABSTRACT: Forest ecosystem development in interior Alaska is associated with dramatic changes in the distribution and supply of resources that support tree growth. With advancing succession, soil nutrients are encountered in increasingly large pools of organic material in the standing crops of trees, shrubs, herbs, bryophytes, and especially the forest floor. In taiga forests the supply of elements important for tree growth is largely dependent on the rate of forest floor decomposition. Fire may rapidly replenish depleted element supplies primarily through combustion of the forest floor.

We examined the effect of the Rosie Creek fire on plant biomass and the pools of important plant nutrients encountered in the forest floor, surface layers of mineral soil, and developing vegetation in examples of the principal forest types burned in the fire. The 3500 ha Rosie Creek Fire occurred during late May and early June 1983 and burned through stands of white spruce, black spruce, paper birch, and aspen in Bonanza Creek Experimental Forest near Fairbanks, Alaska.

In white spruce stands herbaceous development was rapid during the first summer as a result of germination and development of three species from buried seed: Geranium bicknelli, Corydalis sempivirens, and Dracocephalum parviflorum. These species, along with, Epilobium angustifolium, were high in nutrient content because of their ability to take up nutrients that became available immediately following the fire. This trend continued into the second growing season (1984) when these species peaked in cover and biomass. By 1985 they were replaced by more persistent herbaceous species such as Equisetum arvense and Calamagrostis Canadensis Herbaceous biomass in the white spruce stand reached 183 g/m^2 in 1985. In the birch stand, herbaceous development was much slower the first year than in the white spruce stands due primarily to a much lower presence of the species that developed from buried seed. By the third year (1985), however, herbaceous biomass had greatly increased, reaching to 260 g/m^2, due primarily to the rapid development and spread of Calamagrostis canedensis. On a black spruce site, herbaceous development was slow and reached levels of only 26g/m^2 by 1985. The main herbaceous development in this stand was fro_ several grass species. In an aspen stand, the rapid dense development of aspen suckers (346,OOO/ha) provided competition for development of the herbaceous layer and by the third year the herbaceos biomass had declined from 55 g/m^2 to only 39 g/m^2.

Only two of the five stands developed a significant biomass in the tree and shrub categories. In the aspen stand, the rapid development of aspen suckers produced nearly 250 g/m^2 of biomass the first summer following the

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fire. By the end of 1986_ biomass on the aspen site had increased to over 700 g/m^2 with smile of the aspen suckers as tall as 4.4 m. In a younger white spruce stand the rapid development of basal stem suckers from Salix bebbiana clumps and birch sterns resulted in a continuous build-up of biomass which reached nearly 300 g/m^2 by 1985.

The effects of the fire on element supply for growth of the early post-fire community were measured. Estimates of decomposition rate, soil solution chemistry, and net nitrogen mineralization and nitrification were obtained. Laboratory and field bioassays using tree seedlings Here employed to integrate information on chemistry of soil and soil solution. Analysis of element uptake by the developing post-burn plant community was compared with potential N supply and uptake by mature forest types to examine resource utilization by the early secondary successional vegetation.

In most forest types, the fire resulted in losses of nitrogen but increases in phosphorus, potassium, calcium, and magnesium in the remaining forest floor organic matter. Losses of N amounted to 50% of the initial pool size in heavily burned white spruce sites. There was a slight increase in forest floor N in black spruce. Forest floor pH increased in all forest types, principally reflecting increases in Ca. The amount of this increase was greatest in heavily burned locations. Mineral soil chemistry did not show the consistent changes noted in the forest floor with the exception of heavily burned white and black spruce, where significant increases were noted for pH and exchangeable K and Ca.

The soil physical environment also showed substantial change due to the fire. Soil temperature at the 10-cm depth increased from 2 to 4°C in white spruce and aspen to 10°C in lowland black spruce. Forest floor moisture content generally declined in burned white spruce, aspen, and birch but showed no consistent trend in black spruce forest floors. Mineral soil moisture content did not significantly change as a result of burning.

Decomposition rates increased following burning. Increased microbial activity was reflected in greater supply of inorganic nitrogen for plant use in the soil solution and by field estimates using the plastic bag incubation procedure. Nitrification was most dramatically affected by burning, increasing several-fold in rate of supply for the second growing season (1984) following the fire. The improvement in soil fertility was demonstrated by increased growth of bioassay white spruce seedlings in the field. Total seedling biomass was at least doubled in the burned treatments. Laboratory bioassays, using paper birch seedlings, showed that nitrogen was more limiting than phosphorus in burned forest floors.

With the exception of paper birch, the improvement in nitrogen supply following burning was equal to, or several-fold greater than, plant demand during the second season following the fire. In the birch stand, nitrification was only slightly greater than ammonium immobilization with the result that net supply of N was half that of plant demand.

INTEGRATING SILVICULTURE AND GENETICS IN SOUTHEAST ALASKA

Roy Silen

ABSTRACT: Southeast Alaska is surprisingly productive for its latitude. Its climate is mild for its northerly location. Unlike most of western North America it has ample summer rains and very long days. Also, its two major species, Sitka spruce end eastern hemlock, are already the world's tallest in each genera. This high productivity plus almost unfailing dense reproduction needs a special silvicultural/genetics approach to intensive forest management.

The environment of western North America is far more complex than that of eastern North America where most forest genetics theory originated. Environmental gradients are often steep. As large a change in growing season occurs across small areas like the Olympic Mountains as in all eastern United States.

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Growing seasons are often truncated by the high average elevation and in mid-latitudes by seasonal drought. The strong relationship between effective growing season and inherent growth rate seen in farm crops has been investigated for Douglas-fir using growth data from the huge genetic testing program in the Pacific Northwest, which regularly measures 3 million progeny. Instances of a virtually template-like correspondence between local topographic features and inherent growth rate are seen in many examples where genetic variation has been mapped. Local stands are found to have genetic structure in the sense that their normal frequency distributions of family growth rates center over the expected mean for their position along environmental gradients of cold or drought. Thus, whenever environmental gradients are steep, such as in steep topography or on opposite faces of major ridges, two populations only a few miles apart can be genetically quite different. Still, nearly all local populations embrace enough inherent growth variation to amply serve as parentage for present tree improvement programs.

Agronomy and plant breeding are now highly integrated in agriculture by a yield strategy of simply packing more plants per unit area. The strategy recognizes that yield improvement depends not on growth rate alone, but upon three other factors--harvest index, timing of maturation, and breaking growth contraints with agronomic techniques (fertilizer, irrigation, weed and pest control). Agronomic techniques, not genetics, appear involved in improved biomass production. For a crop like corn, it is agronomy that amplified photosynthate yields--genetics is used to assure correct maturation and to stiffen and shorten the stem, provide more upright leaves and smaller roots for closer packing of plants. Without agronomic improvement of the site, the original agricultural land races often do as well as or better than genetically improved ones.

Worldwide, forest genetics still assumes, possibly erroneously, that breeding for faster growth rates will provide amplified yields. Assuredly, faster growing varieties could shorten the part of the rotation from planting until stand closure and between each thinning with more rapid crown closure. But if site cannot be improved with seed, as agricultural breeding demonstrates, true yield amplification must involve a strategy that recognizes all four components of yield. The key is to use silviculture to enhance biomass, and forest genetics to match such enhancement with an appropriate growth rate. Unfortunately, the constraints of cold and drought in western North America limit potential gains in biomass to perhaps 10 to 50 percent, since these particular constraints are hard to alleviate.

The suggested strategy to integrate silviculture and genetics for most of western North America involves first an appraisal of how much yield improvement is practical with fertilizer and pest or weed control, the two widely available techniques for site enhancement. Then forest geneticists should breed for corresponding growth rate improvements (10-50%) stand by stand. Because stands already have genetic variation of 10 to 50 percent above their mean, there is little point to incur the risk of destroying local stand genetic structure which is valuable for its buffering against multitudinal environmental risks. A plan for producing essentially local improved seed from a clinally arranged seed orchard is already under development in Oregon.

For southeastern Alaska, where 90+ percent of cutovers densely restock naturally, the suggested strategy is even simpler. For those sites where fertilizer and weed control can economically amplify biomass production, a high genetic-selection differential is potentially possible as stands are reduced by thinnings from about 5,000 seedlings to about 100 mature stems per acre at rotation. A land race of appropriately faster inherent growth rate should then develop that is as adapted as the native population. The immediate need is for research to identify and quantify potential levels of biomass enhancement, and to provide guidelines for thinning that will accomplish effective genetic selection.

ALASKA'S TREE IMPROVEMENT STRATEGY PLAN - A CHALLENGE

Earl Stephens

ABSTRACT: The State Forester would be the prime mover in organizing a team to develop a Tree Improvement Strategy Plan. Members of the team would come from public agencies and private industries involved in the management of renewable natural resources. A Tree Improvement Cooperative would be formed to develop a budget and implement the Tree Improvement Program.

INTRODUCTION

Conventional wisdom dictates we have a forest tree improvement program in Alaska. Developing a tree improvement strategy plan does not require reinventing the wheel. Forest tree seed orchards have been established from Scandinavia to South Africa, China to Chile, British Columbia to Brazil. The basic principles and technology are adequately recorded in the literature and we have every reason to be optimistic that significant gains can be made. Our task is to design and implement a program that will fit our needs.

We can plan and plan, but unless plans are backed-up by commitment in the form of funds, all is for naught. To say that tree improvement planning in Alaska is on precarious grounds is an understatement. This is a State whose legislature historically has neglected to support the State Land Reforestation Fund. To compound the situation, another budget cut and the only tree seedling nursery funded by the State will be history. And a tree breeding seed orchard program that is not coupled with a level of forest management based upon artificial regeneration loses most of its potential benefits. We need the commitment of the State to manage our forests at a level commensurate with their potential to produce benefits for Society. Alaska has almost twice as much commercial forest land as any of the Lake States, Minnesota, Michigan, and Wisconsin, still, the budget of the Alaska Division of Forestry, not including fire management, is but a third to one ninth of theirs. Finland with 48 million acres of forestland, a bit less than twice that of Alaska, has 8,000 acres of seed orchards based upon thousands of selected trees. Its plan calls for the artificial regeneration of half of its forestland. That's what I call real commitment.

WE NEED A PLAN

Basic decisions have to be made. Of foremost importance, how do we protect from wild fire the products of a tree improvement program - seed orchards, gene pools, plantations? What are our objectives over the short and long term? What kinds of trees do we want in our forests? Are we going to rely mainly on an extensive approach t9 improve the present forest through silvicultural manipulation such as thinning and natural regeneration, my understanding of the current policy on the Tongass National Forest, or should we go for a tree breeding program in combination with an intensive management system including artificial reproduction on only our best sites?

What of the development of trees for our marginal sites of which we have millions of

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acres, especially since recent inventories indicate that earlier surveys overestimated commercial forestland acreages? Where do exotics fit into our situation? Are we more interested in gross volumes of wood to be reconstituted or should we put effort into the production of quality sawlogs? Specific gravity: high for strong Kraft paper or board, or low for publication grades? Insect and disease resistance? What of the role of fire? How about multi-purpose arboreta for gene pools, provenance trials, exotics? Or multi-purpose trees for biomass-silage production, habitat enhancement, and parks? We need a plan, and its development will require our best thinking.

TEAMWORK

We need not only a wide diversity of genotypes in our breeding program but also a diversity of talents on the team that is responsible for designing and implementing the program. Over the years, tree improvement has become recognized as an essential part of forest management the foundation of which is comprised of a host of endeavors ranging from nursery production to wood utilization, habitat manipulation to recreation and water conservation to aesthetics. Integral to the team is silviculture, ecology (plant, animal, and fire), physiology, genetics, cytology, pathology, entomology, pedology, climatology, wood technology, economics and so forth. I suggest we even include a psychologist-marketing person to sell the program to our legislature!

Any tree improvement program to be successful over the long haul must have an operational (production) phase and a developmental (research) phase. The major objective of the former is to apply genetic principles, establish first generation seed orchards and realize gains as rapidly and efficiently as possible. The developmental phase is concerned mainly with the long term need of an adequate genetic base that is essential for additional gains through succeeding generations of seed orchards. Without supportive research the program eventually ends up in a cul-de-sac. It is this research requirement that justifies the need for having such a broad array of talent on the team.

Team members can be selected from a variety of sources, especially those public agencies responsible for the management of the State's renewable natural resources: Alaska's Department of Natural Resources, Department of Fish and Game and Department of Commerce and Economic Development; all, three branches of the U.S. Forest Service; U.S. Fish and Wildlife Service, Bureau of Indian Affairs, Soil Conservation Service, Bureau of Land Management, the University of Alaska, etc. The private sector should be represented by the Native Corporations and the major wood products industries and associations., The private sector and the Department of Commerce and Economic Development will lead the way as to the kinds of wood that will be required in the future, while other members of the team will define the potentials and chart the way of how to get there.

Since tree breeding is a long term proposition, especially in the boreal forest, and requires continuity of effort, funding, record keeping etc., the involvement of public agencies and large industries that have endured the tests of time and are regarded as "institutions of permanence" is of paramount importance.

The team approach offers many opportunities to coordinate efforts and to economize. Immediately comes to mind the existence of two containerized tree seedling nurseries in the State neither of which is operating near capacity. One is managed by the State Division of Forestry, the other by the U.S. Forest Service. Cooperation could be advantageous.

Just becoming aware of each others' programs and budgets could have a lot of merit. A prime example relates to the Forest Inventory and Analysis Section of the Forestry Science Laboratory, u.s. Forest Service. This group during its forest surveys routinely earmarks "site trees", those specimens which manifest best the growth potential of the sample plot. This could be a good start in the selection of candidates for our tree improvement program.

Alden (1987) has done a great amount of thinking and work pertaining to tree improvement and genetics. He has developed a map of seed collection zones of Alaska. Whether you agree or not with his delineations, they represent a monumental effort and provide a foundation upon which to build and make improvements. He also has a myriad of contacts throughout the northern hemisphere that can be counted upon as sources of seed. The same can be said of Stehlik (1987) who manages the State's tree seedling nursery, and who already is using Alden's seed collection zones to map seed sources.

Viereck and Dyrness (1980) have developed a classification system for vegetation of- Alaska. Another awesome piece of work, it could provide the foundation for the recognition of forest habitat types (Pfister et al, 1974) and the refinement of seed collection zone boundaries.

During the period of 1982-86, the Alaska Department of Fish and Game spent at least $7,000,000.00 developing "Habitat Management Guidelines," a large part of which involved the description of the flora and fauna (OMB, 1983). This work also might contribute to the recognition of forest habitat types and the refinement of seed collection zones. With but a little more expenditure of funds, a forest inventory could have been accomplished that would have been of significant value to the State Division of Forestry and the Department of Commerce and Economic Development.

Teamwork will reveal other opportunities for coordination and economies. The State Forester would appear to be the logical person to spearhead the organization of the team to design the tree improvement plan.

FUNDING THE TREE IMPROVEMENT PROGRAM

There is no precedent for the State Division of Forestry to fund the tree improvement program on its own, and really, there is no reason why it should in the State of Alaska. We are all in this together and all can benefit. Resources and talent exist in ample supply and need only to be organized and brought to bear. A cooperative approach appears to be the way to go.

The funding of cooperatives historically has been based upon acreages of woodland owned by the participants or annual production of pulp, paper, lumber. Another approach is to charge the same annual fee for each participant, regardless of size. Funding should not become a factor of contention. Some members might be better prepared to offer services, sites, equipment, labor, etc. in lieu of funds. Immediately comes to mind the practice of the Forest Science Laboratory's selection of "site trees" in its. forest surveys. Increment cores from such trees sent to the Forest Products Laboratory for physical and chemical analyses would be very worthwhile: we need to know the range of variability within our tree populations of such characteristics as specific gravity, tracheid and vessel length, cellulose content, ecological amplitude, etc. This would be a real contribution to our tree improvement program and could be assigned a value for budget purposes. Many more such examples can be cited. We have the capabilities, they need only to be directed.

IMMEDIATE ACTIONS

1. The basic framework for a tree improvement program will be developed within the next couple of months and distributed to potential participants. Accompanying the plan will be tentative ground rules for the formation of a tree improvement cooperative. Recipients will be asked for constructive criticism and invited to participate in a meeting to organize a cooperative.

2. Pending the results of the aforementioned organization meeting, a tree improvement program will be developed along with a plan and budget to implement it.

INTERMEDIATE ACTIONS

Until the tree improvement program gets underway, the Alaska Division of Forestry will initiate preliminary measures that will lead into the major effort of the Cooperative to be organized.

1. Seed Production Areas. - Seed production areas will be developed to coincide with our timber harvesting schedule thus assuring that forests will be regenerated with local seed until better sources become available. An attempt will be made to enhance the quality and quantity of seed as well as reducing the periodicity of production.

2. Records. Nursery records already include seed source as well as some information on seedling performance. Alden's seed collection zones are being incorporated, and effort will be increased to follow-up on seedling performance including site description, site preparation, and such data pertaining to forest management.

3. Tree Selection. Tree selection criteria will be developed and our personnel will be instructed to be on the lookout for candidate trees for use in the tree improvement program. As resources permit, their physical, chemical, phenological etc. characteristics will be described prerequisite to progeny testing.

4. Nordic Proposal to Cooperate in Provenance Research. Alden will describe the proposal in detail. The Division of Forestry agrees in principle and plans to participate the best it can, if not through funds, by offering services, sites, and materiel. It encourages all others interested in forest management to support this endeavor.

5. Arboreta. With the assistance of the Cooperative, design and begin to establish a series of multipurpose arboreta throughout the State to test the adaptability of native and exotic woody plant species to a range of environments and to serve as gene pools.

THE CHALLENGE

The challenge is before us. Let's accept it and make things happen.

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TREE IMPROVEMENT OF SITKA SPRUCE USING PRECOMMERCIAL THINNING

William H. Pawuk

ABSTRACT: Trees representing contrasting phenotypic traits were identified in a 20 year old stand. One hundred clonal cuttings were taken from 70 trees and rooted to evaluate growth in the greenhouse and field. Results will be used to develop precommercial thinning guidelines that favor desired phenotypes.

INTRODUCTION;

Timber harvests from National Forest lands in Alaska increased steadily from the mid 1950's to the late 1970's, then decreased in the 1980's as timber from private lands became available and the timber market declined.

Natural regeneration was usually adequate to restock cutover land and second growth stands quickly developed. Only five percent of the area required supplemental planting. Usually, 10-15 years after harvest, stocking levels of one to ten thousand trees per acre were common. To achieve desired stocking levels and to increase growth, precommercial thinnings were used. Under current guidelines, thinning begins when trees reach 15-20 feet. If stands are particularly dense, more than six thousand stems per acre, they may be thinned earlier. Faster growing trees are favored during thinning and spruce is favored over hemlock.

From 1980-1984, public work contracts averaging 6339 acres per year were awarded for precommercial thinning (USDA Forest Service 1985). This represented about half of the acreage cut 10-15 years previously.

During this same period, planting steadily declined from 800M to 200M seedlings as backlog areas were planted and harvests decreased.

Because of the small amount of planting in Region 10, development of a genetic tree improvement program centered around breeding and seed production has not developed. However, the opportunity exists during precommercial thinnings to select genetically superior crop trees. Genetic gains can be made if phenotypic characteristics can be identified that predict future growth. Trees possessing these traits can then be favored during precommercial thinnings.

METHODS

During the summer of 1985, Sitka spruce trees exhibiting contrasting phenotypic traits were identified in a 20 year old thinned stand. Traits were selected that could be observed during precommercial thinning. These traits were:

1. long vs short branches
2. upright vs horizontal branching
3. dense vs open crown
4. pendant vs normal twigs
5. green vs blue foliage

Seven pairs of trees from each contrast were identified, tagged, and mapped. During January 1986, 100 cuttings were taken from each tree and placed

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in rooting beds. Half of the cuttings from each tree were rooted at the Heintzleman Nursery and half at the Forestry Sciences Lab in Corvallis, Oregon. Rooting success at each location was good, averaging 61 percent over all clones. Differences in rooting percentages among clones occurred but only five clones failed to produce 25 or more rooted cuttings.

During the winter of 1987, all rooted cuttings were planted into 2-gal containers at the nursery. These cuttings will be grown for one year in greenhouses. Then the best trees from each clone will be selected for greenhouse and field testing.

In the greenhouse test, trees will be grown for 2-3 years and evaluated. It is believed that growth differences will be evident at this time. Field grown trees will require longer periods far evaluation. Field tests will also confirm or refute greenhouse testing as a short-cut method for evaluating growth differences among selected clones.

CONCLUSION:

If growth differences are correlated with phenotype, standards can be included in precommercial thinning contracts to select for beneficial traits and against undesirable traits.

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SPECIES SELECTION FOR FOREST DEVELOPMENT IN ALASKA

John N. Alden

ABSTRACT: Yield of forest resources can be improved on more than 40 million hectares of forest and nonforested land and 10 million hectares of timberland in Alaska. Results of early species and provenance trials in Alaska and after nearly a century of forest development in Iceland have shown that Sitka spruce, Lutz spruce, shore pine, and Sukachev or Siberian larch are among the most productive conifers, and black cottonwood is the most productive broadleaf species in subarctic maritime and subarctic maritime-continental transition climates. White spruce, lodgepole pine, jack pine, Sukachev larch, and Siberian larch are recommended for subarctic continental as well as subarctic maritime-continental transition climates. Species with the most potential for long survival and growth in arctic regions are probably white spruce, Siberian larch, and the balsam poplars. Scotch pine and Siberian spruce may also have potential for forest development in dry arctic and subarctic climates.

INTRODUCTION

Compared to forests at other high latitude and altitude regions of the world, interior and south-central Alaska is impoverished in tree species. At least 6 major glacial advances and retreats during the mid to late Pleistocene Epoch (600,000 to about 16,000 years before present (YBP)) probably reduced the tree species and geographic races that were adapted to the severe climate of Alaska (Hopkins 1967, Critchfield 1984). The fossil record, including pollen, indicates that only balsam poplar, *Populus balsamifera* trembling aspen, *Populus tremuloides* Michx., and tamarack, *Larix laricina* (Du Roi) K. Koch, survived the Wisconsin glaciation (80,000 to about 16,000 yap) in Alaska (Hopkins et ale 1981). Paper birch, *Betula papyrifera* Marsh., then white spruce, *Picea glauca* (Moench) Voss, and black spruce, *Picea mariana* (Mill.) B.S.P., migrated north rapidly from southern refugia after the Wisconsin glaciation (Ritchie 1984) and probably reinvaded Alaska from the east (Hopkins et ale 1981). *Populus balsamifera* extends beyond white spruce tree limits in the Arctic and is the most widely distributed tree species.

Coastal forests are more diverse in tree species than interior forests. Coastal species either survived Pleistocene glaciations on nunataks and on exposed offshore land masses (Daubenmire 1968) or migrated rapidly from a southern refugium

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(Ager 1983). The number of indigenous tree species decreases from 15 in southeast Alaska to 10 in Prince William Sound of south-central Alaska. Only Sitka spruce, Picea sitchensis (Bong.) Carr., balsam poplar, and black cottonwood, Populus trichocarpa Torr. & Gray, or P. bpalsamifera L. x P. trichocarpa Torr. & Gray hybrids, survive at coastal tree limits in southwest Alaska.

We estimate that more than 50 million ha (125 million acres) of land can support forest tree species in Alaska (data on file, Institute of Northern Forestry, Fairbanks). Only 11.4 million ha (28.2 million acres) supported indigenous tree species capable of producing more than 1.4 m^3/ha (20 ft^3/acre) annually at mid century (Hutchison 1967). The purpose of this report is to describe the silvicultural and genetic characteristics of several exotic and native tree species with potential for improving the yield of forest resources in interior and south-central Alaska.

CLIMATE AND POTENTIAL SPECIES

The climate of Alaska is strongly influenced by the Pacific Ocean in the south, the Bering Sea in the west, the Chukchi Sea in the northwest, and the Arctic Ocean in the north. Only east-central Alaska has a true subarctic continental climate. Mean annual temperatures within tree limits range from a high of about 5°C (46°F) (cold temperate climate) in southeast Alaska (Farr and Hard 1987) to a low of -10°C (14°F) (arctic climate) on the north slopes of the Brooks Range (Hartman and Johnson 1978).

This region of Alaska can be divided into four major climatic zones as shown on figure 1.

The Maritime and Maritime-Continental Transition Zones

The maritime zone has small seasonal temperature variation and heavy precipitation (400 to 6000 mm). Mean annual temperatures range from -1° to 5°C (30° to 41° F), and permafrost is absent. Clouds and fog are frequent and surface winds are strong, variable, and persistent (Hartman and Johnson 1978). The growing season is 90 to 200 days and produces 600 to 1100 growing degree-days (gdd) above a threshold of 5° C (41° F). Mean July temperature within tree limits ranges from 9° to 13° (48° to 57° F); Mean January temperatures range from -4° to 0° C (25° to 32°F). Mean annual precipitation ranges from 600 mm (24 in) at Homer on the Kenai Peninsula to more than 3500 mm (138 in) in Prince William Sound (Watson et ale 1971, Hartman and Johnson 1978, Farr and Hard 1987).

The maritime-continental transition zone is colder and dryer than the maritime zone, Mean annual temperatures range from -2° to 0° C (28° to 32°F) and permafrost is found in isolated masses. Seasonal and daily temperatures are more variable, cloud cover is less frequent, and winds are lighter and less variable than in the maritime zone. Annual precipitation ranges from 300 to

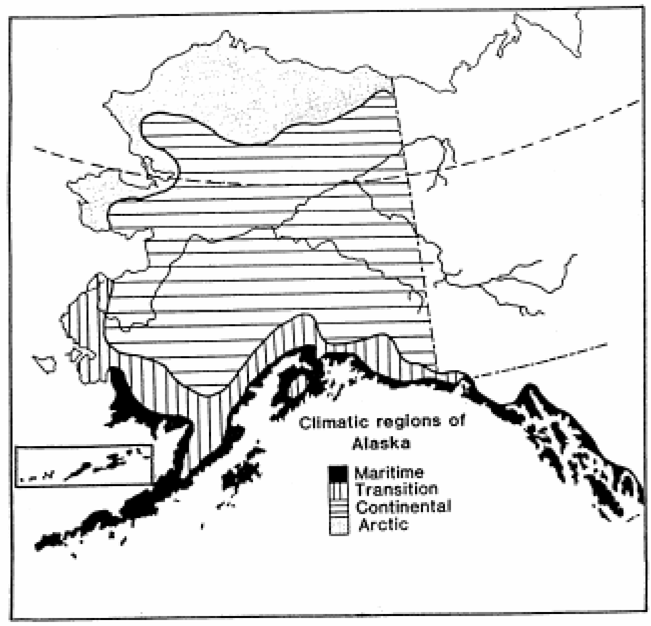

Figure 1.--Climatic zones of Alaska (modified from Hartman and Johnson 1978).

2000 mm (12 to 80 in). The growing season ranges from 80 to 120 days and produces about 700 to 1000 gdd within tree limits.

Species with the most potential for forest development in maritime and transition climates of south-central and southwest coastal climates are Sitka spruce, Lutz spruce, Picea x lutzii Little (the natural Sitka x white spruce hybrid); shore pine, Pinus contorta Dougl. ex Loud. var. contorta and P. contorta var. contorta x var. latifolia western Siberian or Sukachev larch, Laryx sukaczewii N. Dyl., and the closely related Siberian larch, L. siberica Ledeb., and balsam poplar, black cottonwood, and the black cottonwood x balsam poplar hybrids.

The Continental Zone

The continental zone has large seasonal, daily, and diurnal temperature variations. Precipitation (200 to 800 mm, 8 to 32 in), cloudiness, and humidity are low. Surface wind is usually light. Mean annual temperatures range from -10° to -1° C (12° to 30° F). The growing season ranges from 60 to 120 days and produces as many as 1200 gdd. Permafrost is continuous in the west and discontinuous in the eastern parts of the continental zone. Major tree species with potential for wide adaptation and forest improvement in the continental zone are white spruce; jack pine, Pinus banksiana Lamb.; lodgepole pine, P. contorta var. latifolia Engelm.; western Siberian larch; Siberian larch; Dahurian larch, L. dahurica Turcz.; tamarack, L. laricina (Du Roi) K. Koch; and L. czekanowskii Szaf. (L. dahurica x L. sibirica).

High latitude continental species with potential for adaptation to interior Alaska that will not be reviewed are scotch pine, Pinus sylvestris L.,

Table 1--Effects of the soil surface on 1-0 Sitka spruce seedlings after the first growing season at Nyman Ridge, Kodiak Island. More than 30 cm (12 in) of volcanic ash was deposited on the site by the Mt. Katmai volcano on the Alaska Peninsula in 1912. Removal of about 5 cm (2 in) of the organic horizon during site preparation before planting in 1986 exposed the underlying volcanic ash

	Soil surface					
		Organic		Volcanic ash		
Seedling condition	Number of trees	Percent	SD	Number of trees	Percent	SD
Dead	1	0.3		1	0.2	
Dead tops	4	1.1		5	1.0	
Dead foliage	56	16.1*	± 6.8	219	43.0*	± 11.2
Chlorotic foliage	168	48.3	± 9.3	233	45.8	± 11.2
Normal	119	34.2*	± 8.8	49	9.6*	± 6.6
Missing data	---	-----	---	2	0.4	
Total	348	100.0		509	100.0	

*Major differences in seedling condition between organic and ash surfaces.

subalpine fir, Abies lasiocarpa (Hook.) Nutt., and Finnish spruce, Picea fennica (Regel) Kom. (P. abies (L.) Karst. x P. obovata).

The Arctic Zone

Temperatures are less variable but generally colder (-12° to -1° C) in the Arctic zone than in the continental zone. Annual precipitation ranges from 100 mm (4 in) on the Arctic plain to 1000 m (40 in) at 1000 m (3300 ft) above sea level (masl) in the Brooks Range. Strong winds are common near the Arctic coast. The growing season produces from 400 to 800 gdd, and frost can occur at any time of the year. No information is available about the performance of tree species in the Arctic zone. Balsam poplar is the only tree native to the Arctic zone in Alaska. Only northern European and Asian species that range from latitude 68° to 72° N. have the potential to adapt to Arctic Alaska. These species include Dahurian larch; Siberian larch; scotch pine; Siberian spruce, Picea obovata Ledeb.; downy birch, Betula pubescens Ehrh.; European aspen, Populus tremula L.; and balsam poplar, P. suaveolens Fisch.; they will not be discussed in detail.

Picea sitchensis

Sitka spruce is the only species in the genus that is confined to maritime climate in North America. The natural range of Sitka spruce is restricted to A narrow coastal region from the north edge of Kodiak Island and west side of Cook Inlet at Cape Kubagakli (lat. 57° 54' N., long. 155° 04' W.) to the Kenai Peninsula, Prince William Sound, and the east coast of the Gulf of Alaska (Viereck and Little 1975). Sitka spruce ranges inland slightly at Valdez (lat. 61°13' N.) and inland about 60 km along the Copper River to the Bremner River at latitude 60° 50' N. The northernmost population is at latitude 61°29' N., longitude 149° 09' W., and between 20 and 200 m (65 to 655 ft) masl near the terminus of the Knik River. Another northern population is found east of the Lewis River on the south slopes of Mt. Susitna at latitude 61°24' N., longitude 150° 52' W., and 350 masl (1150 ft). Lutz spruce and introgression products of Sitka x white spruce hybridization surround both populations. These populations and the surrounding introgression products may have potential for wide adaptation to south-central and southwest coastal Alaska.

Sitka spruce is an aggressive pioneer species on recently glaciated, or uplifted terrain. It grows best on deep, moist, well-drained soils derived from a wide variety of parent materials (Harris 1978, Fowells 1965). Although Sitka spruce is reported to grow well in soils without organic accumulations, I observed less needle injury on 100 seedlings planted in volcanic ash with an intact organic surface than on 1-0 seedlings planted in volcanic ash with the organic surface removed (table 1). More seedlings planted on the organic surface were vigorous than seedlings planted on the volcanic ash after the first growing season. Needle injury may be physically caused. Vigor of seedlings on organic soils demonstrates the need for research to determine if nutrition in the organic surface of soils and shelter from native vegetation can affect seedling establishment in southwest Alaska. Research is also needed to develop site-specific planting-stock and site-preparation standards for establishing trees in Alaska.

More information about growth, frost resistance, and adaptability of Sitka spruce from the Gulf of Alaska is available in provenance studies and trial and error outplantings in Iceland than elsewhere in the world. The climate and soils of Iceland are similar to the Alaska and Kenai Peninsulas. Results from plantations in Iceland apply to forest development near coastal tree limits in Alaska. Sitka spruce provenances best adapted to Iceland range from latitude 58° to 61° N., in the Gulf of Alaska. Four Kenai Peninsula sources were outstanding among 17 sources from the Gulf of Alaska after 7 to 10 years in provenance trials at four sites in

Iceland (Benedikz 1982). The least productive sources were from Kodiak Island.

Growth phenology of Sitka spruce has been thoroughly studied. In general, annual height growth and susceptibility of Sitka spruce seedlings to frost injury are determined by onset and termination of the growing season. Variation in dates of flushing and onset of growth among wide-range provenances is less than variation in dates of bud formation and cessation of growth. Bud formation and growth cessation are earlier and growth is less for provenances from high latitudes and altitudes than for provenances from low latitudes and altitudes (Burley 1965 and 1966, Lines and Hitchell 1966, Roche and Fowler 1975, Kraus and Lines 1916, Falkenhagen 1977, Kleinschmit 1918, Birot and Christophe 1983). Thus provenances from high latitudes and altitudes are less susceptible to early frost injury.

Outplantings of Sitka spruce dating from 1944 at Adak Island and Cold Bay on Alaska Peninsula (Bruce and Court 1945) and as early as 1805 near Dutch Harbor (Umaknak Island) (Lutz 1963) have demonstrated that Sitka spruce has potential for long survival and natural regeneration on many sites in coastal regions of southwestern Alaska. Cold Bay is 550 km (340 miles), Dutch Harbor is 150 km (465 miles), and Adak is 1500 km (930 miles) west of coastal tree limits in Alaska. Although seed sources are unknown, trees planted in a small grove on Expedition Island in Unalaska Bay in 1830-40 are 20 to 55, cm (8 to 22 in) in diameter at breast height (dbh), 6 to 16 m (20 to 55 ft) tall, and contain 1 to 2.5 16-ft (4.9-m) sawlogs each. Sitka spruce transplanted to sheltered sites near Dutch Harbor in 1943-45 grew 7 to 30 cm (3 to 12 in) at dba and 4 to 9 m (14 to 29 ft) tall in 1986 (measurements on file, Institute of Northern Forestry, Fairbanks, Alaska).

Picea x lutzii

Lutz spruce provenances from Kenai Peninsula grow more slowly but are better adapted than Sitka spruce provenances to sites with less than 800 mm (31 in) of annual precipitation and frequent frost in Iceland (Alden 1984a). The area of Picea sitchensis x P. glauca hybridization extends to the northwest side of Cook Inlet in south-central Alaska (Copes and Beckwith 1977). I have seen hybrids with Sitka spruce on Mt. Susitna, and Little (1953) reports them at Goat Creek near the terminus of the Knik River (fig. 2). An area of P. stitchensis x P. glauca hybridization has been identified 135 km (84 miles) inland on the Haines Highway in British Columbia at 1100 to 1300 masl (3600 to 4300 ft) (von Rudloff 1911). I observed trees with Sitka spruce introgression at 800 masl (2600 ft) on the east slopes of the Coast Range below White Pass, British Columbia, and 4 miles (6.5 km) north of the British Columbia-Yukon border on the Haines-Highway at 950 masl (3100 ft). Sympatric populations of Sitka and white spruce in western North America have many intermediate characteristics because the species are closely related and have no genetic barriers to hybridization. The extent of Sitka and white

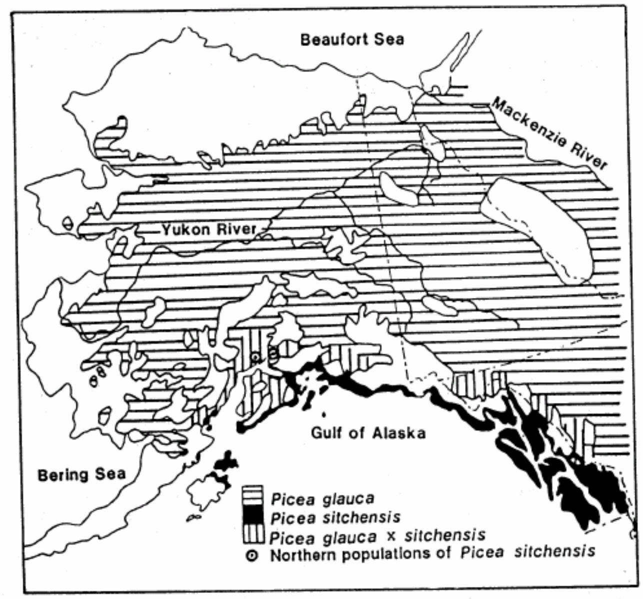

Figure 2.-- Natural range of Sitka spruce, Picea Sitchensis (Bong.) Carr, P. glauca (Moench) Voss (Viereck and Little 1975), and probable extent of P. glauca x P. sitchensis introgression.

spruce hybridization and introgression will not be known until morphological and biochemical traits of many diverse populations are studied in common environments. In the meantime, the spruce complex in Alaska, northwest British Columbia, and Yukon should be sampled as a continuous nomenclatural unit for provenance research and forest development.

Picea glauca

White spruce is an indigenous continental species with potential for forest development in both Arctic and interior Alaska. The natural range of white spruce extends from Joe Creek (lat. 69° 03' N., long. 140° 27' W.) in the Brooks Range of northeast Alaska, to the Kugururok River (lat. 68°09' N., long. 161°28' W.) in northwest Alaska, to the Savonoski River, (lat. 58°32' N., long. 155°20' W.) in southwest Alaska, and to the Copper River at about latitude 61005' N., longitude 144°45' W. in south-central Alaska (Viereck and Little 1975) (fig. 2). The species is widely distributed on silty alluvial and loess soils of river-bottom and upland sites. The best stands in Alaska are found on floodplains, river terraces, and south-facing slopes from sea level to altitude tree limits at about 150 masl (2500 ft). Typical unmanaged stands in interior Alaska average 25 to 35 cm (10 to 14 in) in dbh and 20 to 30 m (10 to 100 ft) in height at 100 years (Farr 1961, Foote-1983). Trees occasionally grow rapidly to 80 cm (30 in) dbh and 36 m (120 ft) tall on productive sites, and mean annual increment may reach 3.5 m^3 per ha(50 ft^3 /acre) (J. Zasada, personal communication). Unmanaged stands near coastal and altitudinal tree limits are less dense, contain smaller trees, and usually

Table 2--Winter mortality[1/] of 1-year-old white spruce, Picea glauca (Moench) Voss and Picea x lutzii Little provenances at the Alaska State Forest Nursery, Palmer, Alaska, on June 1, 1983. The seedlings were wind-pollinated families from provenances in south-central and interior Alaska

Provenance	Number of families injured	Total number of families	Percentage of families injured	Estimated X% seedlings killed per family
South of the Alaska Range				
Copper Center	0	13	0	0
Glenn Highway (east of Palmer)	1	15	7	1
Chitina	4	14	29	1
Summit Lake (Kenai Peninsula)	13	15	87	34
Valdez-Thompson Pass	9	12	75	62
Number injured/total: 4/5 (80%)				
Total	27	69		
Average			40	20
North of the Alaska Range				
Number injured/total: 0/7 (0%)				
Total	0	104		
Average			0	0

[1/]Winter injury was significantly less for families from Copper Center, Chitina, and Glenn Highway than from Summit Lake and Valdez to Thompson Pass at $P < 0.05$.

produce less than 1 m^3 wood per ha (15 ft^3/acre) annually.

Geographic variation among wide-range populations in Alaska has not been studied in detail. White spruce occupies many different habitats, however, and phenotypic variation in morphological traits is high. Heterozygosity (0.28) and polymorphism (0.92) estimated near Fairbanks indicate that white spruce in Alaska is highly variable (Alden 1984b). Two geographic varieties are widely distributed throughout the white spruce range. The common variety albertiana Brown is a tall slender tree with coarse scaly bark and a relatively small ratio of diameter to height. These traits are characteristic of slow-growing phenotypes in dense stands. The variety porsildii Raup, on the other hand, has a wide conical crown, smooth bark with resinous blisters, and relatively large diameter-to-height ratio. These traits are characteristic of rapid-growing phenotypes in open stands. Genetic differences in traits of the albertiana and porsildii varieties have not been confirmed.

Although white spruce is a subarctic species, winter injury varied among white and Lutz spruce provenances in Iceland (Benedikz 1982) and among 12 provenances from interior to south-central Alaska at the Alaska State Forest Nursery, Palmer, Alaska, in 1982-83 (table 2). Provenances studied in Alaska ranged from latitude 60° 42' N. on the Kenai Peninsula to latitude 65°42' N. in interior Alaska (fig. 3) and from 120 to 790 masl (400 to 2600 ft) near tree limits in the Alaska Range (table 3). One hundred open-pollinated seedlings for each of 12 to 15 families per provenance were grown in a greenhouse from May 15 to November 1, 1982. The seedlings were under stress and averaged only 20 to 25 percent (3.2 cm) of the height of white spruce seedlings grown under optimum conditions at conclusion of the first growing season. Mean family height of each provenance was correlated ($r = 0.77$, $P < 0.05$) with mean altitude. The seedlings were moved from the greenhouse to a covered outdoor cold frame in early November 1982. Seedlings of south-central families failed to harden and sustained injury or were killed during the winter (table 2). Seedlings of families and provenances north of the Alaska Range were uninjured. Provenances from south-central Alaska appeared to develop winter resistance at different rates. Of all seedlings for 6 of 9 families from the Valdez to Thompson Pass provenance, 99-100 percent were completely killed. Hardening of the Summit Lake population appeared to be a continuous process on the other hand, because all seedlings of only one of 13 injured families were killed.

The results of this trial demonstrate that white and Lutz spruce require provenance research for forest development in Alaska and that seed zones and transfer guidelines are necessary to reduce the risk of seed movement in artificial reforestation programs.

Pinus contorta var. contorta, P. contorta var. latifolia, P. banksiana, and P. banksiana x P. contorta var. latifolia

Lodgepole and shore pines *are* fast-growing, shade-intolerant subspecies or varieties. Shore pine has wide distribution in the cold maritime climate of southeastern Alaska, and lodgepole pine is found in the subarctic continental climates of interior Northwest America. Shore pine is widely distributed from Glacier Bay throughout southeastern Alaska (fig. 4). The northernmost outlying population is found at Yakutat, Alaska (lat. 59°30' N., long. 134°40' W.). Shore pine

Table 3--Provenance and average height of 1-0 white spruce Picea glauca (Moench) Voss and Lutz spruce Picea x lutzii Little on November 1, 1982. The families were sown at the Alaska State Forest Nursery, Palmer, Alaska on May 15, 1982

	Number families	Latitude	Longitude	Mean altitude (m)	Mean height cm
Willow Island	14	64°14'	148°13'	120	4.6
Gerstle River	15	63°50'	144°53'	400	3.5
Valdez-Thompson Pass	12	61°06'	145°50'	280	3.5
Bonanza Creek	15	64°45'	148°15'	240	3.5
Copper Center	13	61°57'	145°15'	390	3.4
Summit Lake	15	60°43'	149°20'	420	3.2
Central-Circle	15	65°42'	144°26'	240	3.2
Mentasta Pass	15	62°50'	143°30'	680	3.0
Chitina	14	61°35'	148°28'	350	2.9
Glenn Highway	15	61°48'	148°50'	280	2.9
Titlin Junction	15	63°19'	142°38'	520	2.7
Slana Junction	15	62°43'	144°08'	790	2.1
	173				

R = 0.77 for height vs. altitude
Provenance differences > 1.3 cm in height were significant at $P \leq 0.05$.

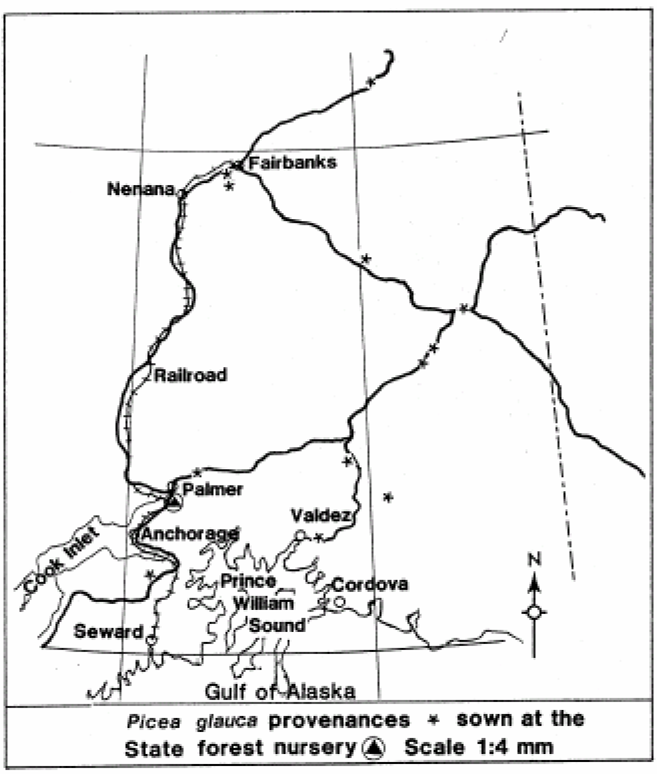

Figure 3.—Twelve Picea glauca and P. glauca x P. sitchensis provenances sown at the Alaska Forest Tree Nursery in May 15, 1982.

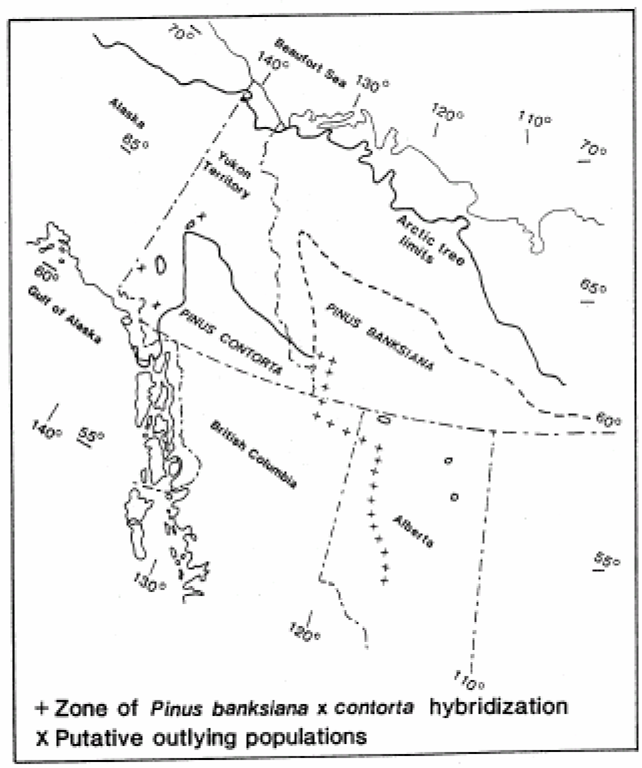

Figure 4.--Natural range of lodgepole pine Pinus Contorta Dougl. ex Loud., jack pine, P. banksiana Lamb., and region of P. banksiana x P. contorta hybridization.

is usually found in open muskegs dominated by peat moss, where site conditions are unfavorable for other tree species. Tree crowns are broad and flattened, and ratios of branch to bole diameter are large. The largest and best-formed trees are found in border areas between poorly drained muskeg and well drained upland soils. Trees normally range from 20 to 30 cm (8 to 12 in) in dbh and 8 to 12 m (25 to 40 ft) in height in southeastern Alaska (Viereck and Little 1972), but trees can grow to more than 60 cm (24 in) in dbh and 25 m (80 ft) in height at 150 to 200 years of age (Mink Creek, lat. 59°16' N., long. 135° 28' W., 250 masl). Shore pine merges with lodgepole pine at less than 50 masl (150 ft) within 20 km (12 miles) of Haines, Alaska, and hybrids are common at higher elevations throughout the upper Lynn Canal region (personal observation; Aldhous, 1376). Provenances from this region grow 3 to 4 m^3 of wood per ha (40 to 60 ft^3 acre) annually in Iceland (Bloendal et ale 1986) and are adapted to cold, dry sites near altitude tree limits. Although Skagway, Alaska, is the most popular provenance among more than 50 outplanted in Iceland, its relative performance has not been tested experimentally.

Shore pine and its hybrids have not been widely planted in Alaska. Provenances from southeastern Alaska and lodgepole pine populations from northwestern British Columbia, however, have potential for long survival and rapid growth in maritime and transition climates in southwestern Alaska.

The major disadvantage of P. contorta in subarctic climates is its susceptibility to snow damage, windthrow, animal damage and disease from the rust fungi, Cronartium componiea Arth. and Peridermium spp. The foliage of shore and lodgepole pine is dense and accumulates large volumes of snow. Heavy snowfall may cause severe bending and breakage of stems and limbs. Root systems of lodgepole pine are shallow in subarctic soils, and trees are frequently uprooted by snow accumulation and wind. Young stands succeed rapidly to cold- and shade-tolerant Picea spp. in the absence of wildfire in subarctic climates. Wildfire cycles of 40 to 60 years are necessary to reduce competition from shade-tolerant species, reduce organic accumulations, and increase the active layer of permanently frozen soils.

Lodgepole and jack pines have potential for rapid migration in dry, continental, subarctic climates. Cones of both species are serotinous, and mature stands retain large quantities of seed; thus, they are aggressive pioneer species after forest fires. Although fire storms are known to disperse seed as far as 50 km (30 miles) (Nyland 1980), pollen fossil data indicate that lodgepole pine arrived in southern Yukon about 4000 YBP and reached central Yukon only 400 YBP (MacDonald and Cwynar 1985). The northern distribution of lodgepole pine approximates a mean annual isotherm of $-5^{\circ}C$ ($23^{\circ}F$), and it is almost exclusively within the northern advance of the 40,000-year-old Cordilleran ice shield. Biochemical and population studies show that subarctic provenances are genetically variable. These observations support hypotheses that lodgepole pine in the Yukon stems from migration and introgression of shore pine and Rocky Mountain lodgepole pine populations and not from populations that may have survived north of Pleistocene glaciations.

Little information is available about the growth and yield of lodgepole and shore pine in Alaska. Subarctic provenances have acquired high winter resistance while retaining the characteristics of southern populations for long growing seasons and rapid height and diameter growth (Hagner 1970, Lindgren 1983). Growth of superior lodgepole pine provenances and a jack pine provenance from northeastern British Columbia planted at 1.8-m (6-ft) spacing averaged more than 1._ cm in dbh, 40 cm (16 in) in height, and 0.003 m^3 (0.11 ft^3) of wood per tree annually from 9 to 12 years of age at T-field Arboretum, University of Alaska, Fairbanks. This growth occurred in spite of snow damage in 1984 and moderate winter injury in 1983 (Alden, in press).

Site x provenance interaction between Whitehorse, Yukon, and Fairbanks, Alaska, for growth was not significant in wide-range provenance trials. Thus, productivity of lodgepole pine on productive sites in interior Alaska may be estimated with a reasonable degree of accuracy from growth and yield of stands in Yukon. Growth for 16 unmanaged stands in southern Yukon averaged 2.5 m^3/ha (35 ft^3/acre) per year for all ages sampled (data from Oswald and Brown 1986), and predicted rates for individual stands ranged from more than 5 m^3/ha (70 ft^3 acre) per year at 30 years of age to 2 m^3/ha (30 ft^3 acre) per year at 110 years of age (fig. 5). Unfortunately, growth rates of most stands were less than maximum when sampled. Productivity of indigenous species could not be compared directly because stands were sampled at different ages and on different sites. Growth rates and yield of potential timber species have not been determined for managed stands in Alaska.

Lodgepole and jack pine are closely related, have few, if any genetic barriers and readily hybridize where their ranges overlap (fig. 4). The subarctic range of both species is poorly mapped. Northern populations of lodgepole pine are small and widely scattered. Outlying northern populations are in Hamilton Creek Yukon, about latitude 64°15' N., longitude 137° 22' W., and on the Dempster Highway at latitude 64°05' N., longitude 138°30' W. Putative populations in the West Hart River, at about latitude 64°45' N. and longitude 137°20' W. need to be confirmed.

Jack pine provenances with potential for forest development in interior Alaska range from northern Alberta and northeastern British Columbia to above latitude 65 N. on the MacKenzie River in the Northwest Territories. The Liard River plateau of northeastern British Columbia and southwestern Northwest Territories is a maze of recent jack and lodgepole pine hybrid populations at various stages of introgression.

Growth and yield of jack and jack x lodgepole pine provenances have not been widely studied in subarctic climates. Jack pine from the Liard River Plateau, in northwestern British Columbia was more productive than 11 subarctic lodgepole pine provenances after 10 years in a provenance study at Fairbanks, Alaska, and Whitehorse, Yukon (Alden, in press; Ying and Illingworth 1986). In addition, seedlings of jack pine and jack pine x lodgepole pine provenances were larger than seedlings of subarctic lodgepole pine provenances in the nursery and after two growing seasons in interior Alaska. More jack pine seedlings sustained environmental injury than lodgepole pine

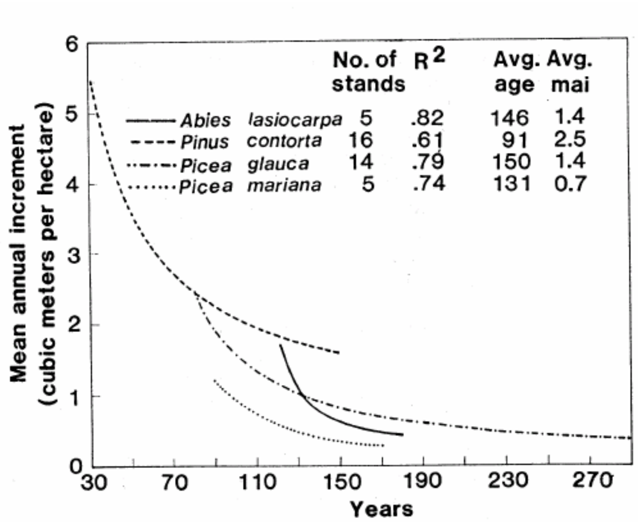

Figure 5.--Mean annual increment as a function of age for each of four unmanaged conifers on upland sites in the Lake Laberge ecoregion, south-central Yukon (data with permission from Oswald and Brown 1986).

seedlings after outplanting, but jack pine recovered more rapidly than lodgepole pine during the second growing season.

The superiority of coastal shore pine provenances in maritime climates and subarctic lodgepole and jack pine provenances in cold continental climates is striking. In general, only provenances from geographical areas of established outstanding performance should be considered for forest development in Alaska.

Larix sibirica and L. sukaczewii

Siberian larch and Sukachev or western Siberian larch are closely related species from northern European U.S.S.R. and western Siberia (fig. 6). The northern range of Sukachev larch extends to latitude 68° N. in European U.S.S.R. and western Siberia. Siberian larch is from colder climates than Sukachev larch and reaches latitude 72° N. in central Siberia. Sukachev larch is considered a subspecies of European larch, *L. europaea* D.C. It undoubtedly hybridizes with Siberian larch in the Ob River region of western Siberia. Rapid growth of the Siberian larches in subarctic climates is attributed to a long growing season. Seasonal growth of native Siberian larch at Krasnayarsk (lat. 56° N., long. 93° E.) in central Siberia begins later and continues twice as long as that of native spruce (*Picea obovata* Ledeb.), fir (*Abies sibirica* Ledeb.), and pine (*Pinus sibirica* Dutour and *P. sylvestris* L.) (Pogosova et al. 1985). The long growth period may predispose southern sources to early frost injury and cause poor form in interior Alaska.

Although from continental climates, Siberian and Sukachev larches grow rapidly in both subarctic maritime and continental climates where mean annual July temperature exceeds 12°C (54°F) (Simak 1979). Trees on productive sites grow as large as 45 m (150 ft) in height and 80 cm (30 in) in dbh at maturity. Both species are routinely planted on severely eroded soils in Iceland where native grasses, herbaceous vegetation, and other trees fail to survive. Annual needle loss is rapidly incorporated into an Avo horizon on eroded soils in moist climates. Mushroom flora, grass, and herbaceous vegetation benefit from increased soil productivity and rapidly occupy the understory of young larch plantations. Research in Iceland demonstrated that one or two ewes with two lambs each per hectare cause little plant and soil disturbance, and the animals gain more weight under larch forests than on open grassland (Alden 1984a).

Provenance variation of the Siberian larches has not been widely studied in Europe and North America. Seed sources for provenance research in western countries are inaccessible. Seeds of North American species are readily available, on the other hand, and species such as lodgepole pine and Sitka spruce have attracted wide attention. A Raivola seed source (lat. $60^{\circ}14'$ N., long. $29^{\circ}35'$ E.) is a productive provenance in the Nordic countries that has been widely planted for many years, however. The Raivola forest was established near the Baltic Sea during the 18th Century and is more than 500 km (310 miles) west of the natural range of Sukachev larch. The plantations grew rapidly, and stands on upper slopes and ridgetops averaged as much as 45 cm (18 in) in dbh, 38 m (125 ft) in height, and more than 1000 m^3/ha (14,200 ft /acre). Nearly 250 years of natural selection in this climate may have produced a superior land race in maritime climates.

The Siberian larches are, however, highly susceptible to *Potebniamyces coniferoum*, the causal agent of larch dieback, a serious foliage and twig disease in maritime climates of northern Europe (Bloendal et ale 1986). The Raivola seed source and native provenances from west of the Ural Mountains to central Siberia should be screened for resistance to early frost injury, disease resistance, and for productivity on a wide range of sites before they are introduced to Alaska.

Populus trichocarpa, *P. balsamifera*, *P.* suaveolens, and their hybrids

Populus species are the largest broadleaf trees in northwestern America. They are not planted as forest tree species in Alaska, and their performance in managed plantations is unknown. Black cottonwood as large as 3 m (9 ft) in dbh and 30 m (100 ft) in height is found in wild populations in the Lynn Canal area of southeastern Alaska (Viereck and Little 1972). Black cottonwood is a maritime species and is Iceland's fastest growing tree. It has grown nearly 14 m (46 ft) in height in less than 20 years on sheltered sites and on moist fertile soils (Bloendal et ale 1986).

The balsam poplars also grow rapidly and are found north of latitude 69° in Alaska and eastern Siberia. The balsam poplars are continental

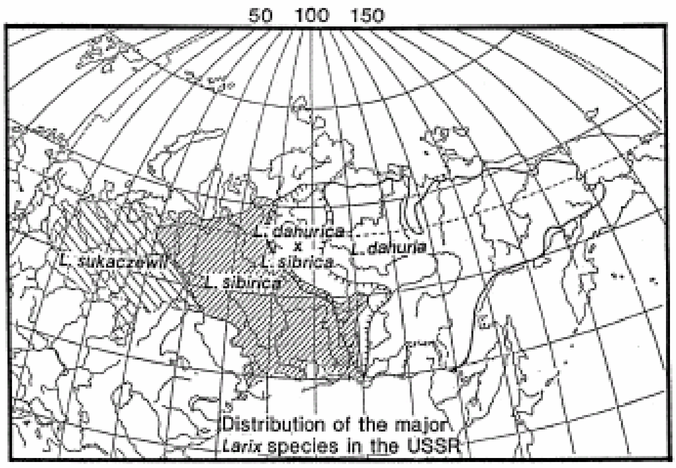

Figure 6.--Natural range of the major *Larix* species in European U.S.S.R. and Siberia (Sokolov 1977).

subarctic species. The largest trees in North America are found along the MacKenzie River of northwestern Canada, where heights of 30 m (100 ft) and diameters of more than 2 m (6.5 ft) at breast height are not uncommon (Fowells 1965). The growth period of *Populus* species is strongly regulated by photoperiod. Thus, provenances are often injured by frosts when transferred to environments with earlier, later, or shorter growing seasons than their native habitats.

SUMMARY AND CONCLUSION

Growth and yield of forest resources can be improved on more than 50 million ha (125 million acres) of potential forest lands in Alaska. A forest development program is needed for afforestation of 40 million ha (100 million acres) of slow-growing and nonstocked land with productive species. Site-specific planting-stock standards and site-preparation technologies are needed to support species and provenance research for forest development. Sitka spruce, Lutz spruce, shore pine, Sukachev or Siberian larch, and black cottonwood are among the most productive species for forest development in subarctic maritime climates. Stem growth of 10-year-old trees in well-managed lodgepole and jack pine plantations at 2 m (6.6 ft) spacing averages 0.003 m^3 (0.11 ft^3) annually (about 100 ft^3 /acre per year) on productive upland sites in interior Alaska. White spruce, the Siberian larches, and the balsam poplars are other fast-growing species in subarctic continental climates and have potential for adaptation to arctic climates in Alaska.

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☆ U.S. GOVERNMENT PRINTING OFFICE:1988-593-153

Slaughter, Charles W.; Gasbarro, Tony (eds.). 1988. Proceedings of the Alaska forest soil productivity workshop: Proceedings of a workshop; 1987 April 28-30; Anchorage AK. Gen. Tech. Rep. PNW-GTR-219. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 120 p.

The Alaska Forest Soil Productivity Workshop addressed (1) the role of soil information for forest management in Alaska; (2) assessment, monitoring, and enhancement of soil productivity; and (3) Alaska research projects involved in studies of productivity of forests and soils. This proceedings includes 27 papers in five categories: agency objectives in monitoring and enhancing long-term forest productivity; practical approaches to assessing soil productivity and tree growth measurements; soil productivity monitoring for project assessment, implementation, and compliance; soil productivity and tree growth in coastal spruce and hemlock forests; soil productivity and tree growth in interior spruce and hardwood forests; and tree improvement and its role in overcoming site limitations.

Keywords: Forest productivity, soil productivity, spruce, hemlock, site limitations, Alaska.

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