EGENERATION
OF PONDEROSA PINE

Proceedings of a Symposium held September 11-12, 1969

Edited by
R. K. Hermann

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Symposium held September 11-12, 1969

Compiled and edited by
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COVER PHOTOGRAPH
Old-growth ponderosa pine, west of Sisters, Oregon.

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CONTENTS

FOREWORD ................................................................. v

ACKNOWLEDGMENTS ................................................... v

INTRODUCTORY REMARKS ............................................. vii

Ponderosa Pine Regeneration Problems in the Southwest .......... 1
Gilbert H. Schubert, U.S. Forest Service, Arizona

Regeneration Problems of Ponderosa Pine in the Northern Rocky Mountains .... 5
C. A. Wellner, U.S. Forest Service, Utah

Ponderosa Pine Regeneration Problems in the West Coast States ........ 12
Ronald S. Adams, California Division of Forestry

Pollen and Seed: A Good Linkage for Reforestation .......... 19
Kim K. Ching, School of Forestry, Oregon State University

The Seed Source Question for Ponderosa Pine .......... 22
Roy R. Silen, Forestry Sciences Laboratory, Corvallis

Management Decisions Relating to Off-Site Plantations ........ 26
H. A. Dahl, U.S. Forest Service, Oregon
L. A. Nicholson, U.S. Forest Service, Oregon

Seeding Ponderosa Pine ................................................. 28
P. H. Cochran, U.S. Forest Service, Oregon

Animal Damage to Seed and Seedlings ................................ 36
Edward F. Hooven, School of Forestry, Oregon State University

Variation in the Root-Growth Capacity of Ponderosa Pine Transplants .......... 40
Edward C. Stone, University of California

Container Planting ......................................................... 47
James Dick, Weyerhaeuser Company

Planting in Pumice and Root Development of Ponderosa Pine ........ 50
Richard K. Hermann, School of Forestry, Oregon State University

Matching Species to Site .................................................. 54
Richard H. Waring, School of Forestry, Oregon State University

Economics and Policy Environments for Forest Regeneration .......... 62
Donald F. Flora, U.S. Forest Service, Oregon

The Role of Moisture Stress and Temperature in the Growth of Seedlings .......... 64
Brian D. Cleary, School of Forestry, Oregon State University
Utilization of Soil and Fertilizer Nitrogen by Ponderosa Pine
A. G. Wollum II, New Mexico State University

Mineral Nutrition and the Drought Resistance of Ponderosa Pine Seedlings
Howard Loewenstein, University of Idaho

Fertilizing Planted Ponderosa Pine on Pumice Soils
J. W. Barrett, U.S. Forest Service, Oregon
C. T. Youngberg, Oregon State University

Disease as a Factor in Regeneration of Ponderosa Pine
Lewis F. Roth, Oregon State University

Herbicides and the Management of Young Pine
Michael Newton, School of Forestry, Oregon State University
Warren L. Webb, School of Forestry, Oregon State University

Role of Brush in Ponderosa Pine Establishment
J. Zavitkovski, School of Forestry, Oregon State University
E. Steve Woodard, Industrial Forestry Association

Animal Damage to Forest Regeneration in the Ponderosa Pine Region of Oregon and Washington
Hugh C. Black, School of Forestry, Oregon State University

TRI System—Total Resource Information for Land Management
John R. Robertson, U.S. Forest Service, Oregon
FOREWORD

Wood has the distinction of being a renewable natural resource. What makes this renewal possible is the process of forest regeneration. Prompt establishment of new crops after harvest of the mature timber will become a necessity if we are to maintain current production of wood despite all the other demands on forest lands.

This symposium was devoted to regeneration of ponderosa pine (Pinus ponderosa Laws.), our most important pine commercially in western North America. The objective was to inform practicing foresters of present knowledge, biological, technical, and economic, of ponderosa pine regeneration.

In forestry, as in other fields, the literature is growing rapidly. The practitioner has neither the time nor the opportunity to sift through it all and, paradoxically, is more prone than ever to remain unaware of valuable information. The symposium was one of many efforts by educational institutions and professional groups to remedy this situation and to improve channels of communication.

ACKNOWLEDGEMENTS

Credit should go to Edward F. Hooven, who conceived the idea of this symposium, and Hugh C. Black for their assistance with selection of topics and speakers. I am greatly indebted to Harold Dahl, U.S. Forest Service, Region 6, and personnel of the Deschutes National Forest for help with planning part of the program, especially the field trip. I gratefully acknowledge the many courtesies and cooperation received from the administration of Central Oregon College and the staff of its forestry department. They made available the fine facilities of their campus and helped to solve our logistics problems. Thanks is also due the Silviculture Laboratory of the U.S. Forest Service at Bend for help with registration of the participants. I would like to recognize the efforts of the crew of technicians from the School of Forestry's Self-learning Center at Oregon State University and my assistant, Lloyd G. Graham.

Finally, I would like to thank all those who contributed to the symposium as speakers and moderators or undertook the arduous task of reviewing manuscripts. Last, I wish to express my appreciation to our school's editorial staff for assistance in preparing the final version of this publication.

Richard K. Hermann, Chairman
means that our abilities to adjust forest conditions must improve. Our technical competencies must increase—and rapidly. The excellent attendance at this symposium is strong testimony to the recognition of the need for improved technical competence. I expect the speakers to come up with better answers.

We are told that the fund of scientific knowledge is currently doubling every seven years. Forestry knowledge must be a part of that explosion. We must incorporate the findings from other fields of science and accelerate the rate of development of new knowledge within forestry. Society must expand its investments in research. And researchers must seek that knowledge which will enable us to solve forestry problems, such as ponderosa pine regeneration, with increased efficiency and effectiveness. Research must be designed to provide new methods and more precise answers.

I am looking forward to hearing the papers of this symposium. Will the researchers tell us what research they are doing? Or will they give you managers specific information that will enable you to improve your regeneration decisions and practices?

The purpose of this symposium is certainly the latter. Knowing Dr. Hermann and several of the outstanding participants he has selected to lead this symposium, I am fully confident that the papers will present the latest and most helpful information available. It will indeed help you to improve your ponderosa pine regeneration decisions and practices.

I am pleased to have the School of Forestry of Oregon State University coordinate this symposium that is designed to get the latest research results into the hands of those who can and will use them. We believe that this is part of our responsibility as a major research unit—to get our research results to those who can use them. And we believe that this additional course in our growing program of continuing education for foresters is part of our responsibility as a professional forestry school. Dr. George Jemison is now helping to redesign our entire program of continuing education so that it may be equal to the challenges of continuing change in our profession. Continuing education may thus soon become of equal importance with our research and resident instruction programs at Oregon State University. We are pleased to coordinate this symposium, we appreciate the wide cooperation of individuals and agencies that make the symposium possible, and we are honored by the outstanding scientists and managers who comprise the symposium faculty.
INTRODUCTORY REMARKS
THE POLITICAL AND ECONOMIC ENVIRONMENT FOR REGENERATION

Carl H. Stoltenberg, Dean
School of Forestry
Oregon State University

In welcoming you to this symposium on the regeneration of ponderosa pine, I should like to make a few remarks on the context, the environment, within which this conference takes place.

At least three major changes taking place in our social, economic, and political environment are of critical importance to forestry and thus have significant implications for each of us. The first of these changes is the tremendous growth of our economy. Combined with a rapid growth in population is an even more rapid growth in economic productivity per capita, and a consequent virtual explosion in consumer power. A glimpse of the magnitude of this consumer power was seen earlier this year as the backlog demand for housing came to the surface. As housing starts rose from 1.5 million last year to a rate of 1.9 million in January of this year, prices of lumber and plywood, and of course stumpage, skyrocketed.

President Nixon’s decision to fight inflation through monetary policy and the construction industry soon prevented the full impact of consumer power from being reflected in the demand for ponderosa pine and other wood products. But the magnitude of that power had been exhibited.

Another form in which that power is being expressed is in the consumer demand for a better environment for living—and this hits us as managers of a major environment, as well as managers of wood-producing systems. Regeneration is of critical importance to both. In producing timber, it may be simply a financial handicap to experience a delay of several years in achieving satisfactory reproduction, or to experience a complete failure of reproduction on certain sites and “difficult conditions”. But when that tremendous force of consumer power is concerned with an immediate re-establishment of a forest environment after logging, the entire privilege of harvesting timber crops may be at stake. In such situations, the compound interest calculations by which planting costs are compared with discounted stumpage prices become inappropriate. It is, in truth, next year’s harvest that is at stake—not a crop 100 years hence. But this is the subject of Dr. Flora’s paper tomorrow.

My point is simply that successful rapid regeneration is always important, but in a growing number of areas immediate success is essential. Regeneration is one of the production alternatives available to some foresters; it is the only route available to others.

Acting on the recommendations of both public and private resource managers and owners, the Oregon Board of Forestry is revising its Forest Conservation Act. If we follow the recommendations of these industry leaders, the Act will no longer prescribe practices that must be followed (seed trees, etc.)—it will simply require successful and prompt regeneration. The methods are left to you—but results are required.

In addition to the growth of our economy and the consequent growth of consumer power, the second change I’d like to mention briefly is the fantastically accelerating growth of technical knowledge—in forestry and in related areas. And the third change, in part a result of so much other change, is our increased uncertainty about the future in forestry. We are recognizing that in the future not only the techniques of forestry may frequently change, but so may our goals.

The growth of the power of consumers, and of their ability to make that power felt throughout the economy (clear through to the forest manager), will mean that we foresters must have a more flexible approach to management goals and practices. And this, in turn,
PONDEROSA PINE REGENERATION PROBLEMS IN THE SOUTHWEST

Gilbert H. Schubert
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Flagstaff, Arizona

REGENERATION PROBLEMS IN THE SOUTHWEST BEAR A STRONG RESEMBLANCE to problems throughout most of the ponderosa pine region. We are troubled by drought, short growing season, rodents, browsing animals, insects, vegetative competition, and other deterrents to success that are typical of the type.

A FEW PROBLEMS DIFFER STRIKINGLY from some other parts of the region. Although we have great difficulty getting natural reproduction, little difficulty is experienced in the Black Hills, where 70 percent of the annual precipitation falls in spring and summer.

Southwestern ponderosa pine differs from other ponderosa pines in an important characteristic related to regeneration problems. Our ponderosa pine seeds have a temperature-controlled dormancy. The seeds do not germinate until the temperature averages above 55 degrees F. By contrast, seeds from ponderosa pines in California will germinate at 32 degrees F if kept moist long enough. In this respect, our southwestern ponderosa pine is a different ecotype.

This temperature difference of southwestern ponderosa pine probably developed because of our long spring drought. Seeds that germinated at the lower temperatures of March and early April failed to survive the drought from late April to July. Therefore, the only pines today are those whose seeds required a higher temperature, which delayed germination until the summer rains started in early July. Whether or not the characteristic actually developed that way makes little difference. The important fact is that our seeds do not germinate until the temperature averages about 55 degrees F and the seeds are kept continually moist for at least 7 days. These conditions are not met until July.

That the characteristics of the Southwest influence both the nature of the ponderosa pines that grow there and the problems of reproducing them is, therefore, evident. Some of the main factors contributing to low survival and poor growth in the Southwest are drought, frost heaving, low temperatures, short growing season, hot dry winds, competing vegetation, root- and stem-feeding animals, and growth inhibitors. But perhaps most important is the seasonal distribution of temperature and precipitation. The two-cycle precipitation pattern, with wet winters and summers and dry springs and falls, apparently limits germination to the period of summer rains in most years. Because rains commonly do not start until July, only a short growing season remains before drought and frosts start. Coordination of a good seed supply with adequate and timely precipitation the following summer is rare. That, and some other characteristics of the Southwest, influence both natural and artificial regeneration.

Ponderosa pine regeneration has always been a major problem in the Southwest. “Gus” Pearson was sent to Arizona in 1908 expressly to study that problem. In those days, the forests were “park like.” Seedlings started only sparingly after cutting, despite measures which seemed adequate. Pearson (6) reported that gaps of 100 years in age classes were common. Long intervals between seedling crops are found on at least half of the 8 million acres of commercial ponderosa pine land in Arizona and New Mexico.

Since 1908, when Pearson started his first studies, only once has seed germination been appreciable before July. That was in early June 1919. Both the requirements of temperature and moisture were met during the last week of May 1919. During that May, the day temperatures averaged 6 degrees F higher than the 60-year mean. And 3½ inches of rain fell in the last 7 days. The monthly mean is only 0.6 inch. That led to the now famous seedling crop of 1919. These 50-year-old trees constitute the last “wave” of natural regeneration in the Southwest. This crop of seedlings now accounts for the surplus trees of from 2 to 8 inches on about 3 million acres. For proper management, however, we have a serious deficiency of trees in the 10- to 20-inch size. Part of this deficiency is a direct result of problems in establishment by natural regeneration; the adverse impact of our environment on seedling establishment keys one of our most serious problems.

If the amount and frequency of precipitation are inadequate during early summer, germination may be delayed until late summer or, in rare cases, deferred until the following summer. Studies at Fort Valley show that seedlings starting after early August are poorly adapted to survive the fall drought, winter frost heaving, or transpiration stress. Only those seedlings that start early enough to put down a deep root can survive the first year. Seedlings had that start in 1919, but not since. This leaves little doubt that moisture and its distribution with time are the most limiting factors that influence natural regeneration in the dry Southwest.

Therefore, management efforts must be directed to use the limited supply of moisture efficiently. Complete
site preparation is one way and a necessity in the Southwest. Chemical site preparation seems to offer the best possibility. Dead grasses serve as a mulch to conserve soil moisture. Ponderosa pine seeds absorb sufficient moisture for germination from the first 24 to 48 hours of wet conditions. For germination to occur, however, the seeds must be kept moist for at least 1 week. On mechanically prepared sites, the seeds must be covered to prevent water loss.

Hayes (1) pointed out that provisions for optimum regeneration should be part of the logging plan. The logging process can be used to prepare a site for regeneration. Logging activity and slash disposal could be combined to leave most of the cut-overs in good condition for reproduction. Slash disposal during nonseed years could be deferred on areas that warrant fire risk. The coordinated effort can lead to a considerable savings in dollars and time.

Competing herbaceous vegetation adds to the drought problem. Some seedling losses on grassy sites are also believed to be caused by growth inhibitors or competition for nutrients. Excellent seed germination is frequently observed in grass, but the seedlings all die. The early season growers such as Arizona fescue (Festuca arizonica), bluegrass (Poa pratensis), and black dropseed (Sporobolus interruptus) are distinctly unfavorable for ponderosa pine and Douglas-fir (2,5). Other grass species such as mountain muhly (Muhlenbergia montana), blue grama (Bouteloua gracilis), and the forb orange sneezeweed (Helenium hoopesii) appear to compete less with pine seedlings.

Areas freshly disturbed by fire or logging commonly are immediately sown to grass in the Southwest. This practice compounds the regeneration problem in areas where water is in short supply.

A recent study at Flagstaff demonstrated that the moisture stress of the soil must be kept low (4). For example, seed germination was progressively depressed and delayed at soil moisture stresses above 3 atmospheres. Root penetration, root dry weight, and cotyledon length also decreased sharply with increased osmotic stress of the soil solution. At osmotic stresses above 11 atmospheres, the seeds failed to cast their seed coats upon germination. Furthermore, seedlings that germinated at high moisture stresses grew poorly even when watered with solutions of low osmotic stress. High osmotic stresses, considerably above the 15 atmospheres tested, occur frequently, even during the summer rainy season.

Transpiration stress may be far more important than formerly believed. Larson (3) observed many 1-year-old seedlings that died when the air was warm and dry and the winds were strong, even though soil moisture was adequate. Wagg and Hermann (7) reported that transpiration stress was also a serious threat to ponderosa seedling survival in Oregon.

Grassy sites frequently support large populations of rodents and insects. Unless these populations are drastically reduced after an area is prepared for regeneration, pine seeds and seedlings form their primary food supply. Abert's squirrels obtain most of their food from the ponderosa pine and consume about one-fourth of the total cone crop. White-footed deer mice, meadow mice, chipmunks, golden-mantled ground squirrels, pocket gophers, shrews, and several species of birds are voracious seed eaters, and some destroy many seedlings. Some of these, such as the ground squirrel, are hard to control. White grubs and cutworms cause serious losses of seedlings, particularly on sandy sites.

Rabbits, squirrels, porcupines, deer, elk, cattle, sheep, and the southwestern pine tip moth cause serious damage in older seedling stands and in plantations. Successful 2- and 3-year-old stands are frequently destroyed or reduced to the point of understocking. Damage extends over at least the first 15 years of the seedling's life.

Frost heaving kills many ponderosa seedlings in the Southwest. Frost heaving is most intense in open, bare areas during late fall and early spring. Heavy losses of seedlings up to 3 years old have been observed frequently at Fort Valley. Larson (3) reported that 1-year-old seedlings that had been partially frost-heaved the previous winter and early spring were unable to survive the spring and early summer drought. Few of the burns caused by large, hot wildfires of the Southwest have restocked naturally. The surface of severely burned soils often seals, and the chemical, physical, and microbial characteristics are changed. Seedlings starting on burned areas are often killed by high surface temperatures of the blackened and exposed sites, by erosion of the soil on steep slopes, and by the impenetrable dry zone in deep ashes. On the other hand, we do have some well-stocked burns where fire did not kill the current seed crop.

Heavy losses of advanced reproduction during timber harvesting is another serious problem. We must direct more attention to protection of young trees. It is estimated that at least 5 million acres of the Southwest are stocked with a mixture of mature sawtimber and young reproduction. If we assume that only half that area is stocked with young trees from seedling to small pole sizes, proper protection during harvest cutting would ease the regeneration task of future years.

Precommercial thinning before harvest cutting at Fort Valley has demonstrated that advanced reproduction can be saved. Some foresters were concerned that stumps would be hazardous to workers in the woods and to equipment. The logging boss was
skeptical at first. Later he indicated his complete approval. Damage to his equipment was insignificant. The fallers were able to locate marked trees in less time. They were able to drop trees with minimum damage to the residual stand. Skidders were able to avoid large stumps, boulders, and crop trees. As an added benefit, the skidding tractors crushed the thinning slash.

Not all areas can be regenerated by natural seeding. Fire or heavy harvest cutting may have destroyed the seed source. We have about 400,000 acres of nonstocked lands that will need artificial reforestation. Another half million acres are poorly stocked. These understocked lands may be reforested either by artificial or natural means, depending on number and quality of seed trees.

Most of the factors already discussed that jeopardize natural regeneration also jeopardize seeding and planting. Although planting has been the most successful method of regeneration to date, the number of successful plantations is small compared to other regions. Through 1968, only 35,454 acres were seeded or planted. Less than half of these acres have adequate stocking. Many of the causes of failure are correctable.

Spring and fall droughts, accentuated by abundant competing vegetation, have been blamed most frequently for poor results. Complete site preparation before seeding or planting has not become standard practice. Even on prepared areas, transpiration stress may be too great for trees with dormant roots. But heavy mortality has also been caused by root-eating insects, tip moths, sawflies, gophers, rabbits, porcupine, deer, and domestic livestock. Poor planting and low-quality stock have also contributed to past failures, perhaps more than we want to acknowledge. Researchers have consistently planted small plots successfully, but field crews have been less successful at planting large plots. On the other hand, we do have some excellent large plantations, such as the one on the Barney Pasture burn.

Our planting season is extremely short. Drought conditions may begin in April and last through June. Rainfall in April averages less than 1½ inches. Rain in May and June averaged only about 7/10 inch over 60 years. Newly planted trees are subjected almost immediately to severe moisture stress. The roots are placed in cold soil and remain dormant for a month to 6 weeks. Unless rains follow planting, the trees soon die. We have been most successful in years with above-average precipitation from April to July.

Planting (and seeding) material not acclimated to the area has also contributed to regeneration failures. I have prepared a map outlining seed collection zones for the Southwest. Although not based on performance data, the seed zones should help reduce losses attributable to planting trees outside their ecological environment.

Another source of losses that needs correction is grazing by domestic livestock. Cattle and sheep severely damage and kill young ponderosa pines in many parts of the Southwest. Plantations may need to be fenced until the trees are out of danger.

Increasing costs of planting are directing research attention increasingly toward natural and artificial seeding. Here we encounter again most of the obstacles to success that were discussed for natural regeneration alone. Deficient moisture and high rodent populations have been the main factors that limit success of direct seeding. As indicated earlier, moisture stress has a powerful impact on seed germination and seedling growth. Moisture stress may curtail direct seeding on half the commercial forest land. On the other half, rodents are the major obstacle. Baiting with "1080" and thallium sulphate-soaked seed and seeding with endrin arasan-coated seed have shown some promise, but have also failed to control some of the larger rodents. We may need to wait for a more effective rodenticide treatment for the more difficult sites.

Planting has been the most successful method to date, but drought, frost heaving, and biotic agents have frequently turned promising plantations into failures. The seedling crop of 1919 stocked most of the original areas that were receptive then. Virtually no natural regeneration has resulted from designed management activities. We need to find ways to make direct seeding successful. In the meantime, foresters should devote more effort to protection of advanced reproduction, improved site preparation, and providing for regeneration in the logging plan.

LITERATURE CITED


4. LARSON, M. M. and G. H. SCHUBERT. "Effect of


REGENERATION PROBLEMS OF PONDEROSA PINE IN THE NORTHERN ROCKY MOUNTAINS

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U.S. Forest Service
Department of Agriculture
Ogden, Utah

THE FOREST

The ponderosa pine country I talk about includes western Montana, Idaho, and northeastern Washington. Figure 1 shows the occurrence of ponderosa pine in this region. Ponderosa pine usually occupies the low-elevation belt between the nonforested grasslands of the valley bottoms or plains and the more mesic forest types at higher elevations. It occupies about 5½ million acres as a commercial forest type and possibly 2 million acres as a noncommercial type. The species occurs as a minor component of other forest types on much additional acreage. Present sawtimber volumes total about 36 billion board feet and growing stock, about 6½ billion cubic feet.

Although the northern Rocky Mountain region is generally rough and mountainous, the ponderosa pine country ranges from gentle terrain to very steep, broken land. I estimate that about half of it is gentle and about half is steep. The species occurs on the great range of soils found in the region, but grows best on deep, well-drained soils.

Climate of the ponderosa pine forests of the northern Rocky Mountains is characterized by summer rainfall deficiency (2). Table 1 and Figure 2 show that July and August generally are dry throughout the ponderosa pine belt; this is a critical factor in establishment of regeneration. Mean annual precipitation varies between 15 and 27 inches over the region. Mean annual temperatures range between 40 and 48 degrees Fahrenheit and mean July and August temperatures range from 60 to 70 degrees depending upon locality.

Productivity of these ponderosa pine forests in terms of Meyer’s site-quality classes (7) ranges from site quality II to site quality VI with most area in site qualities III, IV, and V. According to Forest Survey statistics, the ponderosa pine type of this region is distributed by yield-capability classes as shown in Table 2.

Ponderosa pine forests include a number of habitat types best described by Daubenmire (4) for northern Idaho and northeastern Washington as follows:

- *Pinus ponderosa*—*Festuca idahoensis*
- *Pinus ponderosa*—*Agropyron spicatum*
- *Pinus ponderosa*—*Stipa comata*
- *Pinus ponderosa*—*Purshia tridentata*
- *Pinus ponderosa*—*Physocarpus malvaceus*
- *Pinus ponderosa*—*Symphoricarpos albus*
- *Pseudotsuga menziesii*—*Calamagrostis rubescens*
- *Pseudotsuga menziesii*—*Calamagrostis rubescens, Arctostaphylos phase*
- *Pseudotsuga menziesii*—*Physocarpus malvaceus*
- *Pseudotsuga menziesii*—*Symphoricarpos albus*
- *Abies grandis*—*Pachistima myrsinoides*

I estimate that ponderosa pine is the climax species on about one-third of the acreage of ponderosa pine forests. Douglas-fir is climax over the bulk of the acreage, with grand fir climax over a more limited area.

Wildfire has played a tremendous part in the ecology of ponderosa pine forests and has been the major factor in maintaining this species over the bulk of the acreage where it now grows. It has also caused ponderosa pine forests of the northern Rocky Mountains to tend toward even-age stands rather than the uneven-age forests characteristic of ponderosa pine in many other parts of the West. In the habitat types, however, where ponderosa pine is climax, the uneven-age selection forest is common in this region, too.

NATURAL REGENERATION

For success in natural regeneration certain problems must be considered.

Advance Regeneration

The importance of advance regeneration in the ponderosa pine type has frequently been emphasized (13). Over much of the type, advance regeneration of ponderosa pine, Douglas-fir, western larch, or lodgepole pine often is present and must be considered when deciding on cutting, slash disposal, and regeneration methods.

A serious and frequent problem of advance regeneration in ponderosa pine forests is dwarf mistletoe. This disease is especially prevalent in ponderosa pine in northern Idaho and northeastern Washington and in Douglas-fir throughout the region.
Figure 1. The occurrence of ponderosa pine forests in the northern Rocky Mountain region of the United States.
also occurs commonly on lodgepole pine and western larch. Where the advance reproduction is infected, it must be examined carefully to determine whether or not cutting infected stems will leave adequate stocking for a new stand. If not, it may be better to destroy the advance growth and rely on subsequent regeneration for stocking. In stands heavily infected, to determine whether or not trees are infected is difficult. In such situations, cutting all trees of the susceptible species is common practice.

Advance regeneration is not present over a large acreage of the type. Here, reliance must be placed on regeneration after cutting.

Subsequent Regeneration

Site conditions vary so greatly over the ponderosa pine type of the northern Rockies that it is unwise to generalize about the success of natural regeneration subsequent to cutting. Nevertheless, I will generalize.

Seed losses of ponderosa pine from the time of ovulate bud formation to seed germination are tremendous. In one Montana study (9), involving three experiments at six locations, loss of potential seed for germination was 99.5 percent. Bud failures, abortions, squirrels, insects, mice, chipmunks, and other factors all take a toll.

Because mature ponderosa pine forests tend to be more open than many other forest types, competing low vegetation often is well established in advance of cutting, fiercely and rapidly occupies most sites after cutting, and therefore constitutes a tremendous handicap to the establishment of subsequent tree reproduction. Site preparation to control competing vegetation is an important and necessary practice.

Subsequent ponderosa pine regeneration, especially in central Idaho, depends on the coincidence of a bumper seed crop with a favorable following season for germination and survival of seedlings. These conditions coincide irregularly; the interval between such occurrences may be as long as 20 years (5).

Because ponderosa pine occupies a zone of low precipitation and high temperatures, droughty conditions are frequently a hazard to regeneration success. The species, however, has the capacity for rapid and great root growth during the first growing season; this root growth helps to overcome droughty conditions.

If periodic fires are excluded from ponderosa pine cutovers that have an adequate seed source, reproduction gradually fills in on many habitat types. The time span to obtain adequate regeneration may be far too long, however, to satisfy management objectives (8). Reestablishment in some habitat types is extremely slow.

Because natural regeneration after cutting ponderosa pine usually is slow and uncertain, many land...
Regeneration of Ponderosa Pine

Table 1. Temperature and Precipitation for Selected Weather Stations in the Ponderosa Pine Forests of the Northern Rocky Mountains.¹

<table>
<thead>
<tr>
<th>Station</th>
<th>Normal average temperature</th>
<th>Normal total precipitation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>July</td>
<td>August</td>
</tr>
<tr>
<td></td>
<td>Degrees Fahrenheit</td>
<td>Inches</td>
</tr>
<tr>
<td>WASHINGTON</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chewelah</td>
<td>66.6</td>
<td>64.4</td>
</tr>
<tr>
<td>Spokane (Airport)</td>
<td>70.5</td>
<td>68.0</td>
</tr>
<tr>
<td>IDAHO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coeur d'Alene</td>
<td>69.1</td>
<td>67.8</td>
</tr>
<tr>
<td>Grangeville</td>
<td>67.0</td>
<td>65.9</td>
</tr>
<tr>
<td>McCall</td>
<td>62.8</td>
<td>60.4</td>
</tr>
<tr>
<td>Idaho City</td>
<td>66.9</td>
<td>64.8</td>
</tr>
<tr>
<td>MONTANA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kalispell (Airport)</td>
<td>65.7</td>
<td>63.1</td>
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<tr>
<td>Thompson Falls</td>
<td>69.2</td>
<td>67.6</td>
</tr>
<tr>
<td>Darby</td>
<td>65.1</td>
<td>63.0</td>
</tr>
<tr>
<td>Superior</td>
<td>67.5</td>
<td>65.1</td>
</tr>
<tr>
<td>Average</td>
<td>67.0</td>
<td>65.0</td>
</tr>
</tbody>
</table>

¹Data from climatological summaries of ESSA, U.S. Department of Commerce.

Table 2. Distribution of Ponderosa Pine by Yield-Capability Classes in the Northern Rocky Mountains.

<table>
<thead>
<tr>
<th>Yield-capability classes</th>
<th>Distribution of commercial forest land of ponderosa pine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cubic feet per acre per year Percent</td>
<td></td>
</tr>
<tr>
<td>165+</td>
<td>2</td>
</tr>
<tr>
<td>120 to 165</td>
<td>5</td>
</tr>
<tr>
<td>85 to 120</td>
<td>19</td>
</tr>
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<td>50 to 85</td>
<td>48</td>
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<tr>
<td>Less than 50</td>
<td>26</td>
</tr>
<tr>
<td>All classes</td>
<td>100</td>
</tr>
</tbody>
</table>

management agencies, in the northern Rocky Mountains, plant or seed much of the ponderosa pine type to obtain prompt and adequate regeneration. One major exception is St. Regis Paper Company in northwestern Montana. Their common practice of leaving from four to six seed trees per acre, with understory site preparation by burning or laydown, has obtained adequate stocking in 5 to 8 years on 95 percent of their sites.

ARTIFICIAL REGENERATION

Artificial regeneration presents problems for the land manager.

Direct Seeding

Direct seeding of ponderosa pine in the northern Rocky Mountains has been tried repeatedly ever since the first unsuccessful attempts after the burns of 1910 (10). There have been some successes, but many more failures.

Certain probabilities for success exist for all methods of regeneration; the land manager should consider these probabilities when planning direct seeding in the ponderosa pine belt. Over most of the type, the probabilities for success with direct seeding are rather low. Generally, with direct seeding, a land manager faces the same problems that exist for natural seeding. The needs for success are control of rodents, control of competing vegetation, and favorable moisture conditions. These needs can be met at times throughout the ponderosa pine belt, but it is the frequency with which they can be met that is important. Generally, they do not occur with sufficient frequency for direct seeding to be economical. As a result, planting nursery
stock is the generally accepted method to establish new stands promptly.

Planting

Considerable research and nearly 60 years of experience in ponderosa pine planting have resulted in techniques that are generally successful in establishing trees. Cost and acceptance of some of these practices are frequently questioned, however. I will try to list the generally accepted practices.

First, let's start with the nursery and consider the age of stock. For many years, transplant stock was considered a necessity for success in planting ponderosa pine. At present, 1-0 and 2-0 stocks are used, although most land managers seem to prefer 2-0 stock. Use of long-rooted stock is a common practice, also.

Careful handling and protection of stock from the lifting process all the way through sorting, packaging, storing, transporting, field storing, and final planting are extremely important. Too frequently, planting failures can be traced to damage that occurs during the handling of stock.

Careful site preparation is a must in ponderosa pine country. Lack of adequate control of competing vegetation was for many years the major cause of planting failures in southern Idaho (1). Study of the Town Creek plantations in central Idaho has shown that both adequate site preparation and care in handling stock not only result in better survival but also in better growth of planted trees (6).

Methods of site preparation vary according to conditions of each area to be planted; these site-preparation methods include mechanical, chemical, and fire. According to the Forest Service, Region 1, Reforestation Handbook (11) "Some of the mechanical methods complete the site preparation in a single operation. Many of the methods are combined with the use of fire to eliminate logging or slashing debris and prepare the site for reforestation work. In all treatments the objective is to eliminate competitive vegetation and expose sufficient mineral soil to insure the success of reforestation measures." Handbooks of Regions 1 and 4 (11, 12) list the following measures:

Mechanical
- Dozer scarification
- Dozer-pile slash, scarify, and burn
- Machine terracing
- Machine trenching
- Machine furrowing
- Machine cable-down and burn
- Dozer trampling
- Machine scalping
- Hand scalping
- Slash and burn

Chemical
- Aerial application of herbicides for release from brush or overtopped crop trees
- Aerial application of herbicides to prepare area for broadcast burning
- Spot treatment with herbicides to eliminate competition in planting spots

Fire
- Broadcast burning
- Burning of dozer piles

Much could be written about experience with site preparation for planting in the northern Rocky Mountains. Stripping and terracing methods, developed between 1954 and 1958 on the Boise National Forest by cooperative studies conducted by Region 4 of the Forest Service and the Intermountain Station (1), have proved highly successful in obtaining high survival of planting stock. These methods have been used widely in Region 4 and more recently by the Forest Service in the Bitterroot Valley of Montana. Here they have been equally as successful in obtaining high survival. An increasing problem here and elsewhere is that people don't like the appearance of slopes, especially steep slopes, that have been terraced for planting. Others are concerned about possible unfavorable effects of terraces on the productivity of the site and erosion of soil. An effective alternative to terracing on steep slopes may be difficult to find.

The actual planting job is successfully accomplished by a variety of methods. Planting is done by machine, by auger, and by various hand tools, depending on the individual situation. Though planting is done in both fall and spring, spring planting generally is favored. Fall planting usually is confined to high-elevation basins where snow cover makes spring planting difficult.

Protection of plantations from grazing by livestock, especially in bottom lands, and from damage by rodents is necessary in parts of the northern Rocky Mountains. In some areas deer damage is excessive. Adequate protection against damage by livestock or big game usually is difficult to obtain.

INFORMATION NEEDS

I could list a host of knowledge needs for ponderosa pine regeneration; however, I will confine myself to a few outstanding ones.

A good evaluation is needed for various site categories of the probabilities of success for each alternative for obtaining regeneration so that the land manager may pick the method or combination of methods that will best satisfy his objectives. All
methods of regeneration, both natural and artificial, probably have their place. But we need to be able to recognize where each should be used. I believe ecological habitat types provide the best system for categorizing ponderosa pine country. This means developing ecological habitat types and an understanding of what these mean in terms of regeneration. A good knowledge of soils is also essential.

Also needed are improved ways to control competing vegetation. We need an understanding of the ecology of competing plants; and we need increased research programs on mechanical and chemical means of controlling vegetation. These means must be economical, effective, and acceptable to people.

Furthermore, economical regeneration methods are needed. We need less costly ways to grow nursery stock, to prepare sites, and to seed or plant.

SUMMARY

I see the following as major problems in regenerating ponderosa pine in the northern Rocky Mountains:

Much of the country is mountainous and rough, with steep slopes and frequently with shallow soils. This kind of terrain makes access and management difficult and costly, and poses problems in decisions on best uses of the land that will not damage the soil resource.

Droughty conditions in July and August are severe enough to adversely affect establishment of regeneration.

Losses of seed to insects and animals are very high and frequently require rodent control for success of natural regeneration or seeding.

Competition from understory vegetation is intense and usually requires site preparation after cutting for success of natural or artificial regeneration.

Dwarf mistletoe of ponderosa pine and Douglas-fir must always be considered in planning regeneration measures.

Natural regeneration usually is slow and frequently uncertain. This has resulted in land managers increasingly placing reliance on artificial regeneration.

Direct seeding encounters many of the same uncertainties as natural regeneration. Each situation must be evaluated carefully and the method used only where the probability for success is high.

Planting nursery stock on well-prepared sites is relied on to obtain adequate restocking within acceptable time limits. Planting requires attention to seed selection and supply, nursery practices, planting practices, genetic improvement, plantation care, and planting at a reasonable cost.

Certain clearcutting, burning, and mechanical site-preparation practices that are highly successful in obtaining regeneration are increasingly coming under attack by concerned people. The major criticism is that they result in conditions that are aesthetically unfavorable. Satisfactory alternatives must be developed. They may prove difficult to find and costly.

ACKNOWLEDGMENTS

In preparing this report I drew freely from the manuscript of James D. Curtis and Marvin W. Foiles (3) and the handbooks of the U.S. Department of Agriculture (11, 12). I also wish to acknowledge the helpful reviews by Marvin W. Foiles, Dale O. Hall, Arthur L. Roe, Samuel S. Evans, Jr., and Martin C. Galbraith, all of the Forest Service, U.S. Department of Agriculture; Ernest B. Corrick of Anaconda Forest Products; and Richard D. Griffith of St. Regis Paper Company.

LITERATURE CITED


Regeneration Problems of Ponderosa Pine in the Northern Rocky Mountains


PONDEROSA PINE REGENERATION PROBLEMS IN THE WEST COAST STATES

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California Division of Forestry
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INTRODUCTION

MOST OF US AGREE THAT PONDEROSA PINE IS ONE OF THE FINEST TIMBER TREES in the United States, perhaps in the world (37). It will, in most of its range, regenerate itself if given enough time. Why the concern then for regeneration? The “push” is the growing impatience of some forest owners and managers to want a better job than nature does. Prompt regeneration of recently logged areas and fresh burns, in these days of increasing intensive management, is a necessity (13,21).

Not only forest owners and managers are concerned with ponderosa regeneration. Legislative bodies in all three states of the West Coast have laws or rules that regulate timber-harvesting methods to provide adequate regeneration. State boards of forestry are concerned also. The California board’s statement of policy reflects this (5). Problems have been discussed in the annual meetings of the Western Reforestation Coordinating Committee several times.

THE PROBLEMS

Economy in establishing regeneration is our primary concern. High costs that compete with alternative investments for capital so that owners must capitalize them are a substantial barrier to an unqualified enthusiasm for regeneration (1, 55). Any problem of survival or growth that is satisfactorily solved will help reduce costs and make artificial regeneration more attractive to management.

Drought lasting 4-5 months in summer or severe freezing in winter is a natural barrier (24). Heat, fortunately, appears to cause no difficulty in most areas (18). Let’s investigate more closely some of our regeneration problems.

Natural Regeneration

First, let’s look at silvicultural harvesting treatments to provide for adequate natural seed fall.

Early logging practices, although similar throughout the ponderosa pine range, caused different degrees of regeneration. In areas such as the west side of the central Sierra Nevada Mountains, beautiful young-growth stands evolved. In others, such as part of the east side of the Sierra Nevada Mountains and south central Oregon, only dense brush fields are evident (13, 21, 23, 25).

Numerous factors may delay adequate stocking for 10 or 20 years. We can no longer wait. Among our needs are techniques to provide reliable cone crops at timber harvest. Predicting crops will help (34). But we need more assurance of seed supplies. Can we ever manipulate conifers to produce annual crops as do our fruit orchards?

Control of stocking is difficult. Frequently, regeneration will be too light or too dense. A study of stocking control in conjunction with harvesting was attempted on the Challenge Experimental Forest (11). Areas cut in 1959 and 1960 to provide 25, 50, and 100 thousand sound seeds per acre produced 1,910, 4,020, and 4,820 seedlings per acre in 1961. This result bears investigation in other areas because it indicates some degree of stocking control. Costs of leaving seed trees is an item to consider. McDonald (36) states that before seed trees can be removed stocking should be at least 58 percent.

Overly dense stands of seedlings result in stagnation (38). Although prescribed burning is a possibility for thinning, Wooldridge and Weaver (61) found from studies in north central Washington that uniform stocking is impossible to attain. Much research is needed before this method will become practical.

Hayes (22) suggested a simple formula to aid in planning for natural regeneration that relates seedling density to viable seed available and factors of the environment. The formula is \( ST = VS - ER \). \( ST \) denotes stocking of established seedlings, \( VS \) the viable seed, and \( ER \) the environmental resistance. \( ER \) may be so large that no matter how much seed is produced, no seedlings can become established.

Site Preparation

Consider, next, problems related to site preparation. Present techniques depend on the type of cover and terrain and on whether the areas are old brush fields, recent burns, or logged areas that demand regeneration. In any event, we know bare mineral soil provides the best seedbed (4, 44).

Sites on old brush fields on national forests and private lands in California are most commonly prepared mechanically (9). To remove brush seed requires scalping to at least 6 inches, but doing so removes some
of the better top soil. An alternative is to remove brush with a bulldozer equipped with a brush rake. Subsequent brush seedlings and sprouts may be sprayed with herbicides.

Burning offers a possibility for site preparation in brush fields or logged areas. A combination of burning and chemical spraying has been successful in some U.S. Forest Service operations (7). Be sure to call in the fire experts for burning!

**Artificial Treatments to Enhance Regeneration**

Stocking from natural seed sources may be increased by applying special techniques. An example is a study conducted by the American Forest Products Corporation in the central Sierra Nevada Mountains on slopes densely covered with mountain misery (*Chamaebatia foliolosa*) (3). Just before seed fall, terraces were prepared with a D-9 bulldozer and rodents were controlled with an application of “1080” bait. Scattered seed trees provided sufficient seed to produce a dense stocking of pine seedlings on the terraces. The stand of seedlings is now overly dense and, if not properly thinned, may stagnate. This kind of treatment is probably the most economical to ensure regeneration, but stocking control is a problem.

Broadcast seeding is another not too reliable technique. Although more costly, it may offer improvement in stocking control. Endrin-treated seeds are applied by cyclone-type hand seeders for small areas or by air on large areas in late fall or early winter. Rodent control, of course, is a necessity. To improve the economics, the application of bait and tree seed simultaneously would be desirable. To make this technique successful, however, bait will have to be made more attractive and tree seed less so (28).

Spot seeding offers still better stocking control but is expensive. Then, of course, too many seeds in a spot cause a seedling clump or blank spots that make stocking too light. Graphs to estimate the number of seeds per spot were developed by Schubert and Fowells (42). Their graph is effective if survival figures on local seeding are available. Spot seeding in the eastern part of the ponderosa pine zone in Oregon has been unreliable (59). In this area, moisture is the major limiting factor. In other areas of Oregon, spot seeding has been successful (46, 58). Spot seeding on a prepared site in the Sierra Nevada Mountains provided 88 percent stocking (35).

Drill seeding, of all seeding methods, offers best control of stocking and is generally less expensive than spot seeding. A modified rangeland drill was operated in the first drill seeding in California (41). Results with this machine have been variable. Some modification, however, should improve its operation.

The California Division of Forestry has developed a tractor-drawn test seeder from an agricultural corn planter, somewhat along the lines of the pine seed drill being developed by the U.S. Forest Service (53). Results with our seeder have been encouraging (2). Although only one row was seeded at a time, two rows could be seeded by attaching two seeders to the tractor’s tool bar. Results of a drill-seeding study in two locations are shown in Tables 1 and 2. McDonald (35) compared seeding by two methods with planting seedlings by three methods. Table 3 indicates the results of these comparisons. Although spot seeding was more satisfactory, drill seeding provided adequate stocking.

Planting is the surest method to obtain regeneration. On most medium-to-good sites, survival from planting stock is no problem. Stock can be improved, however, to assure increased survival, rapid growth, and improved form. Good physiological condition of planting stock is an important factor in establishing successful regeneration. A good-quality seedling with rapidly developing root system can overcome much environmental resistance. In some ponderosa pine sites, however, even the highest quality seedling may succumb to an over-riding drought factor (23).

Nursery location with its temperature pattern, soil characteristics, and cultural practices such as seedling lifting dates, fertilizer applications, fumigation, watering schedules, and storage, all affect seedling physiology (33, 39, 48, 49, 50, 51).

Many techniques have been tried to overcome drought at the planting site. Tubed seedlings have been planted in the Northwest and Canada. The California Division of Forestry supplied the Bureau of Land Management in Oregon with ponderosa pine seedlings in


<table>
<thead>
<tr>
<th>Species</th>
<th>Stocking¹</th>
<th>Stocked Sections²</th>
<th>Survival %</th>
</tr>
</thead>
<tbody>
<tr>
<td>White fir</td>
<td>9.3</td>
<td>77.0</td>
<td>4.9</td>
</tr>
<tr>
<td>Douglas-fir</td>
<td>12.3</td>
<td>101.8</td>
<td>5.8</td>
</tr>
<tr>
<td>Ponderosa pine</td>
<td>51.2</td>
<td>422.8</td>
<td>59.4</td>
</tr>
</tbody>
</table>

¹Based on 825 linear drill row sections (6.6 feet long) per acre as 100 percent stocking; drill rows spaced 8 feet apart.
²Per acre.
Regeneration of Ponderosa Pine


<table>
<thead>
<tr>
<th>Species</th>
<th>Stocking 1</th>
<th>Stocked sections 2</th>
<th>Survival</th>
<th>Seed per acre</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Percent</td>
<td>Feet</td>
<td>Percent</td>
<td>Pounds</td>
</tr>
<tr>
<td>White fir</td>
<td>13.6</td>
<td>112.5</td>
<td>66.7</td>
<td>1.69</td>
</tr>
<tr>
<td>Douglas-fir</td>
<td>9.7</td>
<td>79.8</td>
<td>40.7</td>
<td>0.29</td>
</tr>
<tr>
<td>Ponderosa pine</td>
<td>71.8</td>
<td>592.1</td>
<td>93.7</td>
<td>0.56</td>
</tr>
</tbody>
</table>

1Based on 825 linear drill row sections (6.6 feet long) per acre as 100 percent stocking; drill rows spaced 8 feet apart.

2Per acre.

Table 3. Second-Year Survival and Height of All Seedlings by the Planting Method, Sugar Loaf Plantation, 1965.1

<table>
<thead>
<tr>
<th>Method</th>
<th>Survival</th>
<th>Seedling height</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Percent</td>
<td>Feet</td>
</tr>
<tr>
<td>PLANTING</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil auger</td>
<td>92</td>
<td>0.59</td>
</tr>
<tr>
<td>Planting tool</td>
<td>91</td>
<td>0.54</td>
</tr>
<tr>
<td>Machine</td>
<td>89</td>
<td>0.57</td>
</tr>
<tr>
<td>SEEDLING</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seed spotting</td>
<td>88</td>
<td>.27</td>
</tr>
<tr>
<td>Rangeland drill</td>
<td>632</td>
<td>.23</td>
</tr>
</tbody>
</table>

1Represents McDonald, 1966.
2Represents 63 percent of 8-ft. drill row segments stocked.

tar paper containers. Results of the Bureau of Land Management plantings have not been received yet. To my knowledge, little testing to compare container-grown and bare-root ponderosa pine seedlings was done. Watering improved survival (25,60). Sandwich planting consisted of enclosing seedling roots in rectangular pieces of heavy blotting paper soaked in a nutrient solution before field planting (48). Survival from this technique was no better than with bare-root planting. Planting seedlings to a depth of the cotyledon whorl improved survival considerably (14). Dick (15), however, found that coating seedling tops with transpiration inhibitors, Rutex W-3 and Rutex 59, did not improve survival in southern Oregon. Paper mulches around seedlings help retain soil moisture and improve survival (24).

Equipment is a factor in improving the economics of regeneration. Most foresters are familiar with the high costs of hand planting with either bars or mattock-type tools. Under certain conditions the power auger prepares satisfactory planting holes, speeds the planting operation, and improves planting quality. Machines drawn by tractors speed the job and lessen costs on well-prepared sites. Possibly, a more versatile machine that does not require a continuous furrow and can be manipulated more easily around obstacles could be developed, however.

Many plantations, once established, suffer from reinvading brush. Considerable information is available on releasing plantations from competing vegetation with selective herbicides (7,12,19,40). The forest service in the central Sierra Nevada is aerially applying selective herbicides for about $10.00 an acre. Some soils may be deficient in nutrients, slowing seedling growth. Fertilizers applied to plantations, in some instances, have increased growth of seedlings (52,56,57,62), and increased cone production (32).

PESTS

Provision for pest control must be included in any reforestation plan. Animal populations should be sampled before regeneration work. Birds, although difficult to sample, are capable of destroying large numbers of seed during natural seed fall. Eastman (16) found that 24 birds per acre, in central Oregon between September and December when seeds were falling, could consume 58,000 seeds. Direct control of birds is difficult, however, because killing them is socially undesirable. Too, the benefits received in insect control generally more than offset seed destruction. Artificial seeding may be protected by coating the seed with the repellents Arasan or anthraquinones.

Rodents can be particularly destructive in natural and artificial seeding. Compound 1080 is hazardous to apply for rodent control. We hope an operational
substitute will be available soon. Dichlorophenone is a possible substitute (27). Poisons of this type offer only temporary relief from rodents, however (26).

Endrin, our so-called rodent repellent, is somewhat in jeopardy. A less toxic material is needed (29).

Diseases in young ponderosa pine plantations have been reported rarely. Natural regeneration, of course, may be infected with the same seedling soil diseases found in nurseries. Young trees in plantations are subject to Eltroderma and Peridermium (gall rust). Generally, present problems are not great, but they could become so.

Deer are the scourge of regeneration experts in many areas. Biswell (8) in a Coast Range study observed that 66 percent of natural ponderosa pine seedlings and 91 percent of the transplants were damaged by deer. Numerous plantations, however, in the Sierra Nevada Mountains are not damaged after the first growing season when seedlings set winter buds. Analysis of seedling substances that attract deer is needed. Some seed sources seem to be more attractive than others. In direct seeding, palatable forage in buffer crops sown with the tree seed may relieve animal pressures (6).

Porcupine girdle young plantation trees and cause considerable mortality. Strychnine-treated salt blocks and shooting seem only partially successful as controls.

Gophers have caused much damage in certain areas. On prepared sites where terrain is not too steep and rocks are few, a mechanical bait applicator will give good control (10).

We have attributed fewer damage problems to insects than to animals. Insects do take their toll, however. Cone and seed insects have destroyed up to 50 percent of some cone crops (30). Koerber (31) is doing research in California on control of cone beetles (Conophthorus, sp.) and ponderosa pine seed worm (Laspeyresia, sp.) with dimethoate sprays. Stamine strobili of ponderosa pine were heavily infested with xyelids (Xyelidae) in the southern Sierra Nevada Mountains in June 1969 (54). Some plantations have been seriously damaged by tip moths (47). Others, particularly in southern Oregon, have been wiped out by grasshoppers (23). The pine reproduction weevil has been a serious pest in plantations in northern California (20). Various hybrids may be developed to resist some insect infestations, and effective chemicals now are available to control many.

**TREE IMPROVEMENT**

Tree improvement techniques must be stressed here. Much more should be done to increase growth and form of ponderosa pine. More progeny testing is needed to evaluate races and the amount of genetic gain from selections and crosses. Ponderosa pine seedlings from several sources were planted from 1911 to 1928 in Idaho and eastern Washington and Oregon to evaluate racial differences (45). In many instances, plantation-site factors tended to override genetic differences.

The California Division of Forestry hopes to show that growth can be improved to a large extent by controlled pollination with selected parents. Only a token amount of work has been done to improve and expand seed-production areas and seed orchards. Time is running out. Before long, possibly, greatly improved growing stock of ponderosa pine will be in demand.

What has been covered in these few minutes includes a considerable amount of effort by numerous investigators; perhaps not as much as has been done with Douglas-fir, but certainly a respectable amount. Much progress has been made, but only the surface has been scratched. I hope that my contribution today will stimulate you to delve into some of the unanswered questions; to then emerge with techniques for better, less costly, ponderosa pine regeneration.

**LITERATURE CITED**


Regeneration of Ponderosa Pine


Regeneration of Ponderosa Pine


POLLEN AND SEED: A GOOD LINKAGE FOR REFORESTATION

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TREES REPRODUCE MAINLY BY SEEDS. IN CONIFERS SUCH AS PINES, SEED FORM IN CONES through the development of a series of sporophylls. Two kinds of cones or strobili are produced on the same tree, the microsporophyll (male) or staminate cone, and the megasporophyll (female) or ovulate cone. The staminate cone produces myriads of microspores called pollen grains. The ovulate cone produces megasporangia called ovules. After fertilization and proper development, the embryo formed in the ovule becomes seed.

IN THIS SEEMINGLY SIMPLE DEVELOPMENT lie intricate and remarkable phenomena that are characteristic of all organisms, heredity and variation. Heredity is the process that brings about resemblances between parents and progeny and between progeny of the same parents. Variation is the tendency of the progeny to differ from the parents and from each other. Long before man understood the nature of inheritance or the process, he learned to control, somewhat, the heredity of various plants and animals by careful breeding, which led subsequently to many improvements.

Most foresters or forest managers recognize the importance of seed from the correct provenance for their regeneration work. Irrefutable information supporting the importance of seed source has been published by many forest geneticists from studies of geographical seed source and from hybridization programs. Many foresters also realize that, within any given stand, the growth and performance of individual trees vary considerably. This is the exact basis of any genetic improvement program. Variation must be wide, genetically, within the population to be improved. Naturally, one must comprehend that the phenotype, or the properties and outward appearance of a tree, is the combined result of the interaction of the genotype, or sets of genes, of the tree with the environment of the tree. Therefore, judicious silvicultural treatments such as thinning, proper spacing, and fertilization affect seed production or the growth of trees.

Current activities to produce genetically superior seeds or seeds of known origin include many approaches. With the method most commonly practiced, superior, so-called plus-trees are selected in wild stands. Subsequently, seed orchards are established either by seeds or by grafting scions from these phenotypically selected trees. With proper spacing and design, seed can be obtained in this type of production either artificially with pollen of known parentage, or with naturally dispersed pollen.

Other approaches such as an area for seed production, hybridization and selective breeding, and mutagenesis are practiced to increase the abundance of improved phenotypes or new combinations.

Irrespective of the approach, the choice of parents, as pollen source or as seed-bearing plants, is important. For example, Duffield (5) reported that Pinus monticola Dougl., of western Washington origin, crossed with Pinus strobus L., produces hybrids that grow more rapidly than do hybrids from Pinus monticola of Sierra Nevada origin. Also, the height growth of provenance hybrids of Picea abies Karst. in Sweden (14) was superior to progenies of local provenance trees. This study revealed a variation of growth pattern between progenies of different mothers.

To keep pollen and seed in a vigorous condition is a problem in experiments with the production of superior trees for reforestation. Pollen has two major requirements. First, it must be viable and capable of fertilizing the egg cells. Second, it must be able to carry on physiological processes and chemically activate the ovule to develop into seed. The chemical constituents of pollen, although mainly protein and fat, also include vitamins, free amino acids, pigments, and small amounts of two growth hormones (2,6,9,13). These hormones can, in minute quantities, induce the production of more hormones in the female organ of the tree. This, in turn, will activate the development of seed. Generally, pollen viability is affected by temperature, moisture content, and exposure to gases and chemicals before and during storage. Ritter and Miething (16) reported that, of 26 tested agents (fungicides, antibiotics, and insecticides), the majority exerted a strong inhibitory effect on the pollen germination of pine and spruce. Conventional methods of extracting and storing pollen have been tested and reported by numerous investigators for long- and short-term storage (1,7,9,13). Special techniques such as freeze-drying (lyophilization) have proved successful in recent years (3,10) for prolonging the period for pollen storage. This particular
dehydration process is based on the unique properties of ice, which will sublime under certain atmospheric conditions so that the cell wall of the pollen will be unaltered and undamaged.

For instance, Rapid advance in the physiology of pollen growth has enabled researchers to understand better the various factors that control various stages of growing processes. For instance, adding borax and boric acid to a sugar solution markedly stimulated growth of the pollen tube. Another element, calcium, has been related to pectin synthesis in membranes. This cation also affects pollen growth and fertilization (18). Chemical constituents of the pollen, such as the flavonoids, have been reported to be included in the physiology of the reproductive process. Kuhn and Low (12) showed that the failure of two varieties of *Forsythia* sp. to cross-pollinate was caused by the presence or absence of a certain flavonoid in the pollen. This absence would cause incompatible reactions that inhibit pollen growth.

Now, if we assume that we have overcome all obstacles such as unseasonal weather and insect infestation and finally have arrived at the seed collection stage, then harvesting and storage of seed remain.

An article in the October issue of *Science* by Porsild, Harington, and Mulligan (15) reports the successful germination and growth of lupine seed at least 10,000 years old. In 1954, these seeds, found in arctic tundra, were preserved in lemming burrows and deeply buried in permanently frozen silt of the Pleistocene age. After excavation, the seeds were kept in a dry place for 12 years before they were tested for germination. One resulting seedling developed a few flowers at 11 months of age, which was about 2 years earlier than normal for the species in the arctic. This work seems to indicate that seed stored dry, at temperatures well below freezing, could remain viable indefinitely.

Generally, seeds from different species of trees vary in their ability to maintain maximum germination and vitality under similar storage conditions. Some species are more sensitive than others. The degree of longevity of seeds depends upon inherent qualities and environment. Seeds with reduced respiration at low temperature, low supply of oxygen, and moisture withheld can be stored for a long time. Biochemical changes caused by aging, especially in fats of the reserve materials, may also deteriorate stored seeds. Other factors, such as mechanical damages because of careless extraction and cleaning, will also contribute to deterioration of seed.

Prolonged storage of seeds can be enhanced with sealed or airtight containers. Many new plastic bags or containers are suitable for this purpose. The freeze-drying method mentioned for pollen storage has recently been tested and reported by Surber (20).

To collect seed at the proper stage of maturity is important. Fully mature seeds will remain viable longer than seeds collected too early in the fall. The immature, partially developed embryos and the reserve tissues are incapable of sustaining the full-life process. Schubert showed that ponderosa pine cones did not begin to open on the trees until their specific gravities had dropped below 0.62. He also reported that abnormal phenomena, such as reverse germination, were observed only among seedlings derived from immature seed and occurred most frequently in fresh seed (17).

From the Woody-Plant Seed Manual and other published information (8,21), drying and storage conditions for ponderosa pine cones are:

Sun-dry from 96 to 144 hours
Dry by convection at 120 degrees F for 3 hours
Dry to a moisture content below 8 percent of oven-dry weight before storing
Seal in containers at from 32 degrees to 41 degrees F for short-term storage, and
Hold below freezing temperatures for periods as long as 30 years.

In conclusion, I will tell you one of my impressions when I visited the seed orchard owned and operated by
the Swedish Cellulose Company, one of the largest forestry outfits in Sweden. A sign on the gate of the entrance reads, “Good seed does not cost, it pays!”

LITERATURE CITED


THE SEED SOURCE QUESTION FOR PONDEROSA PINE

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SUPPOSE, FOR A MOMENT, THERE WERE NO RESEARCH ON SEED-SOURCE DIFFERENCES of ponderosa pine. Would there be no basis at all on which foresters could decide whether local or nonlocal seed would give the best returns over a rotation? Long before any research, the pattern of variation in the vast natural stands of ponderosa pine provided good information for inferences about the question of seed source. Although no one can separate what is genetic and what is environmental by observation alone, anyone can see that the species is markedly different over its range from west to east, from south to north, and from desert edge to high elevations on almost any major mountain range of the West.

ON THE DESERT EDGE, PONDEROSA PINE is slow-growing, hardly different from the juniper with which it successfully competes for limited moisture, although the juniper successfully competes with it in growth rate. Further up the slope, with more moisture assured, the ponderosa pine gains in height, but finally loses out to various more rapidly growing species. At its moist upper elevational limit, it grows much like the associated firs and pines. It successfully competes with them for light as they, in turn, successfully compete with it for the available moisture. That species are similar in growth rates in areas where their ranges overlap is a common observation. This elevational pattern of growth rate for ponderosa pine is repeated horizontally on a grand scale from the moist western side of the species’ range, where its height sometimes approaches 250 feet, to the droughty eastern side, where it is a slow-growing tree.

One could speculate that the extreme differences between the moisture-loving and the drought-tolerant types, with all the gradations between, simply reflect the reaction of one genetic kind of seed to a good or poor environment. Obviously, a large part of the difference is environmental, because we can observe great variations between rocky and deep soil on the same acre. But, modern genetic research shows that scores of other organisms, including man, exhibit wide variability of large numbers of traits. Detailed studies of these organisms show that there is an intense selection from the available genetic pool of variability for the genetic type that gives the species an advantage in each local environment. Presumably, local ponderosa pine has the same advantage. One would no more expect seed from the droughty eastern side of the Rockies to grow successfully in the moist Cascades than expect transported Pygmies to live successfully under natural conditions in the Arctic. With the question of seed source in ponderosa pine, the forester is usually not dealing with such extremes, but rather with how fine a gradation in environment between these extremes may have developed a genetic difference of importance. Is any movement of seed tolerable? Is the movement limited to the seed’s flight distance? To a 1,000-foot elevational zone? To a 2,000-foot zone? To a 5,000-foot zone? How far north or south in a zone? These are the typical questions that presently have no exact answers from research.

We should consider two more observations about the natural stand of ponderosa pine before we examine the limited information from seed-source studies.

The first observation concerns climatic stability. Climate in western North America has been essentially the same for perhaps 5,000 years. One good indication of this stability is that individual bristlecone pine trees have lived the last 4,000 years on some western mountains. This time span represents ample generations of ponderosa pine for the gene frequencies that characterize a race to essentially stabilize in local seed.

The second observation concerns pollen. Local stands display great diversity. But, in addition, individual trees in any ponderosa pine stand become receptive to pollination at different times over a range of several weeks. Although most pollination must come from neighboring trees or stands, there is no barrier to considerable pollination of early flowers from lower or more southerly stands, and of late flowers from higher or more northerly stands. Thus, each generation would seem not only to represent a stability of type from long selection for a local environment but also to incorporate whatever genes are brought in from other fastergrowing or more drought-tolerant stands from many miles on all sides.

Without research in genetics, then, we can reasonably conclude that the local seed source must have adapted its genetic options into a sensitive balance with the local environment, and that each generation
has had ample resupply of diverse genes to adjust to favorable or unfavorable climatic cycles.

I can illustrate this hypothesized structure for a stand grading from mountaintop to desert, such as we view here on the east side of the Cascades. Locally, the sharp moisture gradient overrides the small changes in temperature with elevation in the ponderosa pine elevational zone. We could expect the seed mix of many trees at any distinct locality along the gradient to represent a stabilization of the optimum average rate of growth that can be sustained in nature against long-term weather extremes, particularly moisture stresses. For a locality along the gradient somewhat higher and westward, where moisture is ample, the seed mix should have higher portions of genes for faster growth and lower portions for drought tolerance. Conversely, lower and eastward, where moisture is less, the seed mix should have lower portions of genes for fast growth and more for drought tolerance. As the local race is always receiving pollen from stands on all sides, presumably it should have the variability to shift considerably toward faster growth should the climatic cycle shift to more moisture. On the other hand, should a droughty cycle prevail, an ample proportion of drought-tolerant types should also be in the seed mix to fully stock the stand after the beetles have had their day.

If these observations of the natural stand lead us to the correct genetic conclusions, we would select local seed as the only reasonable choice for a long-rotation tree crop. Natural selection pressures on any nonlocal seed should be toward restoring the balance of genes as they occur in local seed. Higher proportions of unadapted trees would be expected than with local seed, hence, heavier losses would be expected during adverse periods.

Now, let us see whether these conclusions are altered by research on seed sources. If we regard studies under 20 years of age as having a limited interpretation, then there are only seven studies that provide data on inherent growth and survival in ponderosa pine.

They include the following plantings: Twenty-two races in Idaho, begun in 1911 (3, 13, 15); several races at Flagstaff, Ariz., started about 1911 (4, 9, 10); ten races planted at five sites in Oregon and Washington, started in 1926 (7, 8, 13); New Zealand plantings of seven races, started in 1931 (6, 13); local variation in 81 families, begun in 1933 at Placerville, California (1); variation of progeny from 89 seed trees that originated along an altitudinal transect in the Sierra Nevada, planted at three elevations, started in 1939 (2, 5); and arboretum plantings of many species at Wind River, Washington (11, 12).

These studies tend to confirm several of the genetic inferences I have made from observations of the natural stand (Table 1). My first inference is that inherent rates of growth correlate moderately to strongly with the yearly climatic pattern of available moisture and with favorable springtime temperatures. Races with the highest inherent rate of growth developed in the mild climate west of the Cascade and Sierra Nevada ranges where springtime soil moisture is ample and assured. The lowest rates of growth developed east of the Rockies and in Arizona in areas of deficient springtime moisture and where long drought cycles are experienced. Between these extremes, growth rates grade from west to east clinally, but also respond to differences in moisture and temperature from locality to locality. The evidence for this statement comes from three studies in Idaho, Oregon, Washington, and New Zealand, through 25 to 55 years of testing. About half the variation in racial growth on the plots is accounted for by climate at the source.

Evidence for a similar gradation of growth rates on a single mountain range, such as on the east slope of the Cascade or Sierra Nevada, is convincing. Though not deliberately tested in the same three studies, several examples of reasonably paired seed sources from moist or dry sites in the same mountain range can be cited from data at 25, 40, and 55 years (Table 1). The "rain shadow" effect on inherent growth is observed to occur on the east side of several other western mountain masses in these studies.

Estimates were made of the genetic and environmental proportions of variation in average height

<table>
<thead>
<tr>
<th>Mountain range</th>
<th>High-precipitation zone</th>
<th>Low-precipitation zone</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Seed source, National Forest</td>
<td>Height</td>
</tr>
<tr>
<td>Sierra Nevada</td>
<td>Sierra</td>
<td>141</td>
</tr>
<tr>
<td>Sierra Nevada</td>
<td>Eldorado</td>
<td>138</td>
</tr>
<tr>
<td>Cascade</td>
<td>Rogue</td>
<td>126</td>
</tr>
<tr>
<td>N. Rocky Mt.</td>
<td>Bitterroot</td>
<td>118</td>
</tr>
</tbody>
</table>

1Based on average height of all trees in the plantation.
of races observed on the plots in two of the studies. In both, the estimates were similar, with about two-thirds of the variation ascribed to environment and one-third to seed source. For many reasons, one could expect a lower portion of the observed variation between average heights of natural stands to be genetic, but the major ones are the widely differing races being compared in these studies and research plots deliberately located to minimize environmental differences. Undoubtedly, considerable genetic variation within each race was not estimated from the studies.

Most of the plots of existing studies are in locations with only moderate moisture stress, hence, reactions to long-term climatic extremes have been slow in expression. At the test site at Flagstaff, Arizona, however, with irregular springtime moisture and drought cycles over various periods of years, the expression was rapid (4). The surviving trees are almost entirely from a few races that fit the local dry-springtime moisture pattern—that is, races from Arizona, New Mexico, and the east slope of the Rocky Mountains. All races from moister climates further west and north have few or no survivors. Many seedlings from the westerly races died in the nursery from frosts. Early growth of those that survived through the nursery period was good, which indicated a capacity to grow well as long as suitable conditions prevailed.

At the next most severe site, near Bend, Oregon, the local Deschutes race is showing distinct superiority in survival, yet survivors of several other races still show better growth in height. Superiority in survival requires time for expression on less severe sites.

For example, in the oldest study at Priest River, Idaho, where 22 races have been growing for 55 years, the latest data (14) show low survival for races beyond 200 miles from Priest River. The local Kaniksu race is gaining over other races in both growth and plot volume, although individual trees of a near local race (Lolo) show superior height but lower survival, and a race in a very similar elevation and climatic situation (Umatilla) shows superior plot volume. The research evidence, then, indicates that on the most severe plot, only races adapted for extreme conditions survived. Under less severe conditions, the local or best-adapted race may take half a century to show a distinct superiority in survival and plot volume. Although other races sometimes grow more rapidly, the higher survival of the local race, coupled with reasonably good growth, appears to produce superior volume in the long run.

Genetic differences are expressed over rather small changes in elevation in a remarkably complete sampling along a transect in the Sierra Nevada Mountains near Placerville, according to data contributed by Dr. Tom Conkle, Pacific Southwest Forest and Range Experiment Station, Berkeley, California. The data at 29 years now show that medium-elevation sources exhibit superiority in height growth at medium elevations, and high sources at high-elevation plantations. Medium-elevation sources are still somewhat taller at low elevations. In earlier years, the middle-elevation sources were distinctly superior at all elevations, which reflected where best tree growth normally occurs in the Sierra Nevada Mountains. This middle-elevation group of seed sources, however, now appears to be losing to the local races at higher elevations, but trends are poorly defined at low elevations, with mid-elevation sources maintaining superior height. Differences in survival have developed only weakly at 29 years in this study. The data nicely confirm the concept of gradually changing genetic differences of seed sources with elevation and indicate that small differences in elevation can produce a measurable genetic difference in a seed mix—in this instance, in inherent height growth.

Other important patterns have developed in the older plantations. Needle diseases can be a serious pest of offsite trees. For example, a generalization seen in the Wind River Arboretum, as well as in the test sites west of the Cascades, is that ponderosa pine from drier climates and, incidentally, lodgepole pine, western larch, and Douglas-fir have sustained repeated crippling or killing attacks of needle diseases. Damage from snow and ice is often severe to some offsite races. Trees from high-elevation sources burst buds early at low elevations and are often killed by frost. These same factors damage or kill individuals in the local population, and usually only the difference in severity favors local races.

Although research plots generally support inferences of genetic variability in the natural stands of ponderosa pine, they also present a smattering of perplexing exceptions. We do not have adequate explanations for these exceptions. Yet, the great majority of the limited data in the seven studies seems to confirm inferences from the natural stand.

Since all of life is a balance of gains and risks, what do the foregoing observations and data suggest as an answer to the seed-source question?

Most important is to appreciate that the local seed source is something special. It appears to be the kind of seed combination that incorporates the best gain and least risk our present knowledge can provide. Unless climates change appreciably from the last 5,000 years, the local source will guarantee a good stand.

Under natural conditions, any departure from the local seed source carries unknown risk. If the concept is correct that each stand carries a balanced seed mix of fast-growing and drought-tolerant types attuned to the local environment, then nonlocal types selected for
faster growth would probably sustain greater losses than the local stand in adverse climatic cycles. Observations of both the natural stands and the oldest research plots point to a survival trend in this direction.

The risk is related to the length of rotation. For a short-rotation crop such as Christmas trees, the risk of damage from climatic extremes during the rotation is low. For a 100-year rotation, however, who would take a chance on the weather?

The risk is also related to the site. The outcome of a nonlocal seed source on a severe site is already known from many experiences. One would face less risk on a mild, protected site because the intervals between climatic extremes are longer.

If one wishes to risk a nonlocal, fast-growing race, he can usually find it in areas of assured springtime moisture and mild springtime temperatures.

But, in closing, we must add that our present effort to improve growth rate through genetics is based upon finding well-adapted parents in local stands capable of better growth rates in the local environment. Eliminating the rigors that beset seedlings in early life may change the picture. We also expect to see improvements to the local environment, such as thinning and control of competition, that will assure more moisture to the individual tree. Considerable work is planned or underway to understand the question “How local is local?” But with our limited present knowledge, local seed appears to be the only reasonable choice for most of us, regardless of how high early rates of growth of nonlocal trees may seem to be on our site.

An old Chinese proverb says, “Forester who drops his local genes may also lose shirt.”

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MANAGEMENT DECISIONS RELATING TO OFF-SITE PLANTATIONS

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NO SILVICULTURAL TERM DEFINES OFF-SITE PLANTATIONS. What do we mean by off-site? The first picture most people have of an off-site tree is a twisted, stunted, scraggly, limby runt. This is not always correct, although poor sites may only produce this type of tree. Off-site plantations, I believe, mean stands of trees that are not capable of growing products compatible in volume or numbers with the growth capacity of the near-normal site. Determination of whether or not a plantation is off-site depends on the number of trees in the stand that are adapted to the site and the number the site should grow to commercial sizes. A stocking survey separates on-site and off-site trees to determine the number of trees the site should support.

THE IDENTIFICATION OF OFF-SITE TREES is often difficult. Some of the visible indicators are deformities of trunk, leader, and limb; snow breakage; frost damage; infestations of disease and insects; slow growth compared with native trees; dead limbs or leaders; cropped appearance of foliage; and an appearance of stress, such as poor color or abnormal cone or pollen production.

The number of on-site trees needed depends on site quality and management objectives. This determination should be made before off-site plantations can be identified.

Off-site plantations are created because of three practices: 1, Seed or planting stock originated from unknown seed sources; 2, originated from known sources on sites incompatible with the area reforested; or, 3, was planted for a nurse crop on severe sites. The site has been changed so the native species are no longer adapted to the existing conditions. Consequently, from these practices, stands will not produce the amount of products the site is capable of producing, survivors are subject to damage by machine, insect, disease, and weather, and undesirable ground vegetation may occupy the site and create difficult problems in reforestation. These consequences cause lost growth of commercial products and increased costs in reforestation.

The Briggs Creek Plantation was created on the Siskiyou National Forest in 1911 and 1912. The purpose of the plantation was to determine the adaptability of various species and seed sources to the site. The species planted were ponderosa pine originating from the Okanogan, Wallowa-Whitman, and Siskiyou National Forests; red oak from Arkansas; scotch pine from Germany; Douglas-fir from an unknown source; deodar cedar from India; and sugar pine from California.

The local source from the Siskiyou failed because of poor planting. The initial survival of the other seed sources was from 80 to 90 percent. After 3 years, mortality increased in all species. The deodar cedar, red oak, Douglas-fir, and sugar pine died. The few ponderosa and scotch pine trees now remaining are deformed. The ponderosa pine from the seed from the Okanogan and Wallowa-Whitman forests showed severe deformities and never did get over 25 feet tall. The few surviving ponderosa pine will produce only a minor amount of sound wood. Snow breakage this last winter killed the last Scotch pine.

The sizes (dbh) of the naturals that seeded in around the plantation by 1913 are as follows: ponderosa pine, 32 inches; Douglas-fir, 26 inches; and sugar pine, 2 inches. All had good form and vigor.

The plantation area is capable of growing at least from 500 to 1,000 board feet per acre per year. If native species had been established in 1913, a commercial-size stand, amounting to at least 30,000 board feet per acre, would now occupy the area. These results on the Briggs Creek Plantation and those on many more, installed for the same purpose, demonstrate the importance of reforestation with trees that originate from known sources and are adapted to the site.

Frost damage is basically of two types. Frost heaving literally lifts tree roots from the soil. Frost burning may either kill the tree or current new growth. Damage from frost heaving is readily identifiable. Damage from frost burning, however, is often mistaken for browsing damage as trees assume a hedged appearance. Frost damage may be mistaken for drought, heat, or other causes of mortality. In any event, frost-burn damage is directly tied to the fact that the trees are not adaptable and are off-site.

Trees originating from seed or planted stock are frost damaged for two basic reasons. Source of seed or planted stock is significantly below the elevation in which they are planted. Such trees are more susceptible to frost damage than native stock. The climate may be changed radically if the ground cover is removed by fire, harvesting, windthrow, or other causes. Mortality and
damage are caused by rapid thawing of frozen trees exposed in openings to sunlight. Insects are usually more serious in off-site plantations than in native stands. The main reason is the weakened condition of the trees. The bud-mite infestation was considerably heavier in the Briggs Creek plantation than in the naturals just outside, as reported by insect specialists of the forest service.

The disease problems are serious in weakened off-site plantations and are a possible threat to all native stands. H. H. Bynum and Douglas Miller have reported an unidentified form of *Hypodermella* on off-site ponderosa pine in Douglas county and on a provenance study in Corvallis. This disease is virtually killing the off-site plantations. And a research study is trying to determine the potential threat of this disease to the native stands. The total potential of this disease will not be known for sometime.

The root rots are widespread and attack almost every tree species. Most of the rots will attack and kill the weakened trees first. For example, seedlings from seed collected on the Umpqua National Forest were planted on the Mt. Hood National Forest. And *Armillaria* is spreading throughout this plantation. Mature, vigorous species may have been more resistant. Further research is in progress to provide better answers.

The off-site stands tend to perpetuate themselves through the production of seed and our deliberate planting of seed from the cones. In the Umpqua seed source planted on Mt. Hood, two staked trees out of 16, after 12 years, grew well. And the rest were less than a third their height. This plantation does not have an off-site appearance, but seed collected from these off-site trees will produce trees of lower capacity to utilize the site than seed from the native source. No cones should be collected from the plantation. But how far is the pollen influence around this plantation? The problems in off-site plantations are deformities, snow breakage, frost damage, insects, diseases, and genetics.

In the management decisions of off-site plantations, we must be sure of the seed source and that it is compatible with the areas. We must know the physiological requirements of the trees and that the areas meet these requirements. We need an inventory of all off-site plantations. The cones from off-site plantations should not be picked. The existing off-site plantations should be analyzed to determine whether the plantation should be regenerated or carried to a commercial product. The pollen contamination to nearby stands should be considered. Research is needed on progeny testing to determine the area where each seed source is compatible. When planting nurse crops, do not plant nonnative species. Continued observation, including research, should be encouraged to determine the risk in contaminating native species through insects and disease.
SEEDING PONDEROSA PINE

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INTRODUCTION

Successful direct seeding of Ponderosa Pine (*Pinus ponderosa* Laws.) has several biological and financial advantages. The seedlings are established in place and are not subject to the root injury and shock associated with transplanting. Reforestation is not tied to nursery production schedules. Seeding requires low investment in equipment and facilities, generally costs less per acre than planting, and can be done on rocky or inaccessible sites or large areas where planting is not practical (33).

Seeding operations have disadvantages, however. More seed is generally needed than for production of nursery stock, and adequate seed from the proper source can be difficult and expensive to obtain. Seeding can cost as much per established tree as planting. And more time is required to establish a tree from seed than from nursery stock. Particularly expensive is seed spotting, a form of partial sowing in which spots are selected, several seeds are sown in each spot, and an effort is made to cover the seed (33).

Unfortunately, reforestation by seeding is often less certain than planting. Many ponderosa pine seeding trials, starting as early as 1901, have taken place in areas where the species occurs naturally. Although only a portion of these trials have been reported in literature, apparently failures and near failures far outnumber successes (7, 27, 33). Also, no completely satisfactory explanations are available for many of the successful trials.

FACTORS AFFECTING SEEDING SUCCESS

Small mammals, birds, insects, and diseases can destroy the seed or seedlings. Heat, drought, frost, and frost heaving can also cause seeding failures.

Small Mammal and Bird Depredation

Extensive studies of the relative importance of different kinds of animals as seed and seedlings depredators have not been made in the ponderosa pine region.

Deer mice (*Peromyscus* spp.) are considered the most destructive of the seed-eating rodents (35). Hooven (15) reports that deer mice were primary consumers of seed on a study area of central Oregon, followed closely by golden-mantled ground squirrels (*Citellus lateralis*) and chipmunks (*Eutamias* spp.). Shrews (*Sorex* spp.) are listed by Lawrence et al. (18) as destroyers of seed and newly germinated seedlings. Deer mice are active the entire year (18). In places west of the Cascade Mountains, chipmunks are sometimes active on warm, sunny, winter days, and have destroyed fall-sown seed in the winter (Peter Theisen, personal communication, April 9, 1969.)

Voles (*Microtus* spp.) are not considered to be ponderosa pine seed eaters under field conditions. They may destroy newly germinated seedlings, however, (18).

Bird depredation to seeds and seedlings while seedcoats are still attached to cotyledons can be important (4, 38).

Insect and Disease Depredation

Grasshoppers (*Locustidae*) (20, 34), cutworms (*Noctuidae*) (31, 5), and leaf-eating ants (*Formicidae*) (38) have damaged ponderosa pine seedlings.

Damping-off mortality has been reported by many researchers. Wagg and Hermann (38) found that both *Fusarium* spp. and *Pythium* spp. caused mortality in one central Oregon study. Stein (31) found that damping-off of ponderosa pine seedlings was occasionally serious in southwestern Oregon.

Temperature Extremes

High temperatures at the soil surface are commonly recognized as a cause of mortality to ponderosa pine seedlings (3). Low temperatures can also cause mortality (1, 38).

The maximum or minimum lethal temperatures may depend on the duration of the temperature and development and preconditioning of the seedling (10). The lethal high temperature is probably greater than 130 °F (3). Bernsten found that newly germinated seedlings were killed in growth chambers by minimum temperatures at night of from 15 to 18 °F.

Frost Heaving

Alternate freezing and thawing of the soil, which tends to push or lift the seedlings out of the ground, can cause considerable seeding mortality. Frost heaving can occur in late fall as well as early spring in central Oregon (38).
Drought

Ponderosa pine seedlings have rapidly developing taproots, and thus are not as subject to drought as some other species. Also, seedlings can survive in some soils where the moisture content is considerably below the commonly accepted wilting point (16). Yet, drought can cause considerable mortality (12). Curtis and Lynch (3) state that soil moisture is a critical factor in survival.

Additional Factors

Several other factors may cause seed and seedling losses.

Soil movement that covers seed too deeply will prevent germination or will cause the loss of the seedling shortly after germination (37).

Soil compaction on seed spots also prevented germinating seeds from breaking through the crusted surface in some studies (31). On most soils, best germination usually occurs when the seed is covered with from ¼ to ½ inch of soil. Radicals of seedlings germinating on the surface often dry out before penetrating to moist soil.

Trampling by small mammals, big game, and livestock also causes some seedling mortality.

Some ponderosa pine seedlings less than 1½ months old were apparently damaged by hail in central Oregon this past spring.

SEEDING PRACTICES

Ponderosa pine is generally seeded by aerial broadcast and spot methods. Seeding has also been done with modified rangeland drill (28) and by hand broadcast. Most seeding is done in the fall, although some stratified seed is sown in the spring.

Operational steps for seeding are site preparation, control of small mammals, sowing the seed, and continuing surveillance of small mammal populations with control procedures, if necessary.

Site Preparation

Although shade from certain annual plants can occasionally benefit early survival (37), probably the most practical way of controlling drought and temperature extremes is by exposing the mineral soil.

A seedbed of exposed mineral soil usually reduces the temperature extremes at the surface-air interface because the mineral soil has a higher thermal conductivity and a higher volumetric heat capacity than most natural litter or duff mulches. The lower the thermal conductivity and volumetric heat capacity, the higher the surface temperature will be in the daytime and the lower it will be at night under a given set of weather conditions. Seedlings growing in a reasonably dense mineral soil are not as subject to injury from high or low temperatures as the seedlings protruding through a litter cover. Thus, some form of site preparation that exposes mineral soil and keeps litter away from the seedling increases the chance of survival through the germination period (2).

Except when seeding is done shortly after a fire, some site preparation is necessary. Even after fires, site preparation may be needed to remove ashes and expose mineral soil. Methods of site preparation range from handscraping small areas for seed spots to scraping larger spots (dishpanning), strips, or entire areas with a bulldozer. Sites are sometimes trenched with a disk trencher or contour-terraced.

On the Malheur National Forest, bulldozing strips from 10 to 12 feet apart in old burned areas has proved the most satisfactory method of site preparation for both seeding and planting. Spot seeding, with from 6 to 10 seeds sown in each spot, is done within the strip areas. Two rows of seeds are sown in each scarified strip, and the average spot spacing is about 5 by 6 feet. A light cover of soil is kicked over the seed. Success has generally been good (39). In the Rogue River National Forest, 100 percent of each area to be seeded was scarified with bulldozers (John Hoffman, personal communication). Hand scalping a spot at least 2 feet in diameter down to mineral soil is the method of site preparation for seeding on many forests. Hand scalping should not be done where heavy sod, dense brush, grass, or weeds cover the site.

In machine site preparation, possible erosion problems should be considered. As some soils are unstable and highly erodible, site preparation by machine is not practical. Even on stable soils, the strips should be contoured. On excessive slopes, dishpanning rather than stripping is recommended. In stripping, the dozer blade should be controlled to expose mineral soil but remove little of the surface A horizon. In many forest soils, most of the nutrient capital is in the A horizons, and their removal may substantially reduce future growth. Removal of the A1 and AC horizons of a Lapine pumice soil, for example, would leave a nearly sterile medium for plant growth.

Where the density of rock outcropping prohibits conventional stripping by dozer or where a brushfield is partially stocked, site preparation for seeding by chemicals may deserve consideration. The surface beneath the brush should consist mostly of mineral soil or shallow litter so the roots of the developing seedling can maintain contact with moist soil. Besides the problems with small mammals in most seeding operations, extensive damage by rabbits to seedlings in brushfields can be expected in the years after seeding.

The best course is to choose the cheapest method or combination of methods of site preparation that will produce a seedbed of mineral soil and let the seedling
develop until it can compete successfully with vegetation that invades the cleared area. This method varies greatly between areas. Brush reinvansion in some areas may rule out seeding in favor of planting.

**Small Mammal Control**

Adequate control of rodents is generally regarded by foresters as the main problem in direct seeding. The popularity of seeding continues to rise and fall as new methods of control arise, show some promise, and then fail (33).

Even though I stress control, small mammals are somewhat beneficial. In some areas, many ponderosa pines start from caches made by small mammals. This “planting” may be particularly important on hot, dry sites where seed deposited on the surface would not survive after germination. Further, some small mammals eat the pupae and larva of the pandora moth (*Coloradia pandora*), a potential forest pest, cutworms (*Noctuidae*), and other insects (16). Rodents also eat weed seeds and provide food for furbearers and other animals. Soil mixing, which results from their burrowing, can improve the physical properties and increase rates of infiltration in some soils. Some small mammals, particularly chipmunks and golden-mantled ground squirrels, have esthetic value that will increase as recreation intensifies. No extensive studies have been conducted on the beneficial effects of small mammals. But complete, permanent destruction of all small mammals in any forested area would not be beneficial. Control methods provide only temporary checks on population in small areas for a short time.

The methods of chemical control presented here are those most recently used by the forest service in the Pacific Northwest. Some of these control procedures are not solidly based on definitive research but come from experience and observation by practicing foresters. Methods of chemical control are in a state of flux. For example, as of July 10, 1969, use of one chemical mentioned in this paper, endrin, was banned for all USDA programs except research.

Because of the increasing concern over chemicals and the changing regulations, foresters in private industry should check with the appropriate state agency in planning chemical control programs. Chemical control procedures on land managed by public agencies must be approved by the Federal Committee on Pest Control, 8120 Woodmont Avenue, Washington, D.C. 20014.

Control procedures are aimed at excluding small mammals from seeded spots, reducing them in seeded areas, and repelling them from seed. Adequate amounts of seed are planted so the fraction of the small mammal population that remains after control measures are applied does not destroy all of the seed (7, 28).

**Screens.** Small mammals have been excluded from seeded spots by conical, cylindrical, or rectangular cloth screens (31, 22). Screens are usually effective against small mammals that live above ground. At times, however, small mammals seem to learn to recognize screens as markers and burrow under or push the screen aside to secure the seeds (31, 24). Screens offer no protection from pocket gophers (*Thomomys* spp.), which have wiped out seedlings after they have become established under screens (Erwin Hafenstein, personal communication, April 19, 1969). The screens eventually have to be removed, and the cost per established seedling is probably at least as high as in a planting operation (11). A screen that eventually decomposes and eliminates the need for removal has been suggested but not developed (7).

**Repellents.** Many types of chemicals have been applied to ponderosa pine seed with the hope that small mammals would be repelled. As many of these chemicals are deadly toxicants, the word “repellent” is somewhat misleading. Because the seed has an outer coat that is discarded by small mammals in feeding, only minor amounts of the chemical coatings are ingested. No odor or simple taste factor has been discovered that will effectively stop the feeding of deer mice. Only those compounds that cause some physical discomfort or toxicity appear to “educate” mice (30). Also, the effectiveness of treated seed depends on maintaining an “educated” animal population (29). As small mammals are produced in or migrate to the seeded area, they in turn must be educated before learning to avoid treated seed. Thus, the seed could be destroyed if small mammals continued to appear in a seeded area. Wagg (37) found that rodents were controlled by use of pine seed treated with tetramine (tetramethylene disulpho tetramine) in one study of central Oregon. Tetramine, no longer available in the United States, was only available for research. Most recently, seed has been treated with endrin (generic name accepted by the Entomological Society of America for the insecticide 1,2,3,4,10, 10-hexachloro-6, 7-epoxy- 1,4,4a,5,6,7,8,8a octahydro-1, 4-endo-endo-5, 8-dimethanonaphthaline. The forest service in the Pacific Northwest treats the seed with a formula of 0.5 percent active endrin, Rhoplex adhesive, and a coloring pigment. One percent active endrin has been used in wildfire areas where heavy rodent populations were anticipated. Endrin seems to have some effect on deer mice, but positive control of chipmunks and ground squirrels has not been demonstrated (35). Endrin-treated seeds usually have been sown in the fall with a poison-baiting program. Treating seed with endrin is extremely hazardous and should be done only by trained personnel. Various private seed companies can be contracted to treat and color the seed. Coloring the seed is a good safety
Seeding Ponderosa Pine

Precaution for humans and may also give a certain amount of bird protection (17).

*Poison bait.* Poisoning the small mammal population in the area to be seeded and in a surrounding buffer strip has had varying success. Except in large burned-over areas, a single application of poison bait is seldom effective because of invasion from surrounding untreated areas, a rapid population build-up from the survivors, or both. Fires do not kill many burrow-dwelling small mammals. And large areas that have undergone hot fires may have active rodent populations (29). Poisoning before seeding and one or more times after seeding, if a census warrants, is essential for seeding success.

On the majority of the ponderosa pine forests in Oregon and Washington where seeding has been undertaken in the last 5 years, wheat treated with 1080 (sodium monofluoroacetate) has been used to control small mammals. This is based on the recommendations of the Bureau of Sport Fisheries and Wildlife (35). Strychnine-treated oats have also been used to a limited extent.

Poison baits for application in Idaho may be obtained from the State Supervisor, Bureau of Sport Fisheries and Wildlife, Division of Wildlife Services, Pocatello, Idaho; in Washington through the State Supervisor of the Bureau at 459 Federal Office Building, Seattle, Washington 98104; and in Oregon through the State Supervisor at 710 N. E. Holladay, Room 120, Portland, Oregon 97232. Agreement must be obtained with the Bureau, through the District Supervisor, for placement of lethal baits.

Wheat, depending upon the method of application, may be treated with two different strengths of 1080. In hand application, 2 ounces of 1080 to 100 pounds of wheat is used. From about 1/4 to 1 teaspoon of the bait is placed near runways of small mammals and around logs and other debris where nontarget species may avoid it and where it may stay dry. If this bait gets wet, even by a heavy dew, the 1080 can be diluted until it will be ineffective. Also, the grain may soften, germinate, or mold and lose its effectiveness. About 1 1/2 pounds of bait is distributed per acre (35).

In baiting with helicopter or fixed-wing aircraft, 10 ounces of 1080 to 100 pounds of wheat is used. It is applied at the rate of 1/2 pound per acre. This rate of application provides for one kernel of grain for every 7 to 9 square feet of the baited area. One kernel of this bait will kill a deer mouse and, when properly applied, gives excellent control.

By experience, forest service personnel found 1080-treated wheat to be effective in controlling chipmunks and, to a lesser degree, golden-mantled ground squirrels. If chipmunks and golden-mantled ground squirrels are the primary targets, strychnine-treated oats are recommended (35). Control of chipmunks will seldom be necessary without concurrent control of deer mice.

To control chipmunks and golden-mantled ground squirrels (where 1080 is not used) strychnine-treated oats (1 ounce of strychnine to 12 pounds of oats) is recommended. Bait should be distributed in teaspoonfuls and placed under obstructions to prevent livestock or big game from consuming lethal quantities. The bait should be placed in runways or burrows, under logs, limb concentrations, overturned stumps, or other protected spots (35).

*Baiting buffer strips.* Even if all small mammals are eliminated within the area to be seeded, populations can build rapidly by invasion from outside the baited area. For this reason, buffer strips around areas to be seeded are usually baited. Just how wide this buffer strip should be under any given set of conditions is an unanswered question. Baiting larger areas than necessary increases costs, but baiting inadequately may cause seeding failure. Width of buffer strips have varied between ¼ mile, 50 feet, and 150 feet, with the narrow strips heavily baited.

Gashwiler (8), in a live-trapping study in the Douglas-fir region, found that some deer mice moved 1,410 feet during a monthly check. He found a regular interchange of rodents between the clearcut area and the surrounding timber. The straight-line distance for travel of deer mice between the clearcutting and adjacent timber was from 601 to 700 feet.

In an unpublished administrative study, Hoffman found that individual deer mice traveled as far as 3/4 mile in 3 days (personal communication with John Hoffman). This study was conducted in mixed conifers on the Rogue River National Forest.

These reports suggest that baiting a buffer strip is necessary. And a 700-foot-wide buffer strip must be regarded as a minimum. Hooven (14) suggested a buffer zone 3/4 mile wide in the Tillamook Burn.

*Census.* Although poison baiting will be necessary, in most seeding operations, a census should be run and the results properly recorded and filed before poison bait is placed in the field.

Rodent census may be taken by two methods—trapping with snap or live traps placed at systematic intervals within the area and observance of seed spots. A combination of the two methods may be more effective for some situations (21, 32).

Complete details of a census for rodent control are given in the Animal Damage Control Handbook (35). Briefly, snap or live traps are placed at systematic intervals in a representative portion of the area to be sampled. The traps are placed in the morning and tended daily; the catch is totaled by species. The traps should be left out for 3 days—or longer if the weather is
unusually wet and cold. By experience, foresters found that if the rate of catch exceeds five seed eaters per 100 trap nights, the area should be baited. The seed spot survey can be used alone or to supplement the trapline transects. Seed spots are placed systematically in a representative portion of the area, and the rate of robbery is expressed as a percent of total spots. By experience, foresters found that if the rate of robbery is 6 percent or greater for any one night, control measures should be taken.

Timing the bait application. When seed is sown in the fall, the area is baited from 3 to 14 days in advance. If chipmunks and ground squirrels are the major problem, baiting should be done before they hibernate. In areas where the winters are severe, no baiting is ordinarily done in the winter, but a small-mammal census should be taken immediately after snowmelt the following spring and the area baited if the population of seed eaters is high enough to cause significant losses. The census and baiting (if warranted) should be repeated at intervals of from 2 weeks to a month. Three baits may be necessary; many seeding failures have resulted from a lack of follow-up once the animals were initially controlled. Where the winters are open, a census should be made 2 weeks after fall seeding and again at monthly intervals throughout the winter to monitor the animal populations and determine whether the area should again be baited.

Signing the area. Poison baits and endrin-treated seeds are hazardous and warning signs should be placed in the area. The dog family is susceptible to 1080 poisoning. A 25-pound dog can die by chewing a poisoned mouse.

A warning. Foresters should avoid placement of poison bait and endrin-treated seed where the material will get into streams and in places where children and pets might roam without constant adult supervision. Warning signs must be placed so that any adult, entering the treated area, will know that toxic materials are present.

Sowing Seed

Seeding rate and time of sowing are important additional factors.

Rates. From 2 to 4 pounds of ponderosa pine seed applied per acre is recommended for aerial seeding. A minimum of 15,000 viable seed per acre should be sown.

For spot seeding, about ½ pound of seed per acre should be sown. From 8 to 12 seeds are recommended per spot. And the average spacing of the spots should be about 8 by 8 feet or 680 spots per acre.

Time of sowing. In the fall, seed should, if possible, be sown before October 20 to obtain adequate stratification, although some successful seedings have been sown later in the year.

Stratified seed may be planted by hand in the spring as soon after the snowmelt as possible.

Costs

Costs vary between areas, depending on size of the job, methods used, amount of site preparation necessary, accessibility of the area, amount of seed sown, number of times baiting is necessary, and several other factors. Costs given here were determined from information obtained from foresters on the Deschutes, Rogue, Fremont, Wallowa-Whitman, Wenatchee, Winema, Siskiyou, and Umpqua National Forests.

Ponderosa pine seed costs about $4.85 a pound. Site preparation with a bulldozer can range from $14 to $150 per acre. Average costs for most ponderosa pine areas probably range between $15 and $20 per acre. Hand baiting costs from $1 to $2 per acre, but aerial baiting can run from below 50 cents per acre for jobs greater than 1,500 acres to $1.50 per acre for jobs less than 500 acres. These costs are for a single baiting. Spot seeding can be contracted for between $18 and $20 an acre. Aerial seeding runs from about $3.60 to $1.50 per acre for the contractor.

Other Possible Practices

Although the preceding practices have been regularly applied in most seeding operations, comments on other possible practices in dealing with special problems of birds, insects, disease, frost heaving, and temperature control may be helpful.

Bird control. Other than the coloring of seeds, screening of seed spots, and covering of seed, I know of no attempt to control bird damage to ponderosa pine seed or germinants. For some ponderosa pine seeding, seeds are colored bright green or silver as suggested by Eastman (14). The amount of bird protection obtained by coloring ponderosa pine seed is unknown. However, colored seed has not effectively deterred birds from feeding on longleaf pine (Pinus palustris) seed in Louisiana (25).

Poison-baiting has not been considered, because birds that eat insects and the seeds of weeds are directly beneficial. And all birds add esthetically to the forest.

Supplemental feeding stations have been suggested to lessen the amount of seed taken for food. Hagar (9) found that junco (Junco oreganus) were easily diverted from Douglas-fir seed by supplemental food placed at only one location in a 20-acre cutover.

Several bird repellents applied to tree seed have been tested in the southern pine region. Royall and
Ferguson (25) found that four repellents—thiram A, chloronil, sublimed antraquinone, and thiram D—were successful. Negligible damage to birds was reported even when endrin was applied as repellent.

Covering seed with soil seems to provide some protection (34).

Insect and disease control. Four insecticides—aldrin, dieldrin, chlordane, and benzene hexachloride—were added to the soil that surrounded the seed, in a test conducted by Stein (31). Better germination was obtained with benzene hexachloride, but this was believed attributable to fungicidal properties of this insecticide. None of the insecticides had a harmful effect on germination.

Because cutworms increase rapidly with reestablishment of vegetation after logging or fire (31), prompt attempts to regenerate these areas may prevent cutworm damage.

Control of frost heaving. No practical cultural treatment for protection against frost heaving is known. Unlike tissue injuries from heat and low temperature, those from frost heaving appear less severe under litter cover. Application of an organic mulch in early fall and its removal in late spring would probably reduce frost heaving.

Shading or shielding seed spots. Partial shading of seedlings affords protection from both heat and frost by reducing the incoming shortwave radiation during the day and the net longwave radiation flux at night. Wagg and Hermann (38) found that shading seed spots on pumice soils had little effect on germination but aided seedling survival.

The pumice soils of south-central Oregon have low thermal conductivities and volumetric heat capacities. Consequently, the surface temperatures of these soils vary widely. The unique thermal properties of pumice soils, the dry air mass, the high altitude, and the predominance of clear night skies combine to produce conditions under which seedlings may be exposed to damage by heat and frost in one 24-hour period (2). Quintus (23) found that wooden shingles placed on the west side of seed spots increased seedling survival on pumice soils for 1 or 2 years. The shingles, however, eventually rotted and fell over. And the seedlings died, apparently from shock or smothering, depending on where the shingle fell.

Seeding next to stumps, logs, and rocks, where possible, is recommended to reduce the temperature extremes at the soil-air interface.

SUMMARY

In the Black Hills, adequate soil moisture appears to be the key to successful direct seeding (36). In other ponderosa pine regions, probably four factors, at least, occur simultaneously when seeding is successful. The seed is covered in a seedbed of exposed mineral soil; the soil remains fairly moist near the surface when seedlings are becoming established and the developing roots are always in contact with moist soil during the growing season; destruction of the seed or seedlings by rodents, birds, insects, and disease is controlled; and adequate seed is sown (7, 19, 23, 33).

In areas of various sizes within the ponderosa pine region of the Pacific Northwest, stands are present because of a series of favorable events—a good seed year preceding a mild spring, followed by an abnormally wet, cool summer. On these sites, on south and west aspects, and in many areas where the annual precipitation is below 20 inches, no combination of practical treatments will guarantee seeding success in a normal year. Adequate site preparation and rodent control would have to be coupled with shading or shielding of seedings to obtain survival through the germination period on many of these sites. The use of shingles, screens, or some other method of shielding would probably boost the cost per established tree above that of planting.

Seeding is also ruled out in some areas where unstable soils and steep slopes limit site preparation, and where revegetation of scarified areas is very rapid.

Seeding is a practical method of regeneration on medium-to-good sites where adequate site preparation is possible, necessary small-mammal control can be accomplished, and adequate amounts of site-adapted seed are available for sowing. Under other conditions, seeding success is improbable.

ACKNOWLEDGMENTS

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LITERATURE CITED


Regeneration of Ponderosa Pine


ANIMAL DAMAGE TO SEED AND SEEDLINGS

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THE SEVERITY OF THE PROBLEM IN REGENERATION OF PONDEROSA PINE VARIES throughout the forests of eastern and southwestern Oregon. Reproduction is generally satisfactory along the immediate eastern slopes of the Cascade Mountains and other areas with sufficient soil moisture. Where the annual precipitation, however, is often less than 15 inches, especially in the area of extensive pumice plains to the east of the Cascades, pine reproduction becomes difficult and critical.

Lack of moisture certainly contributes to the paucity of established pine regeneration in many areas. But rodents and birds that consume huge amounts of seed also contribute to the scarcity of trees. They not only reduce the amount of seed by their feeding activities, but destroy many germinating seeds that might otherwise have become established seedlings.

Little work has been achieved in the ponderosa pine region in relation to the innumerable seed-eating mammals and birds and their effects on reforestation. Accurate work to prove the importance of the various species and the extent of their effect on seeds and seedlings is necessary for more complete planning for animal control in future seeding studies.

SMALL MAMMALS

Small mammals are numerous in the pine region of eastern Oregon. Among the most common of the seed eaters are the Douglas squirrel, common western chipmunk, golden-mantled ground squirrel, and the white-footed deer mouse. Rabbits and black-tailed hares, although not seed eaters, possibly feed on the young germinating seeds.

Douglas squirrels generally are less numerous than the other principal seed eaters, but often become numerous when their food becomes plentiful. Tree seed and fungi are their preferred and main source of food during the fall months in northwestern California (12). Harvesting by the squirrel in the fall can remove more than 90 percent of the cones from a single tree (14) and may remove 85 percent of the mature cone crop (16). Cambium, an important food, is added to the diet during the winter and spring when the squirrel cuts off the tips of branches (1).

The yellow-pine chipmunk ranges throughout central and eastern Oregon, mainly in the open-forest areas and never far into the sagebrush plains (2). It is omnivorous and its diet includes seeds, berries, fruits, insects, and fungi. Chipmunks, depending upon climatic conditions, are active from early spring to late fall. They do not hibernate. A chipmunk has only one litter a year. And the young are born in late April or early May. The average size of litter is about four. The young leave the nest in early June and start to shift for themselves. Density varies from two to eight animals per acre. A chipmunk eats more than 200 ponderosa pine seeds per day in captivity. It will cache various food items. One cache, with 35,000 seeds from 20 different kinds of plants, weighed 140 grams (8). This would equal about 3,000 seeds of ponderosa pine.

Gambel's deer mouse is found throughout Oregon east of the Cascade Range. Because of its prevalence, it has been blamed for many failures in regeneration of conifers (20). It has from two to four litters per year, with about four young to the litter. Much of its diet consists of conifer seeds, but it also eats fruits and insects. Cage feeding indicates that the deer mouse can consume from 75 to 250 ponderosa pine seeds per night, and will store many more for the future. Density varies from two to six animals per acre.

The golden-mantled ground squirrel is closely associated with the yellow-pine chipmunk and the deer mouse. All are found in the same area throughout eastern and southern Oregon, and all occupy about the same habitat. The golden-mantled ground squirrel, however, appears to be more intimately confined to the open-forest pine areas than the chipmunk or mouse. It has one litter a year, in late April or May, with an average of five offspring per litter (13). Density varies from 0.5 to 4 individuals per acre. In captivity, this squirrel consumes more than 250 pine seeds per day. Its principal foods are reported to be leaves of herbs and fungi until conifer seed ripens in the fall.

BIRDS

Birds are important consumers of ponderosa pine seed also. Damage is generally done by individuals or
flocks that rapidly move from area to area. Many species are migratory.

Seed consumption starts early in September when the mature cones begin to open. Then, the pinon jay, common to the region of dry juniper and ponderosa pine, picks the seed from the opening cones on the trees and those that fall to the ground. Steller’s jays feed similarly (19). The white-headed woodpecker extensively destroys cones still on the tree. Mourning doves apparently pick ponderosa pine seed throughout the year. The crops of several doves, examined in late spring, averaged 100 seeds each. The mountain chickadee, red-shafted flicker, and the Oregon junco are common and also readily eat conifer seed.

SEED PROTECTION

Protection of pine seed from seed-eating animals and birds is difficult. Mammalian pests may frequently be curbed effectively by baiting, mechanical barriers, or repellents. Repellents are preferable. They should offend by smell, taste, or color. And they can be lethal to the extent that they work as a repellent.

Prebaiting before direct seeding has been successful (17) in protecting sugar pine seed from rodents. Baiting with wheat treated with compound 1080 or thallous sulfate, or both, in fall and winter, resulted in four times as much natural regeneration on a treated area by controlling seed-eating rodents (18). One kernel of wheat treated with 3-percent 1080 is sufficient to kill a mouse. Less is required to kill a ground squirrel, but nearly twice as much is required to kill a chipmunk (11). Therefore, each grain of wheat in the baiting should contain enough 1080 to kill a chipmunk.

Endrin overcoated on the seed is successful in protecting aerially sown Douglas-fir seed in western Oregon. It is also applied in the southeast to protect loblolly and longleaf pine seed from small seed-eating rodents (3). It is nontoxic to the seed or seedling, is effective as a rodenticide at the proper formulations, remains effective, is easy to apply, and is cheap. In cage-feeding tests with ponderosa pine seed treated with a 1-percent effective formulation of endrin, 3 seeds were lethal to the deer mouse, 25 to the chipmunk, and 40 to the golden-mantled ground squirrel. As lesser percentages are ineffective, especially with mice (10), a 1-percent effective formulation of endrin is recommended when direct seeding pine in areas with large populations of mice.

Several repellents have been tested to prevent depredation of pine seed by birds. Considerable work was done with Arasan and sublimed synthetic antraquinine. Apparently Arasan was preferable. Arasan 42-S is a liquid suspension, has no adverse effects on seed germination, is free from harmful dust, and is economical (4, 5).

The bird repellent can be blended with endrin by an adhesive such as a latex or asphalt emulsion. Aluminum powder or monastral green coloring dye is added as a supplemental bird deterrent and as a factor to recognize treated seed.

Direct seeding can be done with a cyclone-seeder or with seed-spotting tools for small tracts. These procedures, however, control rodents ineffectively because of constant migration pressures from outside populations and the exposure of the seed to birds. Aerial seeding, unless conducted on an extensive area with rodent control, would be no improvement.

Mechanical seeders, drawn by mechanized equipment, that drop and press the seed firmly are advantageous because the seed is in contact with the soil (15). A slight covering improves germination. Compression of the surface soil of the prepared seedbed where seed is sown 1/4 inch deep significantly improves pine regeneration (6). Scarification to expose mineral soil augments the conditions for seed germination.

Control procedures are, of necessity, often based on poison baits. The primary objective is to reduce or eliminate the small rodents from a given area for the short period necessary to enable seed germination and seedling development. This procedure is operable in the Douglas-fir clearcuttings west of the Cascade Mountains, but appears impracticable in the pine region of the east side because of the large areas and the animals present. Factors of soil and climate and the habits of the animals cause the difficulty. Selective logging of ponderosa pine does not affect resident populations of animals as does clearcut logging of Douglas-fir. The large rodent populations of the pine region are strongly pressured for living space. Some species have a rapid turnover of individuals in 30 days, often as much as 25 to 100 percent (7). Also, a bait-shyness or aversion to both 1080 and thallous sulfate often appears to develop among resident animals that insures continued depredation of seed.

Emergence of the seedling is no promise that all danger from animals is past. Immediately after germination, seedlings are lost to animals during a period of several weeks. The offending rodent, bird, or insect usually is unidentifiable. The damage ranges from clipping the edges of the cotyledons to complete cutting of the stem. Losses from this damage range from 25 to 80 percent of the seedlings. Although rodents and birds are responsible for the main damage, and insects for about 5 percent, rabbits are thought to contribute a certain amount.

Direct animal control is impractical also because of aesthetic values of the rodents and birds. Baiting would
include both the seeded and control areas. This would cause destruction of many birds apparently unrelated to the problem. Some birds will accept bait or conifer seed, regardless of the aluminum or green coloring. And generally, many segments of the public object to the destruction of birds.

Birds and rodents, because of their extensive feeding on insects, may be beneficial by reducing populations of harmful insects (9). About 80 percent of the diet of the mouse is insects when seed is unavailable. Rodents, because they gather and cache seed, are somewhat beneficial. Many trees are the direct result of a rodent cache, where from one to several seedlings competed successfully and became mature trees. Many vegetative species such as bitterbrush grow from the seed harvested and planted by rodents.

Rodents and birds delay or prevent regeneration of pine by caching and eating conifer seed for food. Success of seeding depends upon baiting or repellents, or both, for mammals, and repellents for birds. Baiting gives temporary control, at best. And the present repellent for mammals, endrin, is a poison. More work is required to exactly define the role of the rodents, birds, and insects in relation to success of direct or natural reproduction by seeding. Many sites west of the pumice deposits and many pumice soil areas can be reforested with relative ease despite the rodents and birds. Apparently available soil moisture rather than animals is the determining factor, and many critical areas are best left unlogged.

LITERATURE CITED


Animal Damage to Seed and Seedlings


**CHECKLIST OF PLANTS AND ANIMALS**

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<th>Common Name</th>
<th>Scientific Name</th>
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<td>Pseudotsuga menziesii (Mirb.) Franco</td>
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VARIATION IN THE ROOT-GROWTH CAPACITY OF PONDEROSA PINE TRANSPLANTS

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I SPOKE TO A GROUP OF PRACTICING FORESTERS SOME YEARS AGO on the subject of planting “dead trees” and whether or not it was a California custom. The discussion focused on the low survival then being experienced in California when ponderosa pine was planted in the fall. I presented preliminary evidence that this low survival was associated with a low seasonal root-growth capacity, and recommended that early fall planting be abandoned in favor of spring planting when the root-growth capacity of ponderosa pine transplants appeared much higher. On the basis of this recommendation, many foresters switched to spring planting shortly thereafter. Of course, as could have been predicted, some disagreed, which slowed progress for a while (5, 12).

THE SWITCH TO SPRING PLANTING along with better site preparation increased survival considerably. Seasonal variation in root-growth capacity, however, proved more complicated than our preliminary studies indicated. Nursery climate has a major impact on root-growth capacity. It is now evident that one nursery may produce transplants whose period of high root capacity is out of phase with the planting environment almost every year. Another may produce transplants out of phase in some years, but not in others, while still another may rarely, if ever, produce transplants out of phase with the planting environment. Consequently, even today we find people planting “dead trees” in California because they are supplied with transplants from the wrong nursery. For me to imply that this activity was solely a California custom was, however, in error. I daresay, even now, a “dead tree planting cult” is operating here in Oregon.

How can this happen? Obviously, no one is going to authorize the planting of dead seedlings—not even when the lines of communication become as formidable as they sometimes do in our public agencies. Instead, what generally happens is that live seedlings are planted, but they are incapable of active root growth, or their root growth is so slow that they can not keep up with the soil-water depletion developed during periods of drought (5, 6, 9).

Usually, when I have questioned the wisdom of planting “dead trees”, those actively engaged in the practice have either vigorously denied it or have disclaimed responsibility for their actions. Invariably, those disclaiming responsibility contend that they have no choice in the matter. Their only authorized guide to acceptability is whether or not the seedlings meet minimum morphological grade standards. When the seedlings meet these standards, there is no basis for rejecting them as suitable planting stock. “After all, what is wrong with a healthy-appearing seedling with a good top:root ratio?”

Today, none of the nurseries where ponderosa pine seedlings can be purchased or requisitioned is equipped to evaluate the root-growth capacity of the seedlings they produce. This is largely because no one has requested this information, and until someone does who is willing to pay the modest extra cost, the nurseryman can not afford to install the test facility required. The commercial nurseryman must keep his prices competitive to stay in business. He can not afford a grading system that increases the price of seedlings, unless the improvement in survival that can result is fully appreciated by the buyer.

Federal and state nurserymen, on the other hand, must justify every added production cost to an administrative hierarchy that may even extend to the legislature. Without strong pressure from the field staff doing the planting, these nurserymen are hard-put to justify a refined grading procedure, if it increases production costs. Recently, I spoke with one of these nurserymen who had read about seasonal variation in root-growth capacity, was excited about the implications, and wanted to grade his nursery stock accordingly. To date, however, he has been unable to get the necessary authorization. His administrative superior contends that such activity should be a function of their research branch. “The nurseryman’s responsibility is clearly one of running a production nursery and he should stick to it.” What this administrator has failed to grasp is that basic research, characterizing root-growth capacity in ponderosa pine transplants, has advanced to the point that the evaluation techniques developed can now be applied operationally to insure quality control in the production nursery.

In many ways this situation parallels the development of quality control in the seed business. Today a seed distributor must guarantee the viability as well as the soundness of the seed he sells. No longer is mere certification that the seed is sound, based on a
simple cutting test, sufficient. Viability, based on a germination test, must also be guaranteed. Cutting tests and grading seedlings according to size and appearance are comparable measures of quality control. Grading seedlings according to root-growth capacity will sophisticate quality control much as germination tests have for seed.

Today, I believe we would find that most experienced nurserymen are fully aware that the capacity of a transplant to develop quickly an effective root system after planting is largely controlled by the environment in which it is grown and to which it is exposed after lifting, before and during the planting operation. The growing environment includes climate, soil, and cultural practices at the nursery. The environmental exposure experienced after lifting is determined by storage facilities, shipping methods, and handling of the seedlings by the planter near or on the planting site. To date, however, no serious attempt has been made to quantify this relation relative to specific nursery and other environments even though it can be done simply (2, 5, 6, 7, 8).

Because of the potential cost benefits and the ease with which this quantification can be accomplished, I find the marketing of ponderosa pine transplants unaccompanied by a certification of their root-growth capacity difficult to justify. The cost of making this certification is modest. Furthermore, if a nursery is too small to afford the initial capital outlay for a test facility, arrangements could be made with some laboratory for this service, much as soil and other agricultural testing services are handled today. To service a nursery with a capacity of 10 million seedlings, for example, the essential equipment and its installation should cost less than $15,000 and would require between 0.2 and 0.5 of a man-hour per thousand seedlings to operate—depending on the number of different seed sources grown and the range of microenvironm ental properties that exist in the nursery beds.

Properly organized under an industrial association or an appropriate public agency, the application of a standard test for root-growth capacity could serve as the basis for establishing meaningful grades for ponderosa pine transplants. With such a grading system once established, initial seedling survival could be guaranteed and costly planting failures, caused by transplants whose root-growth capacity is out of phase with the planting environment, could be avoided—probably at a cost of no more than $1.00 per thousand seedlings planted. The test could serve as the basis for closing nurseries improperly located in terms of climate, relative to the planting sites they supply. And the test could serve as the basis for evaluating new nursery sites before establishment, and so bring administrative and political considerations, which have long played a dominant role in the choice of nursery sites, into proper perspective.

The test for root-growth capacity is not complicated. A representative sample of the seedlings is replanted in a standard environment, and, after an appropriate period—one month in all our tests—is dug up and the root growth that has taken place is recorded. The deficiency in this system is that an immediate evaluation of the root-growth capacity is not forthcoming. With this approach, root-growth capacity can only be measured in retrospect. Once the transplants from a nursery as well as the nursery climate have been thoroughly evaluated, however, and provided a continuous record of the air temperatures at the nursery is maintained and cultural practices standardized, one should be able to predict with considerable confidence the root-growth capacity of seedlings lifted at any time of the year. Current evaluation would still be necessary to detect important, but otherwise unnoticed, changes in the nursery environment and to provide the basis for continued certification of the root-growth capacity.

The standard test environment does not have to be completely controlled to be effective. Considerable fluctuation in the test environment can be tolerated, provided the soil temperature and the initial soil-water content are held constant. A satisfactory test environment can be achieved with a thermostatically controlled water bath in a greenhouse equipped with fog nozzles, a space heater, and an evaporative cooling system large enough to keep the temperature inside the greenhouse within 10 degrees C of the outside temperatures during the testing season.

Before planting in the test environment, roots are pruned 20 cm below the cotyledon scar, and all white root tips longer than 0.5 cm are cut off so their length will not be included with the elongation that occurs in the test environment. The seedlings are then planted in plastic-lined galvanized trays filled with a fertile, light-texture, forest soil, after which, the soil is saturated with water and drained for 24 hours. The draincocks are then closed and the trays immersed in a water bath maintained at 20 degrees C. Water in the bath does not come in contact with the roots, but serves merely as a heat-transfer medium. Twenty-eight days later the trays are removed from the bath and laid on their sides. The soil mass is removed intact by pulling out the plastic liners, and the roots are freed by immersing the soil mass in water.

All new root growth over 1 cm in length is measured. It is white and readily recognized because it does not suberize extensively and turn brown during the 1-month test period. We have found that ignoring new root growth less than 1 cm in length greatly reduces the
measuring time, without significantly changing the evaluation of the root-growth capacity. Both elongation of the lateral roots present when the seedlings are lifted from the nursery beds and of roots initiated during the test are measured (Figure 1).

Over the last 15 years, we have examined the root-growth capacity of ponderosa pine in considerable detail (1, 5, 6, 8, 10, 11). Seasonal variation in root-growth capacity as we have found it is generalized in Figure 2. Throughout the late spring, summer, and early fall, root-growth capacity is low. It then increases slowly and sometime during the winter or early spring reaches a peak. Shortly before the resumption of top growth in the spring it begins to decrease and by the time root growth in the nursery is underway it has reached the summer low. Root-growth capacity does not necessarily peak at the same time each year, however. Over a 3-year period at the Ben Lomond, California Division of Forestry, nursery, for example, the peak was reached in a different month each year. In 1962-63, the peak was reached around March 1, in 1963-64 around February 1, and in 1964-65 around January 1 (Figure 3).

This behavior suggested that climate must play an important role in determining when the peak occurs. To determine whether this was true we grew ponderosa pine seedlings in a controlled environment and examined the effect of cold night exposure on root-growth capacity (1). Seedlings from seed were grown for the first 6 months under a bank of fluorescent-incandescent lamps with a 25-degree-C, 15-hour day and an 18-degree-C, 9-hour night. Over the next 5 months all of the seedlings continued to be exposed to a 25-degree-C, 15-hour day, but were divided so that equal numbers of seedlings were exposed to a 6-degree-C, 9-hour night for 0, 30, 60, 90, and 110 nights. The root-growth capacity of these seedlings was then determined in a greenhouse test.

The root-growth capacity of seedlings that were exposed to 0, 30 and 60 cold nights was low. An exposure to at least 90 cold nights was required before root-growth capacity was increased significantly. Once this threshold exposure was reached, however, additional cold nights continued to increase the root-growth capacity until the cold treatment was terminated at the end of 5 months (Figure 4).

With this information, we analyzed the temperature records from the Ben Lomond nursery over the 3-year period, 1962-65. In all 3 years a minimum exposure of around 1,500 hours to air temperatures of 10 degrees C or more was required before the peak was reached (Table 1). In 1962-63, however, an additional 300-hour exposure was required, apparently because the greater number of warm hours to which the seedlings were exposed before January 1 reduced the effectiveness of the cold exposure to that date. Thus, before the occurrence of the peak of root-growth capacity can be predicted from temperature records kept at the nursery, the relative effectiveness of temperatures between 0 degrees C and 10 degrees C, the minimum length of cold exposure that is effective when followed by a period of higher temperatures, and the interaction between different temperature exposures will have to be further evaluated.

For the effective operation of a nursery where the highly variable initial onset of cold nights in the fall causes the root-growth capacity to peak at different times of the year in different years, it is not necessary to be able to predict when the peak will occur. The nurseryman needs to know only what the last safe date

Figure 1. Root growth of seedlings after transplanting. (A) Root branching, x 7. (B) An elongating root, x 5%. The light-colored part is new growth. (C) Root initiation and root elongation, x 9. The light-colored protuberances to the left are newly initiated roots. (D) Old root with bark peeled to show newly initiated root, x 7. (6).
Variation in the Root-Growth Capacity of Ponderosa Pine Transplants

Figure 2. Seasonal periodicity in the root-growth capacity of ponderosa pine nursery stock. The dashed lines represent root elongation during 1 month in a greenhouse test environment (9).

Figure 3. The shift in the root-growth capacity peak in the course of three lifting seasons at the Ben Lomond nursery (11).

Figure 4. The cumulative effect of seedling exposure to cold nights on the root-growth capacity (1).
will be when he can lift and place seedlings in cold storage. This information is not difficult to obtain, once the minimum exposure to cold temperature required to reach the peak in root-growth capacity has been established for the nursery concerned; for example, 1,500 hours at 10 degrees C or higher at the Ben Lomond nursery. A continuous record of air temperature is all that is needed.

Root-growth capacity may be increased, decreased, or unaffected by cold storage. The determining factor is the time the seedlings are placed in cold storage relative to the occurrence of the peak in root-growth capacity. This relation is shown in Figure 5A for seedlings raised at the Ben Lomond nursery and lifted during 1959-60. On October 7, root-growth capacity was low. And cold storage reduced it to zero. By November 1, it had increased considerably, but cold storage reduced it 65 percent. By December 1, it did not differ significantly from November 1. But cold storage, instead of decreasing it, increased it 35 percent. By January 1, it had increased 15 percent, and cold storage increased it another 25 percent. By February 1, it had increased 50 percent, but cold storage, instead of increasing it, decreased it 15 percent. Around the first of March, root-growth capacity probably reached a peak—we are not certain because we did not lift until March 7—and then began to drop. We estimate that by March 7, it had probably decreased by no more than 10 percent. If so, cold storage decreased it another 75 percent. By April 15, it had decreased 60 percent, and cold storage decreased it still further, almost to zero.

The practical significance of this relation is that cold storage can extend the period that transplants can be supplied with acceptable root-growth capacities beyond the time when root-growth capacity peaks, provided the critical relation between time of lifting and cold storage is recognized.

Table 1. Cold Exposure and the Accompanying Shift in the Root-Growth Capacity Peak of Seedlings Grown in the Ben Lomond Nursery over a 3-Year Period. From Stone (10).

<table>
<thead>
<tr>
<th>Lifting season</th>
<th>Time at degrees C indicated</th>
<th>Time from Jan 1 to peak 1</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Aug 1 to Jan 1</td>
<td>Aug 1 to peak</td>
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<tr>
<td></td>
<td>&lt;6</td>
<td>&lt;10</td>
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<tr>
<td>1962-63</td>
<td>370</td>
<td>880</td>
</tr>
<tr>
<td>1963</td>
<td>560</td>
<td>1,180</td>
</tr>
<tr>
<td>1964</td>
<td>610</td>
<td>1,510</td>
</tr>
</tbody>
</table>

Peaks in root-growth capacity occurred on or about March 4, 1963; January 27, 1964; and December 31, 1964. See Figure 3.

The root-growth capacity of seedlings available on any specific planting date is apparent when we plot the root-growth capacity of both freshly lifted and stored seedlings against the date they are tested in the greenhouse (Figure 5B). Thus, between 1962 and 1965, cold storage would have been required 2 of the 3 years.

Figure 5. (a) The influence of cold storage on the root-growth capacity of seedlings lifted at different times of the year. (b) The use of cold storage to extend the time seedlings with high root-growth capacities are available for planting. Stock grown at the Ben Lomond nursery, 1959-60 (11).
had seedlings with high root-growth capacities been needed from the Ben Lomond nursery around March 1, as often happens. Also, had seedlings been placed in cold storage after the first of February in all 3 years, as is often done, root-growth capacities would probably have been unacceptably low, except in 1963 (Figure 3).

Once ponderosa pine seedlings are graded according to their predicted root-growth capacities, the planter will have to determine the capacity he can safely accept. What is acceptable on one planting site may or may not be acceptable on another, because the seasonal pattern of precipitation, soil temperature, and evaporative stress vary from one region to another, and in any one region the amount of available water and the rate of soil-water depletion vary from one planting site to another. With experience in a given area, however, limits of root-growth capacity can be established above which high transplant survival can be expected, below which poor survival can be expected, and between which survival can not be effectively predicted.

I do not know how most of you feel about the quality of the stock you have been planting, but if planting ponderosa pine were my job, I would insist that the seedlings I bought had a root-growth capacity of 80 cm or more (Figure 6). Seedlings with this root-growth capacity can be readily grown. All you need to do is ask for them.

LITERATURE CITED


Figure 6. Transplants with root-growth capacities of 30 cm (A) and 80 cm (B). New root growth was painted white to show it clearly (11).


CONTAINER PLANTING

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FOREST MANAGERS ARE PLACING RENEWED EMPHASIS ON REGENERATION BY PLANTING. Plantations are expected to ensure regrowth immediately after the area is logged. They are to consist of a closely controlled number of trees capable of rapid juvenile growth in height.

PLANTATIONS ESTABLISHED BY BAREROOT planting have not been consistently successful. Limitations of bareroot planting suggest that it may not satisfy completely the expectations of management. A shortage of bareroot stock, which seems always present, is a minor problem because new nurseries can be built quickly to provide more seedlings. For instance, one nursery, started in 1967, increased the stock available in the Douglas-fir region by 15 percent in the 1968-69 season and is expected to increase it by 33 percent in the 1970-71 season. More important are the problems of available labor, the planting rate of the worker, the length of the period in which bareroot stock must be planted, and the survival and growth.

The gratifying development of contract planting crews is resolving the problem of available labor. Improved leadership and working conditions are reducing the turnover among planting crews. The hiring of 110 men in a season to maintain one 10-man crew is no longer necessary. This leaves the extension of the planting season as an unexplored means of accomplishing the planting task.

Obviously, improved planting techniques, leading to increased survival, would permit planting fewer trees per acre and eliminate some replanting. Improved planting techniques might overcome also the seriousness of “planting check” so that rapid early growth of seedlings would be realized. In searching for other means of overcoming the limitations of bareroot planting, one is drawn to the possibilities of container planting.

The container-grown tree is not a new concept. The Egyptians grew and transported containerized trees for frankincense from 3,500 to 4,000 years ago, as illustrated in a temple near Thebes.

Today's gardeners plant much container-grown material. They generally remove the plant from the container before planting. There are numerous reports of foresters working with small quantities of container-grown stock. Forest geneticists test seedlings grown in containers. Foresters in other regions of the world plant container-grown stock.

Although container planting as practiced is still a hand operation, Weyerhaeuser has approached container planting as a system to be mechanized from start to finish. By capitalizing on desirable characteristics of container planting, we see a planting system that will augment the bareroot-planting system.

A seedling growing in a container can be moved with little or no root disturbance any time with its supply of moisture and nutrients. The normal season for bareroot planting in the Pacific Northwest extends from mid-November through March. With container planting, an additional 30 planting days in October and early November, 20 each in April and May, and from 5 to 10 in June might be realized. This would represent a substantial gain in the time available for planting. Container planting lends itself readily to more complete mechanization. Mechanization of planting could serve both to elevate the status of the planter and to increase his productivity. The protection afforded roots of seedlings by keeping them in the container could offset the detrimental effects of bareroot handling so that improvement in survival and early growth in plantations might be achieved.

The attributes of a container are both positive and negative. The container can have specific dimensions and shape. It confines the contents and has bulk and weight. Units with specific dimensions and shape can be handled very well by machine. Size and shape of the container should be adapted to the rooting development of the tree species concerned. Forest tree species generally require dimensions of greater depth than cross section. This restricts the choice of materials of which containers are made. A poorly designed container confines not only the growth medium but also the seedling's roots. It may restrict movement of moisture into and out of the medium, which may be of insufficient volume to carry sufficient moisture. Nearly one-fifth of the microcontainers I have planted have failed because of desiccation of the seedlings by frost and drought. The shape of the container should facilitate handling. For instance, Jack Walters developed a container that becomes the head of a dibble to
facilitate its planting. Thus, the material and the design of the container itself are critical items.

The bulk and weight of containers are functions of size. Microcontainers such as Walters’ may weigh about 50 pounds per thousand units and occupy 3 cubic feet. A thousand macrocontainers such as ours may weigh 1,600 pounds and occupy nearly 120 cubic feet. Obviously, costs will increase with size. A balance must be struck between degree of successful performance and the total costs that result from increases in container size.

The potting medium must be available in large quantities. It must be homogeneous and readily amenable to handling. It must readily accept moisture and give it up to the seedling as needed. It must also provide the necessary nutrients and physical support for the seedling. Knowledge of natural soils is not directly applicable. One comprehensive treatise on artificial soils has been published by the Agricultural Experiment Station of the University of California. Growth of seedlings in artificial media needs more study.

After considerable work with young seedlings grown from seed in microcontainers of about 25 ml., in which we had only mediocre success, we turned to older seedlings transplanted into macrocontainers. Containerization of bare-root trees from the nursery permits natural selection. Weak seedlings from a seed lot die in the nursery bed. Runts are culled before potting. Only one seedling is potted in a container. Failure because of seed and multiple seedlings are eliminated by starting with transplants. More than 99 percent of the containerized seedlings can be outplanted.

Our concept of planting seedlings in macrocontainers includes mechanization to the maximum. The container should slip into a prepared hole, should be seated on its base, and the sides should contact the surrounding soil. No backfilling of an oversize hole is required. Hole preparation and container placement will be by a machine on a vehicle, except on unaccessible terrain where a two-man team will plant. One man will make the hole. The second will carry containerized trees, insert the container in the hole, and ensure the sealing. Several such teams will be supplied by an off-road carrier to minimize the distance of hand carrying.

Trees will be delivered from the nursery by vans, specially equipped to handle the large volume and weight. At the nursery, trees will be potted by machine and set into beds with a minimum of hand labor. The beds will need irrigation and good drainage, but not valuable agricultural soil. The seedling will grow roots in the container. And the rootlets will be ready to emerge from the container soon after outplanting.

Containers may be classified by the type of plant they carry, by their flexibility, and by material of which they are made. We decided upon a rigid or semirigid container large enough to carry a transplant seedling 18 inches tall through a mechanized process lasting for a year or more. Of the many materials, a linerboard product of our company seemed suitable. Dimensions were based on a review of planting stock. The container is 10 inches deep, 2½ inches in external diameter at the top, and 2 inches at the base.

The first model, procured through our packaging division, was a frustum of a pyramid made of untreated linerboard. Tabs at the base folded in to form the bottom. Roots were able to emerge between the folded tabs. The water-resistant glue and the untreated linerboard, however, were not durable beyond 2 to 3 months. And we wanted a rounded configuration.

The second model was made with a better glue. Several resin impregnations were tested, three of which have increased the container’s life beyond 1½ years. Slits in the walls were made to permit easier root emergence and moisture transfer, but they weakened the compression strength of the container. Perforations 1/8 inch in diameter were found to permit root egress without weakening the container. A simple bottom-closing technique in the third version produced a satisfactory, but expensive, container.

The manufacturing process included six steps with manual handling between linerboard and finished container. We are now working to reduce the basic cost of the container. Major changes in the processing are possible, but they are unlikely to yield an inexpensive container.

Our growing medium is a mix of sphagnum and sand, with an addition of commercial slow-release fertilizer. Although it adds to the weight, sand facilitates rewetting of the peat, which alone is reluctant to wet up. Moisture in the medium during potting is held as high as possible. Wet mixes are especially difficult to handle. Drier ones make more critical the wetting after potting.

Equipment developed for container planting falls into two main categories, items for transplanting and field planting. Two items for transplanting into containers are the potting machine and the dispenser. This past year a second-generation potting machine was operated. The individual trees are placed in the containers by the dispenser before transfer to the potting machine. The two machines are now operated by three women, but eventually one worker will be eliminated. A potential potting rate of over 800 per hour has not been achieved, mainly because of difficulties in maintaining a constant supply of uniform potting mix to the machine. Preparation and supply of soil will be refined.

For field planting, two items have been developed. Remington SL-9 chain-saw engines have been adapted
Container Planting

by modification of the Lewis gear box to drive an auger for scalping around and making the planting hole. Two auger bits are being developed. The first is a type of screw that lifts soil from a hole. The second merely displaces soil laterally as it worms itself into the ground.

The second field device being developed is a mechanical planter. It does not build a furrow as do most other forest planters. It will be controlled, but not assisted, by the operator. Although it presents difficult problems in mechanical design, the basic and perhaps insurmountable problem concerns maneuverability in the field.

During the past 2 years we have planted containerized trees to evaluate survival, growth, extension of the planting season, and costs. Questions of techniques and materials are being tested primarily in western Washington. Survival and growth are being compared with bareroot stock in plots on Weyerhaeuser Tree Farms from Snoqualmie Falls in northern Washington to Coos Bay and Klamath Falls, Oregon. First-year results are encouraging.

I have dwelt on some fundamentals and our approach to the problems. Containers have been developed throughout the world. The fundamental question is not "Can containerized trees equal or exceed the performance of bareroot?" We are satisfied they can, especially under the more severe conditions of site and weather. The real problem is to minimize the cost of each surviving, growing, containerized tree and, having done that, to justify the extra cost of containerization by more rapid growth and greater latitude in the time of planting.
PLANTING IN PUMICE AND ROOT DEVELOPMENT OF PONDEROSA PINE

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THE COMBINATION OF A GOOD CONE CROP AND WEATHER FAVORABLE for initial growth and survival of seedlings is rare in the ponderosa pine region of central Oregon. Foresters must, therefore, rely largely upon artificial regeneration for establishment of new stands of ponderosa pine. Available evidence indicates that, in this region, planting holds greater promise for obtaining a return from the investment made than does any method of artificial seeding, particularly on sites with pumice soils. These soils are quite different from ordinary mineral soils, a fact that should be considered in the planning of planting operations.

THE MAJORITY OF FOREST SOILS in central Oregon is derived from pumice. The most common is Mazama pumice because showers and flows of pumice from ancient Mt. Mazama blanketed large areas east of the crest of the Cascade Mountains from Klamath Falls to Bend. Lapine and Shanahan are the most common forest soils formed from Mazama pumice. Eruptions of the Newberry volcano deposited a sheet of pumice from which Newberry soil developed. Besides these three major pumice soils others occur, although most of these are limited in extent. The pumice soils of central Oregon have two characteristics in common. Generally, they show little weathering because they are still in the incipient stages of development, and their fertility is low. They vary considerably, however, in the size of pumice particles, which range from fine sand to coarse gravel.

The importance of particle size of pumice for planting is perhaps best illustrated by growth patterns of ponderosa pine in Newberry soil that covers the northeastern part of the Fort Rock Ranger District of the Deschutes National Forest. This soil has a layer of Newberry pumice, with an average thickness of 3 feet, overlying older pumice. Newberry pumice is coarse. About 70 percent of its particles, gravel sized, are referred to as popcorn pumice. Weathering of Newberry pumice and accumulation of organic matter is largely confined to the A and AC horizons in the surface 2 to 5 inches of soil. The remainder of the mantle of coarse pumice, the C horizon, is raw and has undergone little change since it was deposited about 2,000 years ago. The layers of pumice below the C horizon have the texture of fine sand and represent a buried soil, which shows a distinct sequence of horizons.

This soil supports amazingly fine stands of ponderosa pine, in spite of its low fertility. For instance, the average content of total nitrogen in the surface 2 feet of soil is about 200 pounds per acre. By comparison, the total nitrogen content in the surface 2 feet of soil in a medium site Douglas-fir stand in western Oregon is about 8,000 pounds per acre. Juvenile growth of ponderosa pine, however, is extremely slow in Newberry soil. Stem analyses of excavated trees indicate that the average rate of leader elongation is between 1.5 and 2 inches a year during the first 50 years of life. After this period, growth begins to accelerate.

Study of the root systems of excavated trees demonstrated how growth is influenced by the characteristics of the soil. Trees form numerous lateral roots close to the surface of the soil as their tap roots penetrate downward slowly. Acceleration of growth of stems in height and diameter occurs usually after tap roots reach the horizon below the coarse pumice. We still do not know exactly why growth is so slow while roots are in coarse pumice. Apparently several factors contribute. Formation of a dense net of lateral roots close to the surface of the soil suggests that supply of nutrients is limiting growth in the unweathered layer of pumice. Perhaps even more detrimental to growth are some of the physical properties of coarse pumice. Particles interlock and yield little to expanding roots. The difficulties that roots have in penetrating the layer of coarse pumice are indicated by the gnarled and twisted appearance of roots from the C horizon of Newberry soil. Furthermore, flow of moisture is extremely slow in coarse pumice. And inability of roots to take up enough water during high transpirational stress—existing through much of the growing season—is most likely an additional limiting factor.

We have found trees in Newberry soil whose stems elongated at an average annual rate of from 5 to 10 inches in their first 20 years after germination. Without exception, the roots of these trees followed old root canals and reached the subsoil in less than 10 years. Obviously, from these observations, any planting technique that provides roots with easy access to the subsoil should increase initial growth of ponderosa pine in Newberry soil.

We experimented with planting after two principal methods of soil preparation. One consisted of drilling
into the soil with a power auger, 10 inches in diameter and 30 inches long. Drilling thoroughly mixed the coarse pumice with the finer textured soil below, which created a column of loose soil through which roots could reach the subsoil (Figure 1). The second approach was to break up the coarse pumice with a ripper blade attached to a tractor.

Construction of a small root cellar allowed us to continuously observe growth of roots. Roots were able to reach the subsoil within 2 to 4 years after planting, both through coarse pumice mixed with fine subsoil and through broken-up coarse pumice, but not through undisturbed coarse pumice. Under greenhouse conditions, roots went through an 18-inch column of mixed fine and coarse pumice in about a month (Figure 2).

Mazama pumice varies in thickness from more than 100 feet close to the source to a few inches at the fringes of its occurrence. Accordingly, Lapine soil, developed in Mazama pumice, also varies in depth. It has actually two layers of Mazama pumice. The upper layer, the C1 horizon, has a high percentage of gravel-size pumice. Closer to the source of Mazama pumice, coarseness of the C1 horizon increases and, in many ways, is like the C horizon of Newberry soil. Below the C1 horizon of Lapine soil is a layer of finer pumice, the C2 horizon, with the texture of coarse sand. Both the C1 and C2 horizons consist largely of unweathered pumice, low in fertility. Mixing of the material in the C2 horizon with a fine-texture, buried soil underneath seems to have occurred in many places.

As one might expect, growth patterns of ponderosa pine are often similar to those found in Newberry soil. Juvenile growth of trees is slow and roots tend to remain in the surface soil for a long time, unless old root canals permit rapid downward penetration. Acceleration of growth of trees in Lapine soil usually occurs shortly after roots reach the C2 horizon. We still are not sure why trees begin to grow faster once their roots penetrate into the C2 horizon. Less mechanical resistance to root expansion and better supply with moisture than in the coarser pumice of the C1 horizon probably contribute to better growth. And, as in Newberry soil, any form of soil preparation that allows a planted seedling's roots to reach the subsoil quickly is likely to contribute greatly to survival and fast initial growth.

Shanahan soil, by contrast, does not display any pronounced textural differences between horizons. Roots of ponderosa pine in this soil appear to have less difficulty in growing downward than in either Newberry or Lapine soil. Soil preparation in Shanahan soil before
planting, therefore, is unlikely to provide benefits that may be expected in soils with layers of coarse pumice.

A plantation established by the U.S. Forest Service near Lava Butte, in a soil resembling a Lapine soil, is a good example of the advantage to be gained by soil preparation in the proper place. The area was furrow-plowed and then planted with 3-0 ponderosa pine. At age 10, 7 years after planting, trees attained an average height of 70 inches (Figure 3). Naturals in the vicinity in the same, but unplowed soil, grew about 1 foot in 10 years (Figure 3). I am convinced that nursery-grown seedlings would not have fared much better in the unplowed soil than did the naturals.

I want to emphasize, however, that soil preparation on pumice sites does not guarantee rapid juvenile growth of ponderosa pine. Aside from serious problems caused by wildlife, climate is often a major obstacle to successful establishment of plantations.

Most pumice sites in central Oregon receive less than 25 inches of annual precipitation. Because of slow flow of moisture in pumice, seedlings are often under moisture stress early in the growing season, particularly in open areas such as clearcuttings or burns. Here, wind and direct solar radiation tend to increase transpiration over that experienced under the shelter of brush or older trees. Hot as summers may get in central Oregon, nightly frosts occur through the growing season and often kill new shoots of young ponderosa pines.

Pumice Flat, an extremely severe site in the northeastern portion of the Fort Rock Ranger District, was perhaps the most challenging of all the sites we selected for our planting trials. We started on Pumice Flat, a large treeless plain surrounded by open stands of lodgepole and ponderosa pine, with seedlings ranging in age from 1 to 4 years on plowed and unplowed plots. Plowing or age and size of planting stock had no discernible effect on survival, which decreased to about 25 percent the second year after planting. Although few mortalities occurred in following years, height growth was minimal.

Our next effort was a combination of planting and fertilizer trials that failed completely. Then we attempted to reduce transpirational stress by planting seedlings in deep furrows (Figure 4). Again, survivals were few because cold air could not drain from the furrows and seedlings were killed by frost. Next, we planted again on flat ground but tried to protect seedlings with a ring of tar paper (Figure 5). The moment seedlings grew above the ring of tar paper, however, shoots were killed by frost or needles were blasted off by wind-driven pumice. Concomitantly, with this last planting trial in the open, we began to plant underneath open lodgepole pine stands. Here we lost

Figure 3. Height increment of ponderosa pine planted after plowing (top) was almost double that of naturally established pines in unplowed pumice.
few seedlings. Survival was almost 90 percent 5 years after planting. And annual height increment ranged from 5 to 8 inches. By contrast, seedlings in the open are less than 1 foot high 10 years after planting. We cannot change a harsh climate, but we can lessen its impact on young trees if we learn to recognize and take advantage of site features that have protective value. Our experience at Pumice Flat indicates that this is sometimes possible even under extremely adverse conditions.

Figure 4. Seedlings planted in deep furrows to reduce transpirational stress.

Figure 5. Seedlings planted on flat ground and protected with a ring of tar paper.
RECOGNIZING THE PRODUCTIVE POTENTIAL of an area and selecting well-adapted species for planting are two of the forester's most difficult problems. These problems are intensified by the West's mountainous topography. Even when we think we know the problems in one area, we find our experience counts little elsewhere. And sometimes elsewhere is only a few miles away!

My colleagues and I have applied, for the last 6 years, an ecological and physiological approach to studying interactions between plants and environment in the Siskiyou Mountains of southwestern Oregon. I will present some of the theory behind this approach and give examples that illustrate how we can recognize and predict the productive potential of different environments.

WHAT IS ENVIRONMENT?

Environment is "something that surrounds", but what does the environment surround? For our purposes, the environment surrounds a plant. Because plants are inseparable from their environment, there may be merit in using them not only to determine what we should measure, but also as an aid in interpreting our measurements.

Many of the environmental variables that affect us have little direct significance to plants. Unlike man, plants cannot identify the direction of slope, the elevation, or even the soil type. Plants respond to the environment because of its action rather than origin. That is, plants can respond to moisture, but they cannot identify the source as snow, rain, or seepage.

Accordingly, then, the elements of the physical environment that interact, but cannot be substituted for one another, can be classified as moisture, chemicals, temperature, light, and mechanical forces. And to these elements of its environment, a plant responds (2, 4, 9).

CHOICE OF REFERENCE PLANTS

To interpret environment, we selected plants with wide distribution for reference. Then, as suggested by Mason and Langenheim (5), we measured environment in a sequence that related to the development and sensitivity of these plants. Douglas-fir and Shasta red fir made good reference species in the Siskiyous because their combined distribution extended over all forested environments.

Sampling from seedlings was convenient and desirable because small plants have greater sensitivity to their environment than large ones. The cambial activity of Douglas-fir and Shasta red fir from 1 to 2 meters tall served to define the growing season at each of the stands described in Table 1. All environmental data were interpreted in sequence to plant development rather than calendar date.

ENVIRONMENTAL MEASUREMENTS AND INTERPRETATION

Measurements were taken around or upon reference plants from 1 to 2 meters tall, according to diurnal and seasonal moisture stress of the plant; shoot and root temperatures; daily light energy in the photosynthetic spectrum (400-700 nm); soil fertility and foliar nutrition; and estimates of mechanical stress from snow creep and ice breakage.

Portable instruments, today, permit the direct determination of moisture stress within twigs of vascular plants (6,8). Moisture stress usually increases during the day and reaches a minimum during the night. The stress during the night reflects the availability of soil moisture to the root system. The increase during the day is attributed to atmospheric conditions such as vapor pressure, radiant energy, and wind speed. Different species of conifers may have slightly different patterns of diurnal stress that are related to their stomatal response (Hinckley, T., Plant Moisture Stress: a Dynamic System as Seen Through the Response of an Organism to its Environment. Manuscript in preparation. 1968). At night, however, sampled conifers show similar values for stress after their root systems are equally well established.

Different seasonal patterns in the minimum stress in sampled Douglas-fir characterize different environments (Figure 1). In an Engelmann spruce stand,
stress remained low, but in a stand dominated by ponderosa pine, critical levels were reached during the growing season. In an oak stand, moisture stress of Douglas-fir reached such high values toward the end of the growing season that no recovery took place at night. In a region such as the Siskiyous, we obtained a good index to the seasonal patterns of moisture stress by comparing minimum stress at all environments near the peak of drought (usually in September).

Records of daily temperature from all the stand environments were analyzed and interpreted as they affect the growth of Douglas-fir seedlings (3). The temperature-related growth potential was 50 percent less in the Engelmann spruce stand than in the oak stand. A temperature index was derived for each stand environment by summing the fractions of growth possible each day during the growing season as determined by experiments with Douglas-fir in a growth room (Lavender, D. P., Some Effects of Air and Soil Temperatures upon the Growth of Douglas-Fir. Manuscript in preparation. 1968). The index was expressed as “Optimum Temperature Days”. In some environments, 2-3 days were required to accumulate the growth potential of one Optimum Temperature Day.

Table 1. Description of Stands in the Siskiyous Mountains.

<table>
<thead>
<tr>
<th>Stand</th>
<th>Elevation</th>
<th>Slope</th>
<th>Aspect</th>
<th>Parent material</th>
<th>Vegetation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4,900</td>
<td>25</td>
<td>W</td>
<td>Granite</td>
<td>White fir, ponderosa pine, Douglas-fir</td>
</tr>
<tr>
<td>2</td>
<td>5,500</td>
<td>60</td>
<td>W, NW</td>
<td>Granite</td>
<td>White fir, Douglas-fir</td>
</tr>
<tr>
<td>3</td>
<td>2,600</td>
<td>45</td>
<td>N</td>
<td>Granite</td>
<td>Douglas-fir, black oak, ponderosa pine</td>
</tr>
<tr>
<td>4</td>
<td>6,300</td>
<td>65</td>
<td>SE</td>
<td>Ultrabasic</td>
<td>Jeffrey pine, incense cedar, western white pine</td>
</tr>
<tr>
<td>5</td>
<td>5,600</td>
<td>65</td>
<td>SE</td>
<td>Ultrabasic</td>
<td>Jeffrey pine, incense cedar</td>
</tr>
<tr>
<td>6</td>
<td>6,700</td>
<td>35</td>
<td>NNE</td>
<td>Granite</td>
<td>Mountain hemlock, Shasta red fir</td>
</tr>
<tr>
<td>7</td>
<td>6,500</td>
<td>20</td>
<td>N</td>
<td>Granite</td>
<td>Shasta red fir</td>
</tr>
<tr>
<td>8</td>
<td>4,200</td>
<td>40</td>
<td>SW</td>
<td>Granite</td>
<td>Ponderosa pine, Douglas-fir</td>
</tr>
<tr>
<td>9</td>
<td>5,100</td>
<td>55</td>
<td>NNE</td>
<td>Metavolcanic</td>
<td>White fir, sugar pine, Shasta red fir</td>
</tr>
<tr>
<td>10</td>
<td>5,700</td>
<td>55</td>
<td>N</td>
<td>Metavolcanic</td>
<td>Brewer spruce, Shasta red fir, mountain hemlock</td>
</tr>
<tr>
<td>11</td>
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<td>35</td>
<td>SW</td>
<td>Granite</td>
<td>Ponderosa pine, shore pine, white fir, Douglas-fir</td>
</tr>
<tr>
<td>12</td>
<td>5,200</td>
<td>70</td>
<td>NSW</td>
<td>Green schist</td>
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<tr>
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<tr>
<td>17</td>
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<tr>
<td>18</td>
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<tr>
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</tr>
<tr>
<td>20</td>
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<td>70</td>
<td>NNE</td>
<td>Mica schist</td>
<td>Douglas-fir, Pacific yew</td>
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<tr>
<td>21</td>
<td>1,800</td>
<td>75</td>
<td>N</td>
<td>Metavolcanic</td>
<td>Douglas-fir, black oak, Oregon white oak</td>
</tr>
<tr>
<td>22</td>
<td>4,800</td>
<td>50</td>
<td>N</td>
<td>Metasedimentary</td>
<td>Douglas-fir, white fir</td>
</tr>
<tr>
<td>23</td>
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<td>10</td>
<td>N</td>
<td>Granite</td>
<td>Engelmann spruce, Douglas-fir, white fir</td>
</tr>
<tr>
<td>24</td>
<td>6,700</td>
<td>45</td>
<td>NNE</td>
<td>Metavolcanic</td>
<td>Mountain hemlock</td>
</tr>
<tr>
<td>25</td>
<td>5,700</td>
<td>5</td>
<td>SE</td>
<td>Ultrabasic</td>
<td>Jeffrey pine, white fir, incense cedar, Douglas-fir</td>
</tr>
<tr>
<td>26</td>
<td>3,700</td>
<td>55</td>
<td>NW</td>
<td>Granite</td>
<td>Douglas-fir, black oak, ponderosa pine</td>
</tr>
<tr>
<td>27</td>
<td>4,200</td>
<td>45</td>
<td>N</td>
<td>Granite</td>
<td>Douglas-fir, white fir, ponderosa pine</td>
</tr>
<tr>
<td>28</td>
<td>6,000</td>
<td>50</td>
<td>N</td>
<td>Granite</td>
<td>Shasta red fir, white fir</td>
</tr>
</tbody>
</table>

*Supplementary stands to verify precision of original data.*

Figure 1. Seasonal patterns in the minimum stress of Douglas-fir from 1 to 2 meters tall.
Conveniently, the highest values approached 100 for the growing season. Thus, the temperature-related growth-potential of each environment studied was a percentage of the maximum possible under the most favorable regimes of temperature, with the assumption that there were no other limiting factors.

The distribution of natural regeneration in relation to effective gradients of temperature and moisture stress is presented in Figure 2. Oak is restricted to the hot and dry sites. Ponderosa pine has a wider distribution and achieves its greatest productivity on sites with low moisture stress (Figure 3). Without fire or other disturbance, however, it is limited to drier sites where its competitor, the shade-tolerant white fir, is unadapted. Pine requires an average of 10 percent of full sunlight (of 400-700 nm wavelengths) throughout the day to just survive. But white fir continues terminal growth with less than 1 percent of full sunlight (1).

White fir, Shasta red fir, and mountain hemlock occur on progressively cooler sites with adequate soil moisture. That is not to say the true firs and hemlock never experience moisture stress. If stands are opened too much, the regeneration may experience transpirational stress that may be sufficient to force closure of leaf stomata, which prevents photosynthesis. Generally, clear cutting will slightly increase the temperature index and, for reasons just mentioned, favor species adapted to high moisture stress. In the high-elevation types, Jeffrey pine, usually restricted to only the most infertile soils derived from ultrabasic rocks, may be a desirable species to plant to provide a cover for the subsequent regeneration of Shasta red fir.

Figure 4 presents productivity of Douglas-fir in relation to the gradients of moisture and temperature. Again, as with ponderosa pine, productivity of Douglas-fir increases as moisture stress decreases. When moisture is adequate (less than 10 atmospheres' stress), temperature exerts a noticeable influence upon productivity. This general trend in productivity is demonstrated with all the tree species (Figure 5). Near timberline on very cool sites, the effect of wind, snow, and ice breakage also contributes to decreased productivity.

The distributions of other species are illustrated in Figures 6, 7, and 8. Western white pine, although most frequent on moist, cool sites, is nutritionally adapted to extend into both drier and warmer habitats if infertile soils, such as those derived from ultrabasic rocks, are
available. Shasta red fir and mountain hemlock appear to lack this ability.

As a group, the hardwoods are restricted to the warmer sites, partly because of their brittleness to ice and snow. Bigleaf maple and black oak are, however, clearly separated, according to their distribution along the moisture gradient.

Knowledge of the limited distributions of many lesser species such as poison-oak, gray manzanita, and mountain heliotrope can be useful in identifying the environment's growth potential even after the forest has been removed (9).

**APPLICATIONS**

The approach presented here, and the actual data, have wide applications, particularly in forest genetics and other fields when direct comparisons between regions are desired. Within a region, once the environmental distributions of trees and other species are known, maps can be constructed from aerial photographs and ground checks that classify all forest environments in relation to such factors as moisture, temperature, and soil fertility. With knowledge of the most critically limiting environmental factor and the present growth potential of each site, the forester can compare the relative returns of various alternatives in management. Also, the results of past experiences from planting selected genetic stock, adding fertilizers, or thinning can all be re-evaluated.

**LITERATURE CITED**


Figure 6. Distribution of tree regeneration in relation to gradients of moisture and temperature. Triangles represent stands on soils from ultrabasic material. Shading indicates frequencies greater than 50 percent. Starred data points indicate supplementary stands to verify precision of original data. Dotted lines indicate appropriate correction where there was disagreement with original data.
Figure 7. Distribution of selected tree and shrub species in relation to gradients of moisture and temperature. Triangles represent stands on soils from ultrabasic material. Shading indicates frequencies of 50 percent or more. Starred data points indicate supplementary stands added to verify original data.
Figure 8. Distribution of selected half-shrubs and herbs in relation to gradients of moisture and temperature. Triangles represent stands on soils derived from ultrabasic material. Starred data points indicate supplementary stands added to verify original data. Dotted lines indicate appropriate correction where there was disagreement with original data.


CHECKLIST OF PLANTS

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Scientific Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cedar, incense</td>
<td>Libocedrus decurrens Torr.</td>
</tr>
<tr>
<td>Douglas-fir</td>
<td>Pseudotsuga menziesii (Mirb.) Franco</td>
</tr>
<tr>
<td>Fir, Shasta red</td>
<td>Abies magnifica Murr. var.shastensisLem.</td>
</tr>
<tr>
<td>Fir, white</td>
<td>A. concolor Lindl.</td>
</tr>
<tr>
<td>Heliotrope, mountain</td>
<td>Valeriana sitchensis Bong.</td>
</tr>
<tr>
<td>Hemlock, mountain</td>
<td>Tsuga mertensiana (Bong.) Sarg.</td>
</tr>
<tr>
<td>Manzanita, gray</td>
<td>Arctostaphylos viscida Parry</td>
</tr>
<tr>
<td>Maple, bigleaf</td>
<td>Acer macrophyllum Pursh</td>
</tr>
<tr>
<td>Oak, black</td>
<td>Quercus kelloggi Newb.</td>
</tr>
<tr>
<td>Oak, Oregon white</td>
<td>Quercus garryana Dougl.</td>
</tr>
<tr>
<td>Pine, Jeffrey</td>
<td>Pinus jeffreyi Murr.</td>
</tr>
<tr>
<td>Pine, ponderosa</td>
<td>P. ponderosa Laws.</td>
</tr>
<tr>
<td>Pine, sugar</td>
<td>P. lambertiana Dougl.</td>
</tr>
<tr>
<td>Pine, western white</td>
<td>P. monticola Dougl.</td>
</tr>
<tr>
<td>Poison-oak</td>
<td>Rhus diversiloba T. and G.</td>
</tr>
<tr>
<td>Spruce, Brewer</td>
<td>Picea breweriana Wats.</td>
</tr>
<tr>
<td>Spruce, Engelmann</td>
<td>P. engelmannii (Parry) Engelm.</td>
</tr>
<tr>
<td>Yew, Pacific</td>
<td>Taxus brevifolia Nutt.</td>
</tr>
</tbody>
</table>
ECONOMICS AND POLICY ENVIRONMENTS FOR FOREST REGENERATION

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MOST OF YOUR DAILY CONCERNS IN FOREST REGENERATION are biologic, technologic, and mechanical. But periodically, perhaps once a year, many of you must consider regeneration in a context that includes alternative uses for the financial resources you have.

To many of you, the notion is repugnant that your work—for which you have trained and in some cases committed whole careers—must compete against activities totally outside your ken. How can you justify regeneration as a more desirable activity than fire protection, roadbuilding, or expansion of your company’s plant? Indeed, why should you? The tools of tree planting certainly can’t be used for much else. The planting crews are not the same people who would build the veneer lathe. Yet, you’re told you are competing with these other activities for money.

Actually, in a few months, forestry tools and crews can’t be converted to other uses. They’re immobile. So you needn’t compete for them. But over a year or so, people can and do move to other places and occupations.

Of even greater significance to you is the mobility of money. Today’s forestry dollar is tomorrow’s Vietnam dollar, as Federal foresters know well. This year’s budget for timber management may be a sales promotion budget next year.

THE MAN WHO CAN HELP YOU is, of course, your friendly neighborhood economist. Four economic formulations may interest those of you who compete with other uses for mobile financial resources.

Classical economic analysis of regeneration opportunities includes an estimate of the stumpage value of the stand when it is to be harvested and discounted back to the present at some rate of interest, and a comparison of the discounted value with the cost of establishing the stand. If the present value of the future stumpage exceeds costs of establishment, the investment is considered worthwhile. A variation of the method eliminates the arbitrary discount rate; instead, returns are related to costs as a rate of return on the investment.

For example, to plant an acre may cost $50. The stand with 25,000 board feet is scheduled for cutting 100 years hence at $30 per thousand. Suppose a discount rate is 5 percent. Then the present value of the $750 in ultimate stumpage income is $6, substantially less than $50, the cost for establishment of the stand. The rate of return on the $50 investment is less than 3 percent. Even for Federal agencies, that rate of return is inadequate to justify the expenditure. This is only an example, but it reveals why foresters have had a dour view of economists, purveyors of a science that is apparently dismal, indeed.

Numerous refinements can be added to this traditional system. Costs of cultural treatments and annual administrative costs can be recognized. Returns from thinnings can be built in. Even the relative likelihood of alternative biologic and economic events can be put into the calculation. The usual conclusion, however, does not change. With future incomes discounted over several decades, forest regeneration is usually economically unattractive.

Estimates of rates of return on timber-growing investments have been published. Here are some:

9 percent, Douglas-fir on high sites, with management
8 percent, Douglas-fir on site 4, with management
5 percent, Douglas-fir on site 3, with management
Less than 5 percent, Douglas-fir on site 2, without management
8 percent, ponderosa pine on site 1, with management
6 percent, ponderosa pine on sites 2 and 3, with management
2 percent, ponderosa pine in western Montana
6 percent, sugar pine
7½ percent, southern pines
5½ percent, loblolly pine plantations
7½ percent, red pine in the Lake states
4½ percent, red pine in the Lake states
3½ percent, red and white pines in the Lake states
2½ percent, northern hardwoods

Inconsistencies occur because of various assumptions used in different analyses. But the results are uniformly unimpressive.

A second kind of economic analysis, widely misunderstood, may interest those of you associated with organizations that have a sustained-yield policy and a substantial inventory of over-rotation-age timber. In this analysis, recognition is taken of the fact that in your reforestation program you expect an increased total yield on your holdings. This in turn raises your
allowable cut, with the increase actually realized through accelerated cutting in the overmature stands.

Suppose you have a simple, though unusual, kind of property with nonstocked land, 100 million board feet of old growth, no age classes in between, and a 100-year rotation planned. You apply one of the conventional allowable-cut formulas, such as Hanzlik’s or the Austrian formula, which have two components to the allowable cut. The first is a growth factor. But on your property net growth is negligible. The second is a portion of the cut taken to reduce the inventory of over-age timber. If you plan to convert it evenly over the first rotation, you will cut 10 million board feet in each of 10 decades. That’s your allowable cut.

Now suppose you decide to reforest a thousand acres. You anticipate producing 25,000 feet per acre over the rotation, which leads to a mean annual increment of 250 board feet per acre per year, or 2½ million board feet per decade on the 1,000 acres. Now, through reforestation, you have produced a growth component for the allowable cut. Obviously, if you had only young stands, you would have no place from which to take this additional 2½ million feet per decade. But we have assumed you have an old-growth inventory of 100 million board feet. Because of the increased allowable cut, your old-growth harvest will change from 10 to 12½ million feet per decade.

When you take the increase depends on whether your increased cutting starts when you plan to establish the stand, when you actually do establish it, or when a subsequent inventory confirms survival and growth of the seedlings. This decision is a measure of your prudent, experience-bred caution. Or your unreasonable conservatism—depending on your point of view!

Any practical economic analysis recognizes income when it is actually generated. And scheduling for evenflow harvest generates actual income early in the rotation. With incomes discounted over a shorter period, the rate of return on the regeneration investment rises. This happens even though you run out of old growth sooner. In the example, 100 million board feet of old growth was to be removed at the rate of 12½ million feet instead of 10 million feet per decade because of regeneration. Thus, instead of 10 decades of old-growth cutting there can be only 8. In rate-of-return analysis, however, a deficit of 20 million feet of timber 80 years in the future can’t compete with an increase of 2½ million feet of timber in this decade. The return on investment becomes 15 percent instead of 3 percent.

If you are willing to forfeit old-growth harvests late in the conversion period for additional old-growth harvests in early years, and if in planning you use classical even-volume flow formulas, regeneration can be justified easily in many instances.

As with the allowable-cut-effect analysis, a third approach to the economics of regeneration is valid only in the context of a particular policy. This policy is that timber will not be cut unless the harvested acres are reforested within a reasonable time. Here, economics can answer two questions. One is simply whether or not the revenues from stumpage or log sales will cover the regeneration cost. This is an oversimplification, however, because of the statistical likelihood that some regeneration will fail and require additional expenditure. Those of you interested in lodgepole pine and contemplating type conversion to ponderosa pine certainly face the second question which is, “Given limited reforestation budgets, which stands on what sites should be harvested and regenerated first?”

I’m covering this third analysis briefly, not because it is less important, but because many of you do not countenance the harvest-regeneration linkage in your policy environments. Decisions in cutting and reforestation are too often made by different people, at different times, and are effected with different budgets.

The fourth approach to regeneration flows strongly from a policy in which society dictates regeneration on every forest acre, irrespective of whether or not income can be wrung from the acre to finance the new stand. I believe that this mandate will soon be binding on all forest managers, public and private. It’s probably not economically rational, but in today’s political atmosphere purely economic decisions are unacceptable. Whether or not the best method is profitable is irrelevant in this analysis. Economics does, however, in the choice of regeneration methods, provide a system for weighing cost of application, regeneration lag, and probability of success.

I have reviewed four different policy situations and the economic analyses they require for your regeneration decisions. The classical discount method is inapplicable to the allowable-cut effect from regeneration. If your policies provide for this effect and you have a reservoir of merchantable timber, the second kind of analysis is appropriate. If, in your policy, timber cutting and regeneration are joint ventures, the third analysis is relevant. And in areas where the timber is already gone, you may face a restoration mandate that requires the fourth approach to economics evaluation.

In summary, first consider the policy environment in which you work, then consult your neighborhood economist.
THE ROLE OF MOISTURE STRESS AND TEMPERATURE IN THE GROWTH OF SEEDLINGS

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TO BETTER UNDERSTAND THE SURVIVAL AND GROWTH OF SEEDLINGS after being outplanted, I will examine, in detail, two important physiological factors, plant moisture stress (PMS) and leaf temperature. These two factors are the result of the seedling's response to its environment, and both are directly related to the seedling's ability to grow in that environment. Besides the external factors that affect PMS and leaf temperature, I will examine how PMS and leaf temperature are related to photosynthesis, growth, and development of the seedling.

THE CONDITIONING IN THE NURSERY before and during planting will affect the vigor or general health of the seedling. We may assume that this treatment has been satisfactory, but now the plant must respond to its new environment. The assumption about satisfactory treatment should not be taken lightly, however, because many of our failures in regeneration are directly attributable to poor treatment and handling of stock before planting in the field. Let us assume, however, that the seedlings were reasonably well cared for and planted properly. Also, we will examine growth and survival of seedlings without the problems of animals, insects, and disease. We must fully recognize, however, that, if present, they may be the factors limiting growth and survival. Given those assumptions, then, the seedling's response to its environment will determine whether growth is large or small and whether the plant survives or not.

Now let us examine the environment in relation to a seedling. The seedling's environment is often characterized by the microclimatologist by the energy-budget concept where incoming and outgoing energy are measured and balanced. But this purely physical approach, which does not examine and describe how the plant responds internally, is inadequate for the physiologist interested in growth, or the ecologist interested in plant distribution. If one concentrates on the physiological response of the seedling to its environment, much of the information collected in an energy-budget study becomes extraneous because the same plant response can be obtained by many different combinations of environmental variables.

Let us now focus on photosynthesis to develop a framework for discussion. This process, rather than some other parameter such as growth in height or diameter, was chosen for several reasons. First, we know more about the photosynthetic response of the seedling to its environments. Second, to examine photosynthesis is really to examine a more fundamental process that makes these other expressions of growth possible.

Figure 1 shows environmental effects on the photosynthetic rate of a seedling. Photosynthesis is shown as the conversion of carbon dioxide and water into a carbohydrate and oxygen. My division is somewhat arbitrary here, because the factors are dependent on each other. A change in one affects the others. Each factor, however, is required for long-term photosynthetic output.

The first, most obvious factor is the light energy that will be converted into chemical energy in the form of carbohydrates and eventually other plant components. The light in the environment can vary in intensity, duration (photoperiod), and quality. Figure 2 shows the photosynthetic response of a ponderosa pine seedling to light intensity. From this curve and observation in the field, ponderosa pine obviously requires high-intensity light for maximum growth. The second factor affecting photosynthesis and growth is

![Diagram of photosynthesis process]

Figure 1. Diagrammatic representation of the environmental effects on the photosynthetic rate of a seedling.

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1 Now with Weyerhaeuser Company, Centralia, Washington.
nutrition. An adequate supply of nutrients is essential if the seedling is to carry on photosynthesis. Not all of the nutrients required by the plant are needed for photosynthesis, but the majority are connected either directly or indirectly with the process. The long-term effect of suboptimal nutrition is similar to light, in that the rate of photosynthesis is a function of nutritional status.

Now, I shall concentrate on the last three factors, the seedling, plant moisture stress, and temperature, with the assumption that light is available and nutrition is not limiting. As we think of the plant, itself, we would classically think of the chlorophyll requirement. But many other components of the plant are included to make a continued synthesis possible.

Plant moisture stress is a measure of the water status of plants. It is analogous to soil moisture stress except it is measured in the plant. Therefore, it is a measure of water availability for plant processes as soil moisture stress is a measure of water availability in the soil for a plant. Formerly, we measured factors such as soil moisture or evaporation. From these measurements, we attempted to infer the water status of the seedling. With recent developments in research, we have the pressure bomb, an instrument that can easily, quickly, and directly evaluate water status of a seedling (5,6).

By noting the changes in plant moisture stress (PMS) in tree seedlings, one can evaluate both the daily and seasonal changes in water stress and then, with this information, obtain a correlation with growth or survival of seedlings. The technique consists of a simple model that shows how PMS relates to other factors of the environment and the data that should be collected to characterize changes in PMS.

The pressure bomb operates on the water-cohesion theory. The water column in a twig (Figure 3) is normally under a tension. One cuts the twig, which releases the tension, and the water column retracts in both directions somewhat like a rubber band that is stretched and then cut. After removal of the bark to the cambium, the twig is placed into the pressure chamber, with the cut surface protruding through the cover. Nitrogen from a supply cylinder slowly increases the pressure inside the chamber until the water column is restored to its original position and a water film appears at the cut surface. The pressure required to do this is a measure of the moisture stress in the plant. PMS is usually expressed in terms of atmospheres or bars (one atmosphere is 14.7 pounds per square inch). Details are recorded elsewhere (1,2).

In an effort to interpret PMS data and their relation to other data collected, we must remember how PMS is related to other environmental factors. PMS is directly related to the transpiration rate (TRP) and the

Figure 2. The effect of light intensity on dry-matter production and on rate of net photosynthesis of Douglas-fir seedlings at 18 degrees C, expressed as percentage of maximum observed (2).

Figure 3. To measure moisture stress in a plant, a cut twig (top) is inserted through a rubber plug in the pressure bomb (bottom). Pressure of nitrogen in the bomb is increased until water in the twig is forced back to the cut surface. This pressure is recorded.
soil moisture stress (SMS) at the root surface (3). For example:

\[
PMS = f (TRP), (SMS_{\text{root}}), \text{ where}
\]

f = function coefficient, which varies depending on value of TRP and (SMS_{\text{root}})

TRP = transpiration rate, and

SMS_{\text{root}} = soil moisture stress at the root surface.

Both the transpiration rate and soil moisture stress at the root are presented in an abridged graphical form in Figure 4. All of these factors, interacting in a complex way, result in some plant moisture stress. If PMS is measured directly, this complex relation can be disregarded. In fact, a correlation of any of these factors by themselves with PMS should not be attempted.

Daily change of PMS in response to these factors is shown in Figure 5. A fascicle of needles, instead of a branch, from each of three 3-year-old ponderosa pine seedlings was measured at frequent intervals during the day. The different rate at which each seedling approached 15 atmospheres results from different amounts of shading by nearby trees. The seedling that reached 13 atm by 8:00 a.m. had full radiation from sunrise, but the other two seedlings had partial or full shade until 9:30 a.m. The finding that all the seedlings reached a plateau in moisture stress by 11:30 a.m., even though differences in temperature and vapor pressure continued to rise until 3:30 p.m., is evidence that stomata closure took place at about 15 atm.

![Figure 5. Diurnal change in PMS for three ponderosa pine seedlings. Points shown are the means of two readings. Paired readings differed from their mean by no more than 1/3 atm.](image)

Therefore, by comparing the PMS of seedlings, one can easily characterize the effects of different environments or different treatments in the same environment. The pressure bomb will be valuable in several areas of forestry. For example, several nurseries operate it to measure changes in PMS during lifting, processing, and planting of tree seedlings. The technique could be easily adapted to help evaluate the severity of drought at different planting sites.

The seasonal changes in PMS are shown in Figure 6. The minimum values were obtained during the 1-hour period before sunrise. Maximum values were recorded on warm, sunny afternoons between 2:00 p.m. and 4:00 p.m. On days with lower temperatures or cloud cover, or both, the maximum PMS was as much as 15 atm lower than shown. After early July, when maximum stress appeared to be near lethal (based on laboratory data collected for the seed source (1), one experimental block of seedlings was irrigated periodically during the remainder of the growing season. The irrigated plot showed only 10 percent mortality, but the remaining nonirrigated seedlings showed 90 percent.

Brix (1) has worked out the relation between PMS and photosynthesis for loblolly pine seedlings (Figure 7). He, besides others, concluded that sharp decline in photosynthesis between 6 and 12 atm stress results from stomatal closure. This conclusion agrees with theory, because stomatal closure will greatly increase the resistance to the diffusion of carbon dioxide and, therefore, will shut down the photosynthetic process. Figure 8 shows how photosynthesis and transpiration...
Role of Moisture Stress and Temperature in the Growth of Seedlings

Figure 6. Seasonal changes in PMS of Douglas-fir seedlings planted at Corvallis. Each point is the mean of eight seedlings.

Figure 7. Relation between PMS and photosynthesis for loblolly pine seedlings (1).

Figure 8. Relation between photosynthesis and transpiration (1).
Figure 9. Growth of Douglas-fir seedlings in relation to constant day and soil temperatures where the contours represent equal fractions of optimum growth. The effect of different night temperatures is slight and has been averaged out (based on data supplied by D. P. Lavender).

LITERATURE CITED


UTILIZATION OF SOIL AND FERTILIZER NITROGEN BY PONDEROSA PINE

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ONE OF THE SOUTHWEST'S MOST PRESSING PROBLEMS IN MANAGEMENT concerns regeneration of ponderosa pine (*Pinus ponderosa* Laws.), particularly after catastrophic fires. Several factors contribute. Conventional planting must be delayed until summer rains begin, about mid-July, which causes a short growing season. Also, long distances from the nursery, unavoidable lack of coordination between times of lifting and planting, and inability to predict future needs often result in a planting stock of poor quality for the forest manager. Alternatives to conventional planting, such as direct seeding and local transplantation of natural seedlings, have been tried with limited success. A potential compromise to the entire problem of regeneration seems possible.

THE CANADIANS INTRODUCED THE CONCEPT of tubed seedlings for regeneration of red pine (*Pinus resinosa* Ait.), white pine (*Pinus strobus* L.), and black spruce (*Picea mariana* (Mill.) B.S.P.). Briefly, seeds are germinated in split plastic tubes, about 3 inches by 9/16 inch, filled with soil. On site seedling development, under a modified environment, continues for about 6 to 8 weeks. Subsequently, the entire tubed seedling is planted. The potential advantages for this type of regeneration seem numerous.

Because of low fertility of many Southwest soils, it was thought that altering the nutrients of the tubed seedling could enhance capability of the soil for future growth, especially after planting. Unfortunately, most fertility studies with ponderosa pine were conducted with periods of growth of a year or more, which is unrealistic when one considers that the entire growing season of planted pine may be from 10 to 20 weeks. Therefore, before the initiation of the field regeneration studies, a series of experiments was conducted to ascertain the effect of added nitrogen, principally in two ammonium forms, on the development of young ponderosa pine seedlings.

LITERATURE REVIEW

Underlying the study of nitrogen in ponderosa pine development is the nature of soil nitrogen. Alexander’s (1) presentation of the basic nitrogen cycle is concise (Figure 1). The organic-inorganic transformations of mineralization and immobilization take place at points A and B, and nitrification and nitrate reduction at C and D. Potential nitrogen losses, because of denitrification, may occur at E. Nitrogen gains to the cycle may come at several points. One such gain is the biological fixation of atmospheric nitrogen, symbiotically at G and nonsymbiotically at F. A chemical gain as nitrogen fertilizer may come at either the NO$_3^-$ or NH$_3$ positions, because the individual may select a variety of nitrogen fertilizers.

Ponderosa pine preference for NH$_4^+$ or NO$_3^-$ is difficult to assess. Possibly the fertilizer, which increases the turnover of forest litter, may be the most efficient to apply (5). Still, the interpretation of studies of source preference may be complicated by such factors as nitrogen transformations that include microbial activity, age of the plant, pH, and soil temperatures. McFee and Stone (8) found NH$_4^+$ the preferred nitrogen source over NO$_3^-$ at two pH levels, 3.6 and 5.9 and at three root-zone temperatures, 12, 20, and 25 degrees C, for *Pinus radiata* D. Don seedlings, grown in short-term experiments. Ponderosa pine would likely show the same preference for NH$_4^+$. A less detailed study, supporting this contention, showed that NH$_4^+$ was the preferred nitrogen source for ponderosa pine (17).

In published reports for ponderosa pine, NH$_4$NO$_3$ was the exclusive nitrogen source. A study in 1959 reported a positive response to an application of 200 pounds per acre of nitrogen, combined with phosphorus and potassium, for ponderosa pine seedlings 12 months old (14). With a modified factorial design, Youngberg and Dyrness (19) studied concentrations of nitrogen, phosphorus, and sulfur on the A and C horizons from four soils in the pumice region of Central Oregon. For a 12-month period of growth, they found highly significant linear and quadratic responses for additions of nitrogen and sulfur and highly significant interactions of nitrogen x sulfur, and nitrogen x phosphorus on all horizons of all soils tested. On older ponderosa pine, a linear response in height growth was noted for added nitrogen concentrations of 0, 200, and 400 pounds per acre (13). Reports of nitrogen fertilization on young ponderosa pine seedlings are sparse. Steinbrenner and Rediske (11) studied the effect of light, temperatures of soil and air, humidities, region and quality of soil, and nitrogen additions on growth and development of young ponderosa pine. Applications of nitrogen at 2 and 6 weeks that totalled an equivalent of 50 pounds per acre, had little effect on growth of ponderosa pine, 10 weeks old. As measured by dry-matter production, the data
Figure 1. Generalized nitrogen cycle for terrestrial ecosystems. A, Ammonification, Mineralization; B, Immobilization; C, Nitrification; D, Nitrate reduction; E, Denitrification; F, N₂ fixation, symbiotic; G, N₂ fixation, nonsymbiotic.

Figure 2. Changes in pH of soil after additions of (NH₄)SO₄ or urea, or with no added nitrogen.

indicated a slight increase in top growth with a corresponding decrease in root growth. Steinbrenner and Rediske concluded that the other environmental variables tested seemed more important in determining initial development of ponderosa pine.

That established pine seedlings can benefit from biologically fixed N₂ has been documented. Wollum and Youngberg (18) showed that the nitrogen contents of ponderosa pine, grown in association with snowbrush (Ceanothus velutinus Doug.), a known N₂ fixer, were higher than that of pine seedlings grown in the open. Of course, this nitrogen would become available only after mineralization of the organically bound N in the snowbrush litter. Conflicting evidence has accumulated for the role of nonsymbiotic N₂ fixation in pine seedling nutrition. Nonsymbiotic N₂ fixation may be stimulated in the vicinity of mycorrhizal roots of some pine species (10, 12). The importance of this stimulation around mycorrhizal roots of ponderosa pine is not directly evident, however.

MATERIALS AND METHODS

Environmental Conditions

The seeds were from either New Mexico (Santa Fe National Forest) or Arizona (Coconino National Forest). The two soils were collected in the Zuni Mountain area of northwestern New Mexico.

Soils. The A1 horizons of the two soils were tested. Both these soils, Fortwingate and Osoridge, are
members of the hapludic Eutroboralf subgroup and the fine, montmorillonitic family. Each soil originated on the Glorieta sandstone formation, with the Fortwingate moderately deep, and the Osoridge shallow. Also, the Osoridge soil contains more stones and has a less distinct A2 horizon than the Fortwingate soil.

**Plant. Culture.** All tests were conducted in replicated culture tubes, 29 by 200 mm. Each tube contained about 20 grams of gravel at the bottom to assure adequate drainage and 80 grams of soil. About five or six ponderosa pine seeds were sown in separate tubes and covered with a thin layer of sand. Germination commenced about 1 week after sowing and continued for an additional week. Then the tubes were uniformly thinned to one seedling per tube. Time zero always corresponded to the time of thinning, or 2 weeks past sowing.

Treatments were made with respect to time zero, and all nitrogen sources consisted of reagent grade (NH₄)₂SO₄, or urea.

All plants were grown under a uniform environment of a 15-hour day of about 3,500-foot candles, a constant root temperature of 22 degrees C, and diurnal day-night temperatures from about 26 to 20 degrees C. According to Steinbrenner and Rediske (11) and Larson (7), these conditions approach optimum for maximum development of root and top for ponderosa pine.

**Chemical Techniques**

Total plant nitrogen was determined by a modified, micro-Kjeldahl technique to include NO₃⁻ (18).

Soil samples were extracted with a 1N solution of K₂SO₄ and the NH₄⁺, NO₂⁻, and NO₃⁻ were determined on extracts, according to the procedures of Keeney and Bremner (6). Where appropriate, urea was determined on the K₂SO₄ extract by the procedure of Watt and Chisp (15).

The estimation of N₂ fixation was obtained by the C₂H₂ reduction technique for the assay of the presence of nitrogenase as reported by Hardy et al. (4), but with modifications.

**SUMMARY**

In an attempt to understand the relation between growth and nitrogen utilization in young ponderosa pine, seedlings were grown under several different regimes of added nitrogen. Early growth was effectively stimulated by nitrogen from (NH₄)₂SO₄. And the top/root (T/R) ratio was not affected adversely. Conversely, equivalent amounts of nitrogen, applied as urea, caused considerable mortality on seedlings less than 6 weeks old. Responses to nitrogen were influenced by seed source. Growth of New Mexico seedlings was increased by (NH₄)₂SO₄, but not urea. For the Arizona seedlings, the growth responses were not significantly different between urea and (NH₄)₂SO₄.

Various components of the system had utilized and transformed the inorganic nitrogen derived from fertilizer nitrogen by the end of the sixth week. Subsequent nitrogen utilization had to come from the mineralization of organic nitrogen. Presumably, only a small portion of the initially supplied nitrogen is utilized before some process of immobilization takes place.

The potential contribution of nonsymbiotic N₂ fixation to the total nitrogen economy of ponderosa pine was negligible under the conditions of these experiments.

**RESULTS**

Studies of plants, seed sources, soils, and nonsymbiotic nitrogen fixation provided insight into growth and nitrogen utilization of young ponderosa pines.

**Plant Studies**

Experimental conditions for the first study were as follows: nitrogen source, (NH₄)₂SO₄ and urea; Osoridge soil; Arizona seed; and treatment times of 3, 6, and 10 weeks.

All seedlings were grown 10 weeks after treatment and were 13, 16, and 20 weeks old at harvesting.

The top and total dry matter production for ponderosa pine was increased by both nitrogen sources at all times of application (Table 1). For early applications of nitrogen, (NH₄)₂SO₄ is clearly the preferred source. For seedlings treated at 10 weeks, however, neither (NH₄)₂SO₄ nor urea was superior. Also, older seedlings had a tendency to be more responsive than younger seedlings to applications of nitrogen. The T/R ratio remained about constant for the control seedlings, began to increase on the older seedlings treated with (NH₄)₂SO₄ and decreased with age for the group treated with urea. Apparently, the principal difference between (NH₄)₂SO₄ and urea on these seedlings concerns root growth. Roots of young ponderosa pine were more sensitive to 100 ppm of nitrogen as urea than to an equivalent amount of nitrogen as (NH₄)₂SO₄. The most reasonable explanation seems related to a pH sensitivity of the young roots. After urea hydrolysis, the NH₄⁺ content
of urea-treated soils was similar to that of soils treated with an equivalent amount of nitrogen supplied as the NH$_4^+$ ion. The pH of the urea-treated samples, however, will increase to about 8.0-8.2 for 7-10 days (Figure 2). During the same time, pH of the sample treated with NH$_4^+$ did not vary significantly from the pH taken before treatment. Apparently, roots of seedlings less than 10 weeks old are affected by initial pH changes to 8.0-8.2 in the root zone, although this pH remains only a small portion of the entire growth period.

The nitrogen-content data indicated that the nitrogen from (NH$_4$)$_2$SO$_4$ was more readily available for uptake than urea nitrogen (Table 2). Also, most of the nitrogen additionally utilized is translocated to the top, with only a small portion of the additional nitrogen retained by the roots. If we assume that all of the additional nitrogen in the treated plants came from fertilizer, the oldest seedlings were able to recover 75 percent of the nitrogen from (NH$_4$)$_2$SO$_4$ and 56 percent from urea. Under forest conditions, this figure would be much lower and probably approaches the 12 percent utilization of added nitrogen reported for Scots pine (Pinus silvestris L.) by Bjorkman et al. (2).

In a second experiment, New Mexico seeds were sown in the Fortwingate soil and treated with (NH$_4$)$_2$SO$_4$ and urea at 1, 3, and 6 weeks. All seedlings were 10 weeks old at harvesting. They had been exposed to fertilizer nitrogen for 9, 7, and 4 weeks, respectively. Several different responses were obvious (Table 3).

### Table 1. Influence of Nitrogen Source and Seedling Age at Nitrogen Application on Dry-Matter Production.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Age at application, weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3</td>
</tr>
<tr>
<td>NO NITROGEN ADDED</td>
<td></td>
</tr>
<tr>
<td>Top dry weight, Mg</td>
<td>159</td>
</tr>
<tr>
<td>Root dry weight, Mg</td>
<td>129</td>
</tr>
<tr>
<td>Total dry weight, Mg</td>
<td>288</td>
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<tr>
<td>Top/root ratio</td>
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<tr>
<td>NITROGEN FROM AMMONIUM SULFATE</td>
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<tr>
<td>Top dry weight, Mg</td>
<td>235</td>
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<tr>
<td>Root dry weight, Mg</td>
<td>156</td>
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<tr>
<td>Total dry weight, Mg</td>
<td>391</td>
</tr>
<tr>
<td>Top/root ratio</td>
<td>1.51</td>
</tr>
<tr>
<td>NITROGEN FROM UREA</td>
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<tr>
<td>Top dry weight, Mg</td>
<td>223</td>
</tr>
<tr>
<td>Root dry weight, Mg</td>
<td>104</td>
</tr>
<tr>
<td>Total dry weight, Mg</td>
<td>327</td>
</tr>
<tr>
<td>Top/root ratio</td>
<td>2.14</td>
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</table>

### Table 2. Influence of Nitrogen Source and Seedling Age at Nitrogen Application on Nitrogen Content.

<table>
<thead>
<tr>
<th>Nitrogen content</th>
<th>Age at application, weeks</th>
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</thead>
<tbody>
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<td></td>
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</tr>
<tr>
<td>NO NITROGEN ADDED</td>
<td></td>
</tr>
<tr>
<td>Top</td>
<td>1.6</td>
</tr>
<tr>
<td>Root</td>
<td>1.2</td>
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<tr>
<td>Total</td>
<td>2.8</td>
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<tr>
<td>NITROGEN FROM AMMONIUM SULFATE</td>
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</tr>
<tr>
<td>Top</td>
<td>4.7</td>
</tr>
<tr>
<td>Root</td>
<td>2.5</td>
</tr>
<tr>
<td>Total</td>
<td>7.0</td>
</tr>
<tr>
<td>NITROGEN FROM UREA</td>
<td></td>
</tr>
<tr>
<td>Top</td>
<td>4.4</td>
</tr>
<tr>
<td>Root</td>
<td>2.4</td>
</tr>
<tr>
<td>Total</td>
<td>6.8</td>
</tr>
</tbody>
</table>

Early application of urea to seedlings resulted in the mortality of 10 of 16 replications of seedlings treated at 1 and 3 weeks. The sensitivity of root growth of young ponderosa pine to urea application was also confirmed. Nitrogen added as (NH$_4$)$_2$SO$_4$ was not detrimental to either growth or survival of ponderosa pine. Top growth

### Table 3. Influence of Nitrogen Source and Seedling Age at Nitrogen Application on Dry-Matter Production.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Age at application, weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>NO NITROGEN ADDED</td>
<td></td>
</tr>
<tr>
<td>Top dry weight, Mg</td>
<td>101(8)</td>
</tr>
<tr>
<td>Root dry weight, Mg</td>
<td>27</td>
</tr>
<tr>
<td>Total dry weight, Mg</td>
<td>128</td>
</tr>
<tr>
<td>Top/root ratio</td>
<td>3.74</td>
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<tr>
<td>NITROGEN FROM AMMONIUM SULFATE</td>
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<tr>
<td>Top dry weight, Mg</td>
<td>130(8)</td>
</tr>
<tr>
<td>Root dry weight, Mg</td>
<td>54</td>
</tr>
<tr>
<td>Total dry weight, Mg</td>
<td>184</td>
</tr>
<tr>
<td>Top/root ratio</td>
<td>2.39</td>
</tr>
<tr>
<td>NITROGEN FROM UREA</td>
<td></td>
</tr>
<tr>
<td>Top dry weight, Mg</td>
<td>110(2)</td>
</tr>
<tr>
<td>Root dry weight, Mg</td>
<td>38</td>
</tr>
<tr>
<td>Total dry weight, Mg</td>
<td>148</td>
</tr>
<tr>
<td>Top/root ratio</td>
<td>2.88</td>
</tr>
</tbody>
</table>

1Surviving replications in parentheses.
was significantly greater for the seedling treated with (NH₄)₂SO₄ than the corresponding control plants. Differences in top growth for the other treatments are less clear. Contrary to most reports, application of nitrogen as (NH₄)₂SO₄ did not adversely affect the T/R ratio during this short-term experiment.

This was confirmed in a time-course study that followed the initial development of seedlings, untreated or treated with (NH₄)₂SO₄, and fertilized at time zero with an equivalent of 100 ppm of nitrogen. The data in Figure 3 indicated that the primary difference during the first 6 weeks of growth between treated and untreated seedlings is in root growth. Roots treated with (NH₄)₂SO₄ were larger than the control roots after 1 week and throughout the entire experiment. Increased top growth was not observed until after 6 weeks of growth.

Seed Sources

Seeds from New Mexico and Arizona were sown in Osoridge soil. Nitrogen as (NH₄)₂SO₄ and urea was added at a concentration of 100 ppm nitrogen at the sixth week. The seedlings were grown for an additional 14 weeks, then harvested. Except for the urea treatment, seedlings from New Mexico seed were larger than the corresponding seedlings of Arizona seed (Table 4). Other investigators noted that growth responses were related to seed size (7). The distribution of the sizes of seeds between the two sources was different. The New Mexico seed, which includes the seed coat, ranged from 14.4 to 60.8 mg, with an average weight of 36 mg. The average Arizona seed weighed 29 mg and ranged in size from 11.2 to 52.4 mg.

For the 14-week period of growth on the same soil, urea was equivalent to (NH₄)₂SO₄ as a nitrogen source for the Arizona seed. For the New Mexico seed, however, (NH₄)₂SO₄ was clearly superior to urea as a nitrogen source. The different responses between seed sources because of nitrogen are not understood. T/R ratios of the Arizona seedlings were not significantly affected by nitrogen treatment, but top growth of New Mexico seedlings, 14 weeks old and treated with (NH₄)₂SO₄, was strongly stimulated, compared to the control.

Soil Studies

The fate of fertilizer nitrogen, added as (NH₄)₂SO₄ and urea, has been studied on both the Osoridge and Fortwingate soils and in the presence and absence of pine seedlings. As results from these experiments are similar, one example from the Osoridge soil represents all the experiments.

Compared to the samples treated with (NH₄)₂SO₄, the content of NH₄⁺ in urea samples gradually builds up, which corresponds to the hydrolysis of the urea (Figure 4). Hydrolysis is completed after 3 days, which corresponded to the maximum content of NH₄⁺ for this
nitrogen. Additions of urea increased the extractable amounts of nitrate nitrogen in both samples. This period of nitrification was characterized by the decrease of NH$_4^+$ and changes of NO$_3^-$ content of the samples. Maximum concentrations of NO$_3^-$ were observed at 28 days for urea samples and 35 days for (NH$_4$)$_2$SO$_4$ samples (Figure 5). As the NO$_2^-$ concentration rarely exceeded 0.1 ppm throughout the experiment, it was not reported. The initial transformations of inorganic nitrogen from fertilizer nitrogen seemed completed by the sixth week, when the results of all treatments approached the control.

The implications of these kinds of nitrogen transformations are far reaching. At best, the ponderosa pine seedling was in contact with fertilizer nitrogen for 6 weeks. If all NO$_3^-$ nitrogen that appeared was from the oxidation of (NH$_4$)$_2$SO$_4$, about 40 percent of the applied N was nitrified. From this point, a certain amount of nitrate nitrogen could be taken up by the plant, assimilated by microorganisms, or lost because of denitrification. As cultural conditions were not conducive to denitrification, losses by denitrification were probably negligible. The remainder of the added nitrogen could be utilized by the plant, assimilated by microorganisms, or immobilized in the organic fraction of the soil. The benefits of fertilization, however, may last longer than 6 weeks. Immobilized nitrogen is not completely lost to the plant, as a certain fraction of the organic nitrogen will be mineralized and become available for plant uptake. In treated situations, the plant could be provided with a slowly available form of nitrogen for a considerable time. With the N$^{15}$ technique, Nommick (9) proposed this explanation to account for changes of plant nitrogen that occurred during the second year on Scots pine after (NH$_4$)$_2$SO$_4$ additions. The available portion would always decrease, however, as a biological stabilization of the nitrogen originally added will be progressive (3).

**Biological Nonsymbiotic Nitrogen Fixation**

The application of the technique of C$_2$H$_2$ reduction in estimates of N$_2$ fixation was discussed by Hardy, *et al.* (4), but two points are pertinent. The assay is specific for nitrogenase, a component of all N$_2$ fixing systems, and 1,000 times as sensitive as the more conventional N$^{15}$ analysis. Rhizosphere samples of ponderosa pine grown on Osoridge and Fortwingate soils, treated with urea and (NH$_4$)$_2$SO$_4$, and the corresponding nonrhizosphere samples were tested for potential nonsymbiotic N$_2$ fixing activity (Table 5).

Under the experimental conditions, fixation was extremely low for both the rhizosphere and nonrhizosphere samples. Webster (16) reported values of from 1.34 to 16.5 micrograms N$_2$ fixed/g fresh wt of
nODULES/HOUR FOR ALDER (Alnus rubra Bong.), BITTERBRUSH (Purshia tridentata (Pursh) D.C.), AND SNOWBUSH. NO SAMPLE IN MY STUDY EXCEEDED 64.9 MICROMICROGRAMS N2/G/DAY. WHETHER THIS REPRESENTS THE MAXIMUM ACTIVITY OF THE SAMPLES OR NOT WAS UNKNOWN. EXTRAPOLATING FOR THE SOIL VALUES, THIS WOULD AMOUNT TO ABOUT 2 MG N/ACRE/DAY FIXED.

EVEN AT THIS LOW FIXATION, A RHIZOSPHERE EFFECT WAS NOTED ON BOTH SOILS. AND ADDITIONS OF FIXED NITROGEN REPRESSED THE RATE OF FIXATION. THE LONG-TERM SIGNIFICANCE OF A CONTINUING LOW FIXATION OF N2 IS UNKNOWN TODAY.

LITERATURE CITED


MINERAL NUTRITION AND THE DROUGHT RESISTANCE OF PONDEROSA PINE SEEDLINGS

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DROUGHT RESISTANCE OF PLANTS HAS TWO COMPONENTS—AVOIDANCE AND TOLERANCE (9). If avoidance is active, the plant avoids drought injury by increased water absorption or by water conservation. If tolerance functions, the plant can tolerate internal drought and, therefore, escape injury. In most higher plants that exhibit drought resistance, avoidance is dominant, although both avoidance and tolerance may be present.

A VARIETY OF METHODS HAVE BEEN APPLIED, or at least proposed, to measure absolute drought resistance. All techniques have drawbacks and most require stringent conditions and precise control for effective results (10). Apparently, these procedures have not been applied extensively in the study of the relations between mineral nutrition and drought resistance of ponderosa pine (Pinus ponderosa Laws.) seedlings. Relative drought resistance (as indicated by seedling survival) was determined for ponderosa pine by one worker. Other investigations were designed to reveal possible correlations between mineral nutrition and morphological and anatomical adaptations that are known to affect the capability for drought avoidance. The total of all this work on ponderosa pine is small. And unfortunately, few definitive conclusions of the effect of mineral nutrition on drought resistance of ponderosa pine seedlings can be made today.

Howell (6) investigated the effect of total concentration of salt in nutrient solutions on development of ponderosa pine seedlings. He worked with a “California” culture solution that contained a total of 1,419 ppm of salts as a standard. Seedling growth in this solution was compared to that obtained when the medium was 5, 10, 50, 200, or 400 percent as concentrated as the standard. The solutions were maintained at a pH of 5.0. Newly germinated seedlings were grown for 19 weeks, and measured after harvest (Table 1).

No significant differences were found for height growth, although some inhibition apparently occurred when the solutions were markedly above or below the standard concentration. Much more effect on root growth was noted. Significantly longer roots were formed in dilute solutions (5 and 10 percent of the standard concentration). And significantly shorter roots occurred in stronger solutions (200 and 400 percent of the standard). The type of root system tended to vary with concentration of the culture solution. Dilute solutions tended to produce an extensive root system with many laterals. Less extensive systems with few laterals were produced in the more concentrated media.

Howell concluded that because root development was affected by varying salt concentration of the culture solution, the salt concentration of the soil solution may influence the kind of root system a ponderosa pine seedling will produce. Therefore, any condition that contributes to the maintainance of a dilute soil solution favors the development of a deep, wide-spread root system and a seedling potentially resistant to drought. And a soil of low fertility may be a better substrate than one high in nutrients. Some evidence from later studies supports this hypothesis.

Steinbrenner and Rediske (14) noted the effects of several factors on the growth of ponderosa pine seedlings in a controlled environment. Among the variables considered, nitrogen fertilization is pertinent to this discussion. In this experiment, a solution of ammonium nitrate was added to half the pots at a rate equivalent to 50 pounds of nitrogen per acre. After seed germination, the pots were maintained in a growth chamber for 10 weeks, then measured.

Fertilization slightly retarded the growth of roots, but increased the height of tops 2 percent. Neither of

Table 1. Measurements of Ponderosa Pine Seedlings Grown in Water Cultures of Various Total Concentrations of Salts (6).

<table>
<thead>
<tr>
<th>Concentration</th>
<th>Height of tops</th>
<th>Length of roots</th>
<th>Dry weight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cm</td>
<td>Cm</td>
<td>Tops</td>
</tr>
<tr>
<td>Ppm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>71</td>
<td>8.45</td>
<td>77.40</td>
<td>0.54</td>
</tr>
<tr>
<td>142</td>
<td>9.70</td>
<td>64.50</td>
<td>0.86</td>
</tr>
<tr>
<td>709</td>
<td>11.39</td>
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<td>1,419</td>
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<td>59.38</td>
<td>1.06</td>
</tr>
<tr>
<td>2,838</td>
<td>10.93</td>
<td>50.11</td>
<td>0.81</td>
</tr>
<tr>
<td>5,676</td>
<td>10.29</td>
<td>34.96</td>
<td>0.91</td>
</tr>
</tbody>
</table>

1 Standard.
these two effects were statistically significant. Root weight was reduced 5 percent by nitrogen addition. A highly significant average gain of 8 percent in top weight was also noted. Therefore, fertilized seedlings had heavier tops in relation to roots than did their unfertilized counterparts. Because of the effect of fertilization on weight of the seedling parts, a significant narrowing of the root/shoot ratio occurred. A wide root/shoot ratio is generally considered to enhance drought resistance (8). Therefore, the study by Steinbrenner and Rediske indicates that seedlings untreated with fertilizer nitrogen could survive droughty conditions better than the treated ones. We should remember, however, that, although weights are usually determined, the key factor in root/top relations is actually the ratio of the absorbing to the transpiring surfaces. A heavy root system will not necessarily have a more absorbing surface than one that weighs considerably less.

The impact of nitrogen, phosphorus, and potassium fertilization on growth of ponderosa pine seedlings was studied by Vlamis, Schultz, and Biswell (15). Nutrients were added to soil collected from two different series in the combinations of none (control), nitrogen-phosphorus-potassium, nitrogen-phosphorus, nitrogen-potassium, and phosphorus-potassium. Per acre, the rates of addition equaled 200 pounds of nitrogen, 131 pounds of phosphorus, and 166 pounds of potassium. Newly germinated pine seedlings were transplanted to pots of the variously treated soil and allowed to develop for 1 year before harvest and measurement.

Regardless of the soil series employed as a substrate, weights of seedling roots and tops were greatly increased by nitrogen fertilization. Because tops were stimulated more than roots, the root/shoot ratio was narrowed (Table 2). Roots and shoots showed little response when a combination of potassium and phosphorus was added without nitrogen. Consequently, root/shoot ratios obtained with this treatment differed slightly from those obtained in controls. This experiment, then, as in the study by Steinbrenner and Rediske, shows that nitrogen fertilization apparently affects adversely the root/shoot ratio of ponderosa pine seedlings.

Potter (12) studied growth of ponderosa pine seedlings in relation to nitrogen and phosphorus nutrition. The work was conducted in the greenhouse, with both sand and soil cultures. Newly germinated seedlings were planted in tubes 1 foot long that were filled with sand. The seedlings were allowed to grow for 170 days. Nitrogen treatments included the addition of 0, 1, 5, 25, 100 or 400 ppm of the element to a basic nutrient solution. Phosphorus treatments included the addition of 0, 0.2, 1, 5, 25, 100, or 400 ppm of the element to a similar basic nutrient solution. Phosphorus was held at 100 ppm in all nitrogen treatments. Nitrogen was held to 100 ppm in all phosphorus treatments. Nutrient solutions were applied to sand in the tubes at the rate of 50 ml per day.

Root elongation appeared unaffected by variation in the nitrogen or phosphorus supply, but root weights were influenced. The green weight of roots was at a maximum when the culture solution contained 25 ppm nitrogen, and a significant reduction in yield was obtained when the medium contained 400 ppm nitrogen. Root weights of seedlings grown under the four highest phosphorus treatments showed no significant differences, but these weights all were significantly greater than the weights of roots from treatments that included lesser phosphorus concentrations.

Root/shoot ratio was significantly affected by variation of the nitrogen nutrition. The variation of the phosphorus supply did not alter the ratio. These responses occurred because roots and shoots were not stimulated in equal proportion by the nitrogen additions, but by phosphorus. Therefore, by the stimulation of phosphorus, green weights of roots and shoots were altered by treatment, but the root/shoot ratio remained about the same in all treatments.

Although the widest root/shoot ratio occurred when no nitrogen was furnished, a gradual narrowing took place as nitrogen in the culture solution was increased. Addition of nitrogen, at rates of 25 ppm and over, produced root/shoot ratios that were significantly less than that found for the treatment with no nitrogen. Seedlings grown with the solution of 400 ppm nitrogen had a root/shoot ratio significantly narrower than seedlings from any other treatment.

Results obtained by Potter with sand cultures were similar to those he found with seedlings grown in the greenhouse on several Arizona soils fertilized with

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Root-shoot ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Holland Salminas</td>
</tr>
<tr>
<td></td>
<td>series</td>
</tr>
<tr>
<td>Control</td>
<td>0.85 0.76</td>
</tr>
<tr>
<td>Nitrogen-phosphorus-potassium</td>
<td>.46 .55</td>
</tr>
<tr>
<td>Phosphorus-potassium</td>
<td>.88  .82</td>
</tr>
<tr>
<td>Nitrogen-potassium</td>
<td>.45  .61</td>
</tr>
<tr>
<td>Nitrogen-phosphorus</td>
<td>.43  .69</td>
</tr>
</tbody>
</table>
Various rates of nitrogen and phosphorus. An increase of soil nitrogen tended to narrow the root/shoot ratio. Phosphorus treatments had little effect.

Working in Idaho, Hauxwell (4) performed growth-chamber experiments that included the effects of various concentrations of nitrogen, potassium, and phosphorus on the development of ponderosa pine seedlings. As in previous studies, measurements of top and root growth were made. Additionally, he determined the capacity of roots for absorption with the method of Wilde and Voigt (16), and determined the survival of seedlings when exposed to drought.

In the chamber, newly germinated seedlings were grown in pots of sand, each of which was irrigated periodically with one of eight nutrient solutions. The eight treatments represented the eight possible combinations of two concentrations of nitrogen, potassium, and phosphorus, selected to represent a situation that might be natural or attained through moderate fertilization. The two concentrations of nitrogen were 56 and 252 ppm; of phosphorus, 15 and 124 ppm; and of potassium, 59 and 196 ppm. Concentration of other plant nutrients was the same in all solutions. The pH was adjusted to about 5.5. After 52 days, the seedlings were subjected to drought of progressively greater intensity, with the moisture content of the sand altered from 2.5 percent at the beginning of the droughting period to 0.8 percent at the conclusion of the experiment.

Hauxwell found an important relation between concentrations of nitrogen and potassium. In solutions of the low nitrogen and high potassium, seedlings developed the widest root/shoot ratios and exhibited the greatest resistance to drought. Survival averaged about 83 percent, regardless of the phosphorus concentration. If the levels of potassium and nitrogen were both low, however, survival fell to an average of 50 percent. The greater capacity of roots for absorption seemed to express the beneficial effect of the high concentration of potassium in treatments that included a low concentration of nitrogen. High concentrations of nitrogen in the nutrient solutions produced seedlings poorly adapted to resist drought. And seedling survival averaged only 33.3 percent. Increased shoot growth, decreased capacity for absorption by roots, and a narrowed root/shoot ratio expressed the deleterious effect of the high concentration of nitrogen.

Because the literature that concerns the relation of mineral nutrition to drought resistance of ponderosa pine seedlings is so limited, possibly results of some work with other pines should be cited.

Root/shoot ratio narrowed with increased concentrations of nitrogen in Corsican pine (Pinus nigra Arnold) seedlings (1). Similar results were found for red pine and white pine (Pinus strobus L.) (5), Scotch pine (Pinus sylvestris L.) (7), Virginia pine (Pinus virginiana Mill.) (3), and jack pine (Pinus banksiana Lamb.) (2). Root dry weight often increased when nitrogen nutrition was raised above a minimum. It often decreased, however, when nitrogen nutrition was raised higher. A more vigorous response, generally, of shoots than roots to nitrogen explains the smaller root/shoot ratios found at the higher nitrogen concentrations.

Pharis and Kramer (11) studied the effects of nitrogen on drought resistance of loblolly pine (Pinus taeda L.) seedlings in sand culture. Instead of determining survival as an index of drought resistance, they measured the ability of seedlings to endure severe moisture stress and recover with minimum decrease in growth. They found that drought resistance decreased when plants were supplied with nitrogen above optimum concentrations. Although the least effect of drought on growth was observed in seedlings treated with suboptimal concentrations of nitrogen, growth of these seedlings was at such a low level before onset of drought that the decrease in effect was of no real importance. Pharis and Kramer speculated that the unfavorable effect of superoptimum concentration of nitrogen may have resulted from a narrowed root/shoot ratio leading to an imbalance between the transpiring and absorbing surfaces. They also speculated that, under drought stress, a nitrogen imbalance may create unique metabolic problems for a seedling.

Shirley and Meuli (13) investigated the influence of nitrogen and phosphorus on growth and drought resistance of red pine seedlings. Plants, grown under various treatments, were repotted in sand of 5 percent moisture content and subjected to drought in a specially constructed machine, in which dried air was continually blown over them. The number of days of survival in the machine was the criterion of drought resistance. Increase in nitrogen content over a no-nitrogen control consistently decreased ability to resist drought. Differences were highly significant. The authors emphasize, however, that although nitrogen starvation apparently increased ability to endure drought, it decreased growth. Under field conditions, adequate top growth is necessary if roots are to elongate rapidly enough to keep pace with retreating moisture supplied in the soil. Therefore, results of this experiment indicate a low-nitrogen regime increased the ability to tolerate drought, but may have reduced the capability for drought avoidance.

Shirley and Meuli found that increased concentrations of phosphorus tended to enhance drought resistance more pronouncedly when the
concentrations of nitrogen were low. The balance between concentrations of nutrient elements may be as important as the concentration of a particular nutrient.

That wide gaps exist in our understanding of the relation of mineral nutrition to drought resistance is apparent. Excessive amounts of nitrogen, however, seem to affect drought resistance adversely, partly because of the formation of unsatisfactory root/shoot ratios. Low concentrations of nitrogen may actually enhance drought resistance, but, at the same time, growth of the young plants may be too severely checked. The most desirable situation is one in which nitrogen is adequate to promote vigorous root growth, but not high enough to overly stimulate top growth. Phosphorus seemingly has less effect on drought resistance than nitrogen. Some benefit from a high phosphorus concentration is indicated, however. A high concentration of potassium may enhance drought resistance on sites with low concentrations of nitrogen. We know virtually nothing about the effects of other plant nutrients on drought relations of pine.

Kramer and Kozlowski (8) noted that little work had been done on relations of mineral nutrition and water of forest trees, and that further research was needed (italics mine). The observation is as valid today as it was then. We must know more concerning the specific effects of each plant nutrient on tolerance and avoidance, the two factors of drought resistance. We must learn the modifications that occur in the capability for drought resistance as we vary the concentrations of not just nitrogen, phosphorus, or potassium, but any nutrient. We should know how the effect of one nutrient may be altered if we change the concentration of any or all of the others. We need to ascertain in what way the status of other factors, such as soil pH, texture, and organisms, modify the impact of a particular concentration of a nutrient on drought resistance. Possible interrelations between mineral nutrition, mycorrhizal development, and drought resistance should be investigated. Finally, genetic factors must not be overlooked. A specific concentration of a nutrient could cause the drought resistance of one strain of ponderosa pine to differ from that of another strain. Selection for drought resistance may be possible.

LITERATURE CITED


FERTILIZING PLANTED PONDEROSA PINE ON PUMICE SOILS

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INTRODUCTION

Practicing foresters have sought means of increasing survival and early growth of planted tree seedlings for many years. Spectacular increases in growth of farm crops, which result from application of fertilizer before seeding, are well known. Foresters, aware of these responses, naturally wonder if fertilizers can improve the growth of planted seedlings. Many have tried. Some trials have been successful. Many others have failed. Why is this? If we compare the soil-plant systems of farm crops and trees, some answers become apparent.

Many farm crops are annual plants that, even without fertilization, have appreciably faster growth rates than coniferous tree seedlings. Generally, farm crop plants have well-developed root systems, able to exploit a large volume of soil. By comparison, coniferous seedling roots utilize a small volume of soil during the first growing season after planting. Farm crops are grown in fields where competition from other plants is minimal or nonexistent. Tree seedlings, however, are often planted on sites with well-established, competing vegetation.

Let’s examine the influence of these two factors, volume of rooting and competing vegetation, on the efficiency of broadcast fertilizer. In a weed-free, cultivated cornfield, conditions are reasonably favorable for broadcast-applied fertilizer to move into the soil for the plants. Roots of the corn plant, free of competing vegetation, respond rapidly and are able to utilize fertilizer over a large area. Fertilizer, however, broadcast over planted tree seedlings, may never reach the root zone of the seedlings because, in many areas, well-established, competing vegetation will utilize most of it.

Experience has shown that banding fertilizer to the side and below corn seed results in greater response than broadcast applications. Similar placement in relation to planted tree seedlings should result in more efficient use of fertilizer and better growth than with broadcast application. By combining site preparation to remove competing vegetation with placement of fertilizer near the roots, we should expect maximum results from fertilization of planted seedlings.

FERTILIZER PLACEMENT AND SOLUBILITY

To make this fertilizer really effective, then, we must place it where the elements will be quickly available to the tree and still be available over several growing seasons. We must take care, however, not to “burn” tree roots by applying the material in direct contact with them. Consequently, some soil should be placed between the fertilizer and seedling roots. This is especially true with readily soluble materials such as ammonium nitrate, ammonium sulphate, and superphosphate. White (3) reported satisfactory results with soluble fertilizer in perforated plastic bags, placed near the root systems of planted pine seedlings on sandy soils. No injury was noted with this treatment. But some slowly available (less soluble) materials placed in direct contact with seedling roots caused injury and poor survival.

Fertilizer pellets for planted tree seedlings have been developed by Crown Zellerbach (1) and have been applied widely. They are made up of slowly available materials with 5 percent phosphorus pentoxide and 28 percent nitrogen as ureaform. (Ureaformaldehyde is a synthetic source of nitrogen, developed for controlled availability.) Austin and Strand reported increased growth and good survival of Douglas-fir seedlings with these pellets in the planting hole. Reports of other workers conflicted with the theory that injury resulted from contact of these pellets with seedling roots. Therefore, probably soil should always be placed between the seedling roots and the pellet.

Other slow-release materials are being produced for planted tree seedlings. Several metal ammonium phosphates have been developed by W. R. Grace Company. (Names of trades, firms, or corporations in this publication are for the information and convenience
of the reader and do not constitute an official endorsement or approval of any product or service.) The most commonly applied is magnesium ammonium phosphate (8 percent nitrogen, 40 percent phosphoric acid, and 24 percent magnesium oxide). Soluble fertilizers have been coated with special materials to give them slow-release properties. Ammonium nitrogen fertilizers have been treated with compounds that prevent nitrification, which reduces the loss by leaching of nitrates (2).

**FERTILIZER FIELD TESTS**

Conflicting results suggest that seedling response to fertilizer may depend on species and on characteristics of the local site, such as rainfall, soil, and temperature. If so, then widely variable responses to fertilizers can be expected in different areas.

Fertilizer trials were made with ponderosa pine planted in the pumice soil region of central Oregon. The pumice soils of central Oregon are young. Rainfall in the region is moderate. And little profile development has taken place. Nutrients of the soil that have accumulated are confined to shallow surface horizons. Youngberg and Dyrness (4), finding the subsoil pumice infertile, hypothesized that the low nutrient content may contribute to the observed lack of root penetration into these layers, although the layers often contained soil water. Therefore, additions of fertilizer to this region of infertile subsoil might markedly increase tree-growth rates. To add support to this theory, Youngberg and Dyrness (5), in a greenhouse study, evaluated the ability of each horizon of Lapine pumice soil to supply nutrients. They found ponderosa pine seedlings responded to additions of nitrogen, phosphorus, and sulfur, but not to calcium and potassium. Nitrogen, the element most lacking in the soil, produced large growth responses when added alone. Good responses resulted from a mixture of nitrogen and phosphorus, nitrogen and sulfur, or all three combined. But additions of phosphorus and sulfur produced no response unless accompanied by nitrogen.

Field experiments were installed in central Oregon with the results from the greenhouse as a guide. Results of four of these experiments are reported here. Three tested nitrogen, phosphorus, and sulfur in various forms, concentrations, and methods of application. The fourth experiment evaluated the most promising fertilizer as determined from the previous three tests.

The first field experiment was a cooperative study between Oregon State University and Weyerhaeuser Timber Company. The experiment was established in the spring of 1961 on the Weyerhaeuser Tree Farm in Klamath Falls, Oregon. Fertilizer treatments shown in Table 1 were tested against trees planted without fertilizer. Cumulative growth in height, over a 7-year period, was the criterion to compare the effects of treatment.

Ponderosa pine seedlings (2-0) were planted at a 5-by 5-foot spacing with a power auger. The planting hole was augered to the coarse, gravelly Lapine subsoil. Fertilizer was added, a small amount of soil was placed in the hole, and the tree was planted.

Each treatment was replicated four times with three trees in each replication. Some ponderosa pine overstory influenced the experimental site, although 40 percent of the original volume had been harvested. No understory of competing vegetation was present.

Another trial was conducted in the Kiwa deer exclosure, 7 miles southwest of Bend, Oregon. The soil is derived from pumice, without the clearly defined horizons found in the Lapine series farther south. Site

<table>
<thead>
<tr>
<th>Element added per tree</th>
<th>Fertilizer</th>
<th>Amount per tree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>Nitrogen</td>
<td>Phosphorus</td>
</tr>
<tr>
<td>1 (Control)</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>NH₄NO₃, CaH₂(PO₄)₂, CaSO₄·2H₂O</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Ammonium nitrate</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Ammonium nitrate, treble superphosphate</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Ammonium nitrate, gypsum</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Treble superphosphate</td>
<td></td>
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<tr>
<td>7</td>
<td>Treble superphosphate, gypsum</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Gypsum</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Magnesium ammonium phosphate</td>
<td></td>
</tr>
</tbody>
</table>

1Control.

2Ammonium nitrate, treble superphosphate, and gypsum.
quality is considered above average for ponderosa pine.

Two-year-old ponderosa pine seedlings were planted by Auger in 1961. And terminal growth was recorded each year through 1966. Each of 11 treatments was represented by four randomized replications of 25 trees each. Treatments applied are shown in Table 2. Pellets and magnesium ammonium phosphate were placed in the planting hole. All other materials were placed in slits adjacent to the planted seedling.

An experiment similar in design to the Kiwa study was established in the spring of 1960, 20 miles southwest of Bend, Oregon, on the Bates Butte burn. Here, site quality is average for ponderosa pine. The soil is a moderately shallow Lapine, which consists of from 2 to 2½ feet of pumice, with considerable mixing of the C horizon with the buried residual soil and upper horizon. Seedlings were 2-0 from the Bend nursery and were planted with a hoe. Treatments applied are shown in Table 3.

The treble superphosphate (TSP) added with ureaformaldehyde pellets was equivalent to the amount of phosphorus in MAP. (MAP here designates the slow-release material of the W. R. Grace Company's magnesium ammonium phosphate, which is 8 percent nitrogen, 40 percent available phosphorus pentoxide, and 24 percent magnesium oxide.) In the treatment of urea and TSP, the nitrogen and phosphorus were equivalent to the nitrogen and phosphorus in MAP.

The most recent study began on the Pringle Falls Experimental Forest, 35 miles south of Bend, Oregon, to determine the effect of initial spacing and fertilizer on the growth of ponderosa pine. Seedlings (3-0), grown in the Bend nursery, were planted in the spring of 1966. Seed source for the seedling stock was Davis Mountain, about 11 air miles from the planting site. The soil is a Lapine, averaging 28 inches of pumice with an infertile C horizon over the old buried profile. Two fertilizer combinations were applied. Four ounces of MAP (9.1 grams of nitrogen, 19.7 grams of phosphorous, and 16.3 grams of magnesium) were placed in the bottom of an augered planting hole. Some soil was added, and the tree was planted. Also, 2 ounces of ammonium sulphate (11.9 grams of nitrogen and 13.6 grams of sulphur) were broadcast in a circle 2 feet in diameter around each tree, 2 weeks after planting. (Original intentions were to supply sulfur as gypsum in the planting hole, but gypsum was not available at planting time.)

Five different tree spacings are being tested, 6 by 6, 9 by 9, 12 by 12, 15 by 15, and 18 by 18 feet. Each spacing is replicated twice in a split-plot design with only one-half the trees on each plot fertilized.

Although MAP was not consistently the best fertilizer in the previous trials, it was chosen for this

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Table 2. Kind and Amount of Commercial Fertilizer Applied in an Experiment at Kiwa, near Bend, Oregon, Begun in 1961.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Nitrogen (Gm)</th>
<th>Phosphorus (Gm)</th>
<th>Sulphur (Gm)</th>
<th>Magnesium (Gm)</th>
<th>Fertilizer</th>
<th>Amount per tree (Ounces)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>None</td>
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<tr>
<td>2</td>
<td>2.42</td>
<td>0.24</td>
<td>0.00</td>
<td>0.00</td>
<td>Ureaformaldehyde, superphosphate</td>
<td>1³</td>
</tr>
<tr>
<td>3</td>
<td>4.84</td>
<td>0.48</td>
<td>0.00</td>
<td>0.00</td>
<td>Ureaformaldehyde, superphosphate</td>
<td>2</td>
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<tr>
<td>4</td>
<td>1.13</td>
<td>2.48</td>
<td>0.00</td>
<td>2.04</td>
<td>Magnesium ammonium phosphate</td>
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</tr>
<tr>
<td>5</td>
<td>2.26</td>
<td>4.96</td>
<td>0.00</td>
<td>4.08</td>
<td>Magnesium ammonium phosphate</td>
<td>1.0</td>
</tr>
<tr>
<td>6</td>
<td>1.20</td>
<td>0.00</td>
<td>1.38</td>
<td>0.00</td>
<td>Ammonium sulphate, 0.2% N-serve (1601)</td>
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</tr>
<tr>
<td>7</td>
<td>1.20</td>
<td>0.00</td>
<td>1.38</td>
<td>0.00</td>
<td>Ammonium sulphate, 0.4% N-serve (1603)</td>
<td>0.2</td>
</tr>
<tr>
<td>8</td>
<td>1.20</td>
<td>0.00</td>
<td>1.38</td>
<td>0.00</td>
<td>Ammonium sulphate</td>
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<td>0.00</td>
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<td>0.00</td>
<td>Ammonium sulphate, 0.4% N-serve (1603)</td>
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<td>2.76</td>
<td>0.00</td>
<td>Ammonium sulphate</td>
<td>0.4</td>
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</tbody>
</table>

¹Control.

²N-serve is a fertilizer additive that delays the conversion of ammonia to nitrate and thus serves as a means of decreasing leaching of nitrogen. It is highly toxic to the organisms converting ammonium to nitrate, and has a low order of toxicity to the organisms or enzymes converting nitrite to nitrate, the general fungal and bacterial populations, and the seedlings of many plants (2).

³Pellets.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Nitrogen</th>
<th>Phosphorus</th>
<th>Magnesium</th>
<th>Fertilizer</th>
<th>Amount per tree</th>
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<tr>
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<td>4.92</td>
<td>4.08</td>
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<tr>
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<td>7</td>
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<tr>
<td>8</td>
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<td>9.84</td>
<td>0.00</td>
<td>Urea, treble superphosphate in slit near seedling</td>
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<tr>
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<td>9.84</td>
<td>0.00</td>
<td>Urea, treble superphosphate broadcast</td>
<td>2.6</td>
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</tbody>
</table>

1 Control; no fertilizer added.
2 Pellets.

experiment because it performed well in the Klamath Falls study under similar soil conditions.

RESULTS

At Klamath Falls, trees fertilized with the slowly available magnesium ammonium phosphate (MAP) showed consistent increased growth in height (Figure 1). MAP-treated trees grew 31.5 inches in 7 years of observation, compared with 20.5 inches for unfertilized trees. Trees fertilized with treble superphosphate grew consistently better than unfertilized trees, but differences were small.

The effect of MAP on root distribution in soil was dramatic. Roots clustered around the fertilized area. And root development lessened sharply a few inches away from the fertilized zone. Such clusters were not evident where other fertilizers were applied.

We would expect considerably greater response of seedlings to fertilization if a partial overstory had not been competing for soil moisture, nutrients, and light.

At the Kiwa site, fertilized trees showed greater average growth of terminals than unfertilized trees (Figure 2). Seedlings, receiving 2 ounces of ammonium sulphate showed greatest response. These trees grew about 40 inches in the 6 years of observation, compared with about 30 inches for unfertilized trees. Additions of MAP resulted in only small increases in growth, probably because the infertile C horizon is not as pronounced as in Lapine soils farther south. The addition of N-serve with ammonium sulphate appeared to have no effect on growth.

The treatment stimulating the greatest seedling response was one pellet of ureaformaldehyde and treble superphosphate. Differences among other treatments, however, were small and, in most cases, statistically nonsignificant (Figure 3). The heavier concentration of MAP resulted in increased growth on two replications, but not on the remaining two. Adding 2 ounces of MAP instead of 1 ounce had no apparent advantage. Also, placing urea and TSP in a slit beside the planting hole, instead of broadcasting around the tree, made no apparent difference.

At Pringle Falls, trees fertilized with MAP 3 years ago have longer, greener needles and longer terminal

![Figure 1](image)

Figure 1. Cumulative growth of leader for the Klamath Falls experiment, 1961-67.
Figure 2. Cumulative growth of leader for the Kiwa experiment near Bend, Oregon, 1961-66.

Figure 3. Cumulative growth of leader for the Bates Butte experiment near Bend, Oregon, 1960-62.

Figure 4. Spacing-fertilizer study at Pringle Falls near Bend, Oregon. Lengths of leader, needle, and bud of ponderosa pine seedlings the third year after planting (age 6) and fertilizing with magnesium ammonium phosphate near Bend, Oregon, 1966.

buds and are taller than unfertilized trees (Figure 4). And, as in Klamath Falls, roots were concentrated around the fertilized zone.

So far, any effect of spacing on tree growth is not evident. Apparently, roots have not extended sufficiently to become competitive even at the 6-foot spacing.

Fertilization was detectable only in the length of needle the first growing season after planting. The second year, the lengths of needle, bud, and leader were all significantly greater (5-percent level of probability) on fertilized trees. The third year, the effect of fertilizer on tree growth was statistically significant at the 1-percent level. Leader length increased markedly the third year after planting on all trees, but the increase was most pronounced on fertilized trees. Table 4 shows the yearly average length of leader.
Fertilizing Planted Ponderosa Pine on Pumice Soils

Table 4. Yearly Average Growth of Leaders.

<table>
<thead>
<tr>
<th>Year</th>
<th>Fertilized</th>
<th>Not fertilized</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inches</td>
<td>Inches</td>
</tr>
<tr>
<td>1966</td>
<td>2.3</td>
<td>2.2</td>
</tr>
<tr>
<td>1967</td>
<td>3.3</td>
<td>2.3</td>
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<tr>
<td>1968</td>
<td>9.5</td>
<td>6.4</td>
</tr>
<tr>
<td>11</td>
<td>15.1</td>
<td>10.9</td>
</tr>
</tbody>
</table>

Needle length of current growth on both fertilized and unfertilized trees, however, increased markedly the second year, then decreased slightly the third year.

Survival of planted seedlings was slightly better on fertilized plots than on unfertilized plots (90 percent compared to 88 percent). Many seedling deaths were associated with animal damage and Armillaria root rot.

Large numbers of shrub seedlings and sprouts are now beginning to occupy the area and promise to offer considerable competition to planted seedlings. Fertilized trees may grow tall enough the next few years, however, to overtop the shrub layer.

Particles of fertilizer could still be detected 3 years after application when roots were exposed (Figure 5). Several seedlings were carefully excavated, and about 75 percent of the original fertilizer was recovered. Therefore, effects of fertilizer should last, at least, another 3 or 4 years.

Effects of the fertilizer appear more dramatic below ground than above. Six fertilized and six unfertilized seedlings were excavated 3 years after planting. Roots of fertilized trees are developing readily in the surface horizons, but tend to congregate around the fertilizer in the C horizon and eventually develop large multiple tap roots that enter the old buried profile at one point and then expand (Figure 5). Multiple tap roots developed on some vigorous unfertilized trees, but they were small and fewer in number than on fertilized trees.

DISCUSSION AND CONCLUSIONS

Before passing judgment on the relative merits of the fertilizers tested, let us briefly review the objectives of fertilizing planted tree seedlings. Essentially, foresters are seeking a growth-promoting substance that will shorten the time required to produce a merchantable product and enable a tree to maintain reasonable growth, survive in the midst of competing vegetation, and increase in size quickly so that it will be unattractive to browsing animals.

Figure 5. Root development, 3 years after planting, of trees fertilized with magnesium ammonium phosphate. Fertilization trial at Pringle Falls near Bend, Oregon.

The fertilizers applied in these studies do not appear to have fulfilled these objectives. In the Klamath Falls and Kiwa trials, for example, the advantage of the 10-inch growth in height in 7 years is unimpressive. If we are to increase survival by quickly forcing growth above competing vegetation, we ought to stimulate growth in height to a much greater extent than was shown by the best treatments in these studies. Also, not many years of the rotation have been “saved” by fertilizer treatment.

We should not interpret results presented here as a final evaluation. Seedling-root excavations on the Pringle Falls study, for example, suggest that impressive responses may come later. The fact that root systems of fertilized trees are far more extensive than those of unfertilized trees indicate this (Figure 6).

Because nitrogen is the element most lacking in pumice soils (5), the substantial growth response to additions of MAP that contains only 8 percent nitrogen is somewhat puzzling. Possibly, the nitrogen in MAP is available for a longer period during the growing season, compared with other fertilizers applied. Also, magnesium might be a more important limiting element than we presently suspect.

The inclusion of trace elements in fertilizers may result in greatly increased growth responses. Exploratory field and laboratory experiments with
various combinations of trace elements such as boron, magnesium, iron, and zinc have shown that, eventually, some of these elements may be essential components in the ideal fertilizer on pumice soils.

Foresters should be aware that exciting possibilities for stimulating growth of planted ponderosa pine with fertilizers may occur. But the forest manager should proceed with caution until more positive results are obtained.

LITERATURE CITED


DISEASE AS A FACTOR IN REGENERATION OF PONDEROSA PINE

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I SHALL EXTEND MY TOPIC SLIGHTLY to consider certain biological influences other than disease that affect pine regeneration and frequently come to the attention of the pathologist. Thereafter, we will direct attention more specifically to the fungi, the primary agents inciting disease. In considering the fungi, however, we will not limit attention to direct pathogenic action, but will consider briefly several other interactions among these organisms and between them and other soil inhabitants, as they may mutually influence establishment and development of the seedling.

THE INITIAL IMPACT OF DISEASE on the silviculture of ponderosa pine in America came early and forcefully. Damage, however, failed to keep pace with the progress of pine management, and, generally, we can regard ponderosa pine today as a healthy species in both youth and age, particularly the ponderosa pine forests of northwestern United States.

This early damage concerned excessive losses from damping-off in the pine nurseries of Nebraska and Colorado during the first two decades of this century. The long-term, destructive consequence of damping-off in these nurseries may have been of less importance than the beneficial results realized from intensive study that followed the epidemic. The work of Carl Hartley et al. (4), a classic in forest pathology, established sound principles for control of damping-off that have since been applicable to these diseases in many other places. Also, Hartley alerted foresters to the necessity of distinguishing between seedling losses resulting from excessive surface temperatures and those from infectious disease. A clear symptomatology was presented that enables the distinctions to be made easily.

That pathologic factors restricting pine regeneration may be either environmental or biological is apparent from Hartley's early work. After excluding a third factor, insects, (though their activities may sometime be mistaken for pathogenic damage) as belonging to the realm of the entomologist, some attention must be given the environmental phenomena that lead to pathologic symptoms in pine. Some of the agents may act so subtly that diagnosis may be difficult or impossible for the ablest pathologist. Damage is sometimes intensified by activities of biological agents. Prevention of damage from these factors is primarily the concern of the silviculturist.

The red belt phenomenon, which results from atmospheric drought and extreme temperature, is perhaps the most familiar environmental disease encountered by the pine forester. It is usually elevationally stratified and apparently results from transpiration losses in excess of water replacement. Certainly, it is most conspicuous in large trees, but may appear in seedlings on exposed sites.

Frost-damaged ponderosa pine is not well documented in the literature, yet considerable evidence indicates that frost is an important factor in natural distribution of ponderosa pine (1). Probably it is the factor excluding this species from the lower, flat forest sites (1). Drought damage occurs in ponderosa pine regeneration and perhaps is the most common cause of failure in establishment of plantations. Here it is easily diagnosed because the history of the stand is brief and usually well-known. Its effects in natural stands or long-established plantations are more subtle and more difficult to diagnose. Drought appears to predispose the stand to severe damage from *Armillaria* root rot.

Today, no factor of the physical environment receives more concern for its impact on ponderosa pine than air pollution. Trees of all ages are damaged. Ponderosa pine is particularly susceptible to fluorine damage and smog of the "Los Angeles" type (5). Injury by fluorine is expressed as a distinctive reddening of the distal portion of affected needles. The effects are cumulative, and increased amounts lead to death of all the needles and finally of the tree.

Staley and associates (14), recently describing a sodium-linked disease of ponderosa pine, indicated that the species may suffer from mineral excesses. As many of these problems arising from the physical environment may be avoided by the silviculturist, let us now consider problems of biological origin where consultation with the pathologist or microbiologist may be required for both recognition and control.

Viruses are common causes of diseases in plants. They have been suspected repeatedly in coniferous trees, although only one reasonably authenticated case in a conifer is known. I have found no mention of viruses in ponderosa pine.

Bacteria and the recently discovered plant mycoplasms cause plant disease. But again, ponderosa pine appears uninfected. It is noteworthy, however, that
bacteria are very common in the soil, abundant in the 
rhizosphere (the soil influenced by diffusible materials 
from the young root) and may, in this location, exercise 
indirect influence on root health.

Nematodes are frequent inhabitants of forest soil. 
They appear to develop large populations in forest 
nurseries and, consequently, are frequently seen in 
microscopic examinations of seedling roots. Their actual 
significance is unsettled. In southeastern United States 
they have been found particularly numerous in soils of 
old fields where they are considered damaging to pine 
development. This group of organisms, in relation to 
ponderosa pine, is currently under investigation at the 
Albuquerque office of the Rocky Mountain Forest and 
Range Experiment Station (10).

Fungi appear to be the constant associates of forest 
trees. Ponderosa pine is no exception. These organisms 
comprise nature's major sanitary crew for the 
decomposition of cellulose and lignin of dead tissues. 
Some extend their sphere of development beyond a 
saprophytic existence and parasitize plants at various 
degrees of specialization and aggression. As these 
organisms manufacture no food, they are completely 
dependent on a source of organic matter for their 
existence. They will associate, in one form or another, 
with the pine tree throughout its life. We might first 
consider fungi on the seed. Fungal spores are abundant 
in the dust of the air. Some that lodge on developing 
cones find them a suitable habitat for growth and are 
more or less closely associated with the seed in its 
development. Few fungi, however, reach the seed before 
the cone matures. And naturally dispersed seed is 
probably very slightly contaminated. Many fungi 
increase on harvested cones if these are allowed to stand 
or are exposed to heat for a prolonged period before 
extration. Fungi, on extracted seed in the form of 
spores, may be harmless or possibly beneficial 
saprophytes, potentially damaging molds, or actual 
pathogens.

Whether or not damage will result from seed-borne 
fungi appears to depend as much on the vitality of the 
seed and the circumstances under which it germinates as 
on the fungi themselves. The number of fungi appears to 
decline with extended refrigerated storage. Some will 
persist, however, until time for seed germination. And if 
seed vitality has deteriorated over this interval, the seed 
may mold. Fowells and Schubert (3) found molding of 
ponderosa pine seed during stratification a problem. 
Stein (15) found that 2 percent of the seed decayed in 
direct seeding trials, and Wagg (17) reported serious 
losses to rot when the seed was planted too deeply. 
Here, of course, the fungi responsible could have come 
from either soil or seed.

Generally, we find the fungi equipped with 
resistant structures, usually spores, which enable them 
to survive, albeit in declining numbers, for prolonged 
periods. Rapid vegetative growth and the ability to 
produce many forms of short-lived spores, however, 
enable the fungi to build large populations quickly. 
Populations rise and fall as the environment is benign or 
destructive. And among the most critical environmental 
factors is availability of a fresh supply of organic food. 
These trends in population are best exemplified in the 
soil where the fungi exerize a variety of effects on the 
health of plants, including ponderosa pine, and where 
they provide a reservoir of infective materials (usually 
spores) to be carried upward in the air currents to cause 
disease and decay in the above-ground environment.

A fresh supply of food, as occurs with annual leaf 
fall, amendments to the forest nursery, or the 
incorporation of organic matter into the soil in 
preparation of a planting site will cause soil fungi to 
increase immensely. This increase is of itself neither 
beneficial nor detrimental, however, because these large 
numbers of organisms will soon compete with one 
other for food. As they succeed or fail, they will 
excrete metabolic products that may deter their 
associates in the phenomenon biologists call antagonism. 
Some fungi may become actually parasitic on their 
associates. A few may go in the opposite direction to 
become symbiotic. These processes, generally, will lead 
to a decline, particularly of unspecialized fungi. As we 
view this situation in evolutionary retrospect, 
competition has, at times, apparently been so keen that 
some fungi adjusted themselves away from the bases of 
dead organic food and adapted themselves to the food 
supplies provided by living plants.

These fungi became facultative parasites that can 
live on dead or living plant tissues. They concern us as 
the cause of root diseases. The mycorrhizal fungi 
comprise a group so specialized that their parasitism is 
nondestructive. They aid absorption by the roots in 
which they develop and thus establish a symbiotic 
relation with the pine. Zak (19) suggested, with 
documentation later provided by Marx et al. (8), that 
these fungi afford protection against invasion of tree 
roots by more aggressive pathogens such as species of 
Phytophthora.

So far, only general fungal behavior has been 
considered. Some concrete examples might now add 
meaning. Consider organic matter in the soil. Probably 
the most desirable situation, in relation to both quantity 
and quality, is the organic matter of the floor of the 
natural forest. I have found no reference to fungal 
limitation of pine regeneration on an undamaged pine 
site. Stock in a pine nursery located on an originally
natural pine site, however, may soon come to suffer serious damage by fungi. Here, the organic component and, consequently, the entire microflora have been greatly modified by intensive nursery practice. Both damp-off and root rot, caused by *Pythium*, *Rhizoctonia*, and *Fusarium*, may become common. *Fusarium* may be introduced into the nursery on seed and, as a consequence of the continuing abundant supply of succulent roots, may become abundant and destructive. Common soil saprophytes are not sufficiently numerous, even when organic matter is in normal supply, to overcome the pathogen. Disease losses may be lessened by organic amendments to the soil.

The early years of pine silviculture in the Nebraska nursery is interesting because, probably, the fungal flora of the native grasslands was carried over to damage the pine nursery stock. Populations of fungi that inhabit the soil, such as *Rhizoctonia* and particularly *Pythium*, are distinctively high in grass lands. These fungi require little raw organic matter and appear able to maintain high populations from the soil solution alone. They may prove troublesome on the reforestation site that has extensive grass cover. Planting ordinarily would be far superior to seeding on such sites.

The denuded burn, the long-unstocked site in which organic matter has been burned out by biological activity and fire, presents another situation. Here, the nutritional base for the beneficial saprophytes that invade the soil is generally depleted, but pathogens such as *Pythium* and *Rhizoctonia* remain. We would expect serious damping-off on such sites, as was found by Wagg (18) in artificial seeding of ponderosa pine in central Oregon and by Stein (16) in southwestern Oregon. On these depleted sites, fungi carried on the seed may become beneficial by offering some antagonistic defense against pathogens from the soil.

The problems just discussed relate to fungi living primarily off the soil. Now consider fungi that inhabit roots. These fungi, as a result of their evolution, rely more heavily for existence on plant roots in the soil than on the soil itself. They become persistent problems in the forest nursery. *Fusarium oxysporum* is an excellent example. Depleted organic matter, combined with high soil temperatures and abundant susceptible root tissue, lead to damage by *Fusarium*. Usually, the disease, which is most conspicuous on the stock the second season, may be reduced by correcting any of these contributing factors. Many seedlings are killed, become conspicuously red-brown in color, and are lost to nursery production. Trees with less severe infections, however, survive and are carried into the field with the planting stock. The fungus probably does not infest the plantation site seriously, but the damaged root systems contribute to failure in the establishment of the plantation. High temperatures, which favor the infecting fungus and, at the same time, contribute to moisture deficiency, frequently lead to losses that are attributed to drought rather than the true pathogenic cause. Normal appearing pine stock in the Bend Nursery, where this disease has been troublesome, has been repeatedly planted in containers at the greenhouse in Corvallis. Trees exposed to the cool, moist, outdoor spring weather thrive, but stock of the same lot suffers a high rate of mortality in the warm greenhouse.

I have suggested that *Fusarium* may not seriously infest the planting sites. Sometimes, however, these sites are already infested with root-inhabiting fungi able to kill the healthiest planting stock (12). *Armillaria mellea* is a commonly occurring example. This fungus is widely distributed in soils of our ponderosa pine region. Losses occur each year to trees of all ages, but are particularly noticeable in small trees. These losses may be only secondarily important where fungus is scattered.

Contrarily, after a sequence of years climatically favorable to *Armillaria* or adverse to the pine, extensive damage occurs to saplings and small poles. Behavior of a persistent, extensive infestation of *Armillaria* may be seen in the vicinity of Glenwood, Washington where extensive acreages are being depleted of pine. *Armillaria* damage is inconspicuous in old-growth timber where beetles attacking infected trees become the ultimate cause of death and obscure the primary fungus. It is easy, therefore, to remove a pine stand and to prepare the site for replanting pine, without knowledge of the disease infestation. When spots of *Armillaria* persist after logging, death of planted stock begins about the third season and may increase for years. The fungus can apparently live long periods in bulky root residues in the soil. It can also attack species of brush associated with the pine. The brush may provide a reservoir of the fungus for reinfection of regenerating pine.

Perhaps the most serious pathogenic losses of pine regeneration result from root diseases. However, diseases of the plant parts above ground may sometimes lead to severe damage.

Because of the dry atmosphere of the ponderosa pine habitat, cankers and stem diseases generally are unimportant. Exceptions occur when the pine is planted on inappropriate sites. The most striking example reaching my attention was destruction of most races in a study of ponderosa pine races at Corvallis, Oregon. At the large-sapling stage, this plantation was invaded by *Atropellis piniphila*. Only the local Willamette race remained disease free. The sturdy Steilacoom and Eldorado races among the exotics were little damaged. I
know of no history of disease in trees of this study at other out-planting sites. The outbreak of cankers at Corvallis was preceded by a heavy attack of needle cast (Hypodermataceae) that I regard as predisposing to the canker epidemic. The foliage disease was unique in attacking needles of the current season. It was another example of the basic problem of attempting to grow ponderosa pine, or indeed, any tree on an inappropriate site.

Aside from the Elytroderma disease, foliar infections of ponderosa pine appear relatively nondestructive in the pine habitat. Needle casts such as Lophodermium and Hypodermella are frequently seen, but usually limited in damage.

Hard pine blister rusts (Cronartium coleosporioides, C. harknessii, C. comandrae), variously regarded by pathologists as diseases of stem or foliage, can cause some problem in ponderosa pine regeneration. Comandra rust frequently forms long, rough cankers on the stems of saplings that result in some mortality in natural stands. This is unimportant in unthinned stands. The importance of the disease in thinned stands is unevaluated. Some danger exists that these blister rusts may infect nursery seedlings in their first or second year. Such infections, inconspicuous and overlooked on the grading belt, frequently are carried into the plantations, where mortality continues for several years after outplanting. Eradication of wild hosts of the rusts, spraying in the nursery, and careful quality control will eliminate this problem.

Pathologists have lived by an axiom that continues to be valid but poorly understood. This is the liability to disease that accompanies tree culture “off site”. This situation has been clearly demonstrated in the race study at Macdonald Forest. In the Tiller area of southern Oregon and elsewhere at moderately high elevations on the west slope of the Cascade Mountains, we are confronted with a serious epidemic of needle blight (Hypodermataceae) in ponderosa pine plantations of unknown seed source. Needles of the current year’s growth are attacked by an unidentified fungus. This disease is a threat of undetermined severity to ponderosa pine in general and is destroying presently infected plantations.

Pine foresters know that foliage diseases in stands of natural pine on native sites can be highly destructive, as demonstrated by the occasional epidemics of Elytroderma. Trees of all sizes are attacked. The fungus persists in the growing points of infected branches, which causes symptoms to reappear year after year, provided the infected branch is alive. Fortunately, spread to adjacent branches is slow. As branches die, either from the disease or natural pruning, trees with only portions of their crown infected will recover.

Infected small saplings suffer particularly. Both mortality and growth loss are high. Losses from this disease can be lessened by stand improvement practices. Complete guidelines for such work, unfortunately, are unavailable.

Something might be said of dwarf mistletoe in relation to pine regeneration. Of course, no mistletoe problem exists in the regenerated stand where the overstory was completely removed before regeneration. Mistletoe, therefore, is a problem in natural regeneration and plantations only under some sort of residual infected canopy. Apparently, natural regeneration of pine is easily obtained on unburned, heavily logged sites with residual cover of either trees or brush. But it may be difficult to obtain when the site is completely denuded. Therefore, leaving the necessary cover to establish the new pine stand seems reasonable, even though this cover may contain considerable mistletoe. Seedlings offer small targets for mistletoe seed, particularly where they are established under, or accompany such cover as manzanita or snow brush. The broad-leaved shrubs provide excellent protection against infection until the pines emerge above the brush. Best practice indicates that as soon as the site is adequately stocked, the overstory should be completely removed to eliminate the source of infection and provide accessibility for release of the seedlings by herbicidal spraying of the brush.

The ponderosa pine forest is, essentially, a healthy forest. Disease losses in regeneration can be minimized by avoiding infested planting sites, by planting healthy nursery stock, by planting only stock ideally suited to the regeneration site, and by planting rather than seeding where ecological circumstances indicate this action.

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Disease as a Factor in Regeneration of Ponderosa Pine


HERBICIDES AND THE MANAGEMENT OF YOUNG PINE

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PONDEROSA PINE HAS SEVERAL FEATURES THAT HAVE A STRONG BEARING on chemical management. Its range is restricted to xeric sites. It is intolerant of shade. And the return on reforestation investments is typically low. The common incidence of xeric conditions suggests that even small amounts of competing vegetation may have an important impact on the small amounts of available moisture. Inability to tolerate shade points to the special need for protection from overtopping brush. The long discount period until harvest strongly points to the need for successful and inexpensive methods for establishment.

Herbicides can effectively control competing vegetation selectively. They may also control spacing by precommercial thinning. This presentation discusses methods of weed and brush control, chemical thinning, and the technical details of practical applications.

WEED CONTROL IN PINE PLANTATIONS

Effectiveness of weed control in ponderosa pine depends on moisture-storage capacity of the soil, the vegetation type, and the season of heavy precipitation. Vegetation type determines the amount and type of herbicide to be applied. Moisture-storage capacity of the soil determines the potential for conserving moisture. The season of maximum precipitation determines when the moisture must be conserved and the season the herbicide must be applied to conserve the moisture during a critical period.

VEGETATION TYPES
AND HERBICIDES FOR CONTROL

Experience with herbaceous weed control for establishment of ponderosa pine has been limited. Climatic conditions throughout the range of this species are much more variable than those of the Douglas fir region, for which forest-herbicide practices have been mostly developed (11). Notwithstanding, probably we can safely generalize for procedures that have consistently reproduced themselves under a wide variety of conditions, especially since effectiveness has been well demonstrated in many nonforestry applications.

Herbaceous vegetation may be broadly grouped into several categories, according to sensitivity to herbicide treatment. Sensitivity is also influenced by stage of growth and physiological state, as conditioned by the distribution of rainfall and general climatic pattern. Because changes in vegetation condition occur with climatic patterns, specific recommendations may be offered by region and vegetation type (Table 1).

Several points should be noted in the interpretation of these recommendations. Atrazine tends to be more readily available for root uptake in sandy soils than in clay soils. Hence, possibility for injury is greater on light-textured soils. The general recommendations are made for soils of loamy, clay-loamy, or finer texture, and should be reduced by 1/2 or 1/3 for coarse textured or sandy soils, especially if low in organic matter. Another important qualification is that movement of atrazine in soil is related to the amount of moisture. Hence, timing of application is based on enough moisture for “activation” without excesses sufficient to cause leaching (8). When a herbicide must be applied in the fall because of snow, simazine (2-chloro-4,6-bis-diethyamino-s-triazine) may have to be substituted for atrazine at rates of one pound per acre greater. All other recommendations remain the same.

Broadleaf weed control includes 2,4-D, a herbicide injurious to pine when applied directly to the foliage. When 2,4-D must be applied, the seedlings should be planted after herbicide application. Or the herbicide should be applied in a directed spray to avoid contact with the terminal buds.

Herbicides, atrazine, simazine, and 2,4-D may be applied together in any ratio. Water, in volumes of 5 gallons per acre or more, is the only material needed as a carrier. When 2,4-D is to be mixed with the other herbicides, the wettable powder should be mixed with the water first, and the 2,4-D added after the other materials are in complete suspension. In mixing, one often notes excessive foaming in the tank. This may be counteracted by the addition of a gallon or two of diesel fuel per batch to the top of the water as an antifoam additive. Oils are occasionally added to increase the effectiveness of atrazine for knocking down resistant weeds. But this procedure is untested on ponderosa
Herbicides and the Management of Young Pine

Table 1. Weed Control Recommendations for Establishing Ponderosa Pine, by Climatic Zone.

<table>
<thead>
<tr>
<th>Dominant weed type</th>
<th>Optimum month</th>
<th>Herbicide¹</th>
<th>Rate²</th>
</tr>
</thead>
<tbody>
<tr>
<td>MORE THAN 20 INCHES PRECIPITATION (EXCEPT S. ROCKIES)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perennial grasses</td>
<td>February</td>
<td>Atrazine + Dalapon³</td>
<td>4</td>
</tr>
<tr>
<td>Annual grasses</td>
<td>Feb.-March</td>
<td>Atrazine</td>
<td>4</td>
</tr>
<tr>
<td>Broadleaf plants</td>
<td>Feb.-March</td>
<td>Atrazine + 2,4-D ester⁴</td>
<td>4</td>
</tr>
<tr>
<td>LESS THAN 20 INCHES PRECIPITATION (EXCEPT S. ROCKIES)</td>
<td>All above</td>
<td>November</td>
<td>Same as above</td>
</tr>
<tr>
<td>Grasses</td>
<td>July</td>
<td>Dalapon</td>
<td>5</td>
</tr>
</tbody>
</table>

¹Atrazine is 2-chloro-4-ethylamino-6-isopropylamino-s-triazine. Dalapon is 2,2-dichloropropionic acid, as the sodium salt. 2,4-D is 2,4-dichlorophenoxy acetic acid.

²Pounds per acre of commercial product. Reduce by one-third on sandy loams or in organic matter, or by one-half on sandy soils.

³Dalapon is not well tested in PNW on pine. It is considered safe in Arizona (7), and appears safe in PNW on Douglas-fir. Better than atrazine alone on rye grasses, fescues, and other atrazine-resistant species. May cause injury after new growth begins.

⁴Plant after spraying; 2,4-D is injurious to pines.

BRUSH—ITS COMPETITIVE EFFECTS AND CONTROL

The intolerance of ponderosa pine to shade puts this species in an inferior position to compete successfully for light with brush. Much has been said about the benefits from brush as a nurse crop and nitrogen fixer (15,16,17). Experimental evidence in the Cascade and Siskiyou Mountains, however, suggests that pine requires nearly full sunlight for satisfactory growth (17; and R. H. Waring, personal communication). During establishment, the attainment of satisfactory growth is essential for proper root development, and for adequate ability to sustain damage from browsing without mortality (12). Zavitkovski and Newton (17) suggest that even those brush species that fix nitrogen may cause a substantial net reduction in growth of conifers with which they are competing, despite the

pine, and oil is known to be risky on pine, especially with the addition of 2,4-D.

These herbicides, applied in plantation establishment, supply a single year of weed control. Ponderosa pine has the important capability of establishing a deep tap root. Therefore, it is much less sensitive to encroachment by weeds after the first year of control than species with a shallower root system. Still, many plantations for high-value purposes, such as Christmas trees and seed orchards, may justify a second year of weed control or perhaps annual applications to sustain a high growth rate. Atrazine, simazine, and 2,4-D are broken down by microorganisms and do not accumulate in the soil. In repeated applications, one may assume that up to a pound per acre of simazine is still in the soil after 1 year. But we may neglect the amounts of atrazine and 2,4-D that may still be present. Two,4-D, especially, breaks down rapidly in the soil.
increased nitrogen. Indeed, such contributions of nitrogen may be marginal. The value of brush as a nurse crop, moreover, depends on the presence of the brush at the time of establishment of the conifer. Most brush species, by the time they are large enough to offer protection to the ponderosa pine, have reached a stage in which the height growth is accelerating. Because the sensitivity of ponderosa pine to shade increases as shade increases, seeding or planting under conditions of increasing shade amounts to a guarantee of subsequent suppression. Dead shade, on the other hand, is static and does not reduce the moisture supply. The capacity for survival and satisfactory growth in a dead brushfield is much better than that in green brush, but still seems not so satisfactory as survival and growth in areas where brush or other vegetation has not developed. This is a controversial subject, however, and apparently no hard and fast rules about dead shade may be stated safely. The detrimental influence of live competition (grass or brush), however, is well-documented and should be minimized unless some factor besides moisture and shade is limiting to the establishment of the plantation.

Ponderosa pine is sensitive to some of the herbicides effective for general brush control. Seasonal variation in sensitivity of pine to these herbicides is quite different from that of Douglas-fir, and to extrapolate from Douglas-fir to pine is dangerous. Ponderosa pine is most sensitive to 2,4-D and 2,4,5-T during the period just before and during bud elongation. Resistance at levels that permit selective control of brush is not attained until needles are fully mature and extended (9,14). As terminal growth tends toward completion, resistance of pine to herbicides increases, and selectivity tends to increase as the pine hardens off (14). Consequently, probably the best season for selective control of brush in pine is in summer, or late summer, but before the brush goes into dormancy.

The most serious problems with brush in pine reforestation apparently occur in California. A substantial amount of work in brush control and reforestation in California has emphasized brushfield eradication, followed by planting of ponderosa pine (1). Emphasis has been either on mechanical scarification, or on repeated aerial-broadcast sprays with up to 6 pounds of phenoxy herbicide per acre in 20 gallons of solution. Despite the high degree of brush control obtained with 3 consecutive years of treatment, infestation by grasses has posed a serious problem. Where grass is likely to become a problem, this brush treatment in preparation for planting may create more severe problems than it cures (5,10).

Much of the work on brush control for pine management in Oregon has been done by Dahms and James (3) and by Dahms (2) who have advocated less severe treatment. The approach of brushfield eradication presupposes that ponderosa pine will not be established successfully with any degree of residual stand of brush. In our opinion, the ecological evidence does not suggest the requirement for such a complete degree of control. Although our evidence is not complete, we believe few brush patches exist that cannot be pretreated just before planting with from 2 to 4 pounds per acre of 2,4-D or 2,4,5-T, or both, to virtually assure first-year survival of the pine. In this way, pine is introduced before grass becomes a problem. Brush may be re-treated as necessary with selective follow-up sprays to insure that resuppression by brush does not become critical. Dahms (2) suggests from 1/2 to 1 pound per acre of 2,4,5-T for such selective release follow-ups.

Hartwell (6) noted, in connection with brushfield rehabilitation, that frequently whether brush influence is critical or not, animal populations in established brushfields pose serious threats to any plantation. Two possible approaches to the solution of the animal-damage problem are possible. One is provision for concurrent baiting of the dead brushfield when introducing the seedlings. The other, extrapolated from Douglas-fir, is that large seedlings may prove an effective deterrent to rabbits (12). Seedlings large enough to provide some protection against deer are probably too large to handle economically in ponderosa pine. Evidence in Douglas-fir suggests that the poorer shoot-root ratio encountered with large seedlings is not a major deterrent to survival (12).

Planting trees in live or dead brush poses a serious problem with the physical process of planting. Planting costs are unquestionably higher than in the open. And some brush patches, nearly impenetrable, may prove uneconomical for planting. The forest service has done considerable work with burning and spraying in site preparation (1,14). Herbicides have effectively dried brush for increased combustability at a time of year when untreated brush is unlikely to carry a fire readily (1,14). The desiccate-and-burn practice, although still in developmental stages, holds some promise for rehabilitation of impenetrable brush fields (Personal communication with W. Schmitt, Weyerhaeuser Company, 1968). Prospective practitioners, however, should note that hot fires stimulate germination of many fire-resistant brush species (5).

The effect of brush on establishing pine seedlings involves light, water, and animals. Broadcast brush control will increase light and reduce transpirational losses of moisture. Therefore, planting pine immediately after spraying should be reasonably successful. In contrast, selectivity in new pine plantations is marginal (with no immediate prospects for improvement). Thus,
planting in green brush and spraying later is impracticable. Where animals are limiting or brush is so impenetrable as to be limiting for planting crews, spraying and burning followed by planting is proposed by some as a logical alternative.

**STAND DENSITY MANAGEMENT**

Ponderosa pine tends to occur in clumps. Within these areas, overstocking commonly is a major problem. Overstocking not only slows the growth of the individual tree, but causes the stagnation of entire stands. Precommercial thinning is important in the management of young-growth pine and has much to do with the costs and successes of the operation.

Ponderosa pine traditionally has been thinned with a power saw to some previously designated spacing. Saw thinning, however, creates hazards of insect buildup, fire from accumulation of red slash, and injury to personnel from falling trees and power saws. In stands where the average tree to be cut is more than 2 inches in diameter, the labor requirement for felling becomes excessive. Chemical thinning may be the most practical approach presently available to overcome these problems.

Chemicals are applied to individual trees by injection. Injection equipment includes an assortment of instruments, which range from hatchet and oil can to automatic tree injectors. Possibly, a slightly higher dosage with hatchet and oil can is needed than with automatic injectors.

The most successful chemicals today for pine thinning are the organic arsenicals. Cacodylic acid and MSMA (monosodium methane arsenate) are effective for killing pines any season of the year. Of these two herbicides, MSMA is cheaper and more effective. Dosage requirements vary somewhat with the nature of the stand. The taller the stand the more widely the cuts may be spaced for a given diameter. Apparently cuts may be spaced somewhat more widely in winter. Generally, every tree up to 3 inches in diameter is given one injection. For every additional 2 inches, an additional injection is given. Thus, a 3-inch tree would receive one injection, a 4-inch tree, two, and an 11-inch tree, five. If the green crown extends to the ground, an injection is needed for every 4 to 5 inches of circumference. If cacodylic acid is applied rather than MSMA, an additional injection or two is required for each size tree. Regardless of the chemical, the material should be applied full strength or slightly diluted with water in winter as necessary to maintain fluid properties of the chemicals. Equipment should be calibrated to deliver from 1 to 1 1/2 milliliters per injection. In ponderosa pine, especially, the injection should penetrate to the sapwood. Improvements in information on silvicides are evolving rapidly. For current information on the best seasons and dosages for any given chemical formulation, consult the label. The law requires chemical companies to provide recommendations substantiated by considerable evidence.

We have been concerned about insect responses to thinning and have given this matter considerable attention. We have found heavy insect infestations, especially *Ips pini* in trees felled with a power saw, and far less infestation in the standing trees treated with either MSMA or cacodylic acid. In dissecting the trees treated with chemicals, we found not only light attacks, but a total inability to raise broods. In year-round treatments with 2-month intervals, we found an infestation with *Dendroctonus ponderosae* only during June. Beginning in August and extending through the winter, we found essentially zero infestation. Even during June, however, those attacks of *Dendroctonus* were considered inconsequential because of total brood mortality. Moderate attacks of *Ips* occurred in all months except August, but with no brood survival at any time (13). Briefly, then, the insect problems with chemical thinning appear to be much less than with mechanical thinning. And we have reasonable confidence that chemical thinning may be accomplished at any season without fear of a major epidemic. Caution is urged, however, because exceptions to this freedom from insects have been reported (4).

Red slash accumulating from mechanical thinning poses a serious hazard of fire. Trees treated with cacodylic acid or MSMA drop foliage within 1 year of treatment; most of the foliage drops substantially sooner than this. That areas of high fire hazard could be treated in August or September with negligible increase in fire hazard before the fall rains is anticipated. By the next fire season, essentially all dead foliage would be on the ground. Therefore, the slash problem would be avoided entirely. Standing dead trees are mostly in the shade of the green dominants and, in the absence of red foliage and direct sunshine, would be substantially less likely to carry a fire than a ground accumulation.

Aesthetic considerations strongly favor chemical thinning over mechanical thinning. Dead needles are always in a ponderosa pine understory. Chemical thinning merely causes a temporary, although striking, increase in the amount of dead foliage present. Even during this brief period, however, the main stand of thrifty green dominants masks most of the discoloration and the stands appear little different from normal.

Costs of chemical thinning vary almost directly with the number of trees per acre to be treated. Treatments applied on a basis of up to several acres in a block suggest an overall average from about 400 to 600 trees per man-hour. Stands of 400 trees per acre or less
take about an hour per acre for a man simply to cover the ground. Thus, the number of man-hours per acre ranges from about 1 in a stand of 400 trees per acre to 5 or 6 in a stand of about 3,000 trees per acre. In stands with more than 3,000 stems per acre, freedom of movement becomes impaired, and the economics of operation alone tend to favor the power saw. The break-even point will depend upon the individual operator and the terrain. Chemical thinning is impractical, however, in extremely dense stands because tree diameters are small and do not lend themselves to efficient treatment with impact-type instruments. Thinning with a power saw approaches a mowing operation as stand densities increase and as diameters decrease. Experience will have to dictate where the break-even point comes between chemical thinning and power-saw thinning, with proper consideration for insects, slash, aesthetic values, and costs.

SUMMARY

The limited information available suggests that herbicides applied successfully in regeneration of Douglas-fir may largely be considered effective and safe for ponderosa pine. With atrazine or dalapon, or both, herbaceous weed control should be sufficient to establish pine in most areas. Two, 4-D and other foliage-active compounds may be applied, but with full consideration of the hazards involved. Ponderosa pine is resistant to atrazine, but the threshold of resistance is probably lower in coarse-textured soils. Resistance of weeds to atrazine will be comparably lower in the coarse-textured soils, however, and less material is needed to accomplish the same job of weed control with the same degree of safety. On some soils, largely rocky and coarse textured or gravelly, vegetation is not responsible for rapid drying. On such sites, good control of weeds alone is not sufficient to guarantee survival. Weed control has no magic. It merely permits a well-planted tree to perform in accordance with the potential of the environment, without interference from competition.

To control brush is much easier than to grow trees in brush that has been controlled. browsing and clipping animals are ubiquitous in brushy areas. And once the brush has had time to develop, populations of these animals mature. Often established trees can be released by selective control of brush. But even trees treated with repellents are likely to be damaged heavily in either live or dead brush. In this respect, once the need for brushfield reclamation is established, complete removal of the brush may be necessary to eliminate animal cover. The most attractive alternative to total removal of brush either by burning or scarification, appears to be the introduction of large planting stock into brushfields after defoliation.

In most precommercial stands of ponderosa pine, chemical thinning offers several benefits over saw thinning. Except for extremely dense stands of several thousand or more stems per acre, chemical thinning with MSMA or cacodylic acid offers an opportunity to reduce cost and, at the same time, reduce hazards of insects and slash. Sociologically, chemical thinning offers additional advantages of improving thinned stands aesthetically and offering employment to laborers during off-season months.

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ROLE OF BRUSH IN PONDEROSA PINE ESTABLISHMENT

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ATTEMPTS HAVE BEEN MADE TO CLARIFY THE ROLE OF BRUSH IN FOREST REGENERATION. Foresters and other professionals interested in the brush problem disagree. Some want to eradicate brush. Others stress the beneficial influences of it. Positive attitudes toward brush may have originated from ecological observations on development of some natural plant communities. Reports on the beneficial role of pioneer species in plant colonization of new or infertile soils (2) are encouraging. Curtis (4) reports that eastern white pine can invade open sites (created by fire or other destructive agents), but the presence of a nurse crop of aspen, birch, or other pioneer species promotes the best regeneration. There are many similar examples.

The nurse crop concept was introduced into European forestry many years ago. It is still frequently applied in one form or another in spite of its high cost (36). The planting of a nurse crop may be called biological preparation (or simply site preparation), but usually it includes both mechanical preparation such as plowing or stump cluthing, and introduction of fast-growing, resistant tree species as a nurse crop (26). Advice on the planting of nurse crops in this country has often been accompanied by words of caution. Toumey and Korstian (25) say that, in most instances where nurse crops have been planted, the resulting stand has not been improved and crop trees have been dwarfed, suppressed, or even killed by the more aggressive nurse trees.

We will summarize some information on brush microenvironment and propose some measures for regenerating ponderosa pine in brushy areas. In doing so, we hope to reconcile some apparently divergent points of view.

BRUSH TYPES OF THE REGION

Manzanitas (Arctostaphylos spp.) and ceanothus (Ceanothus spp.) are the two most common genera in brushfields of the ponderosa pine region. Bitterbrush (Purshia spp.), chinkapin (Castanopsis spp.) and several Rubus and Ribes spp. are some other shrubs. Brush species may occur in pure or mixed stands, often in dense patches interspersed with small openings.

Brush species may be pioneers after destructive fire, but some are permanent members of ponderosa pine communities (6). Their ability to resprout is often responsible for their persistence when repeatedly damaged by fire or by other means. (3, 8, 11, 14, 16, 22, 28).

Both Ceanothus spp. and Purshia spp. are known to fix atmospheric nitrogen (5, 27) but quantities fixed by these species may be quite small (34). Their ability to produce large quantities of litter, however, may be ecologically and silviculturally important (34).

BRUSH ENVIRONMENT

Brushfields create their own microenvironment, which differs strikingly from the macroclimate of the same areas. In general, all major climatic factors, including light, temperature, moisture, and wind, are less variable under closed brush canopies than in the open.

Light

Both intensity and quality of light are modified by closed forest canopies. Reifsnider and Lull (20) summarized the significant studies of light in forest stands. Although quantitative data on light under brush are lacking, references to limiting light are found in some research dealing with detrimental effects of brush on growth of crop trees (3, 4, 9, 35). Drought rather than light is generally considered the most limiting ecological factor that affects establishment and growth of coniferous seedlings in brushfields, although canopies of some broadleaf communities reduce light from 94 to 99 percent. Even leafless canopies may reduce the incident light by 50 percent. This is by far the highest reduction among the climatic factors such as rainfall (from 15 to 30 percent) or wind velocity (from 20 to 60 percent) (20).

Light quality changes with decreasing light intensity. Relatively more radiation is transmitted in wavelengths above 700 millimicrons (almost 50 percent)
Role of Brush in Ponderosa Pine Establishment

than within the visible spectrum (only from about 3 to 14 percent). Additional enrichment in red light is reported for broadleaf communities in comparison with conifers (20). Effects of these qualitative changes on photosynthesis of conifers are not known, but chlorophylls absorb red light between 640 and 680 millimicrons very efficiently.

Sunflecks may contribute a substantial amount of radiation energy, depending on the porosity and height of the canopy. Under hardwood cover in West Virginia, Allard (cited by Reifsnyder (20)) recorded intensities of over 5,000 foot candles, compared to 11,400 in the open. Light intensity under forest cover is correlated with its shade tolerance. Curtis (4) found it was higher under jack pine than under tolerant hardwoods. Canopies of the most common brushfields are quite open, and generally the stands are low. Most brush species are also highly intolerant of shade. These qualities tend to intensify the effects of sunflecks and light penetration into these communities.

The effects of high-intensity light on photosynthesis and chlorophyll destruction in ponderosa pine is not known. It may, however, destroy chlorophyll in Douglas fir (W. K. Ferrell, personal communication) and reduce photosynthesis in loblolly pine (17). If the same is true for ponderosa pine, some shade could be beneficial to young seedlings, especially on steep south slopes.

Temperature

Wahlenberg (28) and Youngberg (31) measured the temperatures of air and soil in snowbrush stands and report that the temperatures were substantially lower (from 20 to 30°F) under brush than in the open. In Youngberg’s study, temperatures at the soil surface, in the open, reached from 145 to 165 degrees F, temperatures too high for successful establishment of seedlings.

Brush also moderates low temperatures and may prevent direct damage from frost to the planted seedlings (J. Gartman, personal communication) or indirect damage caused by frost heaving (10). Plants shade the snow (20) and thus prolong the time during which water will be available for seedling establishment. The plant cover, however, may also delay the beginning of the growing season.

Generally, mild temperatures, combined with humidity under brush, may stimulate development of both pathogenic microorganisms (4, 25) and beneficial microflora.

Moisture

That depletion of soil moisture in brushfields is faster and more complete than in areas with no vegetation is almost a general agreement (1, 12, 24, 30, 32). The opinions diverge, however, when dealing with moisture effects on the establishment and growth of conifers in shrubby communities. Youngberg (31) recommends planting under brush where soil moisture is more favorable for seedling establishment than in the open. Others suggest removal of vegetation to improve and save soil moisture for growth of crop seedlings (16, 23, 35). Part of this divergence may stem from imperfect understanding of terms of some workers (7, 16, 31, 35) such as “open”, “openings”, and “cleared lanes”. A closer examination reveals that the “open” areas of Youngberg (31) are not free from brush competition, because roots of the surrounding shrubs extend into and remove soil moisture from these “open” areas. Because additional moisture is lost by increased evaporation, these “open” areas actually represent the most adverse sites for seedling establishment. The “openings” and “cleared lanes” in other studies (16, 35) were created by mechanically removing brush from circular plots or in lanes. For a limited time, they provide reasonably good planting sites (if animal damage is discounted), with sufficient soil moisture for seedling establishment.

Transpiration from the brush is the main avenue through which most of the soil moisture is lost. Two other significant avenues of water loss from brushfields are rain interception by, and evaporation from, brush canopies (21); and rain interception by, and evaporation from, leaf litter on the ground (13). These two mechanisms may account for 10 to 25 percent of the total rainfall and are particularly important when rainfall is in light showers.

Rowe (21) found higher soil moisture in the immediate vicinity of brush root collars, as did Dyrness (6), Wahlenberg (28), and Youngberg (31). Rain intercepted by brush canopies is carried as stemflow to the base of the plant and increases soil moisture in these microsites. About 15 percent of the total annual rainfall may be concentrated from areas of several square yards occupied by a single brush plant to an area of several square inches near the base. Wahlenberg (28) and Youngberg (31) found these microsites ideal for ponderosa pine establishment.

Transpiration of ponderosa pine seedlings under brush is reduced because of reduced radiation, lower temperatures, higher relative humidity, and reduced wind velocity. These factors may be important in the establishment of ponderosa pine on extreme sites. Drought, however, is the most important ecological factor on these sites and will be more severe under brush than on fresh clearcuttings.

Soil Fertility

Several of the most common brush species of the ponderosa pine region fix atmospheric nitrogen (5, 27).
Nitrogen fixation rates under field conditions are lacking for most brush species. Snowbrush, the only species investigated in the field, fixes only small quantities of nitrogen (34). Brush species, however, produce much litter and thus recycle the nutrients (33, 34). Beneficial effects of litter on growth of conifers have been documented in greenhouse studies by Wollum and Youngberg (29) and by Zavitkovski and Newton (34). In the field, Dyrness (6) observed an increase of total nitrogen under both manzanita and snowbrush, compared to soils without brush cover. Beneficial rhizosphere effects, not necessarily connected with nitrogen fixation, have also been proposed (31).

All these studies indicate that soil fertility will be improved under brush, and this should be considered along with all other beneficial and detrimental influences when assessing the role of brush in forestry.

**Brush and Animals**

Animal populations probably benefit from clearcutting and brush development on extensive areas. Hayes (11) says that before effective fire protection was started in southwestern Oregon, intentional or accidental burns created ideal habitat for deer, and that in recent years extensive clearcutting has added large acreages of such habitat. High populations of rabbits and snowshoe hares in brushfields have been reported by Jemison (16), Gratkowski (8), and Zavitkovski and coworkers (35). Many of the common brush species are palatable to deer and other grazing animals.

In some areas, regeneration methods had to be changed to allow seedling establishment (10, 16). Much damage and mortality of planted ponderosa pine was ascribed to clipping by snowshoe hares in fields of snowbrush (35). Contrary to these reports, brush is said to protect natural and planted seedlings from grazing animals and, therefore, is considered beneficial by some workers (J. Gartman, personal communication and 31). This creates a paradoxical situation in which the same brush that attracted the animals prevents damage by them.

**Mechanical Effects**

Brush will reduce wind velocity and thus reduce transpiration of planted seedlings to some extent. The reduced air movement may also have some effect on carbon dioxide and water vapor concentration. Of more importance, however, may be the mechanical effects of debris (litter) on tiny coniferous seedlings that may be smothered or broken (19, 33). Coniferous seedlings, developing under brush, are characteristically slender and fragile and may be broken under the bending, snow-laden brush during winter (9, 18).

Dense brush also interferes with planting operations and increases the cost of planting (33).

**BRUSH AND PONDEROSA PINE**

Regeneration of ponderosa pine may be natural or artificial.

**Natural Regeneration**

Beneficial effects of snowbrush on the establishment and growth of concurrently developing ponderosa pine have been suggested by Wahlenberg (28). He observed that ponderosa pines frequently emerged above dense canopies of snowbrush. A closer examination revealed that these saplings were usually rooted but a few inches from the root collars of older bushes, an indication that the bushes provided a favorable environment for ponderosa pine establishment. Similar observations were made by Dyrness (6) in the ponderosa pine forests of central Oregon. Unfortunately, these workers did not determine the age of the snowbrush and the pines.

Ponderosa pine apparently can invade and eventually dominate deerbrush fields. Cronemiller (3) found that deerbrush resprouts vigorously after fire, but ponderosa pine, if established at the same time, will dominate and shade out the deerbrush within 8 to 10 years or, if established several years after fire, within about 20 years.

**Artificial Regeneration**

Reports on artificial introduction of ponderosa pine into various brush types are more numerous but less encouraging than observations on natural regeneration. Gratkowski (8) describes regeneration attempts in a large burn in southwestern Oregon. Seeding the fresh burn with ponderosa pine failed completely. But a 72-acre ponderosa pine plantation was successful and, 45 years later, developed into an excellent stand. Several subsequent attempts to introduce ponderosa pine into brush met with complete failure, despite site preparation (bulldozing lanes of variable widths) and large (1-2 or 1-1P1) planting stock. Causes of loss included trampling by cattle and deer, competition of resprouting brush, and cropping of seedlings by rabbits, deer, and cattle. Twenty years after these attempts, the cleared lanes were indistinguishable from the undisturbed brush. Inadequacy of bulldozed lanes were recognized by Jemison (16), who recommended a complete removal of vegetation from planting areas. He says that narrow lanes are insufficient because roots of adjacent shrubs remove moisture, and rabbits that live in the brush destroy the few trees that survive the competition.
Planting experiments in snowbrush fields of the Cascade Mountains revealed that ponderosa pine survived and developed best on freshly burned, clearcut areas without brush competition (35). Under conditions of live, dead, and mechanically removed snowbrush, the survival and height growth were generally poor. When planted concurrently with germinating brush, ponderosa pine is not challenged and will eventually dominate and shade out snowbrush. If, however, the planting is delayed for 2 or more years, survival and growth are severely reduced. Many of the trees under the brush are killed by snowshoe hares, whose populations increase with brush development.

Wahlenberg (28) suggests that brush may increase survival of planted ponderosa pine on extreme sites by providing a milder microenvironment. Youngberg (31) supports this theory, but warns that release from brush competition will be necessary after a successful establishment of ponderosa pine seedlings.

**REGENERATION IN BRUSHFIELDS**

Perhaps the best advice is not to allow brush to dominate ponderosa pine sites. Immediate planting of a freshly burned clearcutting with large stock of local or well-adapted source will provide the best chance of success. Reports of successful regeneration of the fresh burn in southwestern Oregon (8) and excellent performance of planted ponderosa pines in freshly burned clearcuttings (35) indicate that successful regeneration is possible on most sites. Timing is extremely important and may decide whether an area will become a forest or will be lost to brush. This was recognized by many workers (8, 14, 35) and is consistent with sound silvicultural practices.

The problem becomes more difficult if regeneration is delayed for several years or if brush is already present on the site. Overwhelming evidence suggests that successful regeneration of such areas will require some kind of vegetation control (9, 14, 15, 16, 23, 25, 35). This will be required not only to make the establishment possible but also to provide better conditions for seedling growth. Zavitkovski and coworkers (35) found a reduction of 50 percent in height growth of ponderosa pine and several other conifers that developed under brushy conditions. Reports of others on a variety of coniferous species confirm these findings (9, 18, 19).

Other considerations are beyond the scope of this presentation. For completeness, we mention use of better and larger planting stock, site preparation by mechanical and chemical means, fertilization, control of seed-eating rodents and small mammals, and perhaps irrigation.

The evidence suggests very strongly that brush is not compatible with advanced silvicultural methods that use appropriate tools to achieve the best results. For example, use of brush to increase soil fertility is hardly the best approach when forest fertilization is becoming operational. To recommend that brush dominate productive forest sites for a decade or more when appropriate means to regenerate those areas are available would be difficult.

**LITERATURE CITED**


ANIMAL DAMAGE TO FOREST REGENERATION IN THE PONDEROSA PINE REGION
OF OREGON AND WASHINGTON

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INTRODUCTION

During stand development in the ponderosa pine region, pine seedlings and saplings are damaged by deer, elk, livestock, pocket gophers, porcupines, hares, and rabbits. Bears, mountain beavers, dusky-footed wood rats, and grouse may damage pine stands occasionally. Also, insects, voles, and birds damage young seedlings.

The seriousness of animal damage, which reduces or delays the total yield of pine (16), has long been recognized. Now the losses are of increasing financial concern because of rising demands for wood and wood fiber and the increased capital values represented by timber holdings. Management has responded to these economic demands by increasing investments and by intensive forest management, particularly rapid regeneration. Partial cutting and natural regeneration, for example, are being supplanted by clearcutting and planting.

Mortality of trees caused by animals, particularly pocket gophers and porcupines, combined with high natural mortality in the pine region, assumes added importance in the long run. Conversely, minor mortality associated with animal damage may not affect stocking significantly (24).

Natural mortality of seedlings is of added importance in assessing the impact of animal damage, because some resource managers tend to assume that animals cause most tree losses. This assumption arises because reforested areas are examined infrequently and most dead seedlings go undetected, but surviving trees often evidence animal damage because animals or their sign are ever present.

Some differences in feeding preferences of animals for pine seedlings and saplings may be explained by genetic differences among races of pines as well as by differing tastes of the animals. An analysis of data from a ponderosa pine provenance study in Oregon and Washington showed inherent feeding preferences for trees of different seed sources by rabbits, deer, and porcupines (52). Rabbits and deer exhibited the same preferences among the 10 seed sources studied, based on observations made 23 years apart. Porcupines had different tastes than rabbits and deer, but showed the same order of preference for five seed sources at two plantations over 32 years.

SURVEYS OF ANIMAL DAMAGE

In studies of artificial regeneration of ponderosa pine in eastern Washington, Dingle (17) recorded deer, porcupines, pocket gophers, and rabbits as destructive to pine seedlings. Pocket gophers were the most important cause of mortality.

Case histories (17, 31) reveal that pocket gophers may continue a pattern of attrition until the plantation is destroyed. They reduced survival of seedlings in plantations as much as 12 percent in a single growing season and 30 percent in 2 or 3 years in eastern Washington. Dingle (17) concluded that damage by pocket gophers is a limiting factor in the establishment of ponderosa pine plantations.

Studies of survival in pine plantations in southern Oregon (32) show high risk to plantations in the first growing season and loss of increment in subsequent years because of animal damage to surviving trees. Within 1½ years after planting, deer destroyed almost 70 percent of unprotected ponderosa pine seedlings on plantations studied. Animal-caused mortality was moderate in the second and third years, but gophers heavily damaged seedlings and saplings on older plantations. Important losses of seedlings were also caused by other animals.

The urgency of the problem is illustrated by a recent request for assistance in controlling animal damage (Memorandum to Dr. W. H. Lawrence from Area Regeneration Forester, Weyerhaeuser Company, Klamath Falls, May 1969). Noting that animal damage, not drought, is now considered the limiting factor in successful artificial regeneration on the Weyerhaeuser Company's Tree Farm at Klamath Falls, this request reported: "We are especially sensitive, if not neurotic, about this problem these days as we received more than average deer damage due to heavy snows this winter... But what makes us nervous is the fact that we are committed to a sizeable regeneration investment and we are still almost completely vulnerable to the whimsy of every animal that comes along.

In 1957, a study by the Weyerhaeuser Company in Oregon and Washington (27) indicated an average annual loss of $125,000 on naturally regenerated
ponderosa pine stands that ranged to pole-size timber. Porcupines caused the principal damage on about 250,000 acres of land. In 1967, the Company conducted a survey to determine the total effects of animal damage on its timberlands (42), which included 600,000 acres of pine lands. About 8 percent of the acres surveyed had trees damaged by animals. The average loss of yield on the damaged acres amounted to 6,000 board feet per acre. Of this loss, 44 percent was attributed to big game, 35 percent to rodents, 13 percent to bears, and the remainder to porcupines and livestock.

A survey in California (5) indicated that 46 percent of all damage by animals to regeneration involved ponderosa pine, based on frequency of trees damaged. Deer, the primary factor, damaged 35 percent of the trees sampled.

A recent evaluation by the Timber Management Division of the U.S. Forest Service of the priority of animal-damage problems on national forests in Oregon and Washington was based on occurrence of damage, whether damage results in tree mortality, growth suppression, or cost and difficulty of control (7). Excluding seed eaters, animals rated in descending order of concern in the pine region were pocket gophers, deer, rabbits and hares, and porcupines.

Persons in management and research (9) ranked pocket gophers first, on the average, as a problem animal within the pine region in a survey limited to porcupines, pocket gophers, hares and rabbits, mountain beavers, and wood rats. Both the U.S. Forest Service and the Washington State Division of Wildlife Services ranked pocket gophers first. The Bureau of Land Management and Weyerhaeuser Company ranked them second and third. Dr. W. H. Lawrence, Weyerhaeuser Company, predicted that gophers will be their primary problem in newly established pine plantations. Porcupines, on the average, were ranked second among animals considered east of the Cascade Mountains. Hares and rabbits were ranked third, and wood rats were not considered a problem.

This diversity in assessing problem animals reflects different criteria for evaluation by forest managers and researchers, as well as the influences of ownerships with unique combinations of problems and management practices.

A recent survey (13) in the Pacific Northwest noted that the incidence of animal damage is higher on national forests west of the Cascade Mountains, particularly in Oregon, and lower on the east side. Animal problems on national forests appeared more important in Oregon than in Washington.

Browsing was the most common type of problem east of the Cascade Mountains (60 percent). Barking was second (31 percent), then root cutting and stem clipping (19 percent each), and trampling (7 percent).

Deer were the most troublesome animals reported on national forests in the Pacific Northwest east of the Cascade Mountains (nearly 60 percent of problem animals). Porcupines and pocket gophers (each 19 percent) ranked second. Other troublesome animals were hares and rabbits (14 percent), elk (13 percent), and livestock (11 percent). Thirty-five percent of all returns from the survey listed two or more animals that caused problems on the same area.

The survey also revealed some interesting descriptive information on forests east of the Cascade Mountains. The majority of all areas with animal-damage problems had been deforested less than 10 years, but many had been deforested longer than 15 years. Wildfire was a more frequent cause of deforestation than clearcutting. Regeneration from natural or artificial seeding was seldom successful, and most seeded areas were subsequently planted. Replanting was required on nearly 30 percent of these areas.

The survey of animal damage on forest plantations in Oregon and Washington, based on the 25 randomly located sampling plots installed in plantations of ponderosa and Jeffrey pine, or both, indicates that animal damage is the most important regeneration problem in the pine region (4). This survey is one of the best available estimates of the occurrence of animal damage and its impact on reducing production in the region.

Animal damage of some type and in some degree occurred on all pine plots except two (on one, all the trees had died after 2 years). On the average, few seedlings were damaged by animals the year of planting; the percentage of seedlings damaged varied in subsequent years. The percentage of seedlings damaged on individual plots also fluctuated widely among plots from year to year. On the average, however, animals damaged only 12 percent of the unprotected seedlings each year.

Browsing by big game and livestock was the most common cause of seedling damage in 1968. In order of occurrence, browsing was followed by clipping, trampling, and barking. Barking by porcupines and pocket gophers represented 7 percent of all damage recorded. Pulling seedlings, clipping buds, and clipping roots were encountered infrequently. Other types of damage represented 13 percent of the total in 1968.

Based on mean data from the 25 pine plots, big game ranked first in frequency for damage to pine regeneration. Other animals that caused damage, ranked by frequency of occurrence, were pocket gophers, hares, rabbits, domestic stock, porcupines, and grouse. Other
agents, principally insects, represented 14 percent of damage occurrences. In 1968, damage by pocket gophers occurred more often than damage by other agents on the sampling plots installed in 1963-64, but deer accounted for about two-thirds of animal-caused damage on plots installed in 1964-65.

After four growing seasons, survival of uncaged pine seedlings in the first series of plots averaged 52 percent. Average survival of uncaged seedlings in the second series of plots after only 3 years was higher (56 percent). Based on differences between survival of seedlings, protected and unprotected, 51 percent of all pine mortality was caused by animals (Figure 1).

![Figure 1](image1.png)

Figure 1. Mean survival of caged and uncaged ponderosa pine seedlings in both series of sampling plots in Oregon and Washington. Both curves originate at the mean planting data in 1963-64 in the first series and in 1964-65 in the second series.

Animal damage also reduced the height growth of unprotected seedlings. After 4 years, the mean height of uncaged ponderosa pine trees, in the first series of plots in Oregon and Washington, was 12 inches, compared with mean height for caged seedlings of 16 inches (Figure 2).

An example of extreme damage by animals (4) is illustrated by the record of animal-caused mortality on a plot in Central Oregon. Three-year-old, repellent treated ponderosa pine seedlings were planted in April 1964. The plantation is located on a burned site of low quality for ponderosa pine and is within a large fenced enclosure, which excludes deer, but not porcupines, hares, or pocket gophers. With a bulldozer, spots 10 by 10 feet were scalped for planting clusters of five seedlings each.

![Figure 2](image2.png)

Figure 2. Mean height and standard deviation of live ponderosa pine seedlings in the first series of sampling plots in Oregon and Washington. Both curves begin with the mean planted height at the mean planting data. The first remeasurements were made in the summer after planting.

Initial survival of seedlings was good and little damage by animals was observed in the summer of 1964 (Figure 3). Pocket gophers were active on the sampling plot, but did not damage seedlings during the first year. In 1965, many seedlings were clipped or barked by porcupines and pocket gophers and later died. Cattle

![Figure 3](image3.png)

Figure 3. Survival of uncaged ponderosa pine seedlings and occurrence of animal damage to seedlings on Plot 82 in central Oregon. Percentage of occurrence of animal damage is based on the number of seedlings damaged each year divided by the number alive 1 year before and multiplied by 100.
used the area in 1966 and may have trampled or browsed some seedlings, but no mortality was caused by grazing. Porcupine damage continued, so that after 4 years, 59 percent of uncaged seedlings were killed or severely damaged, and two caged seedlings were clipped and girdled. This reforestation effort was a failure despite the costly practices of site preparation, planting 3-0 seedlings, and fencing to exclude deer. Ninety percent of the caged seedlings survived.

IDENTIFICATION OF WILDLIFE INJURIES

Correct identification of causes of damage or mortality to pine regeneration is necessary before direct controls can be applied intelligently, or preventive measures undertaken. Assistance from specialists such as forest-wildlife biologists may be needed.

Many physical and biotic factors such as drought, winter kill, and frost heaving damage or kill pine seedlings. Damaged seedlings may die back, discolor, or defoliate, and injuries may become difficult to see. Dead seedlings soon are broken off and lost. Thus, cause of mortality cannot be determined.

Frequent observation of marked or caged seedlings, or seedlings within fenced enclosures is helpful. Regeneration from natural or artificial seeding and marked samples of young seedlings must be examined periodically throughout the first year to identify losses. Planted seedlings should be examined periodically the first year after planting and annually for several years to identify wildlife-caused damage. The methods followed in the Cooperative Animal Damage Survey (4) provide an example of the kind of plantation records that can be obtained. Stocking surveys made from 1 to several years after seeding or planting are designed to provide only an estimate of the number and distribution of trees per acre and cannot adequately explain causes of plantation failures.

Foliage Clipping and Browsing

Clipping injuries caused by voles, hares, rabbits, pocket gophers, and porcupines are usually distinguishable from browsing injuries caused by big game and livestock (37), especially when examinations closely follow injury. Bud and needle clipping by grouse might be confused with browsing, but are uncommon in the pine region. Partial defoliation by grasshoppers and other insects also may be confused with browsing damage, and frost-damaged foliage appears not unlike browsed foliage. Identification of the agent responsible for foliage clipping or browsing usually must rely on other signs or additional information because of the similarity of injury. Seasonal occurrence of damage often is the best clue to the animal that causes damage, because season of animal use may not overlap. For example, foliage clipping and barking by pocket gophers are usually restricted to the winter (December-January), but most similar damage by porcupines occurs in the fall before snow, or in the late spring. And both kinds of damage may occur on summer deer ranges when deer are entirely absent. These types of damage, however, may be overlapped by clipping by hares and rabbits. Knowing season of use also may help to distinguish between browsing caused by elk, deer, or livestock.

Many signs of animals are transitory, such as tracks in snow or soft ground, soil casts left by gophers when they push soil into tunnels under snow, and porcupine quills and hair. Signs of feeding, droppings, and burrowing are longer lasting, but timely examination is important to insure correct identification and to recognize recent activity.

Several good references are available to aid forest managers in field identification of injuries by wildlife. These include the “Guide to Wildlife Feeding Injuries on Conifers in the Pacific Northwest” (37), the Forest Service’s “Animal Damage Control Handbook” (56), and “A Field Guide to Animal Tracks” (43).

Clipping and Barking by Pocket Gophers and Porcupines

Root clipping in the pine region is nearly always caused by pocket gophers, although in southwestern Oregon mountain beavers may infrequently clip roots or expose roots in contact with their burrows. Root clipping by pocket gophers once detected is easily identified, but may not be noticed in plantations until crowns turn brown from summer drought or seemingly healthy green trees are tipped abnormally by wind (37). Some root clipping of pine saplings that does not kill the trees probably occurs without detection.

Damage to stem or foliage of pine seedlings or saplings caused by pocket gophers and porcupines, which commonly occur together, is not easily distinguished, and wrongly attributing cause of damage is common. In fact, much damage by pocket gophers or other animals probably has been erroneously ascribed to porcupines. Barking caused by rabbits and hares may also resemble that of gophers or porcupines (45). Assigning cause of barking injuries of mature trees is less of a problem, although in southwestern Oregon basal or upper crown “girdling” by porcupines might be confused with damage by bears or tree squirrels (46, 53, 41). Bears frequently leave large strips of bark at the base of damaged trees. Upper bole barking in pines in southwestern Oregon also might be caused by the dusky-footed wood rat, which causes damage that also could be confused with damage by porcupines or tree squirrels. Bark fragments at the base of a tree indicate
barking by squirrels, which remove and discard small strips of bark. This sign is absent under trees barked by wood rats and may be lacking under trees damaged by porcupines.

Clippings of small lateral branches by porcupines or pocket gophers may be undistinguishable. Stem clipping by pocket gophers, however, is usually indicated by the conical stub or the deeply carved stem cutting. Porcupines typically clip stems obliquely, as do rodents, and the individual toothmarks from repeated gnawing are visible on cut surfaces of large stems. Also, porcupines seldom gnaw deeply into sapwood. Both animals leave prominent incisor marks on the exposed sapwood. The small 1/16-inch-wide toothmarks left by pocket gophers are usually distinct from the broader grooves left by porcupines, but the two may overlap, and the presence of toothmarks is not always a diagnostic sign. Porcupines do not eat the outer bark and, unlike pocket gophers, may leave small bark chips around stems of damaged trees. Porcupines may eat some foliage, but usually clip needles to get at the “candles” (new growth).

Gnawing injuries to basal stems may also be caused by voles and usually can be distinguished from barking caused by pocket gophers, porcupines, or rabbits by the fuzzy, roughened appearance of barked stems and the absence of distinct toothmarks.

Clipping of terminal or lateral shoots of small pine seedlings also may be caused by voles and can only be distinguished from clipping made by other rodents by supplemental field signs.

Seedlings should be examined early in the spring after snowmelt. Practically all of the above-ground damage by pocket gophers is done under the snow. Activity of pocket gophers may be identified by earth mounds, soil casts, small seedlings partially or completely pulled below ground, or seedlings tipped abnormally (because of root cutting). Porcupines reveal their activity by droppings, quills, and tracks. Even travelways may be revealed by the pattern of use. In time, however, casts of pocket gophers disintegrate or blow away, injuries become discolored or covered with pitch, and other signs are lost. Also, damaged trees may die, and identification of damage becomes more difficult and less certain.

Above-ground signs for gophers and moles have distinguishing characteristics (56, 43, 34). The earth mounds of pocket gophers are usually fan shaped, and an earth plug marking the burrow entrance frequently forms a visible depression near the edge of the mound. The earth mounds of a mole are roughly circular, often have a lumpy appearance, and lack soil plugs. The underground runways of moles, unlike those of pocket gophers, often form raised ridges in the surface of the ground. Mounds of pocket gophers tend to be irregularly distributed, but molehills are often arranged in an irregular line.

**STATUS AND CONTROL OF ANIMAL DAMAGE**

Emphasis in this review is on population and trends of the principal species that damage trees, nature of damage, damage areas and trends, rating of damage importance, current research on these problems in the region, and recommended controls. Canutt (7) recently considered these factors and mapped recognized problem areas of five groups of animals that included pocket gophers, hares, and rabbits in Oregon and Washington.

**Pocket Gophers**

Five species of pocket gophers in the genus *Thomomys* occur in Oregon and Washington (34). The most important species in the pine region of the two states and the only species in eastern Oregon and Washington is the northern pocket gopher, which is distributed generally east of the Cascade crest. The mazama pocket gopher ranges west of the Cascades and is a major obstacle to regeneration in southwestern Oregon.

Pocket gophers are reported to be increasing. Canutt (7) expects this increase to equal the increase of productive habitats created by clearcutting and wildfires. He also noted that habitat changes caused by increased cutting of lodgepole pine in central Oregon may favor rapid increases in gophers.

Tree losses have been attributed to gnawed roots, clipped and barked stems, and exposure of roots by burrowing (55). Hermann and Thomas (31), found that most damage on ponderosa pine plantations in southern Oregon occurred in winter when gophers tunneled through snow to clip and debark trees. In eastern Washington, gophers have killed many pine trees 1-10 years after they were planted (17).

Principal areas of damage are in the Blue Mountains and eastern and southwestern Cascade Mountains, mainly on large burns and clearcuttings. Canutt (7) reported that many plantings have been destroyed by pocket gophers in the pumice soils of central Oregon. For example, of the ponderosa pine plantations on the Cave Mountain Burn in central Oregon, in 1968, 7 years after planting, 1,600 acres had been lost to pocket gophers (7).

Pocket gophers are rated the principal problem animal in the pine region, and with increased efforts toward rapid regeneration these rodents may become even more destructive.
Regeneration of Ponderosa Pine

Dr. Glenn L. Crouch of the Pacific Northwest Forest and Range Experiment Station is evaluating the effectiveness of herbicide application (Atrazine) and hand baiting to reduce losses of planted ponderosa pines to pocket gophers. He is also studying the relative preferences of pocket gophers for ponderosa, Jeffrey, and lodgepole pines.

The Bureau of Sport Fisheries and Wildlife is cooperating with the Forest Service in a continuing evaluation of the burrow builder, an implement that distributes toxic baits in artificial burrows. Principal objectives of these studies on two ponderosa pine plantations in eastern Oregon are to assess the effectiveness of machine baiting to prevent pocket gopher damage to pine seedlings, to determine the rate of repopulation, and to study the impact of treatment on gopher populations. This evaluation of machine baiting is expected to determine how often problem areas need re-treatment.

The Bureau plans to continue studies to develop control methods for heavy slash areas where the burrow builder cannot operate and to evaluate effectiveness of controlling gopher populations in advance of final harvest and before reforestation. Studies of the pocket gopher’s home range, movements, and food habits are also planned to facilitate development of efficient control methods.

A Forest Service administrative study, begun in 1967, aims to test several techniques for reforesting the Chiloquin burn in central Oregon. The burn was planted with ponderosa pine in 1962, but plantings were mostly destroyed by pocket gophers by 1964. The entire 100-acre study area was treated with Atrazine before applying each of four reforestation treatments, which are: seeding bitterbrush and planting ponderosa pine after bitterbrush becomes established; planting nursery-grown bitterbrush and ponderosa pine seedlings simultaneously; sowing ponderosa pine seed at 5 pounds per acre; and (control) planting ponderosa pine at the same time ponderosa pine is planted in the first treatment. Reforestation techniques are based on the expectation that gophers can be controlled by applying Atrazine to reduce their food supply, and that repopulation of Atrazine-treated areas can be minimized by establishing bitterbrush.

Hand baiting and runway trapping to control pocket gophers on forest areas have been unsatisfactory (7). On range and agricultural lands, extensive control of gophers was achieved with the burrow builder (57). Baiting with toxic compounds is the only control technique proven useful over a wide range of conditions, and is the only current practice that provides a means of coping with extensive problems caused by gophers in forest plantations (10).

Grain or carrot baits treated with strychnine alkaloid were widely used in the past, but Gophacide is recommended for future gopher control because it is less hazardous to other animals and man and is better accepted (2). Efforts to obtain less hazardous, more effective, and more specific poisons resulted in the development of Gophicide [o, o bis (p-chlorophenyl) acetylimidophosphoramideothioate], an organic phosphorous compound that inhibits cholinesterase activity (49). Ward et al. (61) reported that grain baits containing from 0.1 to 0.2 percent Gophacide, properly distributed, gave good control of several species of pocket gophers.

The Forest Service (Region 6) developed a burrow builder, based on the machine developed for agricultural lands (57) to control gophers (8). It was strengthened and modified for work in forest areas. Construction plans for the machine are available from the Forest Service Equipment Development and Testing Center at Missoula, Montana, or the Forest Service, Region 6, Portland, Oregon.

Packing wheels control burrow depth and close the burrow. The baiting mechanism is calibrated to drop baits at about 5-foot intervals, with burrows spaced from about 20 to 30 feet, a rate of about 450 drops per acre. A crawler tractor is recommended to operate the burrow builder over rough terrain. A blade to clear heavy debris facilitates machine baiting in slash or dense cover (2). Canutt (8, 10) listed operational limits of the burrow building with reference to slope, obstructions, soil texture, and soil moisture.

Preliminary evaluation of the effectiveness of the burrow builder in controlling pocket gophers on two ponderosa pine plantations in 1968 indicated over 90 percent control on test plots after baiting (2). The degree of control was estimated by the open-hole technique (49, 58). Damage to seedlings on baited and unbaited areas was not assessed.

The machine operated effectively in areas with large rocks and roots, and usually constructed satisfactory burrows even in dense brush. When the burrow builder can be operated is dependent on soil conditions. On fine-grained, porous pumice soils in eastern Oregon, adequate soil moisture is critical, and treatments probably will be restricted to spring and fall. Spring treatment is suggested, because gopher populations are lowest then. Based on this study (2), treatment should precede planting, if possible, to provide the trees with maximum protection from gophers and machine damage during baiting.

Observations on machine-baited plantations in 1969, 1 year after treatment, indicated that baited areas had been repopulated by pocket gophers and that some damage to pine seedlings had occurred (Personal
Porcupines and their damage are distributed generally throughout the pine region in Oregon and Washington. Population trends may be downward, but the pattern is not consistent (9). In western Oregon, particularly southwestern Oregon, porcupine populations and porcupine damage to ponderosa pine plantations are increasing (9, 20).

The records of the Division of Wildlife Services, in Oregon, show a statewide decline of 37 percent in incidental catches of porcupine between 1954 and 1967. Since 1956, however, the reported catch east of the Cascade Mountains has dropped from 2,159 in 1956 to 782 in 1967—a reduction of about 64 percent. These data are qualified, however, because they also reflect the effects of extensive control of porcupine by poisoning, hunting, and restrictions on trapping predatory animals in eastern Oregon.

Canutt (7) found that porcupine damage is common in eastern Oregon and Washington, but important damage is restricted locally. Respondents agreed that porcupines will remain a chronic problem in the pine region.

The following observations on “Porcupine Devastations” written more than 50 years ago (1) are familiar and might be applicable to some forests today.

“Porcupines are doing an astonishing amount of damage to reproduction and young timber on this district and I would like to stir up all our forces against these pests

“It is very aggravating to ride over an old burn that seems to be restocking when viewed from a distance, only to find that 90 percent of the trees have been ruined by porcupines.”

“The World of the Porcupine,” by Costello (11) discusses the porcupine in Oregon. Written in a popular style, it contains many illustrations, much information on life history, and a comprehensive bibliography.

Damage to pine regeneration results from the porcupine feeding upon the bark and foliage of young seedlings, or bark of the lower branches and main stem of older seedlings and saplings. Young seedlings are often clipped near the ground. Few damaged seedlings survive; barking of saplings suppresses growth and increases the danger of infection by fungi.

Porcupine damage to seedlings and saplings may easily be confused with damage caused by pocket gophers, particularly on plantations exposed to both species.

In mature trees, porcupines chew or strip the bark from conifers and hardwoods. This debarking causes structural deformation of the stem, which lowers the quality of timber and increases chance of infection by insect or disease.

Curtis and Wilson (15) in central Idaho found that porcupines preferred ponderosa pines in the pole class with diameters from 8 to 10 inches. Dodge and Canutt (9) reported that most damage occurs in thinned stands from 10 to 30 years old. Most damage to conifers occurs from the first lasting snowfall until spring thaws. Stand damage may be greater than the proportion of damaged stems would indicate, because in most instances dominant trees are damaged first. Lawrence (36) estimated that an individual porcupine can do as much as $6,000 damage to timber stands in its lifetime.

Porcupines are rated among the least important animals in damaging regeneration and older stands in the pine region, but this damage is expected to increase in western Oregon as more plantations reach sapling and pole size. It may also become more important in eastern Oregon and Washington as regeneration increasingly is based on planting.

Poisoning by means of strychnine-salt blocks has long been the principal method for porcupine control. Dodge (18) showed that sodium arsenite, an herbicide, in powdered form is an effective toxicant. Efforts to control porcupine depredations are currently being practiced by most federal and industrial forestry groups.

Improved bait stations constructed of half-round aluminum culvert have been developed (44) that are more durable than wood and not subject to damage during servicing, maintenance, or relocation. Salt blocks
can be attached without nailing. The aluminum stations are light weight and easily portable. Neitro (44) also lists protective measures to minimize the risks of killing nontarget animals.

Dodge (19) described a wire basket and plastic-bag covering developed to improve safety in use of poisoned salt blocks. The plastic bag, which is torn away after installation, protects the operator during handling. The basket prevents a partially consumed salt block from falling to the ground.

Flights during the winter are an effective means to rapidly survey susceptible plantations (20). Ground personnel, equipped with suitable snow vehicles, can then quickly locate and hunt down the porcupines by tracking on fresh snow.

No repellents exist for the protection of trees against porcupine damage. Tests of TMTD and ZIP have been inconclusive (19). Pentachlorophenol and copper naphthenate (59) are good repellents for use on buildings and signs, but are highly phytotoxic and cannot be used on trees.

Studies of potential attractants for porcupine bait mostly have been negative or inconclusive. Hooven reported that none of the candidate compounds that he tested, which included components of plywood glue and blood meal, appeared attractive to porcupines (Personal communication, Edward F. Hooven, Forest Wildlife Ecologist, Forest Research Laboratory, Oregon State University, Corvallis).

Campbell successfully fabricated and tested particleboard-bait blocks to supplant the standard strychnine-salt blocks for porcupine control (Personal communication, Dan L. Campbell, Biologist, U.S. Bureau of Sport Fisheries and Wildlife, Olympia Field Station, Olympia, Washington). The blocks are a new approach to porcupine baiting. The particleboard blocks are unattractive to livestock and big game. They are small enough (2 inches square) that the amount of toxicant is not harmful to large animals. Therefore, baits need not be protected, or permanent bait stations maintained. This will permit “saturation baiting” or placing multiple baits in porcupine-infested areas rather than relying on a few, widely spaced bait stations. Materials that repel livestock or big game, but are neutral or even attractive to porcupines also may be added to the blocks to increase the effectiveness of this baiting technique.

Recent research has included studies to replace strychnine in the traditional salt blocks with a safer toxicant. Gophacide has shown promise for this purpose (Dodge, personal communication).

Current research includes evaluation of porcupine bait attractants conducted in separate studies at Oregon State University and by the U.S. Bureau of Sport Fisheries and Wildlife, at Olympia, Washington. The research at Olympia, conducted by Dan L. Campbell, includes plans for small-scale field tests of toxic particleboard blocks to control porcupines. Radiotelemetry techniques will be used in evaluating porcupine response to baits. Dr. Wendell E. Dodge, Bureau of Sport Fisheries and Wildlife, Olympia, is continuing his studies of the movements of porcupines west of the Cascade crest in Oregon.

**Deer and Elk**

The mule deer is the most common species of deer in the ponderosa pine region, but black-tailed deer and white-tailed deer also occur. Deer occupy, year-round or seasonally, nearly all forested land in the pine region of Oregon and Washington. Because of the migratory habits of the mule deer, however, most damage to plantations occurs during annual migrations in spring and fall. Plantations at high elevations may be exposed to browsing damage only incidentally or not at all. Conversely, plantations at lower elevations on winter ranges may be subjected to injuries from prolonged and heavy feeding of deer (14).

East of the Cascade Range, fall and winter browsing prevail (14), although in some areas most browsing occurs in late winter or spring (22). Browsing of conifers on winter ranges of deer is usually most apparent during severe winters when deer are concentrated on limited areas. Browsing during the dormant season also occurs in fall on migration routes through plantations (14, 23).

The amount of browsing damage by deer may vary from year to year or seasonally despite fairly constant numbers of deer (33, 12). Many other environmental factors are involved. In the Tillamook Burn, Crouch (12) found that the rate and intensity of deer browsing Douglas-fir was affected by deer numbers, weather conditions, elevation, and forage availability. He identified the relation between deer numbers and weather conditions of foremost importance. Presumably, similar factors influence behavior of deer in the pine region.

The main effect of deer and elk browsing is to suppress growth of trees. In evaluating effects of browsing, note that stand damage occurs only when enough trees have been damaged to reduce or delay total yield (16). Direct mortality may occur when seedlings are pulled out of the ground or trampled, but this is usually confined to the first year after planting and is uncommon.

Treatment of seedlings in the nursery with a foliar repellent before lifting and, in some instances, re-treatment of seedlings by hand sprayer after planting is the best procedure available to protect pine seedlings.
from browsing by big game. Mechanical protection has been used in some instances, but it is too costly for most applications (21, 23, 54). Talich and Inman (54) reported effective protection of heavily damaged ponderosa pine plantations by covering about 100 selected seedlings per acre within the most severely damaged portions of the plantation with brush or wire cages. Mealey (40) reported that effective protection of Douglas-fir plantations subjected to big-game browsing was provided by fencing with nylon netting, but that it was costly and required frequent maintenance.

In early field tests with repellents on ponderosa pine seedlings in central Oregon, Besser and Welch (3) reported that browsing by mule deer on seedlings treated with TMTD (tetramethylthiuram disulfide) or ZAC (zinc dimethylthiocarbamate-cyclohexylamine complex with Rhoplex AC-33) was reduced by 73 percent. Heidman (30) also reported that these repellents, TMTD and ZAC, applied to established ponderosa pine seedlings at the beginning of the growing season were equally effective in reducing deer browsing. Field tests (22) with newly planted ponderosa pine seedlings showed comparable results. Driscoll (22) concluded that ZAC provides the most protection on a year-round basis. He also reported that covering seedlings with brush reduced deer browsing.

In recent field trials, Frewing (23) and Drahos (21) reported ZIP (ZAC with polyethylene polysulfide) more effective than TMTD in protecting pine seedlings from deer. They also recommended re-treating seedlings in the field for the first 2 or 3 years after planting.

Research continues for more effective repellents. The Denver Wildlife Research Center (DRC) is testing deer repellents on ponderosa pine seedlings in clearcuttings and brushfields on the Sierra National Forest in California (Work Unit No. DF-103.4). TMTD and ZIP are being used as standards for comparison with candidate DRC compounds and plastic netting.

Radwan (49) has compiled a comprehensive review of literature on systemic and contact repellents. In 1969, Radwan (50) also extensively reviewed the current status of TMTD.

We need to know why deer choose among forage plants, to be able to predict the effects of changes in the ecosystem on damage by big game. A study by Longhurst et al. (38) on the role of natural plant products in inhibiting browsing is continuing in cooperation with the Forestry Research Center of Weyerhaeuser Company. Deer detect the plants they prefer primarily by odor, and these studies of the mechanism of repellency may lead to increased effectiveness in repellents.

Crouch (13) suggests that habitat modification may have the greatest potential to alleviate or avoid deer browsing problems. He listed several ways of changing forest environments that show promise for reducing or eliminating the problems.

The Rocky Mountain elk is the most common species of elk in the ponderosa pine region. The Roosevelt elk also occurs in the pine region of southwestern Oregon.

Little work has been reported on the effects of elk on ponderosa pine regeneration in Oregon and Washington. Harper (25) found that Roosevelt elk damaged Douglas-fir regeneration in southwestern Oregon only on isolated areas, and this damage was influenced by environmental factors, which included time after logging, treatment of slash, type of logging, habitat type, and proximity to cover. Soil disturbance during logging and slash burning after logging extends the period of forage production and big-game use. The reduction of total vegetative cover by burning and the associated growth of grasses and forbs makes the burned areas favored feeding sites for elk. On cutover areas surveyed for damage to Douglas-fir regeneration, about half of the stands used continually by big game were older than 8 years, and 86 percent had been burned after timber removal.

**Livestock**

Ponderosa pine forests are the most extensive and most important forest grazing areas in North America. In Oregon and Washington, about 25 million acres of forest grazing land furnishes seasonal forage for 250,000 cattle and nearly as many sheep (51). Mule deer and Rocky Mountain elk use the same ranges spring, summer, and fall.

Grazing by cattle and sheep is common throughout much of the ponderosa pine region in Oregon and Washington and in the mixed coniferous stands in northeastern Oregon. Some damage to young seedlings is caused by trampling, but most damage to plantations is caused by browsing, especially browsing of the new shoots or "candles" in late spring. This damage is usually indistinguishable from browsing by big game and can only be identified positively by additional information, such as season of use.

Studies of the effects of forestry and grazing practices in northeastern Oregon have revealed a correlation between the amount of forage available for grazing animals and the density of the forest canopy (28, 60). Four main categories of practices in livestock management were found to improve patterns of forage use in these areas (28): facilitating actions, especially the integration of logging and grazing plans; class of livestock; methods to improve livestock distribution; and proper season of use.
An understanding of the competition between big game and livestock and the factors that influence this relation are essential to predicting and controlling potential damage on pine plantations.

Competition between livestock and big game is influenced by the nature of the forage, the intensity and season of grazing by livestock, and the ability of the land manager to control or improve the distribution of grazing animals (29). Hedrick (29) showed that livestock on forest-game ranges can be beneficial, neutral, or detrimental to forest or game management. He concluded that proper grazing by livestock tends to minimize competition with game animals.

Skovlins et al. (50) studied the relation between grazing of big game and cattle on a typical ponderosa pine -bunch grass range, similar to much of the summer habitat of big game in the pine region of eastern Oregon and Washington. They found that year-to-year differences in amount of deer or elk grazing were mainly a function of the length of grazing during the winter. Deep snows and cold weather may restrict grazing of winter ranges by big game. Conversely, greater big-game use may occur after “open winters”. These studies also disclosed important differences in big-game use because of terrain and the relation to either winter or summer range. They concluded that grazing by both livestock and big game can provide efficient cropping of the forest resource as long as proper use of important species is maintained.

Hedrick and Keniston (unpublished) are studying the effects on pine regeneration of controlled grazing by cattle and deer on a clearcut, burned, and planted grand fir site in northeastern Oregon. Conifers evaluated include ponderosa pine, Douglas-fir, western larch, western white pine, Engelmann spruce, grand fir, and lodgepole pine. Seedlings were planted in April 1965 within three 5-acre enclosures fenced for cattle; one was fenced to exclude deer and elk. All of the plantations were grazed by cattle during the summer, beginning 1 year after planting. Seven captive deer were penned in the deer enclosure for 2 months in the spring of 1969. Examinations in June 1969 showed that animals had browsed, trampled, or buried more ponderosa pines than the other species tested. Most of the seedlings were damaged repeatedly. Deer and elk caused more damage than cattle. A small amount of damage was caused by rodents, and two trees were injured by badgers. Animals, predominantly deer and elk, caused more seedling mortality of ponderosa pine (51 percent) than was attributed to natural causes, mainly undiagnosed physiological causes other than drought.

These studies suggest that combined use by big game and livestock may promote better range utilization on mixed conifer sites without significant damage to conifer regeneration. Coordinated forest and range management programs are needed to more fully realize the timber and forage potential in the mixed coniferous forests of this area (60).

Hares and Rabbits

Clipping damage by hares and rabbits is principally caused to new plantations during the dormant season. Severe clipping damage to older plantations may occur when terminal leaders of seedlings are exposed above deep snow. Hermann (32) noted that few pine seedlings were killed directly by rabbits, but many seedlings were injured by rabbits so severely that they did not recover.

Pedersen (45) reviewed damage caused by rabbits and hares, and control practices. He also described the technique of baiting with strychnine-treated apples.

Treatment of seedlings with TMTD before planting provides some protection against clipping by lagomorphs (3) that can be extended by re-treatment of new growth after planting. Repellents are recommended for all seedlings before out-planting. Hartwell (26) did not consider baiting a satisfactory method for controlling snowshoe hares on Douglas-fir plantations. Planting large (2-2), TMTD-treated seedlings, however, eliminated most clipping damage by hares.

Rabbit damage to first-year planted loblolly pines was reduced significantly by protecting the trees with perforated polyethylene sleeves (39). The seedlings were planted inside a perforated polyethylene sleeve, which physically prevented rabbits from clipping the tree. Campbell (6) reported that sleeves of polypropylene plastic netting (Dupont “Vexar”) placed on individual Douglas-fir seedlings prevented summer browsing by deer during the growing season and clipping of dormant seedlings by snowshoe hares. The only adverse effect of the plastic netting on seedlings reported was tipping of small stems, which was overcome by planting the tubes with small 2-0 seedlings.

No research is in progress or planned on hares and rabbits in the pine region of Oregon and Washington (8).

SUMMARY AND CONCLUSIONS

Many speakers at this Symposium referred to some aspects of animal damage in their reports and most reported having been confronted with these problems in pine regeneration. All were persuaded of the importance of animal damage throughout the ponderosa pine region. The Symposium emphasized the ubiquity and diversity of these problems throughout the region and the differing importance of a particular problem in different parts of the region.

Surveys and case histories of plantation failures have demonstrated the critical importance of
animal-caused problems in the pine region. I have reviewed the need for repeated and timely examinations of plantations and for correct identification of animal-damage problems before controls or preventive measures can be applied.

Pocket gophers are rated the number one problem animal in the pine region in Oregon and Washington and with increased efforts towards rapid regeneration these rodents become more destructive. Herbicides to control gopher damage have some promise, but machine baiting appears the best method available. Preliminary studies demonstrated the effectiveness of the forestland burrow builder, but rapid repopulation by pocket gophers of baited areas may require repeated treatments. Tests with Gophacid in since 1961 have demonstrated its effectiveness in controlling gophers, and it is the toxicant of choice.

Our knowledge of animal problems in the ponderosa pine region is limited. The relations of livestock, big game, and other wildlife to reforestation are complex and not well understood. For example, little is known about the influence of forest-management practices on deer ecology. Logging, slash burning, conifer planting, fertilizing, thinning, and herbicide application all cause profound changes in vegetative composition and abundance, which in turn regulate the numbers and conditions of wildlife (13). With the trend towards more intensive forest management in the region, which results in shorter rotations and more rapid regeneration, the need for more ecological studies of forest-wildlife relations is urgent. Resolving deer-reforestation conflicts in the region will always require close cooperation between foresters and game and range managers.

LITERATURE CITED


**Regeneration of Ponderosa Pine**

**CHECKLIST OF PLANTS AND ANIMALS**

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Scientific Name</th>
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<tr>
<td>Douglas-fir</td>
<td><em>Pseudotsuga menziesii</em> (Mirb.) Franco</td>
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<tr>
<td>Grand fir</td>
<td><em>Abies grandis</em> (Dougl.) Lindl.</td>
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<td>Western larch</td>
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<td>Lobolly pine</td>
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<td>Englemann spruce</td>
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TRI SYSTEM—TOTAL RESOURCE INFORMATION FOR LAND MANAGEMENT

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TOTAL RESOURCE INFORMATION SYSTEM, OR TRI SYSTEM, is a user-oriented system for storage and retrieval of information on the resources of a specific area of land. The Forest Service today employs many people for various programs on management of resources on each administrative unit. Any activity can influence the total environment of an area and affect the ability of an area of land to sustain other activities. To evaluate proposed activities, each person needs access to the total information available on the resources of the area that will be influenced by his decisions, and on the status of other activities in that area.

ONE PERSON MAKES THE DECISION, ultimately, to conduct a management activity. The data he needs to make a sound decision may have been gathered for years by other people. Often much of this information is unavailable to the manager because he may be unaware that it has been collected, may not know where to look for it, or cannot find it. Perhaps it was collected, but not recorded. Or, it may have been recorded in a summary that does not give specific data for a portion of the area.

Region Six spends over one million dollars annually on surveys of timber stands, reforestation and timber stand improvement, range analysis, wildlife habitat, insect and disease control, and hydrology. Most of this information benefits specific projects. But much of it, which has long-term value to all land managers, soon becomes unavailable except to the person who collected it. Where information storage systems do exist, they are usually designed to handle data for a specific function. Data on the resources and activities on a specific area may be stored in several separate systems. Bringing together data that pertain to one area is difficult and sometimes impossible. As more sophisticated functional systems are developed, this problem will be magnified.

The theory behind the TRI System is simple. As information pertinent to a specific area of land becomes available, it is stored in a system with a central index. All information on any area is available to any person who needs it. Information is segregated by the area to which it pertains, not by functional areas of responsibility. The person faced with a decision does not have to assemble data from numerous sources. Duplication in collection and storage of data is eliminated.

Data need not be collected to permit installation of the TRI System. The TRI System is concerned with the storage and retrieval, not the collection of data. When the system is first installed on an area, any available data may be stored in it. As data are collected for specific projects, they will be added. Additional data should be collected as needed. Data may be added at any rate desired. To collect information because of the system, or to collect data for no specific purpose, is unnecessary.

ADMINISTRATIVE UNITS

The TRI System, with a unique indexing system, permits storage and retrieval of data for any land area. The entire area in an administrative unit is subdivided into cells, the basic building blocks of the TRI System.

Cells

A cell is “an area of land of any size or shape for which data is to be stored separately from adjacent land areas.”

The boundary of each area for which data are to be stored is marked on a photo mosaic of a land area. These boundary lines will often cross. When lines have been drawn, to separate all areas for which separate data storage is required, each of the resulting areas between the lines is a cell. Cell boundaries can be changed any time to permit storage of information on a different area. The ability to retrieve previously stored data is not affected by a change in cell boundaries. Each cell is identified by a number. The cell number is only for identification and bears no reference to the physical location of the cell. Cell location is determined by a system of compartments and grids.

Compartments

On a small area, the location of an individual cell could readily be found by looking at the mosaic where the boundaries and cell numbers were shown. On a large area, however, finding the location of an individual cell, without an indication of where to look on the mosaic, would be a lengthy task. To provide geographic location for the cells, without depriving them of their flexibility, the administrative unit where the system is to be
installed is subdivided into smaller areas of land with boundaries identifiable on the ground. Each of these areas is called a compartment. Each compartment is identified by a number and name. The size of the compartment is limited primarily by the physical size of the mosaic for the compartment. The mosaic should not be too large for convenient use on top of an office desk. Each compartment is subdivided into cells. And the cells do not cross compartment boundaries. The compartment serves to locate the cells within it.

With suitable identifiable features, compartment boundaries are selected to coincide with political and administrative units for which data must be frequently summarized. Changes in compartment boundaries may be made as needed and do not require changes in previously recorded data.

**Grids**

To further aid in location of cells within a compartment, a coordinate grid is superimposed on each compartment. And each grid square is identified by a letter and a number. Cell numbers are expanded to include the identity of the grid square in which the major portion of the cell falls. If cell 127 was primarily in grid square C4, the cell number would be 127C4. Cell boundaries do cross grid lines. On surveyed land, the grid is established to coincide with section lines. Even though cell boundaries overlap grid squares, data may be roughly summarized by section or township. With the grid identification, one can locate any cell by scanning only a very small area of the mosaic.

**Project Areas**

Data on management activities such as harvest of timber, range revegetation, stand improvement, and control of insects are different from the data on status of resources such as timber volumes, density of forage, and soil types. To permit efficient handling of these two different types of data, they are stored separately. Data on status of the resource are stored for each cell. Data on activity are stored for each project area. A project area is land where a specific activity is to be conducted. Each physically separate area where an activity is to be conducted becomes a separate project area. A project area may be a part of a cell, all of a cell, or more than one cell. If the project alters the resource characteristics on a portion of a cell, a new cell boundary is usually established. A project area does not stop at the compartment boundary, and may lie in one or several compartments. Project areas are identified by the numbers of the compartments and cells within which they lie.

**PARTS OF THE TRI SYSTEM**

The major components of the TRI System are shown in Figure 1.

**Index**

The index of the system consists of a compartment locator map for each ranger district and an index for each compartment. The compartment locator map is a planimetric map showing boundaries, names, and number of compartments. The compartment index is an aerial photo mosaic at about the scale of the current resource photography. Boundaries and numbers of cells are entered on it in black India ink. The mosaic, with a mylar overlay fastened to it, is mounted on cardboard. The boundaries of all project areas within the compartment are drawn in pencil on the face of the overlay. Each is identified by the type of activity involved. The boundaries of all management units for multiple use that are designated on the multiple-use map of the ranger district are drawn on the reverse side of the overlay in red pencil. Each is identified by its designation from the multiple-use map. The compartment index serves to locate the cells for which data are stored in the computer file and to locate project areas for which data are kept on activity records. Only one copy of the compartment index is maintained. And this is kept at the office of the ranger district.

**Computer File**

The computer file is a magnetic tape record containing a summary of information for each cell. Only items significant to treatment decisions are stored in the computer file. The computer file, however, provides a reference to all additional data on a cell. These additional data are stored either in the activity records or the microfilm file. The format and information content of the computer file can be changed as needed to improve its practicability or satisfy needs of changing information. If a change is made, the computer is programmed to put the data in the computer file into the new format.

A printed listing of all computer-file data for cells in each compartment is stored in a pocket on the back of each compartment index. This provides easy access to stored data for any specific land area at the office of the ranger district. To add or delete data, entries are made on this listing in red pencil. Periodically, these sheets are sent to the computer center, changes are entered on the magnetic tape, and an updated listing is returned to the district.

If information is desired on a specific cell or cells, it can be read directly from the printed listing for a specific compartment. If it must be summarized for
areas of land or cells having common characteristics, a request for an extract listing from the computer file is sent to the computer center. The data stored for each cell are examined by the computer. Cells containing the desired characteristics are identified. The total information stored for each of these cells is printed and sent to the requesting unit. This type of listing can provide a complete inventory for a specific resource, besides a quick and accurate answer to the common question, "How much of this and that have we got, and where is it?" Because all data stored on a cell are extracted as a unit by the computer, to overlook the fact that certain areas are in landscape-management areas or range allotments is impossible.

Activity Records

An activity record card is established for each project area. On this card are recorded data on planned work and work progress on a project area. As the data recorded for different activities vary widely, several different formats for activity records are used. Each type of activity has a card of a different color. The cards measure 8½ by 11 inches. The format of activity records can be changed as needed without changes on cards already established.

Each activity record includes a large-scale map of the project area. It provides space to enter items of information required for directing the activity and ample room for entry of descriptive comments. When a project area is selected for treatment, an activity record card is filled out. The area is entered on the compartment index overlay, and the activity is noted in the computer file. When the type of activity will make it desirable to store data on the area separately, a new cell is established and the project is drawn on the overlay.

Inquiries for data on active projects can be answered by reference to the activity record card for each project area. While an activity is in progress, data are entered on the card currently by the person who does each job. All reports of accomplishment are prepared from data on the activity records. These records will also supply information on accomplishment for cost accounting.

When an activity is completed, data on the type of treatment, time of completion, and changes in status of the resource caused by the treatment are posted from the completed activity record to the computer file. The computer file refers inquiries for data on completed activities to the microfilm file, where an image of each completed activity record card is stored. After microfilming, the completed activity record may be destroyed.

Field Examination Records

All information collected in the field on the status of any resource that can be indexed by land area is entered on a field-examination record. These records may take any form, but they must show plainly the compartment and cell numbers of the area in the upper right-hand corner of each sheet. The field-examination records provide selected items of information to be recorded in the computer file. An image of each field-examination record is stored in the microfilm file. After microfilming, the field-examination record may be destroyed. The computer file refers inquiries for detailed information to the microfilm file where the image of the field-examination record is stored.

Collection of field-examination data and the establishment of record formats are functional responsibilities. The data, stored in the TRI System, are available to all users. The field-examination record may be as simple as a note written on a piece of paper, or as
detailed as a copy of the computer output from a complex program of compilation.

Microfilm File

Microfilming is done at the end of each 6-month period, January through June and July through December. The microfilm file for each period includes one or more microfilm cards, 4 by 6 inches for each compartment. Each of these cards is called a microfiche. The microfiche for each compartment includes images of the index, newly updated computer-file printouts, all activity records completed in the preceding 6 months, and records of all field examinations conducted in the preceding 6 months. If necessary, data for a compartment may be continued on an additional microfiche card.

A complete copy of the microfilm file is maintained at each ranger district and the supervisor’s office. Retrieval of data is possible at either location. Each ranger district has a microfilm reader, and each supervisor’s office has a reader-printer to permit retrieval of hard copies of documents, if necessary.

The microfilm file is the key to the flexibility of the TRI System. Although the boundaries of cells and compartments may change, all past data are recorded with the compartment index that pertains to it. The microfiche file for each period is completely indexed on its own, and subsequent changes do not affect it. The history of activity on any area can be quickly traced back, provided records are available, with no loss in continuity because of changes in record format or indexing. The microfilm file provides unlimited capacity for storage. It will accept any data that can be indexed by land area, regardless of format or content. Data cannot be “lost in the file”. And positive indexing that permits retrieval of data on any specific area eliminates browsing through reams of irrelevant data.

STORAGE FOR OVERLAPPING RESOURCES

Figure 2 shows how data, for several resources on the same area of land, would be stored and retrieved.

When initially storing this data in the TRI System, all of these lines would be transferred to the mosaic as cell boundaries. Each area bounded by lines would become a cell and would be identified by a number as in Figure 3.

All available data applicable to each cell would be stored in the computer file. The computer file would store the fact that cell 6 was in a stand of scattered pine poles, was a part of a campground area, was in a range allotment, and that the range forage consisted of fescue in good condition.

Figure 2. Three functional areas of concern on the same area of land.

To restore the data to its original form, cells having common characteristics can be grouped by the computer. If we wished to retrieve data on the campground, the computer would extract and list all data in cells 6, 8, 11, and 15. Not only would data stored by Recreation be retrieved, but also data on the type of range in cells 6 and 8, and the fact that the timber stand in cells 11 and 8 is different than the timber stand in cells 6 and 15.
DATA ON STREAMS, FISH, AND IMPROVEMENTS

Data on stream flow, fish habitat, and physical improvements are not best suited to indexing by land area with the cell as a data storage unit. Individual streams, roads, or campgrounds, however, on a ranger district or forest can be numbered. And data for each can be stored in a sub-system. These sub-systems can be related directly to the TRI System index on the basis of land areas involved. The TRI System index provides a means for combining related data, based on the land area influenced by items in each sub-system. Several possible sub-systems are shown in Figure 4.

The Transportation System Inventory and Plan and the RIM System (Recreation Information Management System) are examples of existing systems that could be incorporated with the TRI System Index.

With the TRI System and related sub-systems established, data on the forage with a specific range fence, on the volume of timber tributary to a certain road, on the number of non-stocked cutover acres draining into a certain portion of a stream, or on the condition of vegetation on a slope served by a certain ski lift could be retrieved. Also, complex correlations could be made to evaluate combined effects such as the relation of the number of miles of road in a drainage, the erodability classification of soils crossed by the roads, and the observed rates of sediment in the streams involved.

PERSONNEL REQUIRED

All work on the installation of the TRI System can and should be done by the regular staff of each ranger district. The only item best done by outside personnel is the construction of the photo mosaic for the compartment index. The task of installation can most effectively be spread over 2 years. One staffman in the supervisor's office can be assigned to supervise the installation job and provide necessary training and technical assistance.

The TRI System will not add to the paper work of the personnel of the ranger district. Each person who gathers data or conducts activities has the responsibility for entering data in the TRI System. Usually each item must be written down only once. It is then available to others and for summarization into plans or reports. Summarization of data required for plans and reports can be done by clerical personnel or by the computer, depending on the data required. With the TRI System, a

Figure 4. Sub-systems related to the TRI System index on the basis of the land areas involved.
net reduction of time spent providing information to all levels of management should result.

QUESTIONS IN ITS USE

Our experience today shows that people will accept and operate a system as complex as the TRI System, because it provides direct benefits. In our test installations, a significant improvement in the quality of recorded data occurred as soon as people found that the data stored in the system were available to assist them in their work.

Although some of the components of the TRI System, such as the computer file, are complex, operation of the system to store and retrieve data is simple. The TRI System is complex in design, but simple to operate.

If maintenance procedures are not carried through, the system will continue to operate as designed. Although certain information may be missing when looked for, omissions may be rectified as recognized. The actual function of the system for storage and retrieval is unaffected by any failure to maintain data as prescribed.

The system itself places no constraint on the activities of the resource manager. He is free to make decisions, even wrong decisions, and to apply treatments to areas he selects, regardless of the way data are stored in the system. The availability of complete data to answer specific questions will improve the quality of basic land use and treatment decisions by permitting choice of best available alternatives, not by predetermining choices because of specific conditions.

The TRI System is not yet in its ultimate form and probably never will be. The ability to change to meet changing needs in information is a basic characteristic of the system. Its capacity for expansion and improvement is limited only by the imagination of the user. Because of its adaptability, no apparent reason exists for the system to become obsolete in the foreseeable future.

The cost to install the TRI System is shown in Table 1. This cost can reasonably be amortized over a 10-year period to make the annual cost per forest for the first 10 years $4,700 per year. For each subsequent 10-year period, new mosaics should be prepared, and microfilm equipment should be replaced as necessary. Costs for each subsequent decade will probably be about 70 percent of initial installation costs.

After the initial installation is completed, updating of information in the system is the responsibility of the users. A number of presently maintained records will no longer be needed. Maintenance of information in the TRI System should be less costly than maintenance of present records.

An additional annual cost for microfilm supplies, processing, labor, and equipment maintenance will amount to about $1,000 per year per forest.

The TRI System for the first decade, for a single forest, would cost $4,700 for installation and $1,000 for maintenance. Therefore, the total annual cost would be $5,700.

Not included in the estimate of cost to forests is computer programming and computer use. Initial writing of programs cost Region Six about $9,000. Annual cost of revision and maintenance of programs is estimated at $5,000 for the Region. The cost of

<table>
<thead>
<tr>
<th>Cost item</th>
<th>Computation</th>
<th>Cost</th>
<th>Part of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mark compartment boundaries on photos</td>
<td>(120)(6)($5.00)</td>
<td>$3,600</td>
<td>8</td>
</tr>
<tr>
<td>Mark compartment index mosaics¹</td>
<td>(450)($50.00)</td>
<td>22,500</td>
<td>48</td>
</tr>
<tr>
<td>Mark cell boundaries, record data</td>
<td>(4)(450)($5.00)</td>
<td>9,000</td>
<td>19</td>
</tr>
<tr>
<td>Measure compartments and cells</td>
<td>(2)(450)($3.00)</td>
<td>2,700</td>
<td>6</td>
</tr>
<tr>
<td>Make record for each active area</td>
<td>(1/4)(300)(6)($5.00)</td>
<td>2,250</td>
<td>5</td>
</tr>
<tr>
<td>Microfilm equipment</td>
<td>---²</td>
<td>4,814</td>
<td>10</td>
</tr>
<tr>
<td>Maps, mylar, cabinets, supplies</td>
<td>---</td>
<td>1,800</td>
<td>4</td>
</tr>
<tr>
<td>All</td>
<td></td>
<td>47,000</td>
<td>100</td>
</tr>
</tbody>
</table>

¹By contract.

²Camera and film loader shared by 3 forests (1/3 x $6,400), one Microfiche reader per district (6 x $233), one reader-printer for supervisor's office ($1,283).
computer and keypunch per forest, with the system in operation, is estimated at $1,500 per year. An additional cost per forest for initial data entry in the first year is $7,000. These costs are based on operating a single forest. Computer costs can be reduced if several forests are run simultaneously.

Many of the benefits of the TRI System are intangible. Table 2 describes some of the benefits expected on a forest with six ranger districts. The amount of savings for each item is a personal estimate. Readers are urged to make their own estimates of savings for these items and others they might think of.

If the estimated annual savings to the region is $399,000 (19 x $21,000) and the total annual cost is $128,100 (Table 3), the estimated net annual savings will be $270,900.

Table 2. Benefits Expected from the TRI System on a National Forest with Six Ranger Districts.

<table>
<thead>
<tr>
<th>Item</th>
<th>Amount reduced</th>
<th>Annual saving</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Districts</td>
<td>Supervisor</td>
</tr>
<tr>
<td>Plans and reports</td>
<td>480</td>
<td>120</td>
</tr>
<tr>
<td>Familiarize new employees</td>
<td>---</td>
<td>320</td>
</tr>
<tr>
<td>Loss of data&lt;sup&gt;1&lt;/sup&gt;</td>
<td>---</td>
<td>320</td>
</tr>
<tr>
<td>Plots for timber re-inventory&lt;sup&gt;2&lt;/sup&gt;</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Data retrieval</td>
<td>96</td>
<td>30</td>
</tr>
<tr>
<td>Duplicate records</td>
<td>480</td>
<td>160</td>
</tr>
<tr>
<td>Duplicate data collection</td>
<td>480</td>
<td>120</td>
</tr>
<tr>
<td>Co-worker communication</td>
<td>576</td>
<td>---</td>
</tr>
<tr>
<td>Revision of projects&lt;sup&gt;3&lt;/sup&gt;</td>
<td>---</td>
<td>200</td>
</tr>
<tr>
<td>Interoffice communication&lt;sup&gt;4&lt;/sup&gt;</td>
<td>---</td>
<td>100</td>
</tr>
<tr>
<td>Time for decision making&lt;sup&gt;5&lt;/sup&gt;</td>
<td>144</td>
<td>60</td>
</tr>
<tr>
<td>Repetition of mistakes&lt;sup&gt;6&lt;/sup&gt;</td>
<td>---</td>
<td>160</td>
</tr>
<tr>
<td>File maintenance, shipping</td>
<td>30</td>
<td>---</td>
</tr>
<tr>
<td>All</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>1</sup>When an employee is transferred.
<sup>2</sup>Plots reduced 20% by supplying data for stratified sampling and stands without sawtimber from computer file and activity records.
<sup>3</sup>By providing data for timely review of projects.
<sup>4</sup>By duplicate microfilm at supervisor's office.
<sup>5</sup>By ready availability of data for planning.
<sup>6</sup>By providing historical record of past activities and mistakes.

Table 3. Summary of Estimated Costs per Year for Region Six with TRI System Operating on All Forests.

<table>
<thead>
<tr>
<th>Item</th>
<th>Annual cost to region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual cost to install on all forests (19 x $4,700)</td>
<td>89,300</td>
</tr>
<tr>
<td>Annual cost to install computer file ($7,000 per forest initially + 10 years x 19)</td>
<td>13,300</td>
</tr>
<tr>
<td>Annual maintenance microfilm file (19 x $1,000)</td>
<td>19,000</td>
</tr>
<tr>
<td>Annual maintenance computer file (5,000 + 1,500)</td>
<td>6,500</td>
</tr>
<tr>
<td>TOTAL</td>
<td>128,100</td>
</tr>
</tbody>
</table>