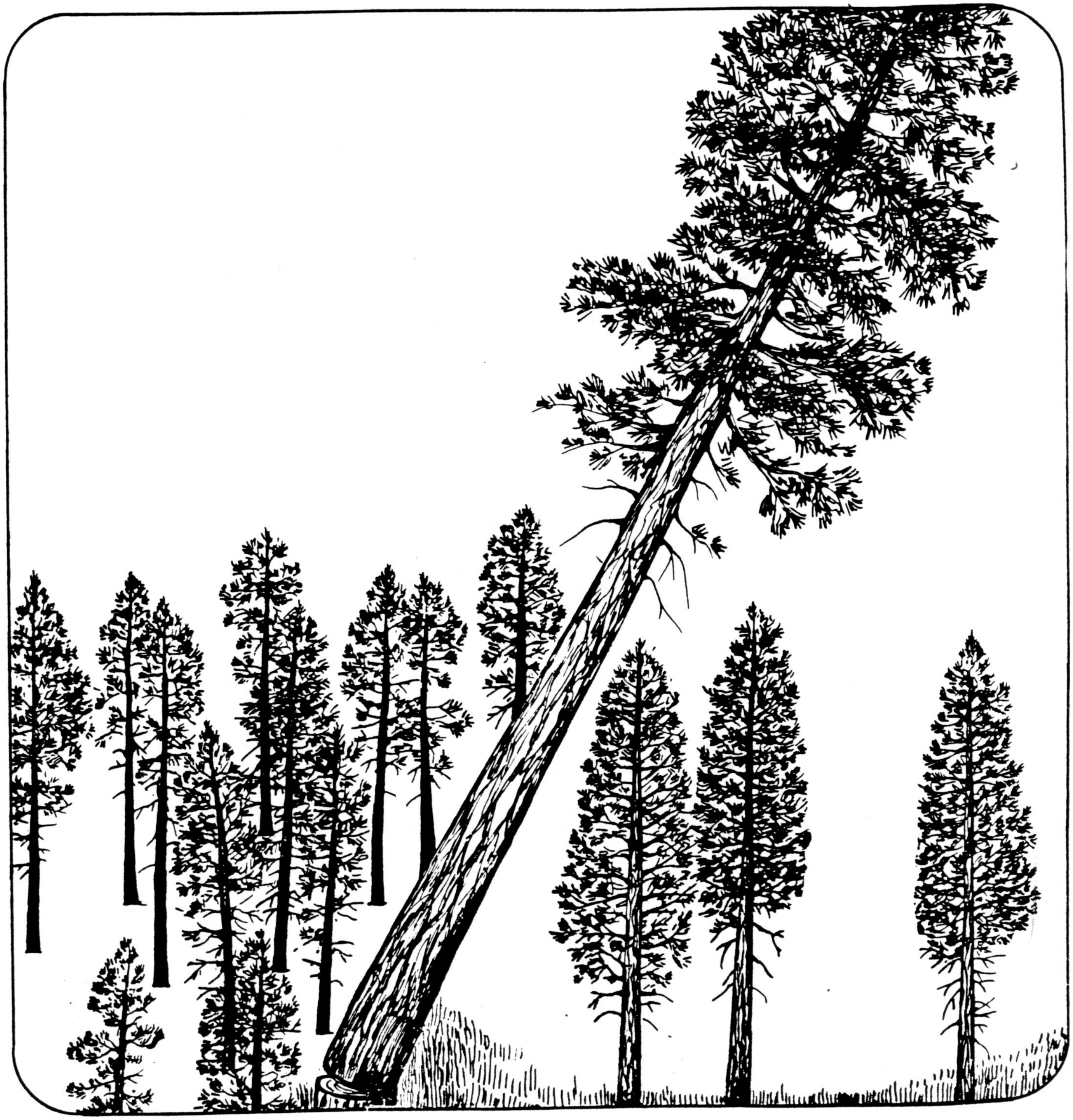
United States
Department of
Agriculture
Forest Service
Pacific Northwest
Forest and Range
Experiment Station
General Technical Report
PNW-97
December 1979

Silviculture of Ponderosa Pine in the Pacific Northwest: The State of Our Knowledge

James W. Barrett



Abstract

The silviculture of ponderosa pine in the Pacific Northwest States of Washington and Oregon is described. The timber resource, growth, and value are discussed first, followed by damaging agents, management, and silviculture. Relevant literature is presented along with observations, experience, and results of unpublished work. Research needs for the future are also proposed.

KEYWORDS: Silviculture, ponderosa pine, _Pinus ponderosa_, Pacific Northwest.

CONTENTS

INTRODUCTION 1

PAST AND PRESENT 2

THE TIMBER RESOURCE 3
Value 3
Commercial Areas and Volumes 3
Harvest and Growth 6

REGIONAL PHYSIOGRAPHIC FEATURES 8

GEOLOGICAL PROVINCES, SOILS, AND PONDEROSA PINE DISTRIBUTION 12
Okanogan Highlands Province 12
Northern Cascades Province 12
Southern Washington Cascades Province 13
Columbia Basin Province 13
High Cascades Province 13
Blue Mountain Province 14
High Lava Plains Province 14
Basin and Range Province 14
Klamath Mountains Province 15

CLIMATE 16

DAMAGING AGENTS 17
Diseases 17
Insects 22
Mammals and Birds 29

ECOLOGY AND SILVICULTURE 33
Compatible Philosophy 33
Ponderosa Pine Plant Communities 33

SILVICULTURE AND MANAGEMENT 36
Planning and Decisionmaking 36
Even Aged or Uneven Aged 37
Treatments 38
Artificial Regeneration 43
Intermediate Cutting 53

GROWTH AND YIELD 66
Juvenile Tree Development and Competition 66
Old, Selectively Cut Stands 74
Tentative Yields of Managed Stands 78

FERTILIZING STANDS 84

USE OF HERBICIDES 85
Need 85
Application 86
Regulations 89

FIRE 89
History and Ecology 89
Fire Effects 90
Prescribed-Fire Options in Ponderosa Pine Stands 90
Planning a Prescribed Burn 91

CONSIDERATIONS FOR THE FUTURE 92

LITERATURE CITED 93

APPENDIX 105

INTRODUCTION

The ponderosa pine[1] forests of the Pacific Northwest have furnished the most accessible timber to farms, mines, and settlements in the central and eastern parts of the Pacific Northwest States since 1860. In addition to a wide variety of wood products, these lands provided abundant grazing for livestock and cover for big game and other wildlife. Recognized as a truly great asset of eastern and southwestern Oregon and eastern Washington, these forests also afford hunting, fishing, camping, and cross-country skiing.

These pine forests are prime examples of how multiple-use management can work; their varied use provides silviculturists with the ultimate challenge. Forest managers are progressing rapidly into intensive management, particularly on the more productive sites. At the same time, managers are being asked to improve forestry practices to protect or improve the forest environment. To meet this challenge, the forester needs a readily available pool of knowledge to make sound management decisions. Fortunately, information about ponderosa pine and its environment has been accumulating for almost 60 years throughout the entire West and for at least 40 years in the Pacific Northwest.

The purpose of this report is to bring together most of what is known about the silviculture of ponderosa pine in the Pacific Northwest. It is intended as a reference for the forest manager and contains the more important facts published about the species in this region plus some previously unpublished data. The silviculture of ponderosa pine for timber production has been emphasized, although other aspects such as grazing, forage for wildlife, and succession have also been touched upon.

I encourage the reader to make use of the literature citations, where more complete coverage will be found. Documented ponderosa pine research cited here comes from throughout the Pacific Northwest, but a notable portion comes from experiments and observations in central Oregon from the USDA Forest Service research facility at Bend, Oregon, and the nearby Experimental Forest, which has a large component of pine. Note that a bibliography on ponderosa pine in the Western United States has been compiled by Axelton (1967, 1974) through 1965 and from 1966 to 1970. With today's computerized library retrieval systems, you need only minutes and a phone call to a major college or university library to be in touch with the latest written information on silvicultural practice. In addition, State and national extension services are available to everyone. Much knowledge and expertise is at hand for solving difficult problems.

Past performance on both public and private land has clearly demonstrated that silvicultural practice is much better based on available knowledge rather than on some personal philosophy founded on suspected influences. When information really is lacking, then keen observation, analysis, and

---

[1] Scientific names of plants and animals mentioned in this paper are given in appendix table 11.

rational decisionmaking are even more necessary. Acquiring knowledge is cheap compared to the resources wasted when operations are conducted in ignorance (Smith 1962).

PAST AND PRESENT

Ponderosa pine forests in the Northwest have been providing useful wood products for over a century. Some cutting for farms, mines, and towns began about 1860, but commercial timber harvesting--mostly on private lands--began late in the 1800's and increased gradually over the next 25 years. Extensive cutting on National Forest land did not begin until about 1910 when railroads were widely available.

On private lands, the first entry was usually an economic clearcutting, dictated by the high fixed cost of railroad logging. Most cutting on Federal lands was by partial cutting, which left some reserve trees for later cuts and as a source of seed. The McGifford and Ledgerwood steam skidders yarded logs into a loading point on the railroad. The old skid trails from these operations are still visible from the air, looking like the spokes of a wheel. Some of the reproduction was apparently already established when the logs were skidded. Fortunately, this has provided some well-spaced stands that grew at acceptable rates for many years after logging.

Logging slash was treated in various ways and frequently without regard to regeneration. Often nothing was done and slash was left to decompose slowly or was broadcast burned as prescribed by State law. If the burning conditions were right, a good seedbed was prepared for the next crop of trees. The only seed trees available after cutting, however, were those unsuitable for milling, never the best trees from the original stand. Occasionally, fires started in the slash from lightning or by human activity and raged out of control over vast acreages. Some of these burned areas developed into brush and remained difficult to regenerate.

After World War II, railroad logging gave way to a new technology based on logging trucks and skidding by caterpillar tractor. The new technology changed the cost basis of the industry and opened the way for management practices that called for lighter cutting on public and some private lands.

Lighter cutting provided an opportunity to reach the vast uncut areas of public land in a short time and to establish a road system badly needed for the suppression of wildfires in the virgin forests. Losses caused by bark beetles during the drought years of the 1930's were so heavy that some foresters thought pine forests would be totally destroyed. Entomologists discovered that they could identify high-risk trees. Not only were these the trees that were the most likely to be killed, but they were also the ones that "produced" more beetles. Consequently, removal of high-risk trees tended to "bug proof" the remaining stand. Light, sanitation-salvage cutting fit in nicely with cutting to "road" the forest for protection.

This type of cutting continued until the early 1960's. Foresters then began to look with admiration at some of the even-aged stands that developed, by good fortune, after the early clearcutting. The trend toward even-aged managing of some stands continues to gain favor among present-day managers.

THE TIMBER RESOURCE

Value

Ponderosa pine dominates about 36 percent of the commercial forest land in eastern Oregon and Washington. The species also occurs as an important component in the mixed conifer stands throughout the pine region. The combined value of products produced from the type in the two States during 1976 was 569 million dollars, indicating that the species is a resource worthy of the most prudent management.

Recent inventories have shown a marked drop in acres of commercial forest land dominated by ponderosa pine. Cutting practice and fire control appear to be the main reasons for this conversion. Periodic ground fires before fire control kept species such as the true firs and Douglas-fir from becoming established in the understories of pure pine stands. With the exclusion of fire has come a massive intrusion of reproduction of other species on the better sites. Thus, when the mature pine is harvested, the land is typed as either mixed conifer or a single species other than ponderosa pine. About 5 million acres are believed to have changed type classification in the last 25 years.

Commercial Areas and Volumes

Stands dominated by ponderosa pine occupy about 6.7 million of the 19.5 million acres (2.71 to 7.89 million ha) of commercial forest land east of the Cascade Range. Only about 4 percent of this total land area in forest is nonstocked. Oregon contains over twice as much land in the ponderosa pine type as Washington.

Oregon has 69 percent of the ponderosa pine growing stock and 71 percent of the sawtimber (table 1). The National Forest System administers about 64 percent of the sawtimber volume east of the Cascade Range in both States; average volume per acre in Oregon is about 13,300 fbm and 12,500 in Washington.

A marked imbalance is now apparent in the size-class distribution. About 73.5 percent of the land is sawtimber, with only 16.5 percent in poles and 10 percent in seedlings and saplings (table 2). This poses a challenge for pine managers over the next several decades. On the encouraging side, much of the land in sawtimber has an understory of seedlings, saplings, and poles in various degrees of suppression.

Table 1--Volume of ponderosa pine growing stock and sawtimber on commercial forest land in eastern Oregon and eastern Washington (1977)[1]

Area	Total growing stock			Sawtimber only		
	Total all owners	ONF[2]	NFA[3]	Total all owners	ONF[2]	NFA[3]
	Million cubic feet (Cubic meters)			Million board feet[4]		
Eastern Oregon	8,257 (234)	2,260 (64)	5,997 (170)	45,672	10,067	35,605
Eastern Washington	3,704 (105)	2,820 (80)	884 (25)	19,095	13,549	5,546
Total	11,961 (339)	5,080 (144)	6,881 (195)	64,767	23,616	41,151

[1] Source: Forest Research Evaluation Work Unit, Pac. Northwest For. and Range Exp. Stn., Portland, Oreg. Prepared for 1980 Resources Planning Act assessment.

[2] Other than National Forest.

[3] National Forests.

[4] International 1/4-inch rule.

Over 50 percent of the land can produce 50 to 80 ft^3 (3.5 to 5.6 m^3/ha) of wood per acre per year (table 3) or roughly 300-500 fbm. Also, encouraging is the estimate that 25 percent of the land area can produce more than 85 ft^3 per acre (5.9m^3/ha) per year.

About 90,000 acres (36 422 ha) (Bassett 1977) or a little over 1 percent of the total land area dominated by ponderosa pine in the region occurs in southwestern Oregon. Ponderosa pine does, however, occur interspersed with Jeffrey pine, true fir, and Douglas-fir types in this area.

Table 2--Area of forest land in the ponderosa pine type by ownership and stand size classes compared with total commercial forest land in 1977 for eastern Oregon and Washington[1/]

Ownership	Stand size class: Sawtimber	Stand size class: Poletimber	Stand size class: Seedlings	All stands	Total commercial forest land	Total in ponderosa pine
	Thousand acres (hectares)					Percent
OREGON						
National Forest	2,390 (967)	440 (178)	297 (120)	3,127 (1 266)	7,046 (2 851)	44
Other public	147 (60)	41 (17)	28 (11)	216 (87)	584 (236)	37
Forest industry	549 (222)	130 (53)	59 (24)	738 (299)	1,627 (658)	45
Private	346 (140)	152 (62)	58 (24)	556 (225)	1,251 (506)	44
All ownership	3,432 (1 389)	763 (309)	442 (179)	4,637 (1 877)	10,508 (4 252)	44
WASHINGTON						
National Forest	337 (136)	48 (19)	28 (11)	413 (167)	2,967 (1 201)	14
Other public	639 (259)	103 (42)	78 (32)	820 (332)	2,268 (918)	36
Forest industry	201 (81)	37 (15)	38 (15)	276 (112)	738 (299)	37
Private	328 (133)	157 (64)	87 (35)	572 (232)	2,193 (888)	26
All ownership	1,505 (609)	345 (140)	231 (94)	2,081 (842)	8,166 (3 305)	25
Total Oregon and Washington	4,937 (1 998)	1,108 (448)	673 (272)	6,718 (2 719)	[2/]18,674 (7 557)	36

[1/]Source: Forest Research Evaluation Work Unit, Pac. Northwest For. and Range Exp. Stn., Portland, Oreg. Prepared for 1980 Resources Planning Act assessment.

[2/]There are 19,516,000 acres (7 898 000 ha) of commercial forest land in eastern Oregon and Washington, but 842,000 acres (340 759 ha) are not adequately stocked with trees.

Table 3--Percent of ponderosa pine type by productivity classes in eastern Oregon and Washington[1]

Ownership	Productivity class (annual growth in cubic feet per acre)			
	20-50	50-85	85-120	120+
	Percent of land area in ponderosa pine			
OREGON				
National Forest	22	59	17	2
Other public	27	48	12	13
Forest industry	26	58	15	1
Private	56	32	10	1
WASHINGTON				
National Forest	27	41	23	8
Other public	12	52	30	6
Forest industry	5	44	40	11
Private	13	48	34	5

[1]Source: Forest Research Evaluation Work Unit, Pac. Northwest For. and Range Exp. Stn., Portland, Oreg. Prepared for 1980 Resources Planning Act assessment.

Harvest and Growth

Annual harvest now exceeds growth in both sawtimber and growing stock volume in ponderosa pine. In cubic-foot growing stock of all ownerships, we are cutting about 50 percent more than growth and in sawtimber, about 80 percent more than growth (tables 4 and 5). On National Forest land, the percentages are even greater. This is not unique to the ponderosa pine type; throughout the entire West, net growth of softwood growing stock in 1970 was about 22 percent less than removals. Net growth of softwood sawtimber was 46 percent less than removals (U.S. Department of Agriculture 1974). These apparent imbalances between cut and growth in the West are not viewed as serious because a large portion of the harvest is from old-growth stands where harvests can exceed growth for some time. In the East, where mature old-growth timber has been gone for many years, net growth (cubic feet) of eastern softwoods in 1970 exceeded removals by 48 percent. As mature ponderosa pine is replaced by vigorously growing young stands, growth will eventually equal and probably exceed cut.

Table 4--Net annual growth of ponderosa pine growing stock and sawtimber in eastern Oregon and eastern Washington (1977)[1]

Half of State	Growth on growing stock			Growth on sawtimber		
	Total all owners	ONF[2]	NFA[3]	Total all owners	ONF[2]	NFA[3]
	Thousand cubic feet (Cubic meters)			Thousand board feet[4]		
Eastern Oregon	119,200 (3 375)	54,000 (1 529)	65,200 (1 846)	518,000	231,800	286,200
Eastern Washington	54,800 (1 552)	48,400 (1 371)	6,400 (181)	310,400	274,500	35,900
Total	174,000 (4 927)	102,400 (2 900)	71,600 (2 028)	828,400	506,300	322,100

[1]Source: Forest Research Evaluation Work Unit, Pac. Northwest For. and Range Exp. Stn., Portland, Oreg. Prepared for 1980 Resources Planning Act assessment.

[2]Other than National Forest.

[3]National Forest.

[4]International 1/4-in rule.

Table 5--Net annual cut of ponderosa pine growing stock and sawtimber in eastern Oregon and eastern Washington[1/]

Half of State	Growing stock			Sawtimber		
	Total all owners	ONF[2/]	NFA[3/]	Total all owners	ONF[2/]	NFA[3/]
	Thousand cubic feet (Cubic meters)			Thousand board feet[4/]		
Eastern Oregon	201,000 (5 692)	92,600 (2 622)	108,400 (3 070)	1,130,800	558,500	572,300
Eastern Washington	66,600 (1 886)	53,500 (1 515)	13,100 (371)	374,600	309,800	64,800
Total	267,600 (7 578)	146,100 (4 137)	121,500 (3 441)	1,505,400	868,300	637,100

1/Source: Forest Research Evaluation Work Unit, Pac. Northwest For. and Range Exp. Stn., Portland, Oreg. Prepared for 1980 Resources Planning Act assessment.

2/Other than National Forest.

3/National Forest.

4/International 1/4-in rule.

REGIONAL PHYSIOGRAPHIC FEATURES

In few other places in the United States can such a variety of landforms be found as in the Pacific Northwest (fig. 1). Elevations range from sea level to over 14,600 ft (4 450 m). Flat river valleys, rolling hills, and precipitous slopes can be found, and frequently these changes in land form occur within just a few miles. As would be expected, a wide variety of soils are found which, in combination with a variable climate, influence the distribution of ponderosa pine and accompanying understory vegetation.

Volcanism in the Cascade Range has greatly influenced soils, although sedimentary and metamorphic rocks abound. Extensive mantles of pumice and ash cover large areas. Because many of these volcanic soils are young and rainfall is limited east of the Cascade Range, little profile development has taken place. Marked changes in the rainfall pattern caused by the Cascade Range rainshadow produce abrupt soil changes.

The highly variable soils and geologic features make silviculture most challenging in this region.

Ponderosa pine occurs as extensive pure stands in 9 of the 15 physiographic and geological provinces (Franklin and Dyrness 1973; Little 1971) of Oregon and Washington (fig. 2): Okanogan Highlands, Northern Cascades, Southern Washington Cascades, Columbia Basin, High Cascades, Blue Mountains, High Lava Plains, Basin and Range, and Klamath Mountains. The species is also found in the Puget Trough, Olympic Peninsula, Willamette Valley, and Western Cascades Provinces. Only those geological provinces where ponderosa pine can occur as the predominant species will be reviewed.

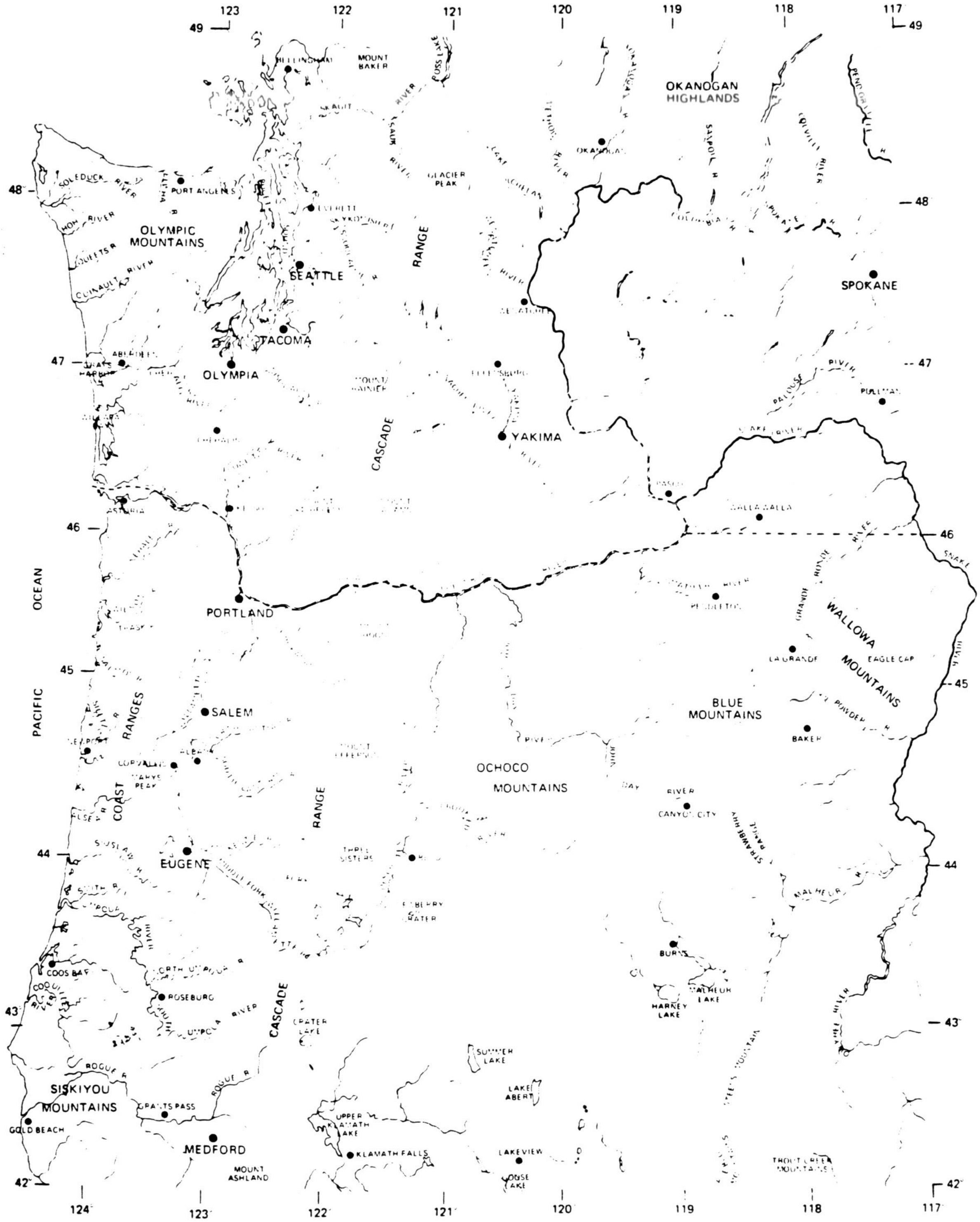


Figure 1.--Major topographic features and some cities and towns in Oregon and Washington.

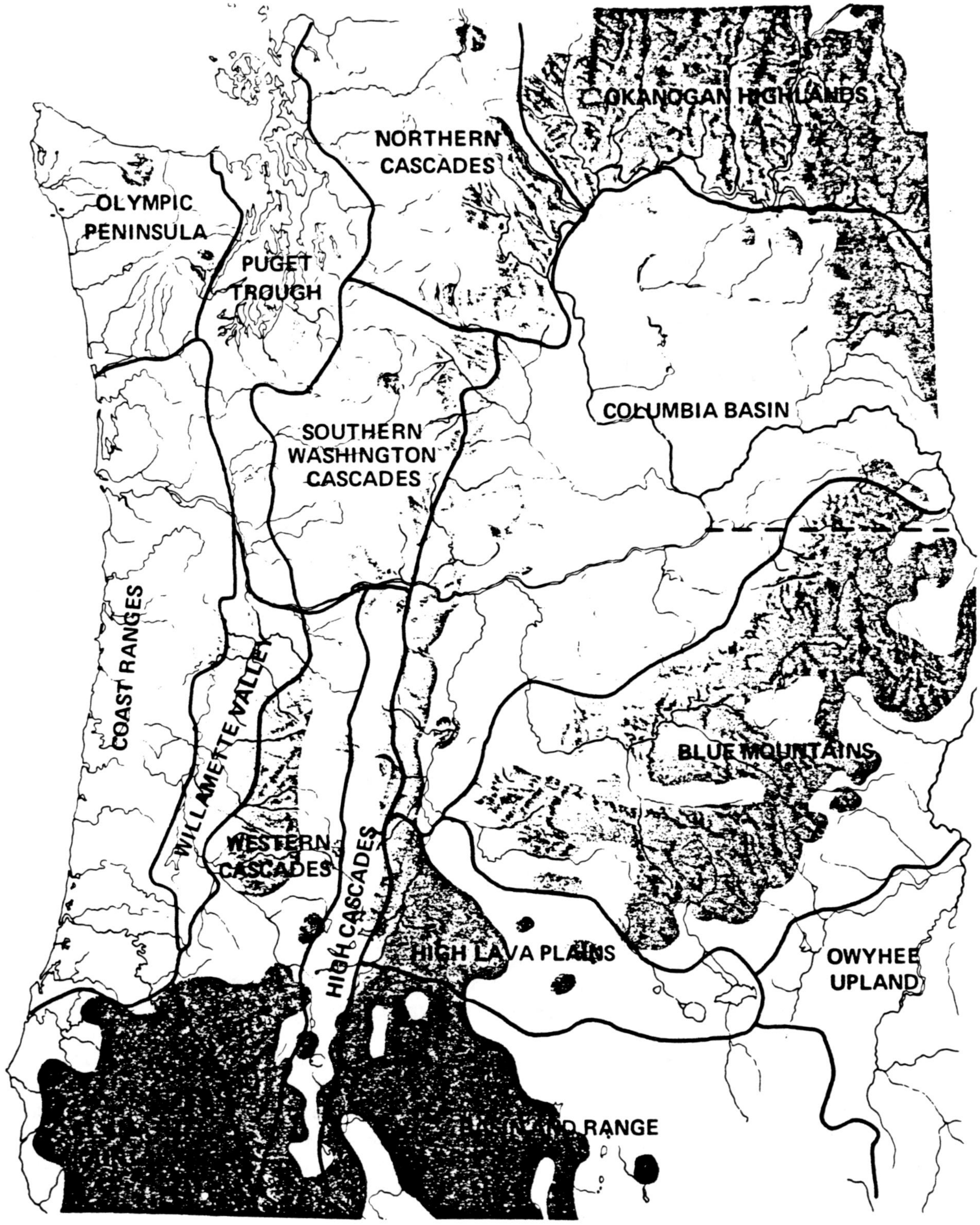


Figure 2.--Physiographic and geological provinces in Oregon and Washington (Franklin and Dyrness 1973) and the distribution of ponderosa pine, shaded area (Little 1971).

GEOLOGICAL PROVINCES, SOILS, AND PONDEROSA PINE DISTRIBUTION

Okanogan Highlands Province

Ponderosa pine is found throughout the province as a principal component of mixed conifer stands and occasionally in pure stands.

The Okanogan Highlands consist of moderate slopes and broad, mounded summits. Much of the province lies above 3,937 ft (1 200 m) except for main river valleys. Six major rivers--the Methow, Okanogan, Sanpoil, Columbia, Colville, and Pend Oreille--divide the province into several upland areas. Deposits of glacial drift are found throughout, because virtually the entire province was repeatedly covered by glacial ice. A great variety of rock types represent Precambrian to late Tertiary. The most abundant of these are granitics, deposited during the Mesozoic.

Soil types are closely tied to elevation. In the mountains at higher elevations, soils derived from granitic parent materials are Xerochrepts (Regosols) and Cryorthods (Podzols). The xerochrepts have weak horizon development, are cold, acid, stony or gravelly sandy loam, with a total depth to bedrock of about 3.3 ft (1 m). The Cryorthods have substantially more profile development, with a light-colored A2 horizon underlain by a B2 horizon of high iron content. Texture tends to be a silt loam.

In the transitional forest grassland areas along rivers, the most abundant parent material is glacial till with a sandy loam texture. These Haploxerolls (Chernozem soils) have a dark, moderately thick A1 horizon underlain by a B horizon with little clay and distinguished by changes in color and structure.

Northern Cascades Province

This province is comprised to a large extent of ancient sedimentary rocks, most of which are folded and at least partially metamorphosed. Intrusions of large granitic batholiths are also common. It is topographically mature with great relief; valleys are very deep and steep sided.

Soils east of the Cascade crest, where ponderosa pine is found, reflect the relatively dry conditions under which they were formed. Most prevalent are Haploxerolls (Chestnut and Brown soils) formed on a variety of parent materials but generally influenced to some extent by volcanic ash and, in some areas, loess. Stone-free silt loams to cobbly loams can be found. Other soils in the eastern portion include Xerochrepts (Regosols) and Haploxeralfs (Noncalcic Brown soils).

Southern Washington Cascades Province

Ponderosa pine is found mostly as a major or minor component of mixed conifer stands in this province. Its distribution is confined mostly to the eastern slopes of the Cascade Range.

The area is made up of generally conforming ridge crests separated by steep, deeply dissected valleys. Andesite and basalt flows dominate, with only minor amounts of igneous intrusive, sedimentary, and metamorphic rocks.

Soils east of the Cascade crest are mostly Haploxeralfs (Noncalcic Brown soils) and Haploxerolls (Chestnut soils). These soils, derived from andesite, sandstone, or glacial till, are also influenced by volcanic ash or loess or both. Soil textures are most often silt loams and loams.

Columbia Basin Province

Ponderosa pine is found on about the entire perimeter of the province and invades the province extensively in south central and northeastern Washington (fig. 2). In general, precipitation is heaviest along the margins of the basin (16 to 24 in (41 to 61 cm) annually) and gradually decreases toward the central portion. In all but the west boundary area, Argixeroll soils predominate (Prairie soils and Chernozems). On the western border, soils have been largely influenced by volcanic activity and have characteristics similar to those found in the Southern Washington Cascades and High Cascades provinces.

High Cascades Province

Ponderosa pine is evident at the lower elevations where it is often an important component of mixed conifer stands. It is found in extensive pure stands in the eastern portion. The area is dominated by a series of prominent mountain peaks. From the northern part of Oregon to the southern border, they are: Mount Hood, 11,235 ft (3 424 m); Mount Jefferson, 10,497 ft (3 199 m); Three Fingered Jack, 7,841 ft (2 390 m); Mount Washington, 7,794 ft (2 376 m); the Three Sisters, 10,094 ft (3 077 m), 10,053 ft (3 064 m), and 10,354 ft (3 156 m); Mount Thielsen, 9,182 ft (2 799 m); Mount Scott, 8,938 ft (2 724 m); and Mount McLaughlin, 9,495 ft (2 894 m).

This province is geologically young, with some lava flows only several hundred years old. The central and southern parts of the province are covered with deposits of volcanic material such as pumice, cinders, and ash. The most extensive deposit of this material resulted from the eruption of Mount Mazama (Crater Lake) about 6,600 years ago. Soils in this volcanic material show little profile development and are classed as Vitrandepts (Regosols). They ususally exhibit a thin, dark A1 horizon of sandy loam or loamy sand underlain by a transitional AC horizon that grades into a course sand or gravelly sand parent material.

Blue Mountains Province

Ponderosa pine grows extensively throughout this province either in pure stands or as a component of mixed conifer forests. Faulted valleys and synclinal basins separate the mountain ranges. These ranges include the Ochoco, Blue, and Wallowa Mountains, as well as the Strawberry, Greenhorn, and Elkhorn Ranges. Slopes in the Blue and Ochoco Mountains are moderate, but the heavily glaciated Wallowa Mountains exhibit great relief. Maximum elevations range from about 6,890 ft (2 100 m) in the Ochoco Mountains to 9,515 ft (2 900 m) at Eagle Cap in the Wallowa Mountains. In the Ochocos, valleys are about 2,500 ft (762 m); and between the Blue and Wallowa Mountains, valleys are 2,950 ft (899 m). Columbia River basalt occupies large areas within the western Blue Mountains.

After the most recent lava flows, much of the area within the central and northern portions of the Blue Mountains was covered by a layer of aerially deposited volcanic ash and fine pumice. Through the centuries, erosion has largely removed the ash from south-facing slopes. Other locations are typically mantled by the material. Many upland areas--especially in the eastern portion of the province--were covered by loess.

High Lava Plains Province

Ponderosa pine is confined mostly to the western portion of this province and also occurs in two isolated areas in the center.

Recent lava flows, cinder cones, and lava buttes characterize this province in central Oregon. Because of low rainfall, many streams flow seasonally and only drain the snowfields high in the Cascade Range.

Extensive volcanic activity took place during the Pleistocene and recent times, especially in the western portion of the province. Paulina Peak, the volcano containing Newberry Crater, erupted about 4,000 years ago, and pumice mantles an extensive area to the north and east of the crater. Mount Mazama pumice is also widespread in the same general area, as well to the south in the Basin and Range province.

On the eastern slopes of the Cascades that support coniferous forests, we find regosolic soils developed on pumice.

Basin and Range Province

Ponderosa pine is found in pure stands over vast areas throughout the western third of the province. At higher elevations, it is an important component of a mixed conifer stand.

This province is characterized by fault-block mountains enclosing basins with internal drainage. Prominent topographic features from west to east are the Klamath Lake Basin, Goose Lake Valley, Winter Rim, Summer Lake, Chewaucan Basin, Abert Lake Basin, Abert Rim, Warner Mountain, Warner Valley, Hart Mountains, Catlow Valley, the Steens and Pueblo Mountains, the Alvord Desert, and the Owyhee Valley.

The province is made up largely of Miocene-to-recent flows of basalt and alluvial sediments. The soils in the western portion developed under forest vegetation. The high plateau area in the northwestern corner is covered with vast deposits of Mazama pumice. Some of the pumice was aerially deposited and some deposited in glowing avalanches that swept down the slopes adjacent to the volcano. Some, but not all, of this material has been reworked by water.

Soils in the area derived from pumice have immature profiles with a moderately thick surface layer with some organic matter accumulation overlying nearly unweathered, yellow and buff pumice gravel and sand. They are slightly acid soils. Because of the high porosity of pumice, this coarse material has water-holding and cation-exchange capacities far greater than would be expected.

Klamath Mountains Province

Ponderosa pine occurs in the eastern three-fourths of the province, sometimes in pure stands, but mostly associated with other species.

The Klamath Mountains are in the southwestern corner of Oregon, south of the Coast Ranges and west of the Cascade Range. The northern portion of these mountains is often called the Siskiyou Mountains. The mountains are rugged with narrow canyons and 2,000 to 5,000 ft (610 to 1 524 m) of relief. They are made up largely of pre-Tertiary strata that have been folded, faulted, and in places intruded by granitoid rocks and serpentinized masses of ultrabasic rocks (Baldwin 1964). Mount Ashland (7,530 ft, 2 295 m) is the highest peak in the Klamath Mountains; to the west, the summits gradually diminish to about 2,500 ft (762 m) before the land breaks off to a narrow coastal plain. The Rogue and Smith Rivers and their tributaries and a few short coastal streams drain the area.

Soils are in two main groupings: in the eastern half, they reflect the effects of drier conditions, especially during the summer; in the western portion, they tend to remain moist considerably longer.

Upland soils in the western half are for the most part Haplohumults (Reddish Brown Lateritic soils). Parent materials for these soils include both sedimentary and basic igneous rocks. The western portion of the province contains a wide variety of valley-bottom soils. The most important, well-drained soils derived from alluvium on terrace landforms are Dystrandepts and Haplumbrepts. In the eastern half of the province, the principal upland soils are Haploxerults (Reddish Brown Lateritic soils), which are continuously dry for a long period of the year. Generally, these are reddish-brown soils derived from sedimentary parent material with bedrock within 1 m of the surface.

Soils on flood plains and alluvial fans in the eastern section of the Klamath Mountain province are principally well-drained Haploxerolls and Haploxeralfs (Prairie soils). For a more complete description of the vegetation in these provinces, consult Franklin and Dyrness (1973).

CLIMATE

The climate of Oregon and Washington is extremely varied and complex because of the interplay between ocean and continental air masses. Most moisture-laden storms approach Oregon and Washington from the west in cyclonic low-pressure systems. These storms shift to the north in the summer, and high-pressure systems off the coast bring dry weather for long periods.

The Cascade Range, which extends from the Canadian border through Washington and Oregon to northern California, forms a vast barrier for the moist air from the Pacific Ocean. During the winter, moisture-laden air masses of the low-pressure system move inland and are forced upward by the Coast and Cascade Ranges. This air is cooled, condensed, and precipitates mostly on the west-facing, windward slopes. The east-facing lee slopes receive much less rainfall. Thus, eastern Oregon and Washington are in a gigantic rain shadow. Much of this moist air from the Pacific falls west of the Cascade crest, although strong pressure systems occasionally force the moisture-laden air over the crest. Higher elevations then receive notable amounts of precipitation, but the lower valleys are dry and usually nonforested.

Most precipitation falls as snow east of the Cascades. Summers are dry, especially during July, August, and September. Average annual precipitation ranges from about 10 to 21 in (25 to 53 cm), with only 2 to 6 in (5 to 15 cm) falling during the growing season. Elevation can have a profound effect on precipitation. Within the type, an increase of 800 ft (244 m) in elevation is often accompanied by an increase of 8 in (20 cm) in precipitation. Ponderosa pine is found as elevation and precipitation increase above the valley floor and with further increases, other species begin to accompany it. Climate, especially precipitation, is important in the natural distribution of pine and an important consideration in artificial regeneration of the species.

Average annual temperatures in the western ponderosa pine type are between 41.8° and 49.8°F (5.4° and 9.9°C), and average July-August temperatures between 62.0° and 69.6°F (16.7° and 20.9°C). Annual extremes are -40° to 110°F (-40° to 43°C) (Fowells 1965). During the growing season, temperatures fluctuate widely from day to night, with ranges of 54°F (12.2°C) possible. Frost may occur any night of the year, and cold air drainage pockets are frequent in Oregon. Frost and frost-heaving also influence the distribution of ponderosa pine; lodgepole pine, for example, is more tolerant of frost than ponderosa pine (Cochran and Berntsen 1973).

DAMAGING AGENTS

Various diseases, insects, mammals, and birds affect ponderosa pine from seedling stage to maturity. Although relations of damaging agents are frequently complex, the literature abounds with research that explains symptoms, life cycles, and control measures. As environmental constraints become more stringent and management intensity increases, the silviculturist will be challenged to manipulate trees and vegetation so that destructive pests are subdued to tolerable levels. Knowledge about life cycles or contagion will aid the silviculturist in prescribing control for these pests.

Diseases

DWARF MISTLETOE

Western dwarf mistletoe, a dioecious flowering plant, parasitizes ponderosa pine and can reduce tree growth. Seed-bearing plants and staminate flowers appear on the host in roughly equal numbers or--under conditions for poor growth--are absent. The forcefully disseminated, adhesive seeds are intercepted by the needles, wash to the stems, germinate, and send sinkers into the current year's tissue. Growth of the mistletoe in the cambium area disrupts the normal flow of photosynthates and water in and around the infected area.

Although the disease is a serious consideration in the management of ponderosa pine in this area, it appears less devastating than the southwestern dwarf mistletoe found in southwestern United States (Lightle and Weiss, 1974). In the Northwest, we probably have a distinctly better chance for cultural manipulation of infected stands than in the Southwest (Strand and Roth 1976).

Silvicultural control of mistletoe in the Pacific Northwest is possible in many developing stands, although complete eradication may need to await the next rotation. Two major alternatives have been found for dealing with the disease. First, if the crop trees in the understory are heavily infected, the stand is usually clearcut, the understory destroyed, and the site prepared and planted. Infected trees along the edge of the planted areas should be removed when the clearcutting is made or before planted trees are 3 ft (0.9 m). If adjoining trees cannot be removed, then an area extending about 100 ft (30.5 m) away from them into the plantation should be planted with a nonsusceptible species.

The second alternative, for moderatly infected stands, is to remove all overstory trees and thin the understory to not less than 15 x 15 ft (4.6 x 4.6 m). In stands with an average potential crop tree d.b.h. larger than 2 in (5 cm), priorities for crop-tree selection are:

- Uninfected dominants and codominants.
- Dominants and codominants with dwarf mistletoe restricted to the lower third of the live crown.
- Dominants and codominants with dwarf mistletoe restricted to less than 50 percent of the branches in the lower half of live crown.
- Intermediates with no visible infection.

All potential crop trees should have at least 25 percent of their total height in live, uninfected crown. Trees with dwarf mistletoe infection in the top fourth of live crown are questionably suitable as crop trees. Acceptable stocking should be selected from trees in the highest priority before selections are made from the next lower class.

Treatments in mistletoe-infected pine stands should create an even canopy. Single story stands are preferable to prevent infection of understories.

ROOT ROT

Armillaria root rot has been in the natural ponderosa pine forests of the Pacific Northwest for a long time (Roth et al. 1977). Recent observations show an increase in second-growth mortality. Much old-growth mortality also is caused by armillaria, especially near the transition zone with Douglas-fir.

Armillaria spreads vegetatively from tree to tree by root contacts or by black, string-like rhizomorphs. The fungus does not spread extensively by spores. In many forests, the sporophores are rarely found.

The best indicators of the disease are white mycelial fans between the bark and wood at groundline. These fans may not be visible in trees just beginning to turn color, or they may be gone from those dead for several years. Impressions of disintegrated fans sometimes remain visible in the inner bark of trees that have been dead for several years. Armillaria damage is often recognized in dense stands as pockets of dead saplings around old-growth stumps or large, nearly treeless openings with a few saplings in the center. Other root rots cause similar disease symptoms, so examination of the root collar for mycelial fans is required to confirm the cause as armillaria.

Roth et al. (1977) have suggested a method of treating seriously infected stands. Inoculum in the form of large roots and stumps is removed from the soil. Infection centers are located and tractors are used to remove stumps and roots of trees with symptoms plus those of adjacent trees without, to create a barrier between the disease foci and the healthy stand. Distance of stump and root removal into trees without symptoms adjacent to those with symptoms should increase as average stem diameter increases (Shaw 1974). Where trees showing disease of 5-, 9-, and 11-in (13-, 23-, and 28-cm) d.b.h. still retain some needles or twigs and bark is still intact, clearing should extend 15, 18, and 25 ft (4.6, 5.5, and 7.6 m), respectively, into healthy trees. Complete control is probably not possible. Some reserve trees may die after treatment, but growth in formerly infected areas will exceed mortality, and this margin should widen with time. Repeated application in future timber sales will further check the disease.

NEEDLE BLIGHT

Elytroderma needle blight is occasionally conspicuous in the forests of the Pacific Northwest. Although less destructive than its alarming appearance suggests, it has reduced growth rates on more than 100,000 acres (40 469 ha) in Oregon and Washington and locally has killed many trees on a few areas of severe infestation (Childs 1968a). From 1940 to 1950, more than 200 million fbm of sawtimber on the Ochoco National Forest had to be salvaged. Great loss has also occurred through premature cutting of diseased trees threatened with death. Outbreaks have been recorded since 1913.

Unlike typical foliage diseases, elytroderma needle blight often persists for several years. Persistence of the outbreaks can be explained. Elytroderma invades twigs and buds as well as needles, survives perennially in twigs, and spreads vegetatively into needle primordia (Sikorowski and Roth 1962). Once a damaging wave of infection has occurred, the fungus is not dependent on annually recurring periods of weather favorable for sporulation, germination, and host invasion to continue causing damage.

The most striking symptom of the disease is the reddish brown "flags" that appear in the spring. Infected needles of the preceding season's shoots stand out in striking red-brown contrast against the normal green foliage. As the season progresses, the red needles are partly hidden by the current year's growth. Later they defoliate. Symptoms vary from tree to tree. Some trees may be engulfed in blighting, but others may have only one branch with symptoms. Compact, pendent witches' brooms of hook-shaped branches are common in trees of high vigor and are thought to perpetuate the disease. Young seedlings are rarely infected (Roth 1959).

Without research on control, little can be done about the disease except to put young stands in thrifty condition, and to salvage threatened mature trees before they die. Where just a few scattered trees are dead or dying from the disease, they should be salvage-logged. Where the stand is substantially infected and repeated cuts at short intervals would raise logging costs, managers should: postpone salvage until heavy mortality is likely to occur, beetle populations are increasing rapidly, or the stand is due for logging; and then harvest all pine except those in a high-vigor class with no more than about 5 percent of the twigs flagged (Childs 1968a).

Where infection during the current outbreak has been light, the disease is unlikely to be seriously damaging in the future. At the other extreme, stagnated stands on and near former outbreak centers are likely to be damaged by another outbreak before they mature. In thinning young stands, Childs (1968a) recommended the following:

- Maintain good spacing. Avoid large openings.
- Select no crop trees flagged within 3 ft (0.9 m) and preferably none flagged within 6 ft (1.8 m) of the leader.
- Select uninfected or only lightly infected crop trees even at a considerable sacrifice of present tree size and quality.
- Do not be bluffed by the disease. Where good pine has grown, good pine will grow again.

Future outbreaks will undoubtedly cause some damage even in vigorous young, mature stands and more severe and rapid damage in decadent, overmature stands. For mature stands, Childs (1968a) suggested:

- Do not take hasty action.
- Evaluate the situation annually on the basis of examinations made in the spring and early summer.
- Revise logging plans to give higher priority to stands where appreciable damage is to be expected within the next few years and to provide for immediate logging wherever infection rates or beetle populations start to increase.
- When logging in lightly infected stands, remove the occasional tree that may be found with more than a third of its twigs flagged or killed; discriminate as much as is practicable against the most heavily infected of the other trees.
- When logging in moderately or heavily infected stands, either cut drastically, leaving only trees with very good, Keen class A or B+ (Keen 1943) crowns and no more than a few scattered flags, or plan to relog within a year or so if necessary. Partial cuts in diseased stands are usually followed by rapid crown deterioration and high mortality of residuals.

COMANDRA RUST

Comandra rust is present in some sapling and small pole stands. In unthinned stands, it is probably unimportant because it is scattered and seldom occurs in more than 5 percent of the stand. In thinned stands, the disease may cause substantial damage. Spores of the fungus are often concealed under bark scales; branch swellings disappear as branches die and drop to the ground, and infected trunks are seldom noticeably swollen. Consequently, thinning crews miss many of the infected trees--leaving a high rate of infection in the crop trees (Childs 1968b).

In mature stands in early stages, the disease is an immediate threat only if infection enters the trunk below midcrown; this is not very common even in young, mature trees and is rare in old growth.

This rust does not spread directly from tree to tree; its alternate host is common comandra. Control by eradication of the alternate host is not practical.

Mature trees obviously infected with the disease should gradually be harvested; the greatest gain in reducing the prevalence of the disease is by removing diseased trees in thinning young stands.

OTHER DISEASES

Annosus root rot can be found in many Pacific Northwest ponderosa pine stands. The disease is almost always associated with earlier cutting operations. The spores of the fungus germinate on freshly exposed stumpwood. The fungus can colonize in stumps and spread vegetatively to surrounding trees along roots. Centers of infection show up as dead seedlings and saplings surrounding large stumps (Russell et al. 1973). The fungus produces small leatherly conks with a tan upper surface and creamy lower surface. These conks are found in the duff on root collars of recently killed trees.

Annosus root rot is not yet serious in this region, but it is increasing; cutting favors it. Infection can be prevented by covering fresh cut stumps with borax. This treatment is registerd with EPA, but is not presently being recommended for use in commercial stands because of the low incidence of disease.

Western gall rust is found on ponderosa pine (Peterson 1960). The rust does not require an alternate host but spreads directly from pine to pine. It causes woody galls on stems and branches; seedlings and saplings may be killed by the disease, but larger trees rarely suffer mortality. Galls on larger trees enlarge with age and cause deformities that reduce lumber quality. No direct control is available. Infected trees, particularly those with stem galls should be removed in precommercial thinning. Cones should not be collected from trees with numerous infections, because some field indications of genetic resistance have been found.

Insects

MOUNTAIN PINE BEETLE

Tree killing by mountain pine beetle, has increased with conversion of old-growth stands to second growth, and this problem seems destined to intensify as more young stands attain susceptible size (Sartwell 1971). Severe infestations in ponderosa pine occur mainly in pure, even-aged stands of poletimber about 50 to 100 years old (Sartwell and Stevens 1975).

Infested trees are first recognized by pitch tubes on their trunks and red boring dust in bark crevices. Later, foliage discolors to greenish yellow and then to reddish brown (Furniss and Carolin 1977). Adult beetles are rather stout, cylindrical, and black, 0.16 to 0.29 in (4 to 7 mm) long. Egg galleries are perpendicular, long, and engraved on both sapwood and inner bark (fig. 3).

In low populations, beetles tend to attack the weakest trees. Fewer than five trees/acre (12/ha) per year are killed, and they occur singly. During outbreaks, which usually last for several years, trees of all crown classes are killed, but dominants and codominants suffer most. The beginning of an outbreak is marked by the clumping of tree mortality in groups of three or more trees. That 1st year, about 5 to 10 trees/acre (12 to 24/ha) are killed. Beetles of subsequent generations expand the clumps, creating holes in stands so large that entry of a new age class of trees is required for full stocking. Peak tree mortality usually occurs about the 5th year of an outbreak, when 50 to 150 trees/acre (123 to 371/ha) are killed. Thereafter, the outbreak declines and usually subsides by about the 8th year. Commonly, an outbreak of mountain pine beetle in ponderosa pine results in death of about half the trees and loss of about two-thirds of the stem basal area.

Figure 3.--Egg galleries of the mountain pine beetle.

High stand density is a consistent characteristic of second-growth ponderosa pine stands severely infested by this insect. Intense between-tree competition at high stand densities is believed to reduce vigor of even the largest trees and, thus, to be the underlying factor in the occurrence of beetle outbreaks (Sartwell and Stevens 1975).

Thinning now appears to be one way of controlling outbreaks in pole-sized ponderosa pine (Sartwell and Dolph 1976). In eastern Oregon, two studies suggest that thinning to recommended basal area levels compatible with most management goals (see stocking level curves, fig. 22) will greatly reduce the incidence of tree killing. Recommended treatment would be thinning to a density well below the maximum stocking level curve, such as 70 to 80 ft^2 of basal area per acre (16 to 18 m^2/ha). This should "bug proof" the stand until the first commercial entry is made. Preferably, stands should be thinned well before any beetle activity is evident.

Spraying infested trees without reducing stand density provides only temporary relief--5 years or less. Thinning of dense stands is presently thought to be the forest manager's first line of defense against mountain pine beetle in northwest stands of ponderosa pine.

PINE ENGRAVER

The pine engraver occurs naturally in all ponderosa pine stands (Dolph 1971 and fig. 4). Individual trees and stands are periodically attacked. Any thinning will attract pine engravers; however, they usually confine their attack to the slash. In "Ips years" that are associated with drought, they may attack both residual trees in thinned areas and nearby unthinned, stagnated stands.

Usually two to three generations a year are produced, depending on climatic conditions. Adults overwinter in the upper few centimeters of soil and litter under the slash from which they emerged or at the base of brood trees. Some may overwinter under the bark of stumps, or dead trees or on the undersides of large pieces of logging slash. The first attack in the spring usually occurs in April or May. These overwintering beetles seldom attack green, healthy trees but prefer weakened trees and thinning slash that was cut the previous fall and early winter. The second flight occurs in late July and August. Slash in which the broods developed is usually too dry for reentry so beetles move to fresh slash. Mating takes place, and broods develop, but this generation of beetles usually drops to the ground for hibernation. Occasionally, a third generation develops when climatic and environmental conditions are ideal. The second flight causes most of the tree mortality. Slash from stands logged or thinned between February and July are most receptive to invasion.

A

Figure 4.—Trees killed by the pine engraver, A, and breeding galleries of the insect, B.

B

Direct control is usually impractical. The present approach is to keep stands healthy. On small ownerships, thinning between August and February is safe, or slash should be disposed of before it is attacked. On large ownerships where thousands of acres are thinned each year, managers should keep enough slash available so that beetles move from one supply of slash to another. Occasionally, a residual tree is lost but overall mortality is usually not serious.

Heat generated under the bark by direct sunlight causes most of the brood mortality in slash of small diameter. Loss of valuable trees in campgrounds occurs when fuel wood infested with Ips is piled against trees in shaded moist locations. Insect broods develop, and emerge in great numbers; some are likely to attack the adjacent tree and kill it. Stacked green wood in a shaded area often provides an ideal incubator for the development of massive hordes of Ips.

WESTERN PINE BEETLE

No other insect that attacks ponderosa pine has had such an impact on the species. During the drought years of the 1930's, losses from western pine beetle, were so heavy that many foresters thought pine stands in the Pacific Northwest were doomed. Entomologists discovered, however, that they could identify high-risk trees. Not only were these the trees that were the most likely to be killed, but they were also the ones that produced more beetles to move on to other trees. Consequently, harvest of these trees tended to protect the rest of the stand.

Periodic salvage sales that harvest trees that have been attacked or are likely to be attacked are necessary to keep beetle numbers manageable. Normally, this insect breeds in a few overmature trees, windfalls, unhealthy trees, or in trees weakened by drought, stand stagnation, or fire (Keen 1952). Under outbreak conditions, it will kill trees of all ages, although trees under 6 in (15 cm) in diameter are seldom attacked. Frequently, this beetle attacks trees jointly with other insects such as the pine engraver in the top, mountain pine beetle in the midbole, or the turpentine beetle, at the base.

The top-killing associates may attack first, thus providing favorable breeding for the western pine beetle (Furniss and Carolin 1977). Their tunnel design is distinguished from other bark beetles by the winding egg galleries that cross and recross each other (fig. 5). Attacks start in late spring and early summer and continue until cold weather.

Figure 5.--Western pine beetle egg galleries on ponderosa pine.

WESTERN PINE SHOOT BORER

The western pine shoot borer has been recognized within the last decade as a notable threat to achieving intended growth in some second-growth and planted stands of ponderosa pine (Stoszek 1973). A recent survey with attractant-baited traps revealed that this insect is common throughout ponderosa pine stands of the Pacific Northwest, in many places as abundant as in southern Oregon where it is known to be a serious pest of plantations.[2]

Damage is often not apparent, and evidence of infestation is obscure to the untrained eye. Symptoms are visible in summer once pine-shoot elongation and needle growth are completed; the most apparent are a disproportionally increased density of needle fascicles and substantially stunted needles on the highest portion of the shoot. The "shaving brush" appearance is a reliable sign of infestation compared to the uniform needle length of an uninfected terminal (fig. 6). A disproportionate ratio of terminal to lateral shoot is another sign of infestation. The feeding tunnel confined to the pith is straight and filled with compacted frass and resin.

Figure 6.--Typical stunted terminal caused by western pine shoot borer.

Not all shoot distortions, however, are caused by the shoot borer; similar symptoms may be caused by abnormalities in bud setting.

Stoszek (1973), working in south central Oregon, concluded that loss in average annual height increment could be up to 25 percent. Surveys of pine plantations indicated increased incidence of infested leaders on drier sites.

So far, control for pine shoot borer has not been developed. Systematic insecticides have performed poorly in field trials. Control by mating disruption with synthetic sex attractants is highly promising, however. This approach requires release of attractants in such amounts that male moths cannot locate females. The insect is now recognized as a threat to intensive forestry in the pine lands of the Pacific Northwest, and researchers are determining if confusion techniques will give acceptable control. They are also testing other methods of suppression.

[2] Manuscript in preparation, "Distribution and hosts of Eucosma sonomana in the Western United States as determined with pheromone-baited traps," by Charles Sartwell, G. E. Daterman, T. W. Koerber, R. E. Stevens, and L. L. Sower.

TURPENTINE BEETLE

The turpentine beetle is widespread throughout the Pacific Northwest. Although commonly observed in dying trees, it is usually not the direct cause of pine mortality. The beetle attacks trees that have been weakened by lightning, fire, drought, flooding, or other insects.

Even when the beetles appear in a stand, their effect on the trees may be only temporary. Large, reddish pitch tubes are formed at the point of attack and are usually located on the lower 6 ft (1.8 m) of the bole. Beetles excavate short, irregular, cave-like egg galleries between the bark and the wood (fig. 7). Eggs are laid in groups at intervals along the sides. The larvae feed out through the inner bark in mass formation, forming a cavity that can be a few square inches or a square foot or more between the bark and the wood.

The beetle is seldom important in commercial timber stands. If control becomes necessary in parks or campgrounds to preserve individual trees, the damage can be stopped by cutting out the attacking beetles where pitch indicates their presence, or by chemical spray or screening the lower bole during the flight period (Furniss and Carolin 1977).

Figure 7.--Galleries of the turpentine beetle.

PINE BUTTERFLY

The pine butterfly is potentially one of the most dangerous enemies of ponderosa pine in the Pacific Northwest (Keen 1952). Some devastating attacks were reported at the turn of the century and in the early 1920's. Defoliation by this insect predisposes pines to attacks by western pine beetle. Pine butterfly has apparently been held in check recently by a natural enemy, the parasitic wasp <u>Theronia</u> <u>atalantae</u> (Poda), and by environmental conditions. Past outbreaks have seldom lasted more than 3 or 4 years before the parasite has the butterfly under control. Tremendous amounts of timber may be lost, however, before the natural enemy has subdued the outbreak.

The adult is a white butterfly with black markings and a wing width of about 1-3/4 in (4.4 cm), generally similar to the cabbage butterfly (fig. 8). Flight occurs in August through October. Emerald green eggs are laid in rows, attached to needles in the tops of trees. The eggs pass

A B

Figure 8.--Pine butterfly: A, adult; B, ponderosa pine branch defoliated by the pine butterfly.

through winter and hatch in June. The caterpillars feed on the needles in the spring, and then the full-grown larvae drop to low-growing vegetation by silken threads and form pupae. In 15 to 20 days, the insects emerge as butterflies, with usually only one generation a year.

Mammals and Birds

POCKET GOPHERS

Pocket gophers are a serious threat to the regeneration of our pine lands. These mammals kill or slow the growth of pine seedlings by cutting or gnawing off roots and debarking main stems of seedlings (fig. 9). In 1970, Barnes (1973) recognized the notable impact pocket gophers had on both ponderosa and lodgepole pine in eastern Oregon and Washington. The problem appears to be accelerating because of intensified forest management, and managers are becoming more aware of gopher damage (Capp 1976). Postponement of final harvest cutting is sometimes being recommended because of the inability to prevent regeneration losses to gophers.

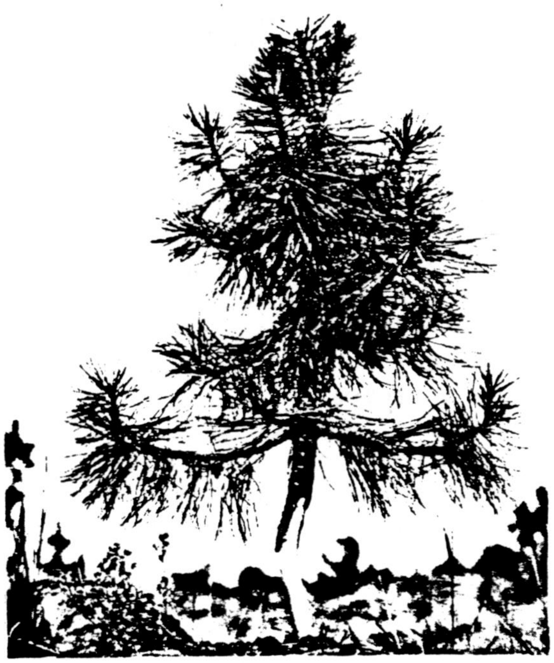


Figure 9.--Planted ponderosa pine, about 3 ft (0.9 m) high, girdled by pocket gophers during the winter, under a 2-ft (0.6-m) snowpack.

Numbers and distribution of pocket gophers are rapidly expanding because forest disturbance generally improves habitat for them. Logging overstory trees encourages herbaceous vegetation (McConnell and Smith 1970), the preferred forage of gophers. Young gophers, after they are weaned and excluded from the parental burrow system, disperse and seek favorable habitat to build their own burrows. This dispersal mechanism allows gophers to establish populations quickly in new habitat. Ditches of road rights-of-way, stream drainages, and natural meadows also support gophers and promote distribution of animals from one silvicultural treatment area to another.

Present control methods are not adequately reducing seedling loss to gophers. These methods, primarily aimed at population reduction by trapping and machine application of toxic grain, are often ineffective because of limitations in operational programs and problems inherent in direct population control (Barnes 1973). Successful protection of tree seedlings has not been well documented despite treatment of tens-of-thousands of acres with toxic baits (Crouch and Hafenstein 1977).

Reducing the required food supply of the gopher is another approach to the reforestation problem, but present information limits application to only a few forest communities. Crouch and Hafenstein (1977) improved survival of planted ponderosa pines by reducing the competition to seedlings from herbaceous vegetation and predation by pocket gophers. Other workers (Howard and Childs 1959, Keith et al. 1959, Hull 1971, and Christensen et al. 1974) report similar relations between herbaceous vegetation and pocket gopher populations.

A promising new development is a seedling protector that provides both above- and below-ground protection (Anthony et al. 1978). It is a cylinder of plastic netting that gradually decomposes in sunlight, and the rate of decomposition can be varied by the chemical composition of the netting. Netting currently being tested requires from 4 to 10 years to decompose by ultraviolet radiation; no known environmental hazards are associated with the plastic or its byproducts (Campbell and Evans 1975).

Grouping plant communities according to the incidence of gophers in natural and disturbed stands and their potential for gopher occupancy after disturbance is another approach to controlling gophers. We may be able to alter silvicultural techniques so that ideal gopher habitat is not created (Volland 1974). Barnes (1974) suggested leaving uncut buffer strips between logged units and gopher populated areas, direct control before harvest where a reservoir of animals occurs within a proposed logging unit, use of site preparation techniques that disturb the soil and vegetation as little as possible, and selective cutting in certain communities. Barnes also emphasized the importance of extensive, on-the-ground reconnaissance to assess gopher populations before silvicultural practices are initiated.

DEER

Mule deer are a concern to reforestation on pine lands of the Pacific Northwest, but the appeal of these animals outweighs their pestiferous side. Although deer feed on natural conifer seedlings, their undesirable interactions with reforestation usually consist of browsing damage in plantations that lie along migration routes to winter ranges (Crouch 1976). Damage depends on the number of deer, weather in the fall and spring and its influence on speed of migration, and the amount and duration of snow cover.

Browsing of planted ponderosa pine can quickly reduce stocking to unacceptable levels, especially where the site is marginal for survival of planted seedlings. Damage on summer range is frequently minimal. Browsing control usually consists of chemical repellents, cages for individual trees, and exclosure fences. Effectiveness is directly proportional to effort expended.

To assess a potential deer problem, a carefully prepared analysis of the site should be made before planting and the following questions answered:

- Is the site marginal for ponderosa pine?
- Is the site in a migratory route?
- Is the site a winter range for deer?

If the answer to any one or more of these questions is yes, then a browsing problem probably exists, and an economic analysis of the control options mentioned above should be made.

In considering chemical deterrents to mule deer browsing, remember that most mule deer browse in the fall, winter, and spring on areas adjacent to winter ranges and on migratory routes. Some damage occurs on summer range, but this is usually minimal. Time of application is important; most repellents for mule deer are applied to individual trees in the fall. Success in preventing browsing varies. Some wildlife specialists believe that the chemical deterrents popular now will not be available in a few years. TMTD (tetramethylthiuram disulfide) and BGR (big game repellent) are federally registered for protecting conifer seedlings from deer browsing. TMTD is usually sprayed on seedlings in the nursery before lifting, but can be applied by hand dipping. Limited success is reported in deterring deer and elk. BGR should be applied to dormant seedlings before bud burst. The active ingredient in BGR is putrified liquid egg. Results of recent tests are promising (Rochelle et al. 1974).

PORCUPINES

Inner bark and foliage of ponderosa pine serve as winter food for porcupines. Death of trees by girdling is not uncommon; more typically, the top of the tree is girdled and dies.

Porcupines are largely nocturnal and ordinarily spend days in a rest tree or den in a rock outcropping. Active rest trees and dens can be identified by broken quills, accumulated droppings, and the odor of urine. In spring, the young are born in these rock dens--one young per female--but juvenile mortality can be extremely low and numbers can increase rapidly in a few years.

Porcupines do not hibernate, and are active throughout the winter when ponderosa pine is their preferred food. During the summer, 85 percent of porcupine food is ground vegetation (Lawrence 1957), with the rest from trees. Ponderosa pine infected with dwarf mistletoe is often subject to heavy damage.

Cougars, bobcats, and fishers are predators of the procupine; they attack and kill porcupines in trees as well as on the ground, flipping the porcupine over to expose the unprotected belly. These animals should not be considered as a sole means of porcupine control because prey-predator relations are generally complex and because of the habits of these predators.

Logging of mature pine stands and thinning the understory stimulates development of ground vegetation and improves habitat for porcupines. Human activity has created an environment much more favorable for porcupines than existed under pristine conditions, which is why porcupines can be a problem if their numbers are left unchecked.

Hunting appears to be the most effective way to deal with large populations covering vast areas or small localized concentrations. In summer and early fall, animals tend to congregate in meadows, irrigated crop lands, cutover areas, and road edges. Road hunting in the early evening can be effective in summer. Winter hunting in concentrated areas is effective, especially after a storm when animals can be tracked easily.

Keeping resident populations to a reasonable level appears to be the answer to control of tree damage. Periodic reporting of animal activity by field personnel would help.

OTHER ANIMALS

Small rodents, principally red squirrels, deermice, golden-mantled ground squirrels, and chipmunks destroy ponderosa pine seed and seedlings. Voles also may destroy newly germinated or planted seedlings, but they are not considered seed eaters. Small mammals are generally not considered a major obstacle to pine regeneration except in occasional localized situations.

Birds consume many seeds, mostly in flocks that move from area to area during migration. Seed-eating usually starts in early September when the cones begin to open. Pinon and Steller's jays, are commonly seen picking seed from partially opened cones of ponderosa pine. The white-headed woodpecker, often destroys much seed in cones still on the tree. Other important seed eaters are the mourning dove, mountain chickadee, common flicker, and dark-eyed junco.

Many birds feed on harmful forest insects, however, so that the benefits from birds usually outweigh the harm. Some silviculturists believe that timing seed crops and site preparation so that adequate seed is mixed with the soil, out of reach of birds and mammals, will increase the number of surviving seedlings.

Most managers do not consider the available measures to control seed eaters to be practical.

ECOLOGY AND SILVICULTURE

Compatible Philosophy

A basic appreciation and understanding of ecology in the ponderosa pine type is important because of its significance in influencing silvicultural practice. Spurr and Barnes (1973) concluded that the silviculturist should seek to understand ecological principles and natural tendencies as they relate to trees and forest communities with which they work.

Forest managers in the Pacific Northwest have become increasingly aware of plant and animal reactions to human activity. During the last three decades, ecologists in the Northwest have found that certain ecological subdivisions are much more sensitive to such activity than others. Thus, an understanding of the ecological subdivision and its composition is advisable before a management prescription for the land and its resource is recommended. To make the management prescription functional, we must first separate these ecological subdivisions so they may be recognized in the field and identified on a map.

Ponderosa Pine Plant Communities

We are fortunate that many ponderosa pine community types or associations have been identified and described throughout the Pacific Northwest. What happens to these associations under various silvicultural treatments must be observed and recorded, so we can eventually predict with reasonable certainty what will happen to each plant community under each silvicultural prescription.

Geologic province	Area	Approximate number of ponderosa pine communities described	Author
Blue Mountains	Eastern Oregon, southeastern Washington	7	Hall (1973)
High Lava Plains	Central Oregon pumice zone	14	Volland (1976)
Basin and Range	South central Oregon	7	Hopkins (1979a, 1979b)
Basin and Range	South central Oregon	5	Dyrness (1960)
Basin and Range	South central Oregon (Silver Lake deer range)	7	Dealy (1971)
Okanogan Highlands Columbia Basin	Eastern Washington	6	Daubenmire and Daubenmire (1968)

The first three authors provided an ecological basis for management guidelines on range conditions and trends, tree stocking, silviculture, succession trends, and vegetative mapping. Eventually all National Forest land in the Pacific Northwest will be described in such a way to aid in making silvicultural prescriptions.

Other workers, such as Dealy (1971), have provided suggestions for the silvicultural manipulation of ponderosa pine communities to preserve the continued well-being of a particular wildlife habitat.

Following is a partial list of ponderosa pine associations that have detailed descriptions available, along with recommendations for management. The most abundant tree, shrub, and herbaceous species across all stands representing the community are used in the nomenclature. A slash (/) separates species of different life forms, and a dash (--) separates those of similar life form.

Blue Mountains Province (Hall 1973)

Ponderosa pine/wheatgrass
Ponderosa pine/fescue
Ponderosa pine/bitterbrush/Ross sedge
Ponderosa pine/blue wildrye
Ponderosa pine--Douglas-fir/elk sedge
Ponderosa pine--Douglas-fir/snowberry/oceanspray
Ponderosa pine--Douglas-fir/ninebark

High Lava Plains Province (Volland 1976)

Ponderosa pine/bitterbrush/bunchgrass
Ponderosa pine/bitterbrush/squirreltail (on Rhyolite)
Ponderosa pine/bitterbrush-sagebrush/squirreltail (on Rhyolite)
Ponderosa pine/bitterbrush-sagebrush/fescue
Ponderosa pine/bitterbrush/fescue
Ponderosa pine/bitterbrush-manzanita/fescue
Ponderosa pine/bitterbrush-snowbrush/fescue
Ponderosa pine/bitterbrush/needlegrass
Ponderosa pine/bitterbrush-manzanita/needlegrass
Ponderosa pine/bitterbrush-snowbrush/needlegrass
Ponderosa pine/bitterbrush/sedge (fig. 10)
Ponderosa pine/bitterbrush-manzanita/sedge
Ponderosa pine/bitterbrush-snowbrush/sedge
Ponderosa pine/sedge-fescue-peavine

A great deal of ecological information has been gathered in recent years that can help silviculturists write prescriptions for specific ponderosa pine associations.

Figure 10.--Ponderosa pine/bitterbrush/sedge plant community. Pine reproduction frequently is absent or sparse.

SILVICULTURE AND MANAGEMENT

Planning and Decisionmaking

A well-conceived land-use plan and a firm long-term management objective and commitment are essential to sound silvicultural prescriptions. Once a stand prescription is implemented, judgments have been made that are often irreversible. Thus, one vital element of successful silviculture is planning.

In meeting management objectives, the silvicultural prescription usually must be varied to meet the particular ecological limitations of the plant community, especially regeneration risks and recognized environmental constraints. Next, management and the silviculturist should agree upon objectives, particularly a priority listing of land uses and the mix of products and expected services, along with monetary returns.

The prescription should address silvicultural systems--effects of various rotation ages, reentry schedules, and stand densities--as they affect the ability to achieve all resource-management objectives. The prescription may include alternatives, because seldom is only one prescription acceptable. Usually the prescription unit is not less than 10 acres (4 ha), although it could cover several small segments that accumulate to much larger tracts. Treatments for the readily identifiable segments may have small differences in initial entries, but they may be made more homogeneous for second-entry treatments.

Land-use planning followed by the implementation of silvicultural prescriptions is relatively new in the pine type, both on public and private lands. These prescriptions should stand the test of time, and they should not be altered arbitrarily to meet allowable-cut demands. Long-term goals for the forest as a unit should be kept intact for the benefit of future generations.

The stand is the unit that is singled out, looked at, measured, and designated for silvicultural treatment. By definition, it is a group of trees sufficiently uniform in species, age classes, and condition to be a homogeneous, distinguishable, manageable unit. Because of past cutting practices in the Pacific Northwest, the manageable ponderosa pine stand is often difficult to recognize. The forest may be a mosaic of even-aged, small groups of immature and mature trees with a scattered understory of reproduction. This frequently calls for redefining the term stand. The boundaries of the manageable unit may be enlarged or reduced, but this flexibility must be reflected in the objectives written into the stand treatment prescription.

Even Aged or Uneven Aged

Rather than professing that even- or uneven-aged management is best for ponderosa pine, we should keep in mind that both methods can be used successfully. This is fortunate because environmental constraints often urge managers of public land into the uneven-aged regime although even-aged is often easier to implement. Actually, no well-documented research in the region shows one form superior over the other, but mature or larger trees have been shown (Barrett 1969) to exert a significant effect on smaller understory trees in both height and diameter growth. This seems to indicate that uneven-aged pine forests will need to be managed with low density to permit younger or smaller trees, which ultimately replace the larger ones, to grow at a reasonable rate. Uneven-aged management cannot be assumed an easy and inexpensive resolution to all other resource conflicts within the pine forests. To be successful, it will require expertise by the silviculturist and possibly expensive stocking-level control throughout all size classes of the structure visualized.

The reason some stands are maintained in uneven-aged management is simply that the lands came that way. An abrupt change to an even-aged regime now would require cutting too many small, young trees prematurely. Similarly, many public forests were acquired through land exchanges with private lumber companies after the merchantable or high-value trees were harvested. The emerging forests were often even aged. Therefore, the management regime on much of the land was decided many years ago by economics, fire, or other natural events.

On public lands, the extent of even-aged management often is limited by environmental constraints. On industrial lands, most ponderosa pine acreages are being converted to even-aged stands and intensively managed for the highest possible yields.

Treatments

COMPLETE OVERSTORY REMOVAL

Probably the most common stand treatment in the pine type today is the orderly conversion of old, mature stands to vigorous second growth. Most stands consist of a mature overstory with a suppressed understory of seedlings or older saplings. Harvesting the overstory and saving the understory resembles the final removal stage of the classic shelterwood silvicultural system. Often the stand conversion results in a four-fold increase in current annual increment rate within a decade, if existing understories can be preserved and used in the next rotation (Barrett 1973). Stands that are likely to suffer heavy mortality, or that are below minimum stocking standards but contain usable understory trees, are given cutting priority[3] as follows:

---

[3] From U.S. Department of Agriculture. 1974. Silvicultural examination and prescription handbook. Region 6, For. Serv., Portland, Oreg.

1st Lightly Stocked Damaged Overstory With Established Understory. Crop-tree stocking is at or above recommended level and at least 4-1/2 ft (1.4 m) tall, but less than pole size. The mature overstory is below minimum stocking level, and trees are in poor condition.

2d Lightly Stocked Healthy Overstory With Established Understory. Crop-tree stocking is at or above recommended level and at least 4-1/2 ft (1.4 m) tall, but less than pole size. The mature, healthy overstory is below minimum stocking level.

3d Lightly Stocked Poor Vigor Overstory With Pole Understory. Crop-tree stocking is above minimum, and crop trees are pole size. Mature trees are below minimum stocking level, are of poor thrift, and will likely die before the stand is scheduled for a regeneration cut.

4th Lightly Stocked Poor Vigor Overstory With Commercial-Thinning-Size Understory. Crop-tree stocking is above minimum, and crop trees are of merchantable size. Mature trees are below minimum stocking level and of poor thrift. Evaluate whether mature trees will survive until a regeneration cut is scheduled for the crop trees. If mature trees will last, do not schedule overstory removal.

5th Lightly Stocked Overstory With Above Minimum Stocking Understory. Crop-tree stocking is below the recommended level but above minimum, and crop trees are at least 4-1/2 ft (1.4 m) tall but less than pole size. The mature overstory is below minimum stocking level, and trees are not needed for seed.

In using these guides, note that the minimum stocking curve shows that a stand of 30 trees, 18 in (46 cm) in diameter or more, constitutes adequate minimum stocking. Sometimes healthy, vigorous overstory stands on higher sites, with slightly fewer trees, grow impressive amounts of wood and should be given low priority for cutting. Careful examination of overstory vigor and growth is necessary before you decide to cut the stand because it is below stocking. Also, strict application of the priority system may result in concentrating the cut in one locale, which may not be advisable. Most ponderosa pine understories are uneven aged but essentially one size-class and are therefore considered even aged for prescription purposes.

SANITATION SALVAGE

Although sanitation salvage cutting (Sowder 1951) as a stand-treatment practice is gradually diminishing, it is still a necessary element of stand management throughout the Pacific Northwest ponderosa pine type. Large acreages of mature timber still exist, and low vigor trees within these stands are subject to attack by insects and disease. Dying trees or trees likely to die in the next few years should be harvested soon after symptoms appear. The need for salvage cutting frequently coincides with drought; when trees are under severe moisture stress, they succumb easily to beetle attack. The two main tree-classification systems used in sanitation salvage cutting are Keen's (1943), discussed in detail later in this paper, and Salman and Bongberg (1942).

Stands continually sanitized for many years frequently show serious depletion of growing stock. Repeated entry without using established skid trails kills reproduction that is growing stock for the next rotation. For this reason, sanitation salvage sometimes keeps pine managers from moving rapidly into intensive management, probably resulting in a loss of production.

REGENERATION HARVESTS

There comes a time in the life of every forest stand when it must be reproduced. Aside from State laws requiring successful and prompt regeneration, no land manager today can afford idle forest land. Successful reforestation is the first important step in a program of intensive forestry.

Two choices for regeneration are available--natural or artificial. Natural regeneration is the renewal of a tree crop by tree- and wind-sown seed; artificial regeneration is the renewal of a tree crop by direct seeding or planting. Obtaining reproduction by natural seedfall under any silvicultural system is usually highly unpredictable on most lower elevation ponderosa pine sites in the region. Many managers plant directly after regeneration cutting, regardless of the silvicultural system, to prevent the site from being taken over by competing vegetation.

In choosing areas for regeneration cutting, you should follow a systematic process so that areas most in need of treatment are dealt with first. Such a priority system (see footnote 3), based on stand characteristics, follows:

1st Mature Stands--Poorly Stocked. The number of merchantable live, sound trees and crop-tree stocking are below minimum. This includes areas where stocking has been reduced by blowdown, disease, heavy defect, fire kill, and factors that cause the stand to exhibit poor growth because stocking levels of desirable species are below minimum.

2d Immature Stands--Poorly Stocked. Merchantable volume is present, the crop-tree stocking level is below minimum, and the stand is not likely to grow to an acceptable level within a reasonable time. This might include areas of manageable size with disease, blowdown, fire kill, storm damage, other defect, offsite plantations, and other areas exhibiting poor growth as a result of stocking below minimum.

3d Mature Stands--Defective or Damaged. The merchantable live, sound, crop-tree stocking level is above minimum, but the stand exhibits poor growth because of much defect and disease or blowdown. The stand is in danger of falling below minimum stocking from continuing insect attacks, disease, or blowdown.

4th Immature Stands--Poor Growth. Merchantable volume is present, and the live, sound, crop-tree stocking level is above minimum; but growth is unacceptable because of tree characteristics--such as low crown density, crown ratio, or other indicators of poor tree vigor--demonstrate that the stand would not benefit from stocking control; the stand is definitely offsite with low volumes; or there is a large amount of defect, disease, or other problems.

5th Mature Stands--Good Condition. The merchantable live, sound, crop-tree stocking level is above minimum, and the stand is still healthy. These stands should be considered for regeneration cutting last.

The two most common regeneration cutting methods used are shelterwood and clearcutting. The selection system is used extensively to preserve the natural beauty of roadside strips, scenic vistas, and recreation areas. The shelterwood method is frequently used at higher elevation where the probability of windthrow is low and seedling establishment is high.

Shelterwood.--The shelterwood method gradually removes the entire stand in a series of cuttings toward the end of the rotation. It is designed to produce even-aged stands. Many of the stands in the region are naturally occurring shelterwoods where the reproduction has been in existence for 10 to 80 years. The shelter often consists of 10 to 40 mature trees per acre (25 to 100/ha) that are the seed source for reproduction. The overstory trees are harvested in one to three separate cuts over 3 to 5 years or more.

Recent experiments, however, have suggested that heavy volumes of overstory may be carefully removed in a single timber sale and still leave adequate stocking (Barrett et al. 1976). In areas that are difficult to regenerate, saving the existing understory is considered preferable to destroying the understory and starting from seed or nursery stock.

In other areas where the understory is poorly stocked and new reproduction is needed, a one- or two-cut shelterwood sometimes may be successful. The first cut should be made during or directly after a good seedfall. Cut trees should be selected from below, leaving 10 to 15 (25 to 37/ha) of the best-formed trees per acre (fig. 11). Piling and burning the logging slash directly after seedfall has aided in seedling establishment on several experimental sites, apparently because seed becomes thoroughly mixed into the soil. Damage to seedlings has been reduced by harvesting the shelterwood trees when seedlings are only about 12 inches (30.5 cm) tall and after an 18 inch (45.7 cm) snowfall. Managers, concerned about the unpredictability of obtaining natural reproduction, sometimes choose to supplement the natural reproduction by spring planting at least the minimum recommended number of trees under the shelterwood.

Figure 11.--A shelterwood created during a good seed year. Abundant seedlings were observed the folowing year, but numbers gradually diminished to several hundred per acre four growing seasons later. Developing snowbrush may offer severe competition to remaining seedlings. Some managers prefer to plant under the shelterwood to be assured of adequate stocking before brush takes over the site.

Clearcutting.--In this method, all trees in the area--large and small--are cut, which leads to establishment of an even-age high forest. On public lands, the method is used with discretion in the ponderosa pine type. Some industrial silviculturists, however, have used the system extensively in south-central Oregon. Large areas have been clearcut, the slash windrowed, and burned, and the area planted.

On public lands, the method is used in treating areas heavily infected with dwarf mistletoe. These clearcuttings are usually confined to less than 20 acres (8 ha), and the land is planted immediately after harvest--before competitive vegetation develops.

Selection.--The selection system aims to create uneven-aged stands and is used for their continual regeneration. When cutting first began in this type on public lands, it approximated a heavy grade of selection cutting and evolved into tree selection or group selection. From this, gradually evolved the system of partial cutting that left 15 to 30 percent of the merchantable volume for accelerated increment and a source of seed. Meyer (1934) predicted that this method of cutting would eventually eliminate the older age classes, leaving the younger ones, and end in a transition to even-aged stands. On many public and private lands, the next entry will convert large acreages to essentially even-aged stands.

To maintain uneven-aged stands, cutting in lower, submerchantable size classes is frequently necessary to stimulate growth of different aged trees. This practice, although necessary for perpetuating the uneven-aged regime, is questionable for producing optimum yield.

Seed Tree.--This method seeded many industrially held lands in the early days of logging ponderosa pine. The seed trees left, however, were often the smaller nonmerchantable or poorly formed trees. The slash was burned and the seedbed was often bare mineral soil or ash. Some lands were profusely regenerated, but large acreages were not, and they reverted to unproductive brush fields.

The "text book" seed-tree method has not been used to any great extent because too few trees are left to seed the areas adequately. A light shelterwood is preferred to the two to four trees per acre (5 to 10/ha) commonly left with the seed-tree method.

Artifical Regeneration

GENETIC CONSIDERATIONS

Planting and seeding presents an opportunity to preserve the genetic quality of the original stand, to improve upon it, or to lower the capacity to produce the desired volume or quality of wood. Because the stand will probably exist for many decades, a well-chosen genetic background is obviously important. Seed or seedling stock should be carefully chosen from a reputable nursery that buys or collects certified seed from known locales and elevations. The few existing offsite plantations are visible reminders of the disadvantages of planting poor nursery stock.

The most promising step forward in ponderosa pine seed collection on public lands and some private lands in the Pacific Northwest has been the "plus-tree program." Briefly it consists of selecting outstanding trees in the forest, called "good phenotypes;" that is, the effects of the tree's environment and its genetic constitution have produced a good outward appearance, according to an objective scoring system. The goal of the program is to increase the rate of volume growth per acre. Trees are selected on their past diameter and height growth compared to other trees in the stand. Other characteristics--such as limb size, taper, and crown--are also considered. A portion of the seed from each tree is nursery planted, then outplanted, and evaluated. Although the plus-tree program is well underway in many areas, it frequently can not supply enough seed for fullscale nursery production. Seed must be collected in the usual manner, keeping in mind the following:

- The altitude of seed sources is one of the most important factors in a selective breeding program (Wang 1977).
- Ponderosa pine has genetic differences in cold resistance, growth initiation, growth rate, tree form, needle characteristics, and wood properties (Wang 1977).
- At this stage in our tree improvement program, use seed for regeneration within the zone where it was collected until it is proved satisfactory in other locations.
- Collect seed during good seed years. During poor years, seed quality may be questionable (Schubert 1974).
- Collect only mature cones. Viability of immature cones is low, and seedlings are often of poor quality.
- Collect seed from squirrel caches only as a last resort.

If a choice exists between using existing advanced reproduction or destroying it in preparation for clearcutting and planting, the following intense natural selection should be considered:

- Most dense seedling or sampling-sized trees originated after a bumper seed crop with at least 200,000 seeds falling per acre (494,208/ha).
- Out of the 200,000 seeds that fell, 15,000 to 20,000 seeds per acre (37,066 to 49,420/ha) may have germinated and produced a seedling the first year.
- Frequently 5,000 to 8,000 seedlings per acre (12,355 to 19,768/ha) survived and grew to sapling size.
- Precommercial thinning leaves 180 to 250 trees per acre (445 to 618/ha).

The genetically improved stock available now may not be superior to the naturally selected trees. Also, by using in situ reproduction, we are helping to preserve our Northwest ponderosa pine gene pool (Silen 1976).

SITE PREPARATION

With the exception of a clean burn, all ponderosa pine sites need preparation before planting. This requires removing competing vegetation and obstacles that impede planting. Soil should be disturbed enough to create a good planting bed, but not endanger the site to erosion. Plantations subjected to excessive competition from brush soon after planting fail or grow so slowly that the site is eventually taken over by the competing vegetation. Use of an acceptable herbicide is often necessary, or the site will have to be prepared and replanted.

Scalping or narrow stripping is often inadequate to keep competing vegetation from taking over the site. Complete mechanical site preparation is preferred, but it may involve some environmental trade-offs. Adequate site preparation on many ponderosa pine sites is often severe, temporarily irreparable, and may destroy some land-use values for a few years. Nevertheless, it may be necessary for stand establishment.

WHEN TO PLANT

The ideal time to plant on many of our lighter soils is within 4 to 6 weeks after snowmelt in the spring. The soil is charged to field capacity after the fall rains and winter snowpack. Weather conditions from day to day during this time, however, may not always be favorable.

In the spring, areas ready to plant are frequently bare of snow before access roads are open. Plowing the roads or using snowmobiles or helicopters to reach the site before planting conditions become critical is often advisable. This is especially important on harsh, south-facing slopes.

Seedlings lifted in the nursery and planted during the period of maximum root growth capacity (January to March) have the most vigorous root growth after planting and the best chance to avoid damaging moisture stress (Cleary et al. 1978). When high elevation, late spring planting is necessary, seedlings should be lifted during maximum root-growth capacity and placed in cold storage until the site is ready in the spring.

Weather conditions at the time of planting can cause severe tree moisture stress. Weather guidelines for safe planting have been developed based on physical laws that govern seedling moisture loss (Cleary 1971).

The following weather guidelines presented by Cleary et al. (1978) are based on both physical laws and certain assumptions. Before the table guidelines are used, Cleary suggests reading the discussion (chapter 8, Cleary et al. 1978) so that you understand how these guides were generated and why certain conditions are less favorable than others.

Follow these steps to use table 6:

- Measure wind velocity with an inexpensive wind meter, air temperature, and wet bulb depression with a psychrometer. (A standard fire observation kit will work.)
- Find the point in the table corresponding to measured air temperature and wet bulb depression.
- If the point is outside the conditional zone, planting may proceed.
- If the point is inside the conditional zone, planting may proceed only when wind speed does not exceed the value appearing in the table.

Table 6--Weather guidelines for lifting and planting ponderosa pine, giving maximum allowable wind velocity for a given air temperature-wet bulb depression combination (from Cleary et al. 1978).

Air Temp. (°F)	Wet bulb depression (°F)[1] 1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0
30															20
31															19
32															19
33															18
34														19	18
35														19	17
36														19	17
37														18	16
38													20	18	16
39													19	18	15
40													19	16	15
41													19	16	14
42													18	16	13
43												20	18	15	13
44												19	17	15	13
45												19	17	15	12
46												18	16	14	12
47												18	15	13	11
48											19	17	15	12	10
49											19	16	14	12	9
50											18	16	13	11	9
51				Plant if wind velocity is less than 20 MPH.							18	15	13	10	7
52										20	17	15	12	9	7
53										19	16	13	11	9	5
54										18	16	13	10	7	5
55										18	15	12	9	7	4
56										17	14	11	9	5	3
57									19	16	13	10	7	5	2
58									19	16	13	10	7	4	1
59									18	15	12	9	5	3	
60									18	14	11	8	5	2	
61									16	13	10	7	4	1	
62								19	16	12	9	6	3	No planting—	
63								19	15	12	8	5	2	regardless of	
64								18	15	11	7	4	1	wind velocity.	
65								18	13	10	7	3			
				Plant						Conditional zone[2]					

[1]Dry bulb temperature reading minus wet bulb.

[2]Planting allowed if wind velocity is less than value in table for a given air temperature-wet bulb combination.

SEEDLING CARE AND HANDLING

All preplanting precautions should be carefully followed to assure the highest possible survival of planted trees. Planting dead trees is often the result of poor care during transit and storage at or near the planting site.

During transit, trees must be protected against drying, heating, freezing, molding, and mechanical damage. Seedlings should be kept within a temperature range of 34° to 38°F (1° to 2°C) to reduce water loss and minimize metabolic activity, which can raise the temperature of seedlings in a shipping bag. Severe tissue damage can result from freezing and thawing.

Unrefrigerated trucks may be used for transporting seedlings short distances. Trees should be transported during cool but not freezing parts of the day. During warm weather, cool, wet sphagnum, or chipped ice or snow should be packed between the bundles. If the truck is not enclosed, the seedlings should be covered with canvas, with some air circulation provided between trees and the cover. Periodic checks during transit should be made even in refrigerated trucks to assure that temperatures inside the bundles are below 40°F (4°C). For long transit, a refrigerated truck is necessary.

After trees have arrived at their destination, they should be examined for evidence of heating, drying, freezing, or mold before planting or short-term storage. Trees shipped in bundles should be watered and allowed to drain. Trees shipped in bags should be sprinkled with about a pint of water and resealed promptly. If trees are to be held several days before transportation to the planting site, they should be stored at 34° to 36°F (1° to 2°C) and above 90 percent relative humidity in a room with good air circulation.

At the planting site, bagged trees should be kept refrigerated, if possible. They should never be stored in the sun or where air temperatures exceed 55°F (13°C). Solar radiation combined with air temperature can raise bag temperatures rapidly to the critical level. Bundled trees may be stored in a trench dug in the snow. At least 6 in (15 cm) of snow should be left between the ground and the trees. Bundles should be separated with packed snow, and the trench covered with snow.

NUMBER OF SEEDLINGS TO PLANT

Several important considerations--besides the first product to be harvested--must be included in the decision on how many trees to plant. Some managers have commonly planted 200 to 300 trees per acre (494 to 741/ha) with the object of having about 180 to 240 trees per acre (445 to 593/ha) with an average stand diameter of about 8- to 10-in (20- to 25-cm) d.b.h. available at the first commercial entry. Recent examination showed too many genetically inferior trees would have to be maintained to meet the stocking goals.[4/]

The recommendation now is that 400 to 500 trees per acre (988 to 1,236/ha) be planted. Then a precommercial thinning is made after the stand is well established; trees are 8 to 10 ft (2.4 to 3.0 m) tall and dominance is clearly expressed throughout the stand. This procedure should eliminate most of the inferior trees early in the life of the stand.

PLANTING

Planting is one of the most costly investments in producing a forest. In establishing the plantation, commitments for continued protection and maintenance of the stand are made for many years. Mistakes at planting time are costly because they could conceivably be carried until the stand is finally harvested. At present, planting is the surest way to obtain ponderosa pine regeneration in the Pacific Northwest (Adams 1970). The great majority of planted lands consistently maintain adequately stocked, healthy trees. Few naturally regenerated stands do.

Natural regeneration takes place successfully in selectively cut stands, but it occurs slowly over many years. In contrast, natural regeneration under a seed tree, shelterwood, or clearcut method frequently appears successful the first several years after germination, but then seedlings succumb to birds, browsing, brush competition, frost heaving, or some other climatic action; by the time seedlings are well established, the stand is understocked. Exceptionally successful regeneration from natural seedfall does occur on higher than average sites.

Some reasons for success of planting over seeding or natural regeneration are:

- Roots are placed deep and can develop rapidly, so the tree is less likely to suffer from drought.
- Trees have a good start in competing with brush and grass.
- Well-planted, large seedlings are less likely to frost heave than the smaller, natural seedlings.
- Planted trees can survive after a moderate amount of browsing.

Plantations do occasionally fail, and the reasons can usually be traced to one of four reasons:

- Improper care of seedlings before planting.
- Poor site preparation.
- Improper planting techniques.
- Animal damage.

[4/]Study conducted by Leslie P. Yates, Deschutes National Forest.

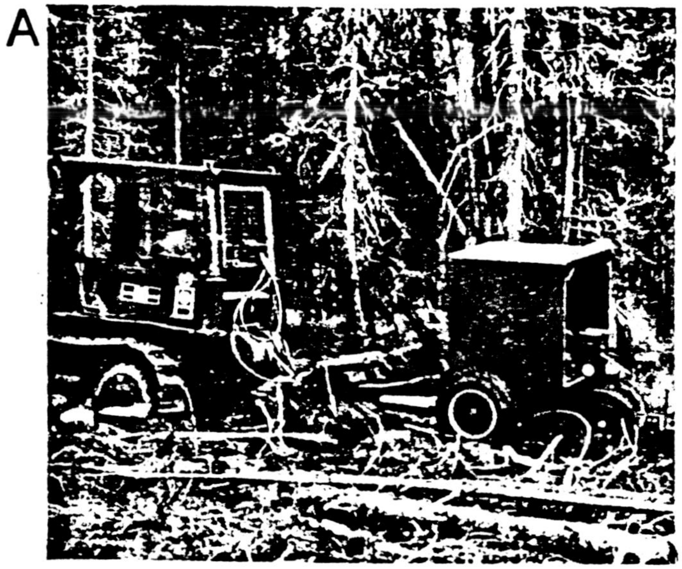
The two most successful planting techniques have been auger planting (fig. 12) and machine planting (fig. 13).

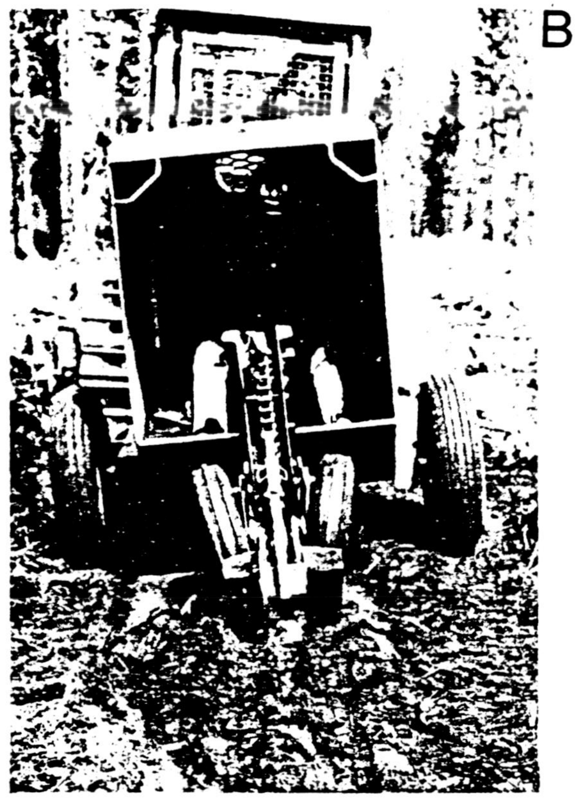
Figure 12.--On areas that cannot be machine planted, auger planting has been successful in lighter nonrocky soils.

Auger planting has been preferred in areas where the terrain or large rocks will not permit machine planting. The auger has been the choice over the planting bar or hoe, mainly because it permits the tree to be planted in loose soil with the roots well distributed in a deep hole, with less chance of "J-rooting." On some of the pumice-mantle soils of central Oregon, the auger often penetrates the fertile, old, buried horizon. This increases chances for rapid root extension and development (Barrett and Youngberg 1970), because the auger allows mixing of the infertile C1 and C2 horizons with the moderately fertile A1, AC, and D horizons. In heavier soils, the auger loosens the soils in the planting hole and creates a much more suitable soil medium for developing a vigorous root system. Augers are more efficient in noncompacted, clean-scouring, rock-free soils such as sandy loams, sandy clay loam, and fine pumice. Augers should operate at 300 r/min or less. Faster rates will move the soil too far away from the planting hole.

If machine or auger planting cannot be used, the tile spade is often preferred. The main objections to the planting bar and hoe are that roots are often "J-rooted," and the roots are all in one plane rather than well spaced throughout the planting hole.

So far, comparative field testing of container-grown ponderosa and lodgepole pine seedlings with bare-root stock has favored the latter. Lower survival of container-grown trees was attributed to heavier animal damage than experienced by the older, woodier bare-root stock (Cleary et al. 1978).





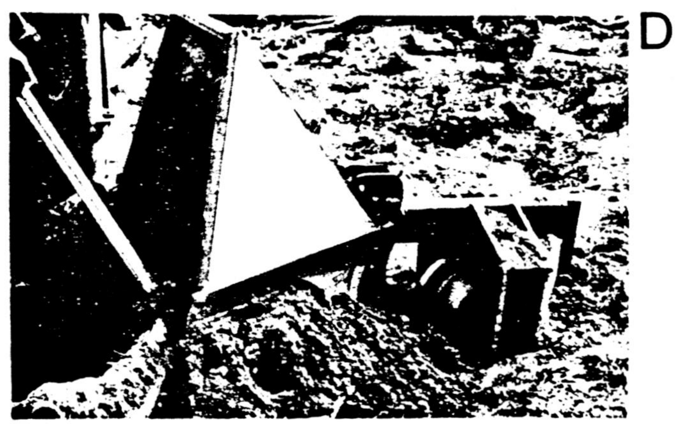


Figure 13.--The Whitfield Forest Land Semiautomatic Transplanter was used with a high degree of success in central Oregon: A, the planter operating on pumice soil; B, hydraulic system levels planter on sloping ground; C, operator feeds trees into the fingers of the semiautomatic planting mechanism; D, V-plow mounted on the C-frame removes obstacles from the planter's path, and floating coulter regulates the desired depth.

Natural Regeneration

SEEDFALL

Seed production of ponderosa pine is not regularly periodic in the Pacific Northwest. On the average, we might expect adequate crops of seed every 4 to 5 years, although some controversy exists over what constitutes an adequate crop. Dahms and Barrett (1975) reported that during the 22 years from 1953 through 1974, in only 5 years were 200,000 seeds per acre (494,200/ha) or more produced.

The question of how many seed are required to produce an acceptable crop of seedlings is not well answered. Reports vary widely outside the Pacific Northwest region. Foiles and Curtis (1973) reported that 55 seeds were needed to produce one established seedling on scarified soil. The majority of reports indicate that on the drier sites enormous amounts of seed are required for adequate regeneration. Occasionally, a year occurs in the Northwest when almost no seed is produced over a large area. Frost injury to developing conelets may be the reason (Sorensen and Miles 1974).

Seedfall usually starts in earnest late in September and continues through the winter. In one study in Oregon, Dahms and Barrett (1975) found about 38 percent of the seed from mature and immature trees had been shed by early October. By November, 82 percent of the seed had fallen, with the balance dispersed during the remaining months. Variation about the mean was great, however. For example, in the bumper year of 1958, 89 percent of the crop had fallen by October 7.

Soundness of seed was related to time of seedfall and size of crop (Dahms and Barrett 1975). Seeds shed by early October and November were 84-percent sound, and those falling between early November and the following late spring or summer were 69-percent sound.

In an old-growth stand, a significant relation was found betwen the total number of seeds produced and percent of sound seed (fig. 14). In poor seed-production years, seed was of poor quality.

Not much ponderosa pine seed disseminates beyond about 100 ft (30.5 m) from the seed source (Barrett 1966). If prevailing winds are strong enough, seed can be blown 8 chains (161 m) into a clearcutting; seed numbers at this distance, however, are only about 3 percent of those at the timber's edge. At 2 chains (40 m), seed numbers were only 22 percent of those at the timber's edge. Similar results are confirmed by workers in nearby Idaho (U.S. Department of Agriculture 1940). They found that 82 percent of ponderosa pine seed falling within 7.6 chains (153 m) of the timber's edge was confined to an area only 1.5 chains (30 m) from the source.

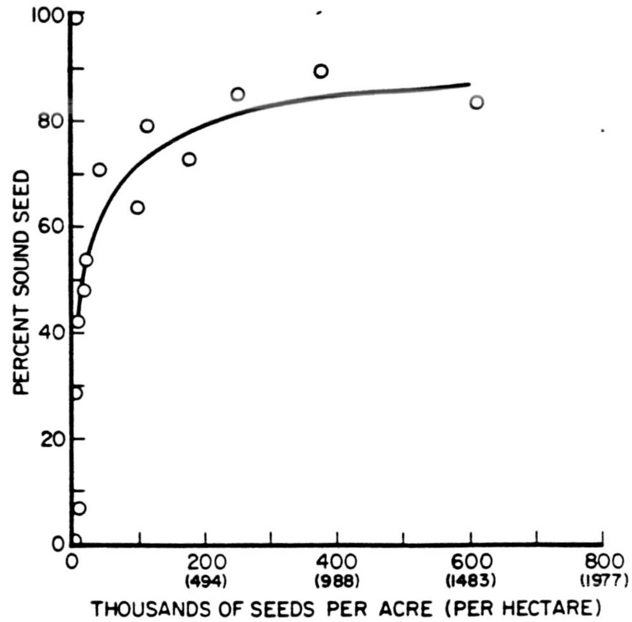


Figure 14.--Percent of seed that was sound related to crop size, old-growth ponderosa pine (adapted from Dahms and Barrett 1975).

Seed trees should be chosen with great care because they are the genetic foundation of the next crop. Dominant trees are the best choice for seed production (Fowells and Schubert 1956). Preferably, trees should have a vigor class (Keen 1943) rating of A or B. The number of old cones at the base of the tree is a good indication of the tree's ability to produce seed.

Wind firmness is an important consideration in the Northwest. This is especially critical on slopes subject to prevailing seasonal winds where shallow soils or hardpans have encouraged the development of layered root systems. Your judgment of this factor may be enhanced by examining nearby stands that have been subjected to winds for many years. Selection of the best disease-free dominants with wind firmness and good seed-production potential is the key to a good supply of seed.

NATURAL SEEDLING ESTABLISHMENT

Seedling establishment by natural regeneration in the ponderosa pine type east of the Cascade Range is highly unpredictable. This may not always be so, however. Our present knowledge will not permit us to regenerate most areas by natural seeding, especially in clearcut and shelterwood systems because of many complex, interrelated environmental factors. Often the forester has little control over these factors, which can mean success or failure in stand establishment from seed. Because our goal is a successful stand, I will discuss only factors we can partially control that will improve chances of natural regeneration.

Prolonged moisture for germination, growth, and life during the critical heat of July and August is essential. Because summers are usually dry, conservation of moisture is critical. Germination usually occurs in early spring, but rapid drying of the germinating medium often causes death of the seedling. Partial shading of seedlings affords protection from both heat and frost by reducing incoming shortwave radiation during the day and longwave radiation flux at night (Cochran 1970). A well-implemented shelterwood sometimes accomplishes this. Working the seed into the soil during logging slash piling or site preparation can often implant the seed deep enough in pumice soils so that desiccation of the root system is lessened.[5] Although a light layer of duff and slash can act as a mulch and a radiation regulator, it can also harbor seed- and seedling-eating animals.

Existing ponderosa pine 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. Managers interested in regenerating ponderosa pine stands by natural seed dispersal should do the following:

- Limit the undertaking to above-average sites.
- Leave a shelter of 10 to 20 trees per acre (25 to 49/ha).
- Time logging and slash disposal so that seed is mixed with the soil at least several weeks before germination.
- If necessary, apply herbicides to keep competing vegetation to a minimum until seedlings are out of danger of being overtaken by the understory vegetation.
- Seriously consider planting at least a minimum of trees to assure adequate stocking.

Intermediate Cutting

Once the pine stand is established, some type of silvicultural control over stand development is necessary to attain the intended management goal--perhaps including water, wood, forage, and wildlife--but prudent management almost always necessitates some form of tree cutting.

Natural young ponderosa pine stands established in the early 1900's often became seriously overstocked. Exceptions are the special areas where stockability is far below average (Maclean and Bolsinger 1973). On most areas, stand-density control in the management of this species is one of the foresters' most useful concepts. Without density control these forests often succumb to this sequence of events: stagnation; insect attack; tree death; understocking; and final harvest of volume well below the total potential of the land. With density control, the manager can increase the amount of usable wood produced and often enhance other resources of the forest as well.

[5] Barrett, James W., data on file, USDA For. Serv., Silviculture Laboratory, Bend, Oregon.

A good program of intermediate harvest should have a cutting schedule that designates an appropriate stand density at intervals throughout the life of the stand. These schedules, which form the operational base for a managed forest, should be in graphs or tables, usable by both field and office personnel.

The term intermediate cutting is often misinterpreted. Here it refers to the various cuttings made during stand development from established seedling to established regeneration and final harvest. The objectives of these cuttings are improvement of the existing stand, regulation of growth, and usually provision for early financial return. No effort is directed to regeneration.

These cuttings may consist of thinnings, which are aimed primarily at controlling growth by regulating stand density. Thinnings made in young stands to regulate species composition and quality are often referred to as release cuttings and in older stands are called improvement cuttings. Sanitation salvage cuttings harvest trees that have been attacked or are likely candidates for attack by insects, disease, or both to prevent spread to other trees. Precommercial thinnings are made in stands so small that none of the felled trees are taken from the forest and used. Commercial thinnings are those where all or parts of the trees removed are used.

PRECOMMERCIAL THINNING

Precommercial thinning is usually the first cutting that takes place in a newly created stand; it is now a major undertaking on public and some private pine lands east of the Cascade Range on vast areas of natural pine regeneration. This regeneration may be as dense as 20,000 stems per acre (49,421/ha), but more commonly 3,000 to 7,000 stems per acre (7,413 to 17,297/ha), 40 to 80 years old, 2 in (5 cm) in diameter, and about 12 ft (3.7 m) tall. Other dense young stands are found with fewer trees per acre and average diameters of 4, 6, or 8 in (10, 15, or 20 cm). Stands considered unmerchantable now but that will contain a salable number of merchantable excess trees in 10 years are not usually considered for precommercial thinning.

Identifying financially attractive precommercial thinnings should be done carefully to take advantage of the potential for individual tree growth and comparative financial return. Guidelines are now available to aid in the selection of appropriate stands to thin (Sassaman et al. 1977). Vigorous, small-diameter stands on good sites are generally more attractive for thinning than a large-diameter stand on an average site. Generalizations about selections of this kind are inappropriate, however. You should consider each thinning alternative as a separate event and use the appropriate benefit-cost ratios for comparison as suggested by Sassaman.

Stands may be precommercially thinned when dominance is clearly expressed in the stand. Crowns should extend above the general crown cover with dominants receiving full light from above and partly from the sides. Codominant trees should be well represented and readily distinguishable.

Precommercial thinning of stands overtopped by mature trees is not recommended. Greatest response to thinning is obtained by complete harvest of the overstory. This does not mean that some overstory trees cannot be left for wildlife or reasons of esthetics. It does mean, however, that some loss in understory tree growth will result (Barrett 1969).

Growth response from precommercial thinning is affected by spacing, understory vegetation, site, and amount of overstory. The effect of spacing and understory vegetation on height and diameter growth is clearly shown in the Pringle Falls experiment (Barrett 1973). Here, the overstory was completely removed from an understory of saplings averaging about 2 in (5 cm) in diameter and 12 ft (3.7 m) high. Diameter and height growth increased with wider spacing (figs. 15, 16). Diameter growth appeared to reach its maximum to respond quickly, but height growth took considerably longer (fig. 17). This experiment also showed that in areas with brush species--such as bitterbrush, snowbrush, and greenleaf manzanita--the positive effects of thinning can be nullified for at least a decade by competition. This effect is most prominent at wider spacings where areas not occupied by tree roots are quickly taken over by brush. More recent results suggest that as tree crown increases, the competitive effect of these understory plants may be subdued. Other studies have shown somewhat the same effects of spacing on diameter growth (Barrett 1968, 1972, 1973; Mowat 1953), but did not show a significant effect on height growth.

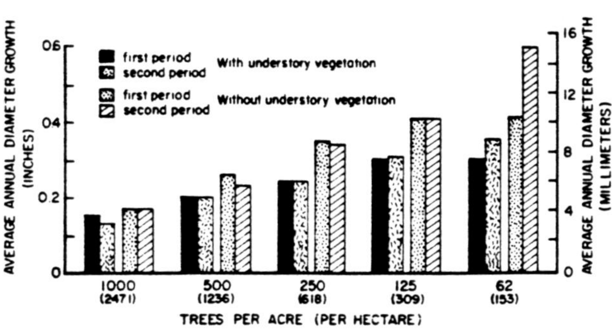


Figure 15.--Average annual diameter increment of ponderosa pine saplings during the first and second 4-year growth periods (adapted from Barrett 1970).

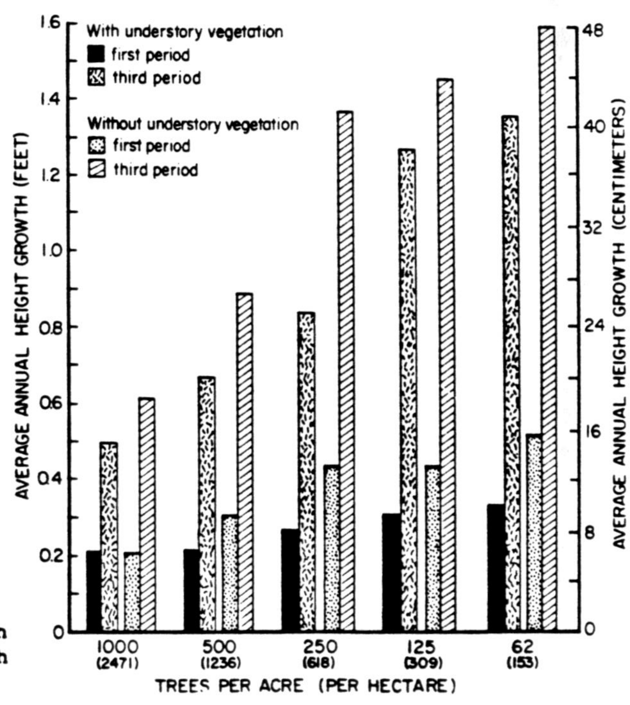


Figure 16.--Average annual height growth during the first and third 4-year growth periods (adapted from Barrett 1973).

After removal of the overstory and thinning, the annual volume increment of the sapling understory increased rapidly. During the first 4 years after thinning, 500 trees per acre (1,236/ha) produced only 12 ft^3 per acre (0.8 m^3/ha) per year in the Pringle Falls study (fig. 18). But after 12 years, the rate increased to 44 ft^3 (3.1 m^3/ha) or 3.5 times what the old, mature overstory was producing. Current annual increment is expected to peak at the 6-ft (1.8-m) spacing in about 20 years after thinning and produce about 110 ft^3 per acre (7.7 m^3/ha) per year, which may be the maximum periodic capacity of this site to produce wood fiber.

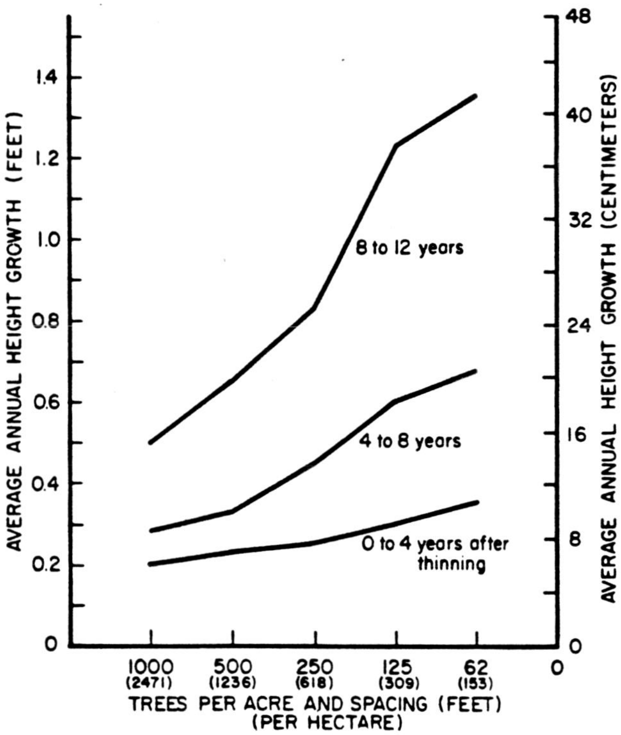


Figure 17.—Average annual height growth of released saplings during the first, second, and third 4-year growth periods in the Pringle Falls spacing study. Understory vegetation was allowed to develop naturally (adapted from Barrett 1973).

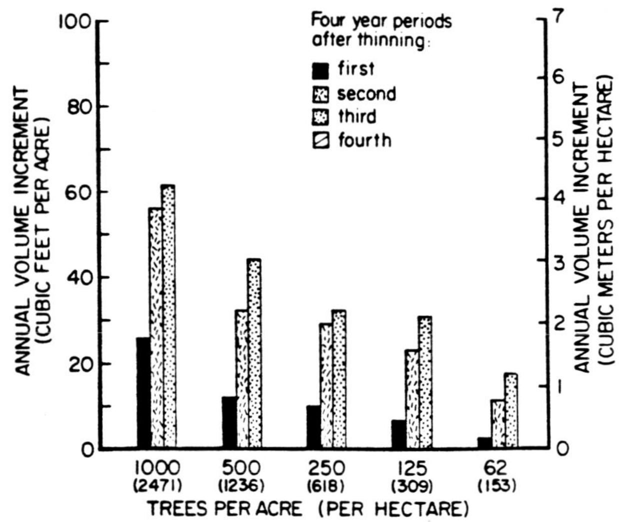


Figure 18.—Periodic annual volume increment of ponderosa pine saplings thinned to various spacings. Understory vegetation was left to develop naturally (Barrett 1973).

Average diameter of the various stands directly after thinning and 16 years later are as follows:

	Trees per acre				
..	1,000	500	250	125	62
			Inches (cm)		
Vegetation left	2.0-4.0 (5.1-10.2)	1.9-4.7 (4.8-11.9)	2.1-5.7 (5.3-14.5)	2.2-7.1 (5.6-18.0)	2.2-7.7 (5.6-19.6)
Vegetation removed	1.7-4.1 (4.3-10.4)	1.8-5.1 (4.6-13.0)	1.9-6.8 (4.7-17.3)	2.5-8.5 (6.4-21.6)	2.2-10.1 (5.6-25.7)

Some individual trees at the widest spacings have reached a diameter of 12.5 in (31.8 cm) 16 years after thinning.

Present thinning recommendations for this type of stand vary with environmental constraints and management objectives. Large areas of saplings and small poles in Oregon are being thinned to 150 to 200 trees per acre (371 to 494/ha), however. Where a roundwood market is anticipated, leave-tree numbers could be increased.

Overstocked pole stands also will respond to thinning, although detectable response the first few years after thinning is almost always confined to diameter growth. Released dominant poles grew twice as fast in diameter as their unreleased counterparts in a study in central Oregon (Barrett 1963 and fig. 19). Poles were thinned to about 156 trees per acre (385/ha) and grew at the rate of 1.6 in (4.1 cm) per decade during the 6 years after thinning.

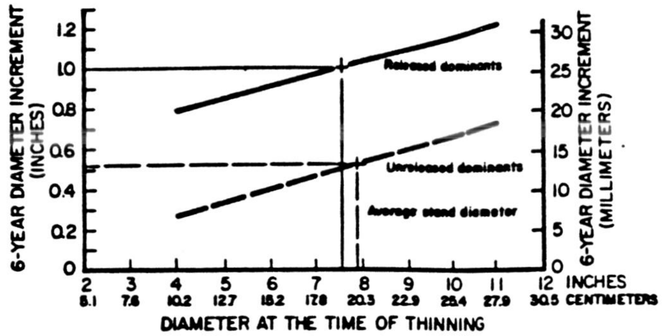


Figure 19.--Average 6-year diameter growth of dominant ponderosa pine related to initial diameter (adapted from Barrett 1963).

So far, the most satisfactory machine for precommercial thinning in this region is the conventional light chain saw with cutting bar. One worker can thin from 2 to 5 acres (0.8 to 2.0 ha) a day depending on density and size of the trees. Other machines that flail or "chew up" unwanted trees have not proved satisfactory, because tree selectivity is poor and the number of acres thinned per day is low.

Many managers think that slash from precommercial and commercial thinning represents a risk to the investment. Slash can be both harmful and beneficial, yet it is most often a hazard to the residual stand. Thinning slash is most often reduced to lessen the risk of catastrophic fire; the risk is greatest during the short period when foliage and smaller branches dry out and remain on the slash. Some owners of large private lands identify high fire-risk areas (from past fire and lightning history records) and treat only the slash on these lands, because this is more efficient and less costly than trying to treat all of it.

The "Tomahawk" (Dell and Ward 1969) is viewed as a reliable method for treating large quantities of thinning slash. This machine (fig. 20) is a slash-cutting tool mounted on the front end of a D-6 or D-7 crawler tractor. The Tomahawk cuts and crushes the slash, but the tracks of the tractor also contribute greatly to the crushing action. Although the machine has limitations, it is considered to be the most economical equipment available for meeting slash disposal objectives. A disadvantage of the Tomahawk is that slash must dry at least one season before it crushes satisfactorily, so a high risk of fire may be present during one season. When green slash is crushed by the Tomahawk, the larger stems do not touch the ground, so it is still a fire hazard when it dries. When the Tomahawk is used in dry slash that breaks readily, some ground disturbance occurs and a portion of the slash is partially worked into the soil. Some silviculturists are concerned about the possibility of nitrogen depression when slash is worked into the soil. Cochran (1968) believes this is not a problem unless the slash is chipped and actually mixed with the soil. He reported one instance where the nitrogen contributed to the soil from the foliage was about equal to the amount necessary for slash decomposition, so no net loss occurred.

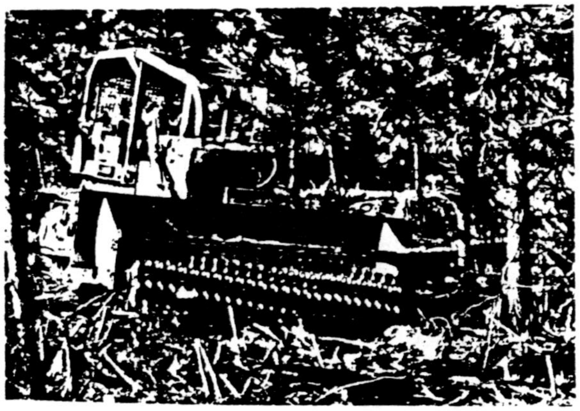


Figure 20.--The Tomahawk is probably the most useful machine found so far for treating large quantities of thinning slash.

Medium-sized crawler type tractors without the Tomahawk attachment are being used successfully to crush thinning slash. This method works well if the slash is dry and of small diameter.

In stands that average 2 to 5 in (5.1 to 12.7 cm) in diameter with leave trees widely spaced, thinning slash can be bulldozed into piles for burning. This method is especially useful where the intent is to seed the area to grass or cover for wildlife.

In pole stands that are being precommercially thinned and stands that are being commercially thinned for the first time, piling and burning can be difficult. Bucking the slash is frequently necessary so that the cut tree stems may be maneuvered between reserve trees without scarring standing tree butts.

Preliminary trials in prescribed burning of thinning slash shows considerable promise. Principles and prescriptions for using this silvicultural tool are presently being worked out.

Complete slash disposal is too expensive in most thinned stands. Exceptions may be campgrounds and heavily traveled roadside strips. Generally, managers have three goals in thinning-slash treatment: to decrease the risk of ignition; to break up the continuity of the slash; and to diminish the amount of slash.

Precommercial thinning in plantations in the Pacific Northwest is just beginning; growth results are reported for only one thinned plantation (Barrett 1972). Trees were planted at 6- x 6-ft spacing (1.8- x 1.8-m) spacing and thinned 33 years later to 8.8, 10.2, and 17.6 ft (2.7, 3.1, and 5.4 m). Response to thinning was good, even though the stand should have been thinned at a much younger age. Trees grew in diameter at the rate of 1 to 3 in (2.5 to 7.6 cm) per decade after thinning. As with other recently begun thinning trials in small poles, spacing has not yet affected height growth. The most surprising result was that although the heaviest thinning in these full-crowned trees reduced basal area 65 percent, trees in the treatment grew 80 percent of the volume produced by four times as many trees.

COMMERCIAL THINNING

The first commercial thinning in a previously unthinned ponderosa pine stand is an important undertaking in stand management, because it sets the stage for the future accumulation of wood on the best trees. Select reserve trees carefully on the basis of growth rate (present diameter and height), general health, and stem quality. Retain the best crop trees. Spacing should not be overemphasized in this thinning, because good crop trees will soon use the rooting area formerly occupied by a cut tree. One option in commercial thinning is to mark desired crop or leave trees with paint and allow the logger to remove all other merchantable material. This frequently works well for several reasons. First, the marker focuses on the best crop trees, not on the trees to be cut. Second, the logger sometimes takes the small trees, so better use is made of the forest's productivity. Third, the trees to be retained are evident to loggers, and they can protect them from damage. The tree marker can easily make a quick prism check on stocking level.

Commercial thinnings in previously unthinned stands usually remove the average stand diameter or slightly greater because an occasional large rough tree is harvested. Subsequent thinnings will be "free thinnings," where trees are removed from all crown classes.

Commercial thinnings in young stands are frequently badly needed but difficult to accomplish. Harvest trees are sometimes small and "limby". The first 16-ft (4.9-m) log usually is grade 5 (Gaines 1962). A few grade 4 logs are cut, with the remainder in grade 5. These grades saw mostly into No. 3, 4, and 5 common lumber with an average of about 55 percent of the log volume recovered as rough green lumber (Woodfin 1978). Density before thinning, in basal area, is often high. The amount of salable timber, however, may be less than 2,000 fbm per acre. To wait for later sales often endangers the stand to further beetle attack, but to sell sooner often requires a subsidy on public lands for removal of the material. About 2,000 fbm per acre is the minimum that most loggers are willing to harvest, although the amount appears to getting lower each year as pine stumpage becomes difficult to obtain. The subsidy for lesser amounts may be accomplished by including the commercial thinning in sales of larger mature timber.

Objectives of the first commercial thinning in previously unthinned stands are to reduce current mortality, to forestall future mortality by reducing density, and to provide a current stocking level that will allow optimum growth until the next stand entry.

We are not yet confident of the minimum amount of stocking that will produce maximum periodic volume increment in these stands. This information should be forthcoming soon from levels-of-growing stock studies established about 1965.

An example of density regulation in commercial thinning is shown in figure 21. The stand is on a low site containing 110 trees per acre (272/ha) with an average stand diameter of 10 in (25.4 cm) (point A). The stand can be thinned back to the recommended stocking-level curve of 65 trees per acre (161/ha), point B, or 75 trees (185/ha), if the developing course of an 8-in (20.3-cm) stand is followed.

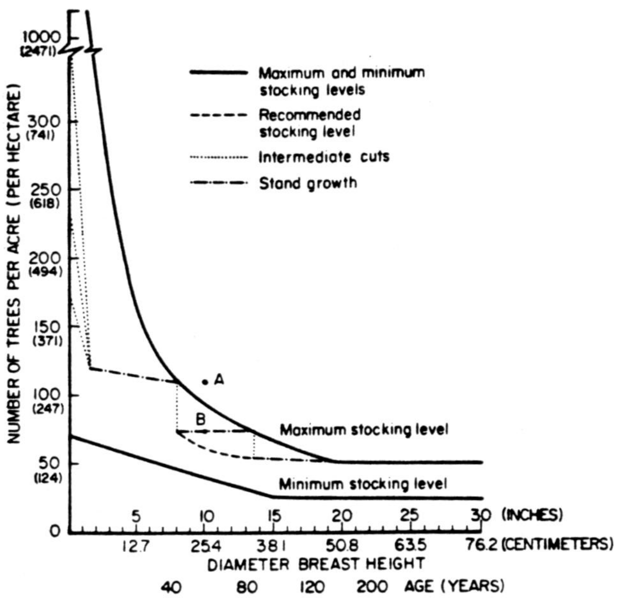


Figure 21.--Stocking-level curves for ponderosa pine where site index is V and lower (Meyer 1961), an example of precommercial thinning to 120 trees per acre (296/ha).

IMPROVEMENT CUTTING

Generally, improvement cutting is needed in stands that are close to maturity, overstocked, show evidence of annual beetle attack, or are being invaded by unwanted species. These stands are usually, but not always, in transitional zones at the higher elevations on notably productive sites. Although between 100 and 150 years old, these even-aged stands, if fully stocked, are often producing gross increments of over 100 ft^3 per acre (7 m^3/ha) per year (Barrett 1974) or more than 700 fbm per acre per year. Even at 100 years old, these stands respond to thinning by increasing in diameter growth. Basal areas are often well over 200 ft^2 per acre (46 m^2/ha), and mountain pine beetle is almost always moderately evident. Present recommendations are to thin these stands commercially from below, removing only as much basal area as necessary to reduce mortality. This preserves the productivity of the stands, while subduing the activity of mountain pine beetle (Sartwell 1971). Annual height growth at this stage in stand development is beginning to lessen, and large reductions in growing stock can drastically reduce current increment.

Some improvement cutting in combination with prescribed burning may be necessary where fir has invaded lower elevation pine stands. The fir may encourage the development of undesirable levels of tussock moth.[6]

The elimination of incense-cedar is a never-ending process in some pine stands where it has invaded from seed of overmature trees. Early removal of these old trees is recommended.

Sanitation and salvage cutting are intermediate cuts that have been practiced since the initiation of management of our pine forests and are covered elsewhere.

Sanitation cutting, often combined with salvage cutting, harvests trees that have been attacked or are good candidates for attack by insects or disease (Sowder 1951). The object is to prevent these pests from spreading to other trees or stands. Sanitation salvage cutting is still practiced to varying degrees throughout the region and is considered essential to preserving the health and vigor of stands where a large portion of old growth is still retained.

DENSITY CONTROL

Although density control is not a method of intermediate cutting, it is discussed here because it affects the size of trees cut.

Stand-density manipulation is one of the silviculturist's most important means for influencing product size, stand-volume increment, and final yield. In addition, stand density can influence development of understory vegetation, water yield, soil stability, and habitat for wildlife and domestic stock. Therefore, any guidelines for density control must have enough flexibility to cover many alternatives for management. In the Pacific Northwest, as in most other areas in the country, merchantability standards are changing rapidly and no one really knows what will be the minimum-sized tree that can be profitably harvested in a given number of years. Also, esthetic values may put further constraints on density control.

Before any density control is implemented, a thorough stand examination is recommended. Homogeneous stands are delineated, and density, size classes, and other pertinent information are recorded. Then, density regulation may be prescribed for each stand.

[6] Unpublished report, "A timber type evaluation of historical Douglas-fir tussock moth outbreak areas in Oregon and Washington," by Robert E. Martin and Jerry T. Williams. U.S. Dep. Agric., Douglas-fir Tussock Moth Res. and Dev. Prog. Final Rep. (on file at the For. Sci. Lab., Corvallis, Oreg.).

Presently, the National Forest System in Region 6 is using stocking-level curves to aid in precommercial and commercial thinning. These are supplemented somewhat by the "Managed Yield (MGLD)" computer program that--given predicted stand characteristics, such as tree sizes and stocking rates--calculates the expected volume, basal area, and so on for the specified ages. As described by Sassaman et al. (1977):

> The physical stocking guides used in the estimation of managed yields are commonly called stocking level curves. Basic features of stocking level curves are outlined in the Forest Service Silviculture Examination and Prescription Handbook (Region 6). By definition in the handbook, a stocking level curve is a management tool used to compare the stocking of a given timber stand in relationship to a desired (biologic) stocking level under managed conditions. Generally the curves express a desired number of trees per acre for a given diameter breast height and/or at a given age by site classes. The curves for ponderosa pine (fig. 21, 22) are based on the growth and yield tables obtained from USDA Bulletin 630 (Meyer 1961), research data from the Pacific Northwest Experiment Station, and observations of growth of stands of various densities throughout Region 6.

The guides have three curves. The upper curve shows the maximum number of healthy trees per acre for the stand's average diameter. If more trees are left, experience has shown that an unacceptable growth rate and a higher probability of insect attack and disease result. The middle curve is the recommended stocking level; it represents growing stock that will occupy the site and produce optimum wood fiber on usable stems. The bottom curve represents the lowest stocking level that will produce a harvest cut but will not produce commercial thinning volume, nor will the full site potential be used during the early part of the rotation. Stocking below this usually results in growing space occupied by unwanted trees and sometimes by undesirable understory vegetation. The curves imply that as long as the silviculturist operates between the recommended and maximum levels, the site will be fully used for production.

A demonstration of field use of the guide is shown in figure 22. In this illustration, a sapling stand is reduced from several thousand trees per acre to 180 (445/ha) point A, where average stand diameter is about 2 in (5 cm). The stand grows until it reaches an average stand diameter of 10 in (25 cm), point B, or the maximum stocking-level curve. At this point, the first commercial thinning is made, and the stand is thinned leaving 130 trees (321/ha), point C. The next entry for an intermediate cut will be made when these trees grow and reach the maximum stocking level curve and so on through point G until the final harvest is made, sometime along line H.

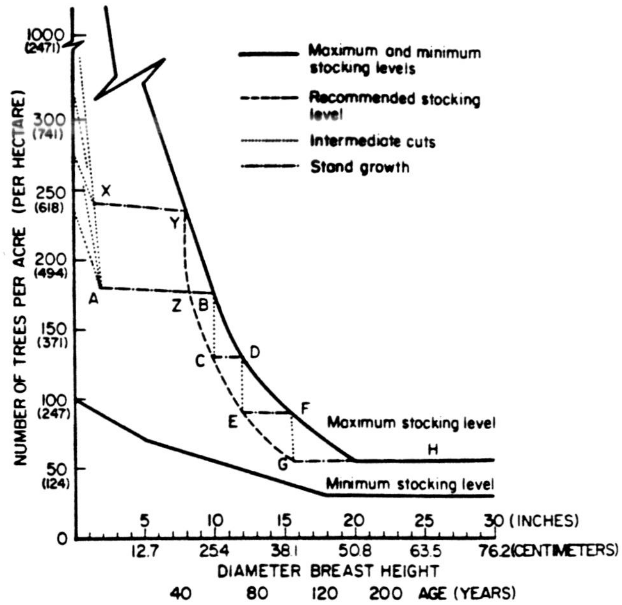


Figure 22.--Stocking-level curves for ponderosa pine where site index is IV or better (Meyer 1961). An example of precommercial thinning to 180 and 240 trees per acre (445 and 593/ha).

In an area where a roundwood market appears possible, the dense stand may be reduced by precommercial thinning to 240 trees per acre (593/ha) point X (fig. 22), with an average diameter somewhat less than 2 in (5 cm). These trees are allowed to grow until they reach the maximum curve, point Y, with an average stand diameter of 8 in (20 cm). A roundwood harvest is then made, reducing the stand to about 180 trees per acre (445/ha) point Z, shown for the sawlog regime. Theoretically, the whole curve system would move to the right as the potential of the land to produce increases. The present state of knowledge on density regulation limits us to the two curves of figures 21 and 22. More curves may come with additional data from thinning studies.

Also, useful in ponderosa pine density control is the maximum basal area concept. Visualize a maximum basal area management level on site V land (Meyer 1961) in figure 23 (Barrett 1977) of 120 ft^2 per acre (27.5 m^2/ha). This maximum is arbitrarily here because of a hypothetical potential mountain pine beetle problem (Sartwell 1971), although the stand is well beyond the maximum stocking-level curve shown in figure 21. The stand can grow to this level but should not exceed it, because of the danger of insect attack. This upper limit influences initial stand density. Suppose we thin a sapling stand to 380 trees per acre (939/ha). We can see from figure 23 that when the stand attains 120 ft^2 (27.5 m^2), average stand diameter will be slightly more than 7.5 in (19 cm). Then, a market for trees 7.5 in (19 cm) or less would be needed if thinning is from below. In contrast, a stand thinned to 200 trees per acre (494/ha) would have an average diameter slightly over 10 in (25 cm) when it reaches this upper limit of basal area where it is susceptible to insect attack. Labor conditions, depressed markets, and weather may force delays in commercial thinning stands in the future. Therefore, upper limits or "panic levels" should be set where some density regulation must occur. Strict adherence to the recommended stocking-level curve would lessen this problem.

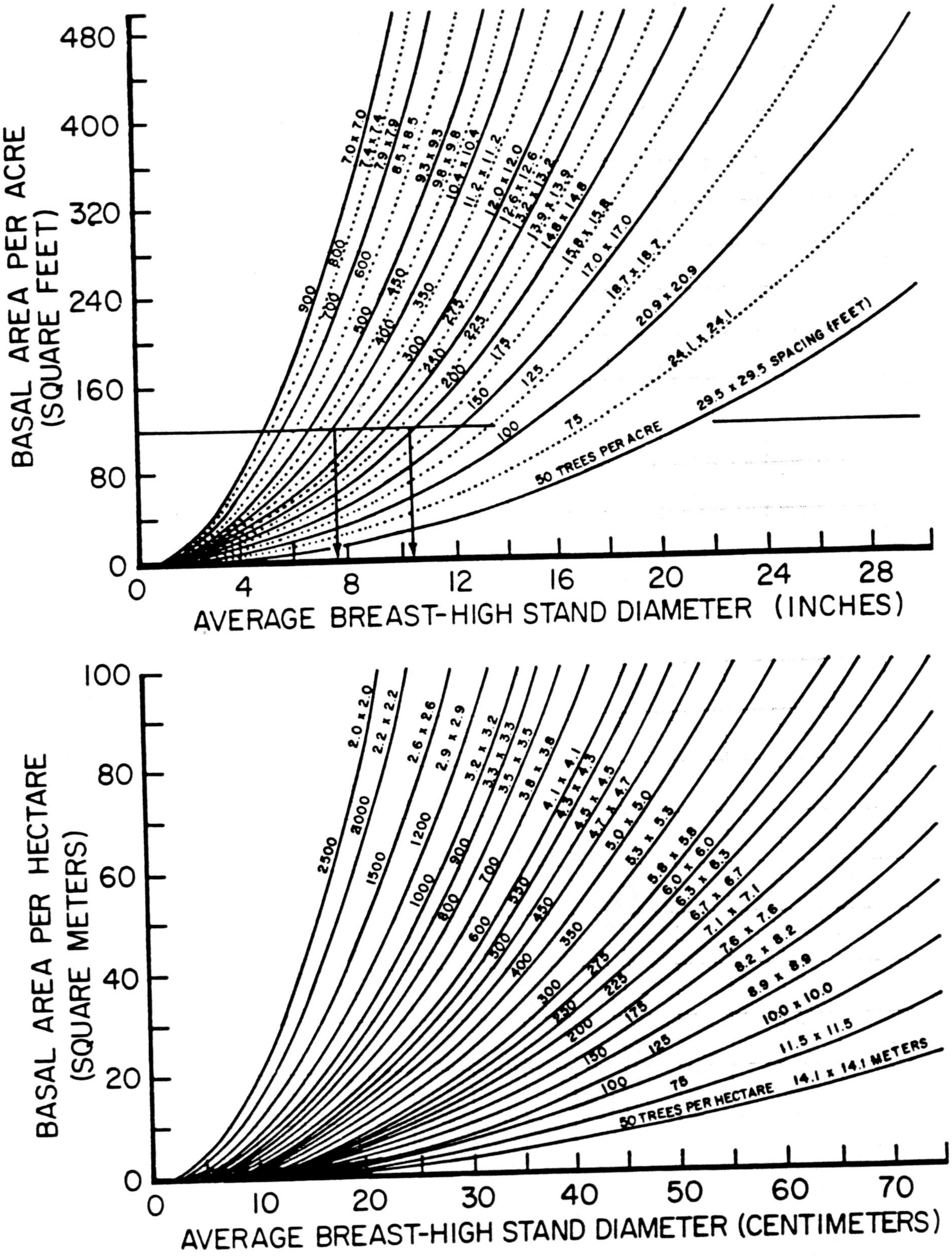


Figure 23.--Guide for stand basal area, average d.b.h., and tree spacing relations (Barrett 1977).

GROWTH AND YIELD

Juvenile Tree Development and Competition

After a natural or planted ponderosa pine seedling is established, a multitude of competitive influences can affect growth. Some of them are a necessary part of the plant community's stability, but frequently the competition may be reduced so that desired tree growth may be obtained.

Brush can be highly competitive with tree growth. Although brush has disadvantages, the beneficial effects should not be discounted. Bitterbrush and snowbrush, for example, are nitrogen fixers (Youngberg 1966). They are also probably an important link in the soil-plant-water continuum on some soils; where this is true, the competitive species should be suppressed only long enough to obtain the desired juvenile tree growth.

Sometimes brush can be a serious deterrent to development of young trees. Picture a ponderosa pine/bitterbrush-snowbrush/needlegrass community burned from lightning. The site is auger-planted with 2-0 ponderosa pine. Initial tree growth is impressive (fig. 24). Snowbrush seed, dormant in the soil for years (Gratkowski 1961) germinates and brush that survived the fire resprouts. Snowbrush grows profusely. After the third growing season, annual height growth of most of the planted trees begins to lessen. Some terminals of the more severely stressed trees have internodal lengths of only a few inches. If the brush is left untreated, brush and trees will fight for supremacy of the site for many years. Similar competitive effects are common when existing brushfields are contour-stripped and planted.

Figure 24.--Planted ponderosa pine, showing reduced height growth from brush competition. Snowbrush was treated with herbicides 1 year before picture was taken.

Just as serious, but less obvious to the casual observer, is the competitive effect of brush in recently thinned sapling stands. Both diameter and height growth of individual trees are reduced (Barrett 1973). Some form of brush control early in the rotation appears advisable where young stand growth is seriously impaired.

Grasses and other herbaceous plants can be serious competitors with natural seedlings and planted stock. This appears to be most serious when stands in fringe areas are regenerated. Often, the growth rate of grasses and sedges is faster than the seedlings, and the seedlings succumb to severe moisture stress and die.

Early tree growth can also be profoundly affected by competition with other trees. Historically, many ponderosa pine stands regenerated after abundant seedfall, on an ideal seed bed (sometimes prepared by fire); often, 5,000 to 10,000 saplings per acre (12,355 to 24,700/ha) developed. Trees often average 2 in (5 cm) in diameter, 12 ft tall (3.7 m) and 70 years old. A heavy, mature overstory frequently suppresses this reproduction. A great range in densities occurs, and each density usually exhibits different rates of height and diameter growth because of intertree competition. Size is often a poor indicator of age in these suppressed natural stands.

DIAMETER GROWTH

Ponderosa pine responds to release at almost any age if it has sufficient crown to take advantage of the additional growing space. This has become most evident in stands from 30 to 80 years old that have been suppressed for many years (fig. 25). Occasional dramatic increases in diameter growth after thinning led two workers to wonder how fast a ponderosa pine can grow under ideal conditions as a free-growing tree. Dahms and Silen[7/] visualized the free-growing tree as one extreme in the spectrum of possible spacing that could be readily identified in natural stands. After excavating roots, they concluded that roots might overlap slightly from two trees 80 ft (24.4 m) apart, but set this distance as the criterion for selecting 20 free-growing trees. Trees ranged from 5 to 20 in (13 to 51 cm) in diameter and from 19 to 36 years old. All trees averaged 4.9 in (12.4 cm) of growth during the last decade. Trees with no competitive groundcover averaged 6.5 in (16.5 cm) of growth per decade (3+ rings per inch), but those completely surrounded by understory vegetation grew only 3 in (7.6 cm) (fig. 26). The authors concluded that the potential for diameter growth had been grossly underestimated and much wider spacing should be tested.

[7/] Unpublished report, "An informal study of free-growing ponderosa pine trees," by Walter G. Dahms and Roy R. Silen, U.S. Dep. Agric., For. Serv. Prog. Rep., Pac. Northwest For. and Range Exp. Stn., Portland, Oreg. (on file at USDA For. Serv. Silvic. Lab., Bend, Oreg.) 1956.

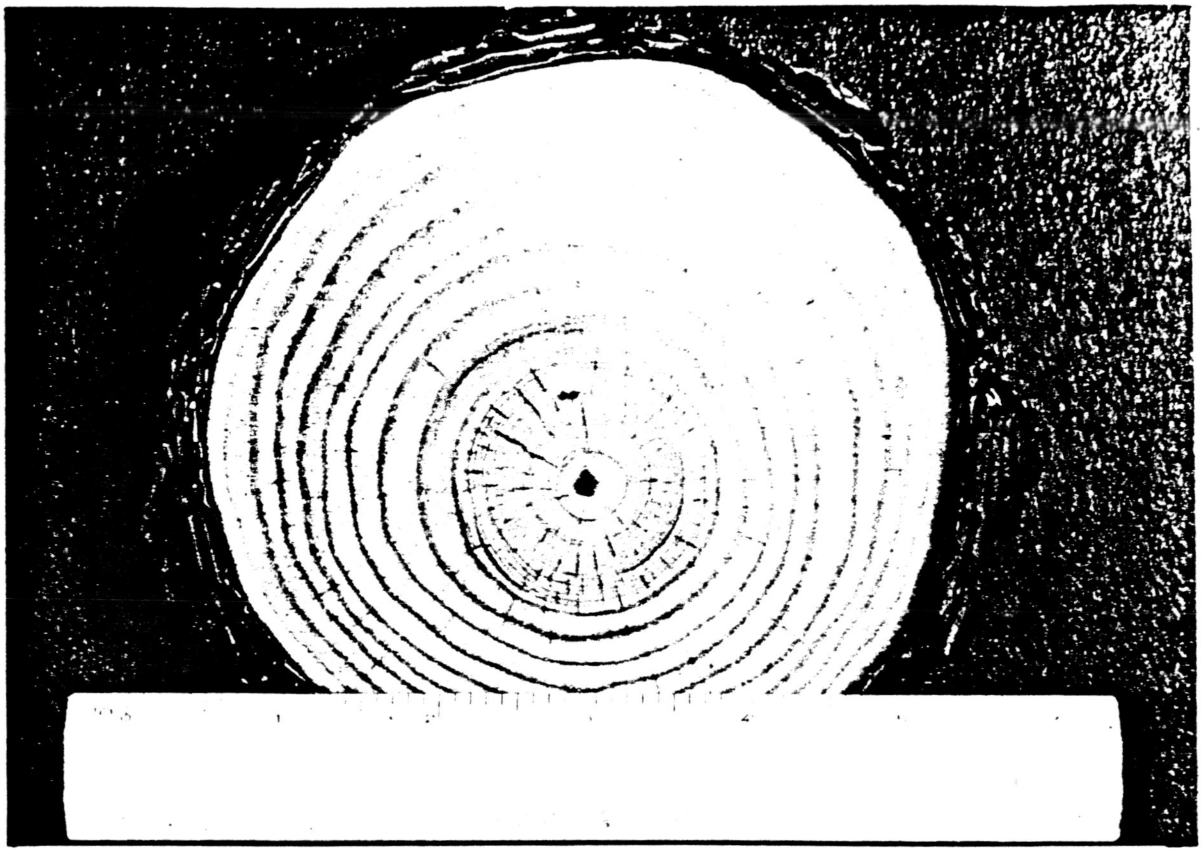


Figure 25.--Cross section from a sapling that was suppressed for over 40 years before release.

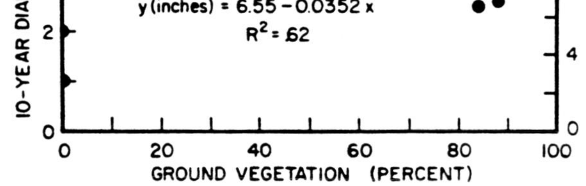


Figure 26.--Relation of 10-year diameter growth of free-growing trees to percent of ground covered by brush, grass, and other herbs (Dahms and Silen 1956).

Spacing trials before the study by Dahms and Silen consisted of modest spacings of from 6 to 9 ft (1.8 to 2.7 m). Mowat (1953) reported annual diameter increments from 0.04 to 0.16 in (1 to 4 mm) with this type of thinning.

Crop-tree thinning trials (Barrett 1969), where only trees within a few feet of the reserve tree were cut, showed only modest growth rates of 0.5 to 2.0 in (1.3 to 5.1 cm) per decade. Rates varied depending on the size of the circle of release, tree vigor, and presence or absence of overstory. Where release circles were large enough to approach an area thinning, increased growth rates were sustained. Where circles of release were small and crop trees far apart, the cleared area was quickly occupied by roots outside the circle and growth rates diminished soon after release.

More sophisticated spacing studies established in the late 1950's and early 1960's incorporated a wider range of spacings (Barrett 1968, 1970, 1972, 1973). The relation of average annual diameter growth to trees per acre for seven different studies in sapling-sized stands during the 10 years after thinning is presented in figure 27. The Pringle Falls spacing study (Barrett 1970, 1973 and figure 27--upper curve), where brushy understory vegetation was controlled, emphasizes the importance of this competition. Note how closely the diameter growth rates at the wider spacings match those of the free-growing trees (fig. 26) where ground vegetation was low. I recognize that the relations indicated in figure 27 are trends computed from only seven studies. The magnitude of the growth differences between vegetation treatments and between tree numbers may or may not apply to other areas. Understanding the general effect of tree density and understory vegetation on diameter growth, however, is important in the manipulation of second-growth stands.

A realistic assessment of stand diameter-growth would not be gained by randomly boring a few trees to compare with figure 27. Plots should be established, trees bored, and increments measured and averaged.

HEIGHT GROWTH

Height growth of immature stands of ponderosa pine in the Pacific Northwest can be influenced by site, age, stand density, overstory, brush, and shoot-boring insects. All are important considerations in evaluating stand performance and the need for silvicultural treatment.

Mowat (1950, 1953) first recognized the depressing effect of stand density and overstory presence on height growth in paired thinned and unthinned plots throughout the region. Lynch (1958) also acknowledged density as a factor in height growth when estimating site index in young, dense stands. The full significance of these observations in young, suppressed stands was not recognized until a wide range of tree spacings was observed (Barrett 1970, 1973). This study showed marked increases in height growth after thinning and overstory removal (fig. 28). In addition, height growth increased with wider spacings, although the response was not immediate. Trees

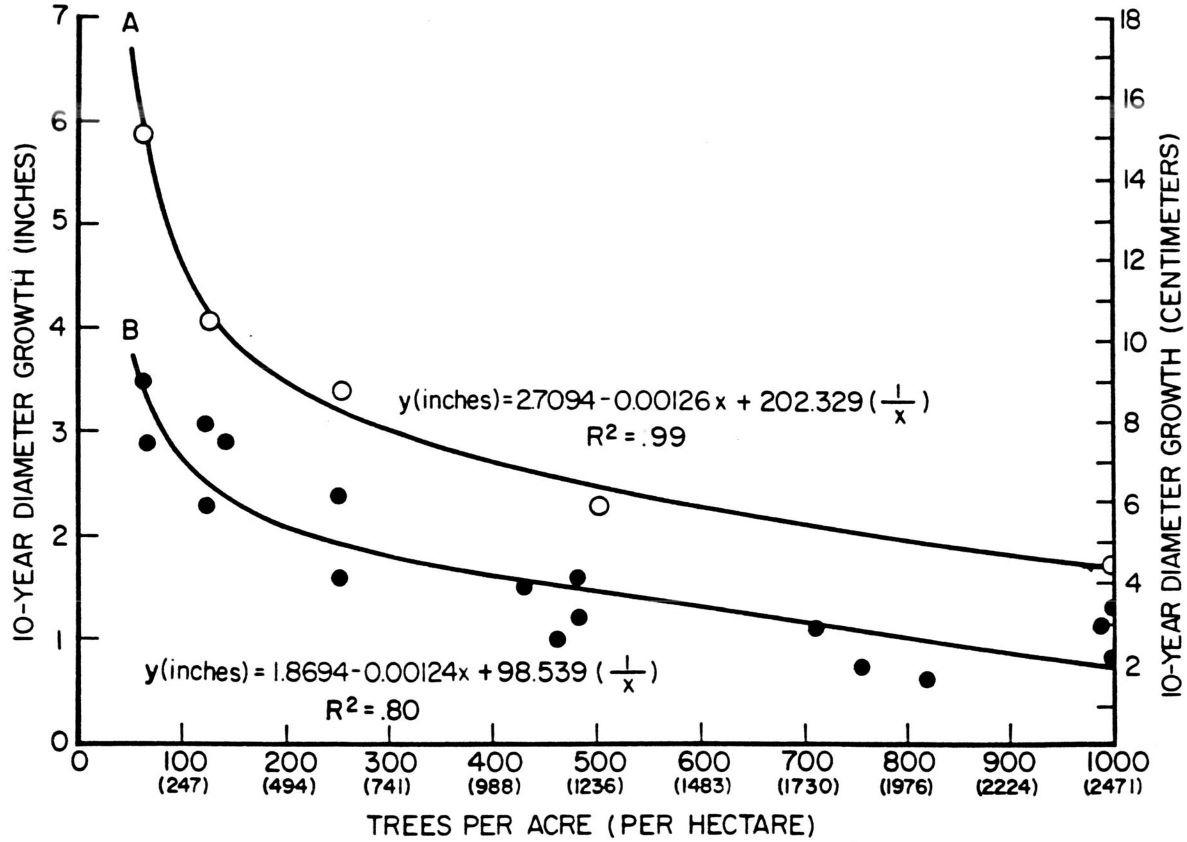


Figure 27.--Relation of 10-year diameter growth to trees per acre after thinning suppressed sapling-size ponderosa pine: A, understory vegetation controlled (Barrett 1970, 1973); and B, understory vegetation allowed to develop naturally (Mowat 1953, Barrett 1969, 1970, 1973).

did not reach their full capacity for height growth until more than a decade after thinning. Evidently, some time is needed in thinned sapling stands for roots to occupy fully the additional growing space and for tree crowns to expand before the total capacity for height growth can be expressed.

Height-growth response in pole-sized trees is apparently delayed several years after thinning until sufficient crown buildup takes place. Barrett (1963, 1968) found no response after 5 and 6 years, but Oliver (1979)--working in northern California--found a trend of height growth related to basal area 5 to 10 years after thinning. During the period 10 to 15 years after thinning, he found height growth was clearly related to basal area. The average tree in heavily thinned plots grew more rapidly than the average tree in lightly thinned plots.

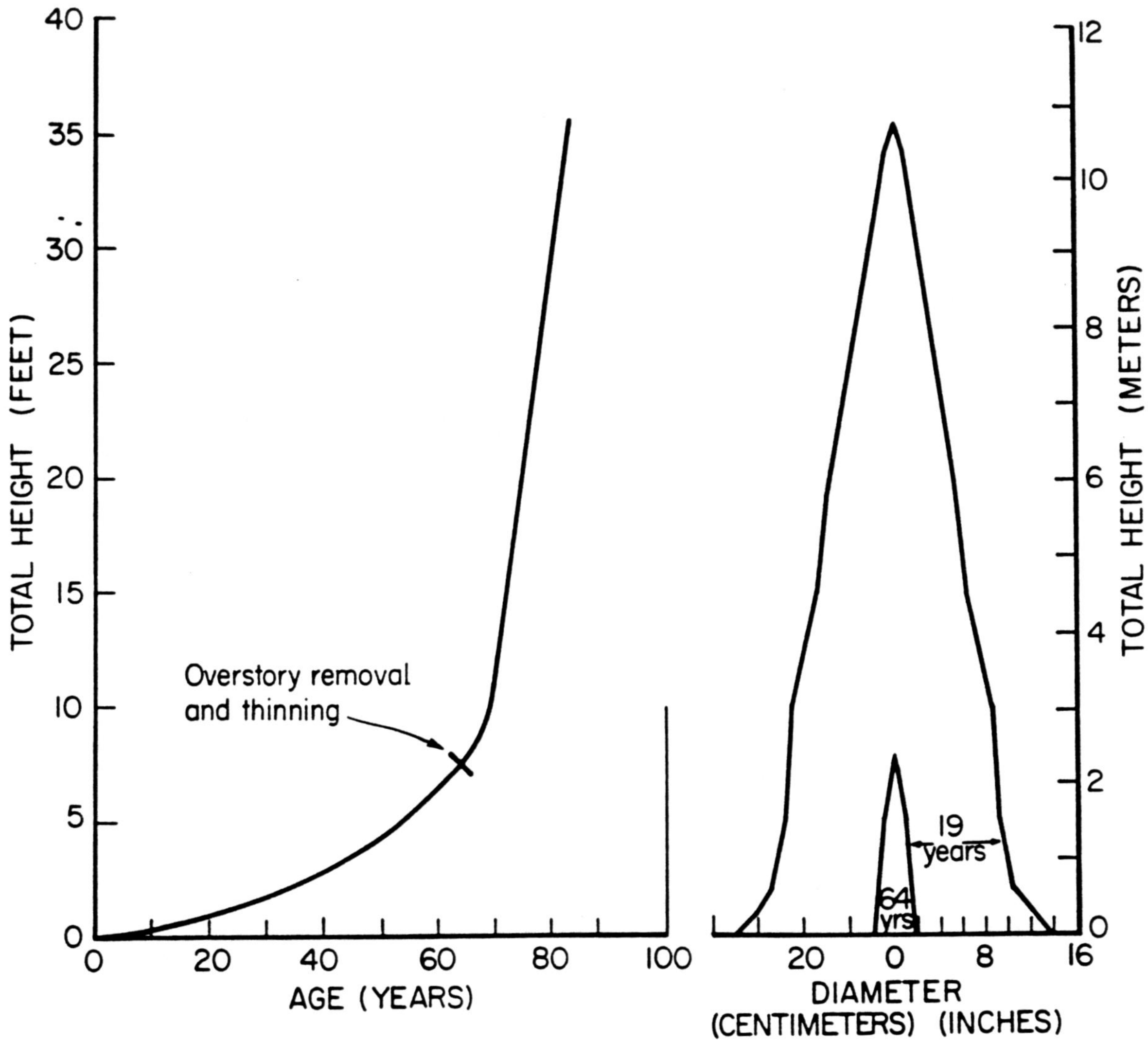


Figure 28.--Typical height-growth curve of an 83-year-old sapling released at age 64 and the stem profile before and after thinning.

As site quality increases with elevation, precipitation, exposure, and soils, annual height growth improves. Early growth, when uninhibited by stand density or overstory, is rapid and then tends to fall off with increasing age (fig. 29, Barrett 1978).

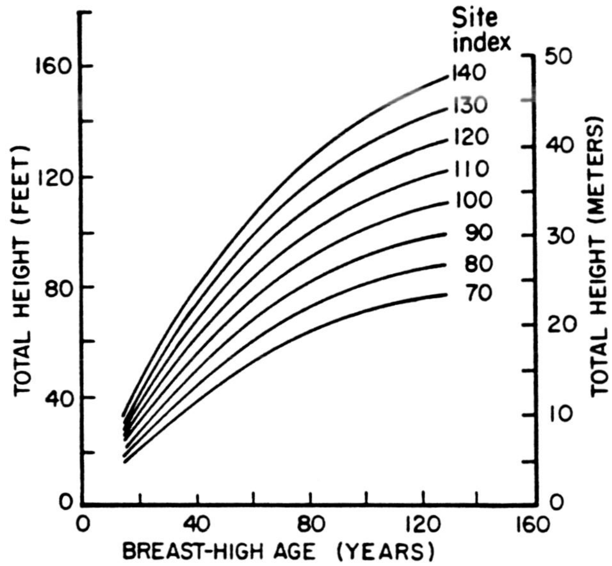


Figure 29.--Height-growth curves for managed, even-aged stands of ponderosa pine in the Pacific Northwest; heights represent the tallest trees in the stand (Barrett 1978).

VOLUME YIELD

An appreciation of the potential for volume increment in second-growth stands is necessary for making silvicultural recommendations. Most existing understory trees originated after hot fires and exceptional seed crops. With the exclusion of fire, many dense stands have stagnated and stands at lesser densities have grown at barely acceptable rates, frequently depressed by old-growth trees. If the overstory is removed from these dense stands and the stands are not thinned, they frequently reach their maximum annual increment quickly (fig. 30, line A); but the wood accumulates on trees that probably never will be merchantable because of their small size and density.

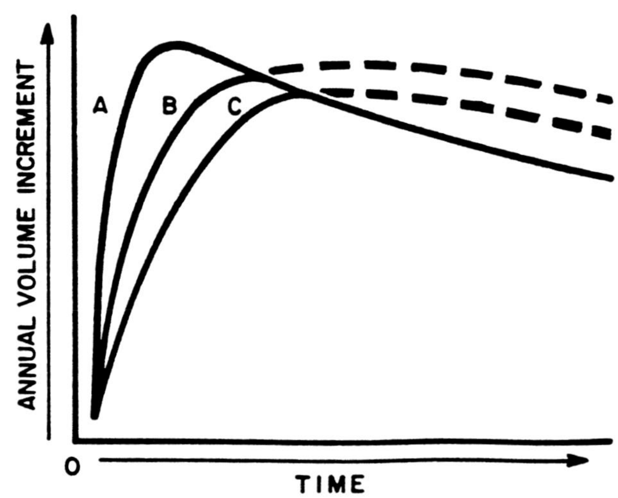


Figure 30.--Current annual increment with increasing time: A is a fully stocked natural stand; B and C represent different degrees of thinning in stand A.

Occasionally, mortality from insects or disease occurs and trees are released. Mortality occurs in patches, however, leaving large nonstocked holes in the stand. If the trees are thinned early in the life of the stand, current annual increment is not maximized as quickly, as shown in line B, in figure 30. Fewer stems simply take longer to occupy the growing space. Theoretically, the wider the spacing the longer it takes to maximize this annual production, as shown by line C, which represents a stand thinned to a wide spacing. A good example is in the periodic annual increment observed in the Pringle Falls ponderosa pine spacing study (fig. 18, Barrett 1970, 1973). Current increment is maximizing first at the narrow spacing, which may never produce a usable product; maximum production is anticipated somewhere between 80 and 110 ft^3 per acre (5.6 and 7.7 m^3/ha) per year.

These results lead to two useful ideas for managing young stands still suppressed by old growth. First, these young stands free of overstory--whether planted or thinned--have the ability to build cubic-foot production rapidly to five times or more of what the old-growth overstory was producing at the time of harvest. Second, some compromise must be made between leaving widely spaced, rapidly growing individual trees and narrowly spaced, slower growing trees that are collectively producing more wood at a slightly earlier age. This emphasizes the importance of early density regulation in ponderosa pine management.

On the other hand, evidence is accumulating that the same amount of wood fiber can be produced in about 50 years over a wide range of densities, provided the trees start from seedlings at reasonable densities and are not subjected to overstory suppression or brush competition. In one study (Barrett 1971), results suggest that, on an average site, around 160 to 180 trees per acre (395 to 445/ha) can grow as much usable wood as three to five times as many trees (fig. 31).

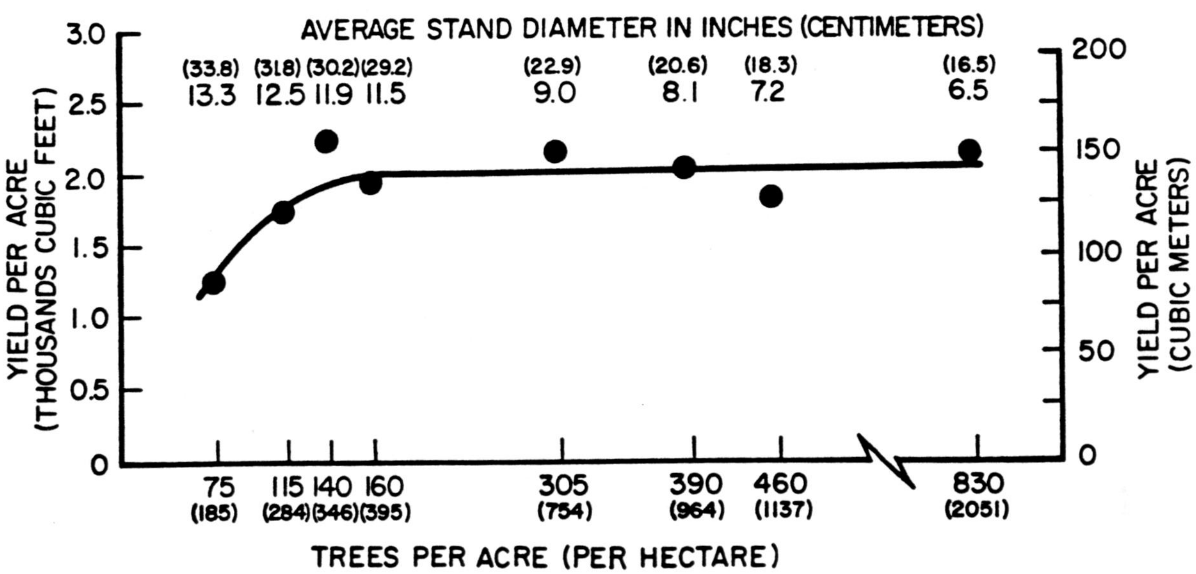


Figure 31.--Total yield and average stand diameter of site IV second-growth ponderosa pine at age 45 for various initial tree numbers per acre (Barrett 1971).

Initial densities below 160 trees per acre (395/ha) may produce a usable tree in much less time, but tree quality and area volume production may suffer. Therefore, if we plant or allow to grow 500 to 1,000 natural seedlings per acre (1,236 to 2,471/ha) till dominance is clearly expressed, then thin the stand to 160 trees or more per acre (395+/ha), and control understory vegetation early in the rotation, a major portion of the total productive capacity of the land may be captured during at least 50 years of growth.

Old, Selectively Cut Stands

DIAMETER GROWTH

Growth of older trees in selectively cut stands is affected by competition, but age and tree characteristics also play a prominent role. Keen's (1943) tree classes have long been recognized as a means of designating the growth potential of different types of trees. Briegleb (1945) described a method for using this classification in calculating volume growth of ponderosa pine forests in the Northwest.

Because Keen's system of tree classification is used so frequently in selection cutting of older stands throughout the Northwest, it is presented here in abbreviated form. Under this system, individual trees are grouped into four age classes; young, immature, mature, and overmature--designated by the numbers 1, 2, 3, and 4--and into four-crown-vigor classes; as full, good-to-fair, fair-to-poor, and very poor vigor--designated by the letters A, B, C, and D. A young tree of full vigor would be classed as 1A, a mature tree of very poor vigor a 3D. The classes are pictured in figure 32 and described fully in tables 7 and 8.

Briegleb has shown that diameter growth rate is strongly related to tree class (fig. 33).

Diameter growth rates vary within tree classes depending on tree diameter. For young vigorous trees--tree classes 1A, 1B, 2A, and 2B--diameter growth often diminishes as tree size increases. For older trees of good thrift--classes 3A, 3B, 4A, and 4B--the relation of tree size to diameter growth rate is reversed. Diameter growth rate is independent of tree size in most C-vigor classes. Trees of poor vigor--D-crown trees--in all age classes, consistently show a decline in diameter growth with increase in size. Although some large-diameter, old trees are growing slowly in diameter, remember that a yearly addition in diameter of a given thickness accumulated on a 20-in (51-cm) tree adds more volume than on a tree 10 in (25 cm) or less. Therefore, where an even flow of old-growth ponderosa pine is being maintained by selection or group selection, relative diameter growth of these trees becomes an important consideration in what will be left as growing stock during the conversion period.

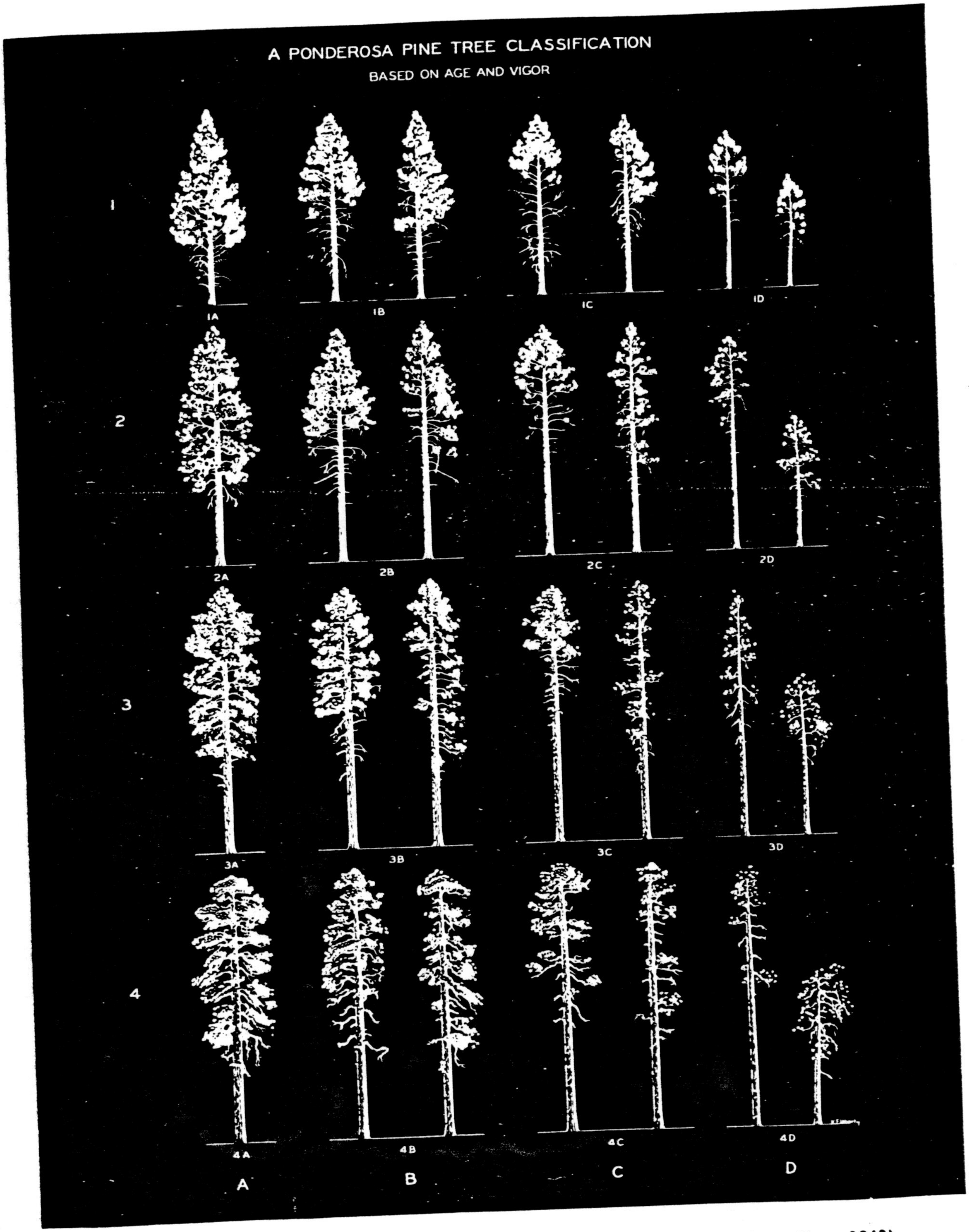


Figure 32.--A ponderosa pine tree classification, based on age and vigor (Keen 1943).

Table 7--Age Classes (After Keen, by Briebleb 1945)[1]

Character	Class 1	Class 2	Class 3	Class 4
Maturity	Young	Immature	Mature	Overmature
Age	Usually less than 80 years	Approximately 80 to 180 years	Approximately 180 to 300 years	More than 300 years
D.b.h.	Rarely over 20 inches	Rarely over 30 inches	Rarely over 40 inches	Usually large diameters in dominant trees
Height	In lower canopy usually less than 60% of total height of mature canopy	Height usually less than 90% of total height of mature canopy	Height practically that of general crown canopy (except of intermediate, suppressed, or topkilled trees)	Full height of general canopy (except suppressed, spike-topped, or broken trees)
Growth and taper	Thrifty trees making rapid height and diameter growth. Rapid taper.	Considerable height growth still in progress; good diameter growth in thrifty trees. Taper considerable.	Height growth practically complete; diameter growth slow. Moderate taper.	Making no height growth; diameter growth very slow. Least taper.
Bark color	Dark grayish brown to black (except at extreme base)	Dark reddish brown on lower half of bole; dark bark on upper half	Light reddish brown on lower three-fourths of bole; dark bark showing in upper one-fourth of bole	Light yellow; uniform color throughout bole (except at extreme top)
Bark plates	No plates. Rough bark, deeply furrowed, with narrow ridges between fissures	Narrow smooth plates between fissures	Moderately large plates between fissures	Plates usually very wide, long, and smooth; fissures often rather shallow
Branches	Branches upturned in upper three-fourths of crown; small for diameter of bole	Mostly upturned in upper half of crown; lower half horizontal or drooping; small to medium for diameter of bole	Upturned near top; middle horizontal; lower ones drooping; moderate for size of bole	Large, heavy limbs, often gnarled or crooked; mostly drooping, except in extreme top
Whorls	Whorls distinct in upper crown	Whorls distinct in upper half of crown	Whorls indistinct except at extreme top of crown	Whorls indistinct and incomplete
Top	Top usually pointed	Top usually pointed, sometimes rounded	Top usually pyramidal or rounded, sometimes pointed	Usually flat, occasionally rounded or irregular

[1]Description primarily applicable to central and southern Oregon and northern California, Site IV.

Table 8--Crown-vigor classes (After Keen, by Briegleb 1945)[1/]

Character	Class A	Class B	Class C	Class D
Crown vigor	Full, vigorous	Good to fair	Fair to poor	Very poor
Crown length	Long, 55% or more of total height; or less only if more than average width	Average length, less than 55% of total height (approximately 30% to 55% if full and wide) or a longer crown if narrow or somewhat thin	Short (from 10% to 30% of height, if crown of normal density) or long, sparse, and narrow	Very short (less than 10% of total height) sometimes merely a tuft at top of tree, or somewhat longer when sparse and ragged
Crown width	Usually average width or wider (narrower if very long and dense)	Usually average width or narrower; may be flat on one side	Usually narrow or flat on one or more sides	Usually very narrow and sparse, or limbs all on one side
Crown density	Usually full and dense or of medium density if longer than 55%	Usually of full to medium density, not sparse or ragged	Often sparse and ragged except at very top	Sparse and ragged
Foliage	Needles of average length or longer, usually dense and thrifty	Needles of average length, usually dense and thrifty	Needles often short and thinly distributed, but of normal length and density when confined to top one-third of crown	Needles often short; foliage sparse or scattered or only partially developed, but of normal length if reduced in quantity
Position	Usually isolated or dominant, rarely codominant	Usually codominant; sometimes isolated or dominant, rarely intermediate	Usually intermediate; sometimes codominant or suppressed, but rarely isolated or dominant	Usually suppressed or intermediate, but may occupy other positions if greatly reduced in vigor.
Diameter	Large for age	Average or above for age	Usually below average for age; sometimes larger in decadent trees	Decidedly subnormal for age, but very old, decadent trees may be of large diameter

[1/] The descriptions apply to the usual types of trees found in each class; where exceptions occur, the size of living crown and amount of foliage are the primary considerations in determining the vigor class.

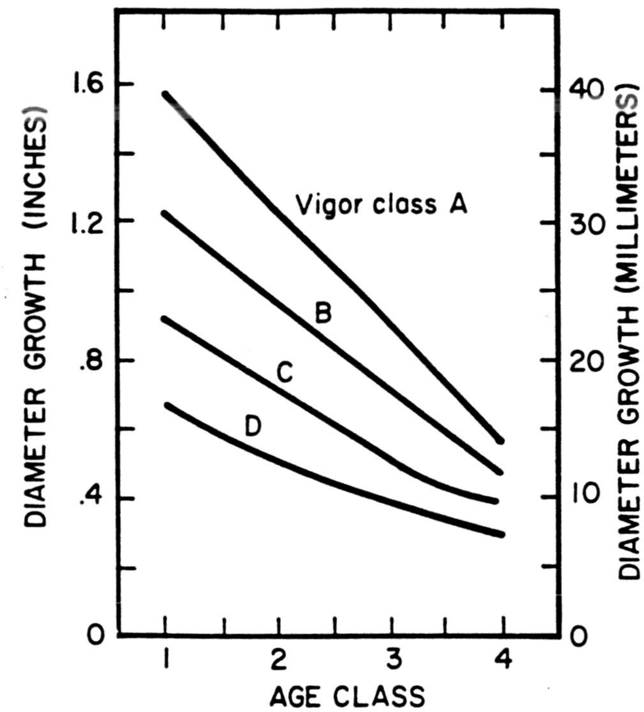


Figure 33.--Normal 10-year growth in d.b.h. by tree class (Briegleb 1945).

Some managers of selectively cut forests prefer to supplement their tree-vigor classification with an increment hammer, at least until they have confidence in their judgment of a tree's comparative growth. Keen's vigor classes are also helpful as a training aid in designating trees to be cut.

As you would expect, stand growth can be extremely variable under different methods of cutting. Mowat (1961) reports gross increments of from 28 to 220 fbm per acre per year.

Tentative Yields of Managed Stands

Yield information for managed stands based on observation of actual growth is scarce. What is available is on short periods of growth during various ages on different sites, which does, however, give some clue for periodic diameter, height, and volume increment. In addition, rough approximations of gross periodic increments and mean annual increments for natural unmanaged stands can be made using Meyer's (1961) yield table for uncut even-aged "normal" stands. These yields, if discounted for periodic thinnings, give another estimate of site productive capacity under management. From these bits and pieces of information, a first approximation of a managed-stand yield has been published for an average site (Sassaman et al. 1977). These yields (table 9) were developed for thinned stands with average leave-tree diameters of 2, 4, 6, and 8 in (5.1, 10.2, 15.2, 20.3 cm) d.b.h. on an above-average site (site index 78, 100-year basis). A sapling stand with an average diameter of 1.5 in (3.8 cm) before thinning is thinned to 180 trees per acre (445/ha) averaging 2 in (5.1 cm) d.b.h. and 12 ft (3.7 m) high. Although the stand may actually be 50, 60, or even 80 years old, the stand is given an adjusted age of 13 years in the yield table because the tree's dimensions are similar to a natural or planted tree growing without serious competition. Similarly, the 4-in (10.2-cm) crop trees are given an adjusted age of 22 years. Stand development with commercial thinnings were calculated by the computer program "Managed Yield."[8]

A managed-stand yield simulator based on additional growth data is now being constructed for various sites and ages and will be available from the Pacific Northwest Forest and Range Experiment Station in 1981.

STAND GROWTH

Although more and more even-aged management is being done in ponderosa pine stands of the Pacific Northwest, in a large segment of land--along highways, scenic vistas, recreation areas, and watersheds--selective cutting is an option. Another option may be an irregular shelterwood or some modification of even-aged management. Getting maximum growth in these areas, while preserving esthetic values, requires skill and care.

Structure of the reserve stand, expressed in terms of composition by Keen tree class and diameter of trees, is a major determinant of growth, often outweighing wide differences in volume of growing stock (Mowat 1961). Other stand characteristics being equal, more growth can be made by larger reserves of growing stock. In the Pacific Northwest, however, uneven-aged stands that have been lightly cut often lack younger trees of good vigor. Trying to gain increment by leaving heavier volumes often results in a loss, because the additional trees left may be of poor vigor, older, and usually larger--less efficient producers of the stand. Trees that may die before the next entry may also be included. On the other hand, trying to increase growth by removal of all mature, overmature, and low-vigor trees results in a reduction of growing stock such that the site is only partially used. Individual trees may grow fast but are not able to compensate for the low volume per acre. The growing stock reserve that will maximize volume increment obviously lies somewhere between these extremes.

[8] Developed by U.S. Forest Service, Division of Timber Management, Region 6, Portland, Oregon.

Table 9--Yield per acre of ponderosa pine precommercially thinned to leave-tree diameters of 2, 4, 6, and 8 inches on land with an average site index of 78 (adapted from Sassaman et al. 1977). Metric equivalents are given in table 9a.

Stand characteristics									Intermediate harvests				
Stand age	Trees	Average diameter at breast height[1]/	Average height	Basal area	Merchant-able volume to a 6-inch top	Scribner volume to a 6-inch top	Total volume[2]/	Mean annual increment[3]/	Trees	Average diameter at breast height[1]/	Basal area	Merchant-able volume to a 6-inch top	Scribner volume to a 6-inch top
Years	Number	Inches	Feet	Square feet	Cubic feet	Board feet	Board feet	Cubic feet	Number	Inches	Square feet	Cubic feet	Board feet
						LEAVE-TREE DIAMETER 2 INCHES							
13	900+	1.5	12	12	--	--	--	--	--	--	--	--	--
37	175	10.0	38	95	1,130	3,913	3,913	31	48	11.0	32	402	1,471
60	124	13.0	56	114	2,253	9,715	11,185	44	41	13.0	38	745	3,212
80	81	16.1	68	114	2,735	13,112	17,794	48	24	16.0	34	800	3,822
100	56	18.8	78	108	2,888	15,031	23,536	48	--	--	--	--	--
120	56	21.3	86	139	4,019	22,046	30,551	50	--	--	--	--	--
140	56	23.4	94	167	5,095	28,837	37,342	50	--	--	--	--	--
160	54	24.9	100	183	5,850	33,870	42,375	49	--	--	--	--	--
180	53	25.9	106	194	6,511	38,555	47,060	47	--	--	--	--	--
200	52	26.7	110	202	6,999	41,918	50,423	45	--	--	--	--	--
220	51	27.4	113	209	7,390	44,586	53,092	42	--	--	--	--	--
						LEAVE-TREE DIAMETER 4 INCHES							
22	900+	2.9	23	44	--	--	--	--	--	--	--	--	--
43	175	10.0	42	95	1,202	4,247	4,247	28	48	11.0	32	430	1,586
60	124	12.2	55	101	1,924	7,963	9,549	39	41	12.0	32	612	2,504
80	81	15.3	67	103	2,427	11,275	15,365	43	24	15.0	30	689	3,177
100	56	18.1	77	100	2,644	13,604	20,870	44	--	--	--	--	--
120	56	20.4	85	127	3,645	19,666	26,933	45	--	--	--	--	--
140	56	22.5	93	155	4,664	26,129	33,396	46	--	--	--	--	--
160	54	24.0	99	170	5,385	30,780	38,046	44	--	--	--	--	--
180	53	25.0	105	181	6,014	35,258	42,525	43	--	--	--	--	--
200	52	25.8	109	189	6,480	38,495	45,762	41	--	--	--	--	--
220	51	26.5	112	195	6,857	41,077	48,344	39	--	--	--	--	--

						LEAVE-TREE DIAMETER 6 INCHES							
32	900+	4.2	31	93	--	--	--	--	--	--	--	--	--
50	175	10.0	46	95	1,452	5,526	5,526	29	50	11.0	33.0	533	2,070
70	122	12.2	64	99	2,131	9,215	11,286	38	40	12.0	31.4	671	2,883
90	80	15.1	74	100	2,496	11,947	16,900	41	23	15.0	23.2	707	3,375
120	56	18.6	82	106	2,930	15,217	23,545	40	--	--	--	--	--
140	56	19.9	90	121	3,616	19,634	27,962	40	--	--	--	--	--
160	56	22.4	96	153	4,736	26,572	34,899	40	--	--	--	--	--
180	54	23.4	102	161	5,234	29,959	38,236	40	--	--	--	--	--
200	53	24.2	106	169	5,671	33,039	41,367	38	--	--	--	--	--
220	52	25.4	109	183	6,277	37,162	45,489	33	--	--	--	--	--
						LEAVE-TREE DIAMETER 8 INCHES							
45	900+	5.3	40	153	1,930	--	--	43	--	--	--	--	--
60	175	10.0	48	95	1,479	5,610	5,610	25	48	11.0	32	523	2,017
80	124	12.4	62	104	2,205	9,577	11,594	34	40	12.0	31	658	2,814
100	82	15.0	72	101	2,474	11,706	16,537	37	23	15.0	28	694	3,284
120	58	17.5	80	97	2,623	13,401	21,515	37	--	--	--	--	--
140	58	19.6	88	122	3,567	19,179	27,294	39	--	--	--	--	--
160	58	21.2	94	142	4,411	24,554	32,668	39	--	--	--	--	--
180	56	22.3	100	152	4,843	27,178	35,293	37	--	--	--	--	--
200	55	23.1	106	160	5,351	30,801	38,916	36	--	--	--	--	--
220	54	23.9	110	168	5,800	33,893	42,008	35	--	--	--	--	--

1/Average diameter of all trees.
2/Scribner volume to a 6-inch top.
3/Merchantable volume to a 6-inch top.

Table 9a--Yield per hectare of ponderosa pine precommercially thinned to leave-tree diameters of 5.1, 10.2, 15.2, and 20.3 centimeters on land with an average site index of 78

Stand characteristics							Intermediate harvests			
Stand age	Trees	Average diameter at breast height[1]	Average height	Basal area	Merchantable volume to a 15.2-cm top	Mean annual increment[2]	Trees	Average diameter at breast height[1]	Basal area	Merchantable volume to a 15.2-cm top
Years	Number	Centimeters	Meters	Square meters	Cubic meters	Cubic meters	Number	Centimeters	Square meters	Cubic meters
LEAVE-TREE DIAMETER 5.1 CENTIMETERS										
13	2,224+	3.8	3.7	2.8	--	--	--	--	--	--
37	432	25.4	11.6	21.8	79	2.2	119	27.9	7.3	28
60	306	33.0	17.1	26.2	158	3.1	101	33.0	8.7	52
80	200	40.9	20.7	26.2	191	3.4	59	40.6	7.8	56
100	138	47.8	23.8	24.8	202	3.4	--	--	--	--
120	138	54.1	26.2	31.9	281	3.5	--	--	--	--
140	138	59.4	28.7	38.8	357	3.5	--	--	--	--
160	133	63.2	30.5	42.0	409	3.4	--	--	--	--
180	131	65.8	32.3	44.5	456	3.3	--	--	--	--
200	128	67.8	33.5	46.4	490	3.1	--	--	--	--
220	126	69.6	34.4	48.0	517	2.9	--	--	--	--
LEAVE-TREE DIAMETER 10.2 CENTIMETERS										
22	2,224+	7.4	7.0	10.1	--	--	--	--	--	--
43	432	25.4	12.8	21.8	84	2.0	119	27.9	7.3	30
60	306	31.0	16.8	23.2	135	2.7	101	30.5	7.3	43
80	200	38.9	20.4	23.6	170	3.0	59	38.1	6.9	48
100	138	46.0	23.5	23.0	185	3.1	--	--	--	--
120	138	51.8	25.9	29.2	255	3.2	--	--	--	--
140	138	57.2	28.3	35.6	326	3.2	--	--	--	--
160	133	61.0	30.2	39.0	377	3.1	--	--	--	--
180	131	63.5	32.0	41.6	421	3.0	--	--	--	--
200	128	65.5	33.2	43.4	453	2.9	--	--	--	--
220	126	67.3	34.1	44.8	480	2.7	--	--	--	--

LEAVE-TREE DIAMETER 15.2 CENTIMETERS

32	2,224+	10.7	9.4	21.4	--	--	--	--	--	--
50	432	25.4	14.0	21.8	102	2.0	124	27.9	7.6	37
70	301	31.0	19.5	22.7	149	2.7	99	30.5	7.2	47
90	198	38.4	22.6	23.0	175	2.9	57	38.1	5.3	49
120	138	47.2	25.0	24.3	205	2.8	--	--	--	--
140	138	50.5	27.4	27.8	253	2.8	--	--	--	--
160	138	56.9	29.3	35.1	331	2.8	--	--	--	--
180	133	59.4	31.1	37.0	366	2.8	--	--	--	--
200	131	61.5	32.3	38.8	397	2.7	--	--	--	--
220	128	64.5	33.2	42.0	439	2.3	--	--	--	--

LEAVE-TREE DIAMETER 20.3 CENTIMETERS

45	2,224+	13.5	12.2	35.1	135	3.0	--	--	--	--
60	432	25.4	14.6	21.8	103	1.8	119	27.9	7.3	37
80	306	31.5	18.9	23.9	154	2.4	99	30.5	7.1	46
100	203	38.1	21.9	23.2	173	2.6	57	38.1	6.4	49
120	143	44.5	24.4	22.3	184	2.6	--	--	--	--
140	143	49.8	26.8	28.0	250	2.7	--	--	--	--
160	143	53.8	28.7	32.6	309	2.7	--	--	--	--
180	138	56.6	30.5	34.9	339	2.6	--	--	--	--
200	136	58.7	32.3	36.7	374	2.5	--	--	--	--
220	132	60.7	33.5	38.6	406	2.4	--	--	--	--

1/Average diameter of all trees.

2/Merchantable volume to a 15.2-centimeter top.

FERTILIZING STANDS

Previous discussions in this paper have shown that diameter and sometimes height growth can be increased in young stands by thinning and brush control. The increased growth rate probably results from additional soil moisture and nutrients available to leave trees. This has led some researchers to speculate that fertilization might increase wood production in the drier portions of the region.

The work of Youngberg (1975) and Agee and Biswell (1970) suggests that fertilizing unthinned dense stands of ponderosa pine is not a reasonable practice. Dense stands tend to stagnate, and some of the increased growth is added to trees that will never reach usable size. If fertilizer is added to thinned stands, only the growth rate of trees that will be harvested as usable wood will benefit. Youngberg (1968) applied 200 lb nitrogen (N) per acre (224 kg/ha) to a dense, small pole stand of ponderosa pine and to an adjacent stand thinned to 12- x 12-ft (3.7- x 3.7-m) spacing. Five years after treatment, increases in basal area were:

	Percent
Unfertilized, unthinned	19
Fertilized, unthinned	25
Unfertilized, thinned	35
Fertilized, thinned	50

Since then, Cochran (1973, 1977, 1978) has installed experiments in central and eastern Oregon that have expanded our knowledge of fertilizer response. He found that N in the form of urea produced the most response. In central Oregon, recent results suggest that when N is combined with sulfur (S) it becomes an even greater growth stimulant. An experiment in central Oregon (Cochran 1978) on typic Cryandept (Shanahan series) soil, developing on Mazama pumice showed that a thinned stand with an initial basal area of 90 ft^2 per acre (20 m^2/ha) and producing 60 ft^3 (4.2 m^3/ha) per acre per year may be increased to 80 ft^3 (5.6 m^3/ha) by the addition of 200 lb (224 kg/ha) of elemental N per acre (fig. 34). A suggested benefit from the addition of 30 lb (34 kg/ha) S per acre was a new fertilizer, sulphated urea 40-0-0-6--applied at 500 lb (561 kg/ha) per acre--would approximately duplicate what Cochran tried.

Response to fertilization in other parts of the region is questionable. Cochran (1978) believes, however, that N at 200 lb per acre (224 kg/ha) (urea at 435 lb per acre (488 kg/ha)) will increase growth of many pine stands on nonpumice soils east of the Cascades in Oregon and Washington. Response is now known to last at least 4 years in some areas and as long as 8 years in others.

Cochran (1975) also reported large increases in grass production by the addition of fertilizers in thinned stands of lodgepole pine in the pumice zone.

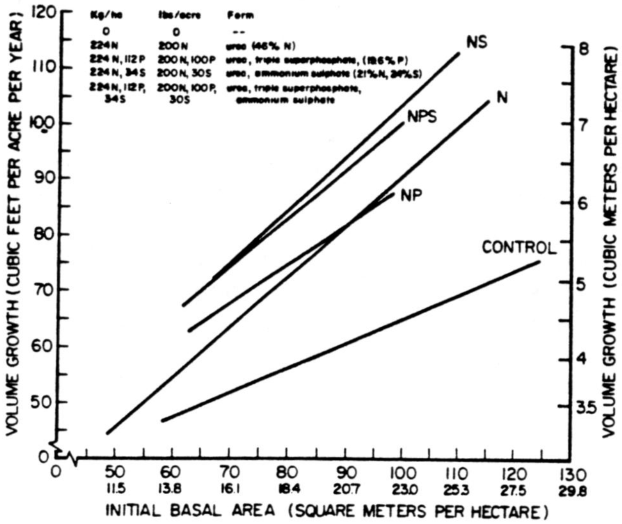


Figure 34.--Individual regressions for volume growth in response to fertilization with nitrogen (N), phosphorus (P), and sulfur (S) as a function of initial basal area (Cochran 1978).

Fertilizer trials with planted stock on pumice soils have been disappointing. Placing fertilizer in the planting hole has not produced the desired increase in height growth (Barrett and Youngberg 1970). The best of the fertilizers tested produced only an average 10-in (2.5-cm) height growth advantage in 7 years. The object of these trials was to find a growth-promoting substance that would stimulate height growth so that the seedling would be better able to compete with understory vegetation, be unattractive to browsing animals, and survive under adverse weather. Many times the desired height growth has been shown to be attainable by elimination of competing vegetation through adequate site preparation.

USE OF HERBICIDES

Need

Frequently we need to control vegetation that is competing with trees in ponderosa pine stands in the Pacific Northwest, almost always early in the rotation--when the site is being prepared for planting or when established young trees must be released from competing vegetation.

Many acres of ponderosa pine forest land east of the Cascade Range are occupied by native shrubs, mostly evergreen. In southwestern Oregon, competing evergreen and deciduous brush and tree species abound. Trees may be absent because seedlings are unable to compete with the brush; if trees are present, they are unable to grow at acceptable rates because of competition for light and soil moisture. Brush frequently overtops young trees for many years in forest openings, and wood production ceases for decades. Where trees overtop the brush and make acceptable height growth, brush is not considered a problem. Indeed, some brush species may contribute nutrients or otherwise benefit the site (Youngberg 1966). Grasses and sedges can also compete with pine seedlings on drier sites.

Some of the most troublesome brush species in eastern Oregon and Washington are greenleaf manzanita, snowbrush, golden chinkapin, Sierra chinkapin, and antelope bitterbrush. Manzanita is the most light-demanding species and is found in large and small openings in the forest canopy. Snowbrush often occurs with manzanita in openings but is more shade tolerant and can be found growing well beneath adequately stocked pine stands. Chinkapin is found on north slopes at higher elevations on moist sites. It has a high tolerance for shade and can be found thriving under heavy overstories. Bitterbrush grows abundantly, from semiarid conditions to transitional zones at the higher elevations where it is replaced by snowbrush, low-growing shrubs, or both.

Greenleaf manzanita, snowbrush, and chinkapin are all evergreen. Bitterbrush is deciduous. Snowbrush and chinkapin sprout after death or cutting of the aerial parts, but greenleaf manzanita does not. Response of bitterbrush to various cultural practices is not clear; plants have been observed to sprout after prescribed burning, damage by logging, and occasionally after spraying.

Application

Over the past several decades, much public attention has been drawn to the use of herbicides in our forests. During this time, we have learned much about using these chemicals safely and effectively. Gratkowski (1975) states:

> Although use of herbicides is complicated, research and experience during the past 20 years have shown that only a few herbicides are useful in Pacific Northwest silviculture. With modest effort, foresters can readily learn to consider the factors involved, prescribe treatments, and use these few herbicides safely and effectively.
>
> Safety and economy demand that herbicidal chemicals be used as sparingly and infrequently as possible to accomplish our silvicultural objectives. Effective use requires that we apply minimal amounts of herbicides at the proper time of the year to obtain the maximum degree of control on undesirable species without damaging desirable tree species, wildlife browse, or esthetically desirable shrub species.

Herbicides are used to release conifers from competing vegetation by increasing the amount of light reaching the pine seedling and decreasing competition for soil moisture. All the vegetation need not be killed; we only need a high degree of defoliation, a fair amount of top-kill, and as little resprouting as possible.

Phenoxy herbicides, especially 2,4-D and 2,4,5-T, are now the most useful herbicides in silviculture. As release sprays, these herbicides are most effective when applied at 1 to 3 lb acid equivalent per acre (1.1 to 3.4 kg/ha) (Gratkowski 1975). These chemicals are used on 75 percent of the acreage treated annually. Atrazine, picloram, silvex, and amitrol-T are also used frequently. Successful application is a combination of correct dosage, timing (season), and the best selective chemical.

EFFECTIVENESS OF HERBICIDES ON BRUSH

Dahms (1961) reported foliage sprays of 2,4-D and 2,4,5-T to be highly and equally effective on manzanita from early May to early July. One-half pound per acre (1.1 kg/ha) in an emulsion carrier or 0.75 lb (0.8 kg) in a water carrier gave 80-percent brush kills. He found that as the season progressed from summer into fall, brush became less and less susceptible to these herbicides. His tests during the fall, however, were not extensive; further research is needed.

The most effective chemical to control snowbrush in central Oregon is 2,4,5-T, but Dahms (1961) found that snowbrush sprouted vigorously after all chemical treatments. Rates of 1 lb/acre (1.1 kg/ha) in an emulsion and 1.5 lb (1.7 kg/ha) in water produced good kills. Gratkowski (1975) found late summer sprays of 2,4,5-T in water carriers safely released ponderosa pines from snowbrush competition in southwestern Oregon.

Bitterbrush has been killed without resprouting in experimental plots using 1 lb per acre (1.1 kg/ha) 2,4,5-T in water and diesel oil. In one area in central Oregon, 2 lb per acre(2.2 kg/ha) of 2,4,5-T in water were applied to a plantation just before pine and bitterbrush bud burst to suppress manzanita and snowbrush without killing the bitterbrush. Unseasonably warm weather followed the spraying and a 90-percent kill of the snowbrush and manzanita resulted without detectable effect on bitterbrush. This trial, which was never repeated, needs to be explored further.

Dahms (1961) found that 2,4,5-T was the most effective chemical on chinkapin, and an emulsion was better than a water carrier. Mid-June treatments produced a better kill of aerial parts than treatment in late September, but fall treatment may delay sprouting. Gratkowski (1975), working in southwestern Oregon, found chinkapin resprouted abundantly after initial treatment of mature plants; repeated treatments are needed to get a high kill.

EFFECT OF HERBICIDES ON PONDEROSA PINE

Dahms (1961) found that ponderosa pine in central Oregon can tolerate about twice as much 2,4,5-T as 2,4-D and about twice as much of either chemical in water as in an emulsion. Recent studies by Gratkowski (1978), however, showed no practical difference in damage from 2,4-D and 2,4,5-T on small pines during the autumn-spring period in the Cascade Range. This relation needs to be tested in the drier portions of eastern Oregon and Washington. Dahms (1961) found tolerance of pine also varied with season. Trees were most damaged by early July treatments and least damaged in late September. This is also true in southwestern Oregon (Gratkowski 1961, 1977). Gratkowski (1978) found ponderosa pine susceptible to damage from foliage sprays of 2,4-D and 2,4,5-T before height growth began in the spring. He found trees most susceptible during active growth in May and June. He concluded that late summer treatment is best for minimum damage to ponderosa pine.

The importance of season of application should be emphasized. Dahms (1961) found in central Oregon that, as the season progressed into fall, ponderosa pine was less damaged by spray application but some brush species became more difficult to kill. On the other hand, Gratkowski (1975) found that late summer was the only period when ponderosa pines can be safely released from brush competition with phenoxy herbicides in southwestern Oregon. Successful release spraying has been achieved in central Oregon from mid-May to mid-June with slight damage to the pine, but on some areas sprayed during this season, extensive damage to the pine was observed. Gratkowski (1977) believes we can eliminate this damage with late summer sprays of 2,4,5-T in a water carrier. He cautioned, however, that unusual August rain can result in late summer leader growth or induce physiological changes that make pines susceptible to damage from late August or early September herbicidal sprays.

Late summer spraying also has some distinct operational advantages east of the Cascade Range. Elevation influences the initiation of brush and tree growth in the spring. In the spring, lower elevation brush fields may be ready to spray but slightly higher fields are still partially covered with snow. This frequently results in spray-timing problems and necessitates recalling aerial spray equipment, adding to the cost of applying the herbicide. Late summer spraying could eliminate this problem. Again, let me emphasize that Dahms' (1961) work suggested that brush species east of the Cascade Range are much less susceptible to spray as summer progresses into fall. Therefore, further spray testing in eastern Oregon and Washington is needed during the late summer to determine if adequate brush kills can be obtained.

GRASS CONTROL

Atrazine is one of the most useful herbicides for grass control in the Pacific Northwest (Gratkowski 1975). Crouch and Hafenstein (1977) found it very effective on herbaceous vegetation in south central Oregon when applied by helicopter at 4 lb of active ingredient per acre (4.5 kg/ha) in the fall. Application before autumn rains begin is recommended, because the formulation must be leached into the soil where it can be absorbed through the root systems of susceptible grass species.

Dalapon is also effective in controlling grass competing with pine seedlings. Usually it should be applied at least 2 weeks before planting.

Gratkowski (1975) did not recommend atrazine-dalapon mixtures on ponderosa pine after observing extensive defoliation of pines.

Trials by Dimock (1977a) of a combination of 8 lb per acre (9 kg/ha) dalapon and 4 lb (4.5 kg/ha) atrazine as a broadcast spray shortly after planting gave excellent grass and forb control without damaging the pine. Control persisted through the second growing season. Dimock (1977b) also reported good results with Velpar R and Roundup.

Regulations

Federal and State regulations now require that only herbicides labeled and registered for forest use be applied on forest lands. Questions on registration of a particular formulation should be directed to the appropriate State Department of Agriculture, the Oregon State Board of Forestry, the Washington State Department of Natural Resources, or the Environmental Protection Agency, which is now responsible for federal registration of all pesticides. Federal foresters applying herbicides on forest land must consult their regional pesticide coordinator to secure approval for treatment.

FIRE

History and Ecology

Fire scars on old-growth trees present good evidence that repeated low-intensity fires burned over most of the ponderosa pine type. These ground fires consumed branches, fallen trees, understory vegetation, and some young trees. The fires burned from 6 (Soeriaatmadja 1966) to 47 years (Weaver 1959, 1961) apart, with most occurring somewhere between the two extremes (Martin and Johnson 1979). Low-intensity fires kept many of the pine forests open and parklike and also served to maintain ponderosa pine in areas where the more tolerant climax tree species would have attained dominance. The reason for this is that saplings or larger-sized ponderosa pine are much more fire resistant than many of the true firs and Douglas-fir. Fire-control activities, initiated about 1900, have resulted in a replacement of ponderosa pine with white fir, grand fir, incense-cedar, and Douglas-fir.

Succession has been influenced by the presence or absence of fire. Different species of brush react differently to fire. Bitterbrush, for example, may be completely killed by a hot ground fire but survive low-intensity fires. Brush species such as manzanita and snowbrush may increase after fire because it aids in germination of their seeds (Gratkowski 1961). Periodic ground fires may advance, back up, or merely hold succession at a given stage (Martin et al. 1976). A moderately hot fire, for example, may thin an overly dense stand and move it forward in succession to a mature ponderosa pine-bitterbrush community. Exclusion of fire has frequently altered vegetation to an unfavorable condition and has promoted the buildup of fuels so that wild fires can become catastrophic.

Through careful, prescribed burning today, managers can duplicate some of the more favorable natural fires of the past to accomplish specific objectives on a definite area.

Fire Effects

Fire effects depend on the fuels and weather conditions. By careful prescription and application of fire, the forest manager can modify fire intensity and fuel consumption, which affect what the fire will do to plants, water, atmosphere, soil, and nutrients.

Plants, especially trees, have varying degrees of resistance to fire. Ponderosa pine is probably the most resistant of western trees throughout its life (Martin and Dell 1978) and thus has a distinct advantage for survival in a prescribed burn of mixed conifers. Western larch is next, because of its thick bark and ability to grow new leaves after scorching. Old larch trees are considered more resistant to fire than pine. Large Douglas-fir is resistant because of its thick bark, but the crowns are sensitive to scorching. Lodgepole pine is much less resistant. Fire kills hemlock, true firs, and spruce much more readily than other trees.

The ability of grasses, shrubs, and short trees to maintain themselves through periodic burning depends upon their sprouting and seed characteristics. Martin and Dell (1978) present a useful summary table on effects of fire on 25 plant species.

Wildfires and intensely hot slash fires over large areas can affect water by increasing turbidity, changing chemical content, and influencing flooding and low water levels. Prescribed burning can be conducted to make these negative effects minimal or even to improve water quality and quantity (Ingebo and Hibbert 1974). Watershed experts should be included in prescription writing if water quality is a concern.

The greatest public concern in a prescribed burn is smoke. Atmospheric stability and wind direction must be considered to avoid problems in smoke-sensitive areas.

Fuels in prescribed fires contain nutrients vital to the plants you want to grow. Most of the nutrients will remain in place unless the fire becomes too hot or heavy precipitation follows the burn. Soils may actually become water repellent in areas where heavy fuel concentrations are consumed.

In view of these effects of fire on plants, water, atmosphere, and soil nutrients, fires that accomplish the objective but are still of low intensity are essential.

Prescribed-Fire Options in Ponderosa Pine Stands

Use of prescribed fire on lands east of the Cascades in the Pacific Northwest is relatively new, but research, interest, and use as a silvicultural tool are progressing rapidly. The expanding research project at the U.S. Forest Service Silviculture Laboratory in Bend, Oregon, on the use of prescribed fire will supply many of the answers needed for full-scale operation within the next 5 years.

Even though prescribed burning has just started in this region, some use may be made of it already. One of the "safest" options we have open to us now is where old-growth overstory has been harvested, the understory saplings thinned, and the thinning and logging slash piled and burned. Several years after thinning, tree seedlings and brush respond to additional light and soil moisture and begin to compete with crop trees (Barrett 1973). Light burning, as soon as fuel accumulation is heavy enough to carry the fire, would allow the remaining crop trees to develop their maximum capacity for diameter and height growth. Subsequent fires at 10- to 15-year intervals would kill unwanted reproduction and brush.

Another option showing promise and needing further work is burning under thinned stands where trees have been left that are lightly to moderately infected with dwarf mistletoe. Most infections are concentrated in the lower branches and fire will scorch these branches, thus reducing infections per tree.

Brush fields with a few scattered sawlog-sized trees may be burned successfully although the treatment prescription may call for an herbicide or desiccating chemical in combination with fire.

Light thinning slash that is partially green may be burned safely without crop-tree damage if residual trees are at least 10 to 12 ft (3 to 3.7 m) tall. Very low intensity burns will leave trees 6 to 8 ft (1.8 to 2.4 m) tall unharmed (Wright 1978). When stands reach 30 ft (9 m), thinning slash of around 30 tons per acre (67.2+/ha) has been reduced by burning.[9/]

We can now maintain clean understories in merchantable ponderosa pine stands that have a litter and grass understory. We do not yet have the answers to burning heavy accumulations of windfalls, tops, litter, and shrubs, or using fires to thin dense stands of ponderosa pine safely (Wright 1978). Fire prescription for a wide variety of purposes needs to be documented. Fire effects on herbs and shrubs need to be carefully recorded--not only immediate effects, but species shifts with time and recovery periods for desirable species. Only through careful documentation and recordkeeping will the usefulness of prescribed burning become available to the practicing forester.

Planning a Prescribed Burn

Planning a prescribed burn in the inland Northwest has been described in great detail by Martin and Dell (1978), who recommend the following preparation for a prescribed burning operation:

[9/]Martin, R. E. 1978. Principles and prescriptions for burning ponderosa pine thinning slash. Paper presented at AAAS-SAF Meeting, Seattle, June 1978. Being prepared for publication.

1. Reconnaissance of the area, including inspection and classification of the plant community.

2. Determination of specific objectives and how these objectives fit into management goals for the land unit as a whole.

3. Analysis of budgeting, costs, manpower, equipment, and other logistical needs that must be considered in planning and accomplishing the burn.

4. Thorough review of the planned burning and discussion with other disciplines to identify potential current and future influences and impacts of the burn on all resources.

5. Scheduling of time required to accomplish planned burning for the optimum time of year, including coordination needed with other units, agencies, etc.

6. Determination of specific prescription elements (fuel, weather, and ignition) needed to accomplish objectives.

7. Preparation of a written plan that provides a place for summary documentation of all factors.

CONSIDERATIONS FOR THE FUTURE

A large portion of silvicultural and management research in ponderosa pine forests has concentrated on regeneration, growth, stand development, and final harvest. Our knowledge has expanded tremendously in these areas. Little, however, has been done to show how different silvicultural systems contribute to or detract from various multiple-use objectives. Much documented information exists on such things as forage production under different degrees of canopy cover, thermal cover for big game, nesting habits of birds, watershed yields, and brush development under various stand density regimes--among others. Some information is available on favorable or unfavorable responses of various habitat types to certain silvicultural systems. This knowledge needs to be brought together into one publication for land managers so they may estimate the full impact of tradeoffs where one resource may be emphasized over another.

Throughout the West is a glaring lack of replicated silvicultural systems trials in various major habitats of the ponderosa pine type. These could be benchmark studies that would serve pine managers for many future rotations. Many disciplines--such as management of watersheds, range, wildlife, timber, landscape, logging, fuels, and prescribed burning--could be included in the undertaking. In addition to providing new information, studies of this kind will help to validate present-day predictions in a multitude of disciplines. Also, they would provide excellent ground for communicating with the public on management of renewable resources.

The conversion by fire control of 25 percent of the commercial forest land east of the Cascades to mixed conifer or some single species is an alarming prospect to some insect ecologists. Drastic changes in the forest brought about by human activity are potentially dangerous. Such a conversion needs to be critically examined so we do not create breeding habitat for an undesirable insect.

The yield tables for managed stands of ponderosa pine, to be generated in a year or two, will be based on limited data and will need updating as growth information becomes available. Even though a change in research emphasis occurs, these spacing and levels-of-growing-stock studies, established in the 1950's, can continue to improve our yield estimates. They should be periodically measured, maintained, and reported for several decades.

As is often true, abundant knowledge creates the need for more. Ponderosa pine stands in the Pacific Northwest grow under such varied conditions that solving silvicultural problems in this region is a never-ending process that will continue to challenge the ingenuity of foresters.

LITERATURE CITED

Adams, Ronald S.
1970. Ponderosa pine regeneration problems in the West Coast states. In Regeneration of ponderosa pine. R. K. Hermann, ed. p. 12-18. Symp. Proc. Sept. 11-12, 1969, Oreg. State Univ. Sch. For. Pap. 681, Corvallis.

Agee, James K., and Harold H. Biswell.
1970. Some effects of thinning and fertilization on ponderosa pine and understory vegetation. J. For. 68(1):709-711, illus.

American Ornithologist's Union.
1957. Check-list of North American birds. 5th ed. 691 p. Port City Press Inc., Baltimore, Md.

Anthony, Richard M., Victor G. Barnes, and James Evans.
1978. "Vexar" plastic netting to reduce pocket gopher depredation of conifer seedlings. In Proc. Eighth Vertebrate Pest Conf., p. 138-144. Univ. Calif., Davis.

Axelton, Elvera A.
1967. Ponderosa pine bibliography through 1965. USDA For. Serv. Res. Pap. INT-40, 150 p., Intermt. For. and Range Exp. Stn., Odgen, Utah.

Axelton, Elvera A.
1974. Ponderosa pine bibliography II. 1966-1970. USDA For. Serv. Gen. Tech. Rep. INT-12, 63 p., Intermt. For. and Range Exp. Stn., Ogden, Utah.

Baldwin, Ewart M.
1964. Geology of Oregon. 2d ed. 165 p., illus. Univ. Oreg. Coop. Bookstore, Eugene.

Barnes, V. G., Jr.
1973. Pocket gophers and reforestation in the Pacific Northwest: A problem analysis. Spec. Sci. Rep. Wildl. No. 155, 18 p. U.S. Fish and Wildl. Serv., Washington, D.C.

Barnes, Victor G., Jr.
1974. Response of pocket gopher populations to silvicultural practices in central Oregon. In Wildlife and forest management in the Pacific Northwest, p. 167-175. Hugh C. Black, ed. For. Res. Lab. Sch. For., Oreg. State Univ., Corvallis.

Barrett, James W.
1963. Dominant ponderosa pines do respond to thinning. USDA For. Serv. Res. Note PNW-9, 8 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Barrett, James W.
1966. A record of ponderosa pine seed flight. USDA For. Serv. Res. Note PNW-38, 5 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Barrett, James W.
1968. Response of ponderosa pine pole stands to thinning. USDA For. Serv. Res. Note PNW-77, 11 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Barrett, James W.
1969. Crop-tree thinning of ponderosa pine in the Pacific Northwest. USDA For. Serv. Res. Note PNW-100, 13 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Barrett, James W.
1970. Ponderosa pine saplings respond to control of spacing and understory vegetation. USDA For. Serv. Res. Pap. PNW-106, 16 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Barrett, James W.
1971. Ponderosa pine growth and stand management. In Precommercial thinning of coastal and intermountain forests in the Pacific Northwest, p. 5-9, illus. Wash. State Univ., Pullman.

Barrett, James W.
1972. Large-crowned planted ponderosa pine respond well to thinning. USDA For. Serv. Res. Note PNW-179, 12 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Barrett, James W.
1973. Latest results from the Pringle Falls ponderosa pine spacing study. USDA For. Serv. Res. Note PNW-209, 22 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Barrett, James W.
1974. High yields from 100-year-old ponderosa pine. USDA For. Serv. Res. Note PNW-220, 12 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Barrett, James W.
1977. A field guide for stand basal area, average diameter, and tree spacing relationships. USDA For. Serv. Res. Note PNW-298, 4 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Barrett, James W.
1978. Height growth and site index curves for managed, even-aged stands of ponderosa pine in the Pacific Northwest. USDA For. Serv. Res. Pap. PNW-232, 14 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Barrett, James W., and C. T. Youngberg.
1970. Fertilizing planted ponderosa pine on pumice soils. In Regeneration of ponderosa pine, p. 82-88, R. K. Hermann, ed. Symp. Proc. Sept. 11-12, 1969, Oreg. State Univ. Sch. For. Pap. 681.

Barrett, James W., Stanley S. Tornbom, and Robert W. Sassaman.
1976. Logging to save ponderosa pine regeneration: A case study. USDA For. Serv. Res. Note PNW-273, 13 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Bassett, Patricia M.
1977. Timber resources of southwestern Oregon. USDA For. Serv. Res. Bull. PNW-72, 29 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Briegleb, Phillip A.
1945. Calculating the growth of ponderosa pine forests. USDA For. Serv. Prog. Rep., 60 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Campbell, D. L., and J. Evans.
1975. "Vexar" seedling protectors to reduce wildlife damage to Douglas-fir. U.S. Fish and Wildl. Serv. Leafl. 508, 11 p. Washington, D.C.

Capp, J. C.
1976. Increasing pocket gopher problems in reforestation. In Proc. Seventh Vertebrate Pest Conf., p. 221-228. Univ. Calif., Davis.

Childs, T. W.
1968a. Elytroderma disease of ponderosa pine in the Pacific Northwest. USDA For. Serv. Res. Pap. PNW-69, 45 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Childs, T. W.
1968b. Comandra rust damage to ponderosa pine in Oregon and Washington. USDA For. Serv. 8 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Christensen, M. D., J. A. Young, and R. A. Evans.
1974. Control of annual grasses and revegetation in the ponderosa pine woodlands. J. Range Manage. 27(2):143-145.

Cleary, B. D.
1971. Weather guidelines to improve initial survival of planted seedlings. 9 p., illus. Weyerhaeuser Co., Centralia, Wash.

Cleary, Brian D., Robert D. Greaves, and Richard K. Hermann.
1978. Regenerating Oregon's forests. 286 p. Oreg. State Univ. Ext. Serv., Corvallis.

Cochran, P. H.
1968. Can thinning slash cause a nitrogen deficiency in pumice soils of central Oregon? USDA For. Serv. Res. Note PNW-82, 11 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Cochran, P. H.
1970. Seeding ponderosa pine. In Regeneration of ponderosa pine, p. 28-35, R. K. Hermann, ed. Symp. Proc. Sept. 11-12, 1969, Oreg. State Univ. Sch. For. Pap. 681. Corvallis.

Cochran, P. H.
1973. Response of individual ponderosa pine trees to fertilization. USDA For. Serv. Res. Note PNW-206, 15 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Cochran, P. H.
1975. Response of pole-size lodgepole pine to fertilization. USDA For. Serv. Res. Note PNW-247, 10 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Cochran, P. H.
1977. Response of ponderosa pine 8 years after fertilization. USDA For. Serv. Res. Note PNW-301, 7 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Cochran, P. H.
1978. Response of pole-size ponderosa pine stand to nitrogen, phosphorus and sulphur. USDA For. Serv. Res. Note PNW-319, 8 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Cochran, P. H., and Carl M. Berntsen.
1973. Tolerance of lodgepole and ponderosa pine to low night temperatures. For. Sci. 19(4):272-280, illus.

Crouch, Glenn L.
1976. Deer and reforestation in the Pacific Northwest. In Proc. Seventh Vertebrate Pest Conf., p. 298-301, Charles C. Siebe, ed. March 9-11, 1976, Univ. Calif., Davis.

Crouch, Glenn L., and Erwin Hafenstein.
1977. Atrazine promotes ponderosa pine regeneration. USDA For. Serv. Res. Note PNW-309, 8 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Dahms, Walter G.
1961. Chemical control of brush in ponderosa pine forests of central Oregon. USDA For. Serv. Pac. Northwest For. and Range Exp. Stn. Res. Pap. 39, 17 p. Portland, Oreg.

Dahms, Walter G., and James W. Barrett.
1975. Seed production of central Oregon ponderosa and lodgepole pines. USDA For. Serv. Res. Pap. PNW-191, 13 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Daubenmire, R., and Jean B. Daubenmire.
1968. Forest vegetation of eastern Washington and northern Idaho. Wash. State Univ. Agric. Exp. Stn. Tech. Bull. 60, 104 p., illus. Pullman.

Dealy, J. Edward.
1971. Habitat characteristics of the Silver Lake mule deer range. USDA For. Serv. Res. Pap. PNW-125, 99 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Dell, John D., and Franklin R. Ward.
1969. Reducing fire hazard in ponderosa pine thinning slash by mechanical crushing. USDA For. Serv. Res. Pap. PSW-57, 9 p., illus. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Dimock, E. J. II.
1977a. Enhancing survival of conifers with herbicides on dry sites. West. Soc. Weed Sci. Proc. 30:74-75.

Dimock, E. J. II.
1977b. Enhancing survival of planted conifers with herbicides on grassy sites. West. For. and Conserv Assoc., "What's new in reforestation" Proc. (In press.)

Dolph, Robert E.
1971. Oregon pine Ips infestation from red slash to green trees--a misconception. In Precommercial thinning of coastal and intermountain forests in the Pacific Northwest, p. 53-62, illus., David M. Baumgartner, ed. Symp. Proc. Feb 3 and 4, 1971, Coop. Ext. Serv. and Dep. For. and Range Manage., Wash. State Univ., Pullman.

Dyrness, Christian Theodore.
1960. Soil-vegetation relationships within the ponderosa pine type in the central Oregon pumice region. Ph.D. thesis, Oreg. State Univ., Corvallis. 217 p.

Foiles, Marvin W., and James D. Curtis.
1973. Regeneration of ponderosa pine in the northern Rocky Mountain-Intermountain Region. USDA For. Serv. Res. Pap. INT-145, 44 p., illus. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Fowells, H. A., and G. H. Schubert.
1956. Seed crops of forest trees in the pine region of California. U.S. Dep. Agric. Tech. Bull. 1150, 48 p., illus.

Franklin, Jerry F., and C. T. Dyrness.
1973. Natural vegetation of Oregon and Washington. USDA For. Serv. Gen. Tech. Rep. PNW-8, 417 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Furniss, R. L., and V. M. Carolin.
1977. Western forest insects. USDA For. Serv. Misc. Publ. No. 1339, 654 p., illus.

Gaines, Edward M.
1962. Improved system for grading ponderosa pine and sugar pine logs in trees. USDA For. Serv. Tech. Pap. 75, 21 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Garrison, G. A., and J. M. Skovlin.
1976. Plant names and symbols for ecosystems inventory and analysis. USDA For. Serv. Gen. Tech. Rep. PNW-46, 263 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Gratkowski, H.
1961. Brush seedlings after controlled burning of brushlands in southwestern Oregon. J. For. 59(12):885-888, illus.

Gratkowski, H.
1975. Silvicultural use of herbicides in the Pacific Northwest forests. USDA For. Serv. Gen. Tech. Rep. PNW-37, 44 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Gratkowski, H. J.
1977. Seasonal effects of phenoxy herbicides on ponderosa pine and associated brush species. For. Sci. 23(1):2-12, illus.

Gratkowski, H. J.
1978. Annual variation in effect of 2,4-D and 2,4,5-T on ponderosa pine. For. Sci. 24(2):281-287, illus.

Hall, Frederick C.
1973. Plant communities of the Blue Mountains in eastern Oregon and southeastern Washington. USDA For. Serv. R-6 Area Guide 3-1, 62 p. Pac. Northwest Region 6, Portland, Oreg.

Hopkins, William E.
1979a. Plant associations of south Chiloquin and Klamath Ranger Districts, Winema Natl. For. USDA For. Serv. R6-ECOL-79-005, 96 p., illus. Pac. Northwest Region 6, Portland, Oreg.

Hopkins, William E.
1979b. Plant associations of the Fremont National Forest. USDA For. Serv. R6-ECOL-79-004, 106 p., illus. Pac. Northwest Region 6, Portland, Oreg.

Howard, W. E., and H. E. Childs, Jr.
1959. Ecology of pocket gophers with emphasis on Thomomys bottae Mewa. Hilgardia 29(7):277-358.

Hull, A. C., Jr.
1971. Effects of spraying with 2,4-D upon abundance of pocket gophers in Franklin Basin, Idaho. J. Range Manage. 24(3):230-232.

Ingebo, P. A., and A. R. Hibbert.
1974. Runoff and erosion after brush suppression on the natural drainage watersheds in central Arizona. USDA For. Serv. Res. Note RM-275, 7 p., Rocky Mountain For. and Range Exp. Stn., Fort Collins, Colo.

Ingles, Lloyd G.
1973. Mammals of the Pacific States. 506 p., illus. Stanford Univ. Press, Stanford, Calif.

Keen, F. P.
1943. Ponderosa pine tree classes redefined. J. For. 41(4):249-253, illus.

Keen, F. P.
1952 (rev.). Insect enemies of western forests. U.S. Dep. Agric. Misc. Publ. 273, 280 p., illus.

Keith, J. O., R. M. Hansen, and A. L. Ward.
1959. Effect of 2,4-D on abundance of foods of pocket gophers. J. Wildl. Manage. 23(2):137-145.

Lawrence, William H.
1957. Porcupine control: A problem analysis. For. Res. Notes. 43 p. Weyerhaeuser Timber Co., For. Res. Center, Centralia, Wash.

Lightle, Paul C., and Melvyn J. Weiss.
1974. Dwarf mistletoe of ponderosa pine in the Southwest. USDA For. Serv. For. Pest Leafl. 19, 8 p., illus.

Little, Elbert L., Jr.
1953. Check list of native and naturalized trees of the United States (including Alaska). USDA Agric. Handb. 41, 472 p.

Little, Elbert L., Jr.
1971. Atlas of United States trees. Volume 1. Conifers and important hardwoods. UDSA For. Serv. Misc. Publ. 1146, 211 p.

Lynch, Donald W.
1958. Effects of stocking on site measurements and yield of second-growth ponderosa pine in the Inland Empire. USDA For. Serv. Res. Pap. 56, 36 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Mc Connell, Burt R., and Justin G. Smith.
1970. Response of understory vegetation to ponderosa pine thinning in eastern Washington. J. Range Manage. 23(3):208-212.

MacLean, Colin D., and Charles L. Bolsinger.
1973. Estimating productivity on sites with a low stocking capacity. USDA For. Serv. Res. Pap. PNW-152, 18 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Martin, Robert E., Dan D. Robinson, and Walter L. Schaeffer.
1976. Fire in the Pacific Northwest: Perspectives and problems. Proc. 15th Annu. Tall Timbers Fire Ecol. Conf., p. 1-23. Tall Timbers Res. Stn., Tallahassee, Fla.

Martin, Robert E., and John D. Dell.
1978. Planning for prescribed burning in the inland Northwest. USDA For. Serv. Gen. Tech. Rep. PNW-76, 67 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Martin, Robert E., and Arlen H. Johnson.
1979. Fire management of Lava Beds National Monument. In Proc. First Conf. on Sci. Res. in National Parks, Vol. II, Nat. Park Serv. and Am. Inst. Biol. Sci., Washington, D.C. p. 1209-1218.

Martin, Robert E., and Jerry T. Williams.
1978. A timber type evaluation of historical Douglas-fir tussock moth outbreak areas in Oregon and Washington. USDA/DFTM R&D Program Final Rep., 45 p., illus.

Meyer, Walter H.
1934. Growth in selectively cut ponderosa pine forests of the Pacific Northwest. U.S. Dep. Agric. Tech. Bull. 407, 64 p., illus.

Meyer, Walter H.
1961. Yield of even-aged stands of ponderosa pine. U.S. Dep. Agric. Tech. Bull. 630, 59 p. (Revised.)

Mowat, E. L.
1950. Cutting lodgepole overstory releases ponderosa pine reproduction. J. For. 48(10):679-680.

Mowat, Edwin L.
1953. Thinning ponderosa pine in the Pacific Northwest--a summary of present information. USDA For. Serv. Res. Pap. 5, 24 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Mowat, Edwin L.
1961. Growth after partial cutting of ponderosa pine on permanent sample plots in eastern Oregon. USDA For. Serv. Pac. Northwest For. and Range Exp. Stn. Res. Pap. 44, 23 p., illus. Portland, Oreg.

Oliver, William W.
1979. Fifteen-year growth patterns after thinning a ponderosa-Jeffrey pine plantation in northeastern California. USDA For. Serv. Res. Pap., Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif. (In press).

Peterson, Roger S.
1960. Western gall rust on hard pines. USDA For. Serv., For. Pest. Leafl. 50, 8 p., illus.

Rochelle, James A., Illo Gauditz, Katashi Oita, and John H. K. Oh.
1974. New developments in big-game repellents. In Wildlife and Forest Management in the Pacific Northwest, p. 103-112, H. C. Black, ed. For. Res. Lab. Sch. For., Oreg. State Univ., Corvallis, Oreg.

Roth, Lewis F.
1959. Perennial infection of ponderosa pine by Elytroderma deformans. For. Sci. 5(2):182-191, illus.

Roth, Lewis F., Charles G. Shaw III, and Leonard Rolph.
1977. Marking ponderosa pine to combine commercial thinning and control of armillaria root rot. J. For. 75(10):644-647.

Russell, Kenelm W., Robert E. Wood, and Charles H. Driver.
1973. Fomes annosus stump infection in ponderosa pine sapling stands of eastern Washington. Wash. Dep. Nat. Res. Rep. No. 27, Olympia.

Salman, K. A., and J. W. Bongberg.
1942. Logging high-risk trees to control insects in the pine stands of northeastern California. J. For. 40(7):533-539.

Sartwell, Charles.
1971. Thinning ponderosa pine to prevent outbreaks of mountain pine beetle. In Precommercial thinning of coastal and intermountain forests in the Pacific Northwest, p. 41-52, illus., David M. Baumgartner, ed. Symp. Proc. Feb. 3-4, 1971, Coop. Ext. Serv. and Dep. For. and Range Manage., Wash. State Univ., Pullman.

Sartwell, Charles, and R. E. Dolph, Jr.
1976. Silvicultural and direct control of mountain pine beetle in second-growth ponderosa pine. USDA For. Serv. Res. Note PNW-268, 8 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Sartwell, Charles, and R. E. Stevens.
1975. Mountain pine beetle in ponderosa pine: prospects for silvicultural control. J. For. 73(3):136-40.

Sassaman, Robert W., James W. Barrett, and Asa D. Twombly.
1977. Financial precommercial thinning guides for Northwest ponderosa pine stands. USDA For. Serv. Res. Pap. PNW-226, 27 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Schubert, Gilbert H.
1974. Silviculture of southwestern ponderosa pine: The status of our knowledge. USDA For. Serv. Res. Pap. RM-123, 71 p., illus. Rocky Mountain For. and Range Exp. Stn., Fort Collins, Colo.

Shaw, C. G. III.
1974. Epidemiological insights into Armillaria mellea root rot in a managed ponderosa pine forest. Ph.D. thesis. Oreg. State Univ., Corvallis.

Sikorowski, Peter P., and Lewis F. Roth.
1962. Elytroderma mycelium in the phloem of ponderosa pine. Phytopathology 52(4):332-336, illus.

Silen, Roy R., with Ivan Doig.
1976. The care and handling of the forest gene pool. Pac. Search 10(8):7-9.

Smith, David M.
1962. The practice of silviculture. 7th ed, 578 p., illus. John Wiley and Sons, Inc. New York and London.

Soeriaatmadja, R. E.
1966. Fire history of the ponderosa pine forests of Warm Springs Indian Reservation, Oregon. Ph.D. thesis. Oreg. State Univ., 132 p. Corvallis.

Sorensen, Frank C., and Richard S. Miles.
1974. Differential frost tolerance of ponderosa and lodgepole pine megasporangiate strobili. For. Sci. 20(4):377-378.

Sowder, James E.
1951. A sanitation-salvage cutting in ponderosa pine at the Pringle Falls Experimental Forest. USDA For. Serv. Res. Pap. 2, 24 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Spurr, Stephen H., and Burton V. Barnes.
1973. Forest ecology. 571 p., illus. The Ronald Press Co., New York.

Stewart, R. E., and T. Beebe.
1974. Survival of ponderosa pine seedlings following control of competing grasses. In Proc. West. Soc. Weed Sci. 27:55-58, illus.

Stoszek, Karel J.
1973. Damage to ponderosa pine plantations by the western pine shoot borer. J. For. 71(11):701-705.

Strand, M. A., and L. F. Roth.
1976. Simulation model for spread and intensification of western dwarf mistletoe in thinned stands of ponderosa pine saplings. Phytopathology 66(7):888-895.

U.S. Department of Agriculture, Forest Service.
1940. Annual report. Intermt. For. and Range Exp. Stn., Ogden, Utah.

U.S. Department of Agriculture, Forest Service.
1974. The outlook for timber in the United States. USDA For. Serv. For. Resour. Rep. No. 20, 374 p. Washington, D.C.

Volland, Leonard A.
1974. Relation of pocket gophers to plant communities in the pine region of central Oregon. In Wildlife and forest management in the Pacific Northwest, p. 149-166, Hugh C. Black, ed. Symp. Proc., For. Res. Lab. Sch. For., Oreg. State Univ., Corvallis.

Volland, Leonard A.
1976. Plant communities of the central Oregon pumice zone. USDA For. Serv. R6 Area Guide 4-2, 113 p. Pac. Northwest Region 6, Portland, Oreg.

Wang, Chi-Wu.
1977. Genetics of ponderosa pine. USDA For. Serv. Res. Pap. WO-34, 24 p., illus. Washington, D.C.

Weaver, Harold.
1959. Ecological changes in the ponderosa pine forest of the Warm Springs Indian Reservation in Oregon. J. For. 57(1):15-20.

Weaver, Harold.
1961. Ecological changes in the ponderosa pine forests of Cedar Valley in southern Washington. Ecology 42(2):416-420.

Woodfin, Richard O.
1978. Ponderosa pine lumber recovery--young growth in northern California. USDA For. Serv. Res. Pap. PNW-237, 13 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Wright, Henry A.
1978. The effect of fire on vegetation in ponderosa pine forests. A state-of-the-art review. Texas Tech. Univ. Range and Wildl. Info. Ser. No. 2, 21 p. Coll. Agric. Sci. Publ. No. T-9-199. Texas Tech. Univ., Dep. Range and Wildl. Manage., Lubbock.

Youngberg, C. T.
1966. Silvicultural benefits from brush. Soc. Am. For. Proc. 1965:55-59.

Youngberg, C. T.
1968. Effects of fertilization and thinning on the growth of ponderosa pine. Agron. Abstr. 140.

Youngberg, C. T.
1975. Effects of fertilization and thinning on the growth of ponderosa pine. Soil Sci. Soc. Proc. 39(1):137-139, illus.

APPENDIX

Table 11--Plants, diseases, insects, mammals, and birds[1/]

Common name	Scientific name
HERBS AND SHRUBS	
Bitterbrush, antelope	*Purshia tridentata* (Pursh) DC.
Bunchgrass	*Agropyron* sp.
Chinkapin	*Castanopsis* spp.
Golden	*C. chrysophylla* (Dougl.) A.DC.
Sierra	*C. sempervirens* (Kell.) Dudl.
Comandra, common	*Comandra umbellata* (L.) Nutt.
Fescue	*Festuca* sp.
Manzanita, greenleaf	*Arctostaphylos patula* Greene
Needlegrass	*Stipa* sp.
Ninebark	*Physocarpus* sp.
Oceanspray	*Holodiscus* sp.
Peavine	*Lathyrus* sp.
Sagebrush	*Artemisia* sp.
Sedge	*Carex* spp.
Elk	*C. geyeri* Boott
Ross	*C. rossii* Boott
Snowberry	*Symphoricarpos* sp.
Snowbrush	*Ceanothus velutinus* Dougl. ex Hook.
Squirreltail	*Sitanion* sp.
Wheatgrass	*Agropyron* sp.
Wildrye, blue	*Elymus glaucus* Buckl.
TREES	
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco
Fir, true	*Abies* spp.
Grand	*A. grandis* (Dougl.) Lindl.
White	*A. concolor* (Gord. & Glend.) Lindl.
Incense-cedar	*Libocedrus decurrens* Torr.
Pine	*Pinus* spp.
Jeffrey	*P. jeffreyi* Grev. & Balf.
Lodgepole	*P. contorta* Dougl.
Ponderosa	*P. ponderosa* Laws.
DISEASES	
Dwarf mistletoe	*Arceuthobium* spp.
Southwestern	*A. vaginatum cryptopodum* (Engelm.) Hawksw. & Wiens
Western	*A. campylopodum* Engelm.
Needle blight	
Elytroderma	*Elytroderma deformans* (Weir) Darker

DISEASES (Continued)	
Root rot	
Armillaria	*Armillaria mellea* (Vahl. ex Fr.) Quel.
Annosus	*Fomes annosus* (Fr.) Cke.
Rust	
Comandra	*Cronartium comandrae* Pk.
Western gall	*Endocronartium harknessii* (J.P. Moore) Y. Hirax
INSECTS	
Beetle	
Mountain pine	*Dendroctonus ponderosae* Hopkins
Turpentine	*D. valens* Le Conte
Western pine	*D. brevicomis* Le Conte
Borer, western pine shoot	*Eucosma sonomana* Kearfott
Butterfly, pine	*Neophasia menapia* (Felder and Felder)
Engraver, pine	*Ips pini* Say
Wasp, parasitic	*Theronia atalantae* (Poda)
MAMMALS	
Bobcat	*Lynx rufus* (Schreber)
Chipmunk	*Eutamias* spp.
Cougar	*Felis concolor* (Linnaeus)
Deermouse	*Peromyscus* spp.
Deer, mule	*Odocoileus hemionus* (Rafinesque)
Elk	*Cervus* spp.
Fisher	*Martes pennanti* (Erxleben)
Gopher, pocket	*Thomomys talpoides* (Richardson), *T. mazama* (Merriam)
Groundsquirrel, golden mantled	*Callospermophilus* spp.
Porcupine	*Erethizon dorsatum* (Linnaeus)
Squirrel, red	*Tamiascurus* spp.
Vole	*Microtus* spp.
BIRDS	
Chickadee, mountain	*Parus gambeli* Ridgway
Dove, mourning	*Zenaidura macroura* Linnaeus
Flicker, common	*Colaptes auratus* Linnaeus
Jay	
Pinon	*Gymnorhinus cynocephalus* Wied
Steller's	*Cyanocitta stelleri* Gmelin
Junco, dark-eyed	*Junco hyemalis* Linnaeus
Woodpecker, white-headed	*Dendrocopos albolarvatus* Cassin

1/Nomenclature follows, for trees, Little (1953); for grasslike plants, forbs, and shrubs, Garrison and Skovlin (1976); for insects, Furniss and Carolin (1977); for mammals, Ingles (1973); and for birds, American Ornithologist's Union (1957).

For Sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C., 20402