United States
Department of
Agriculture

Forest Service

Pacific Northwest
Forest and Range
Experiment Station

General Technical
Report
PNW-121

April 1981

Silviculture of Mixed Conifer Forests in Eastern Oregon and Washington

K.W. Seidel and P.H. Cochran

Authors

K.W. SEIDEL is research forester and P.H. COCHRAN is research soil scientist at the Silviculture Laboratory, Pacific Northwest Forest and Range Experiment Station, Bend, Oregon.

ABSTRACT

Seidel, K. W., and P. H. Cochran.
1981. Silviculture of mixed conifer forests in eastern Oregon and Washington. **USDA** For. Serv. Gen. Tech. Rep. PNW-121, 70 **p.** Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

The silviculture of mixed confier forests in eastern Oregon and Washington is described. Topics discussed include ecological setting, damaging agents, silviculture, and management. The relevant literature is presented, along with unpublished research, experience, and observations. Research needs are also proposed.

Keywords: Silviculture, mixed stands, coniferae, timber management, regeneration (stand), eastern Oregon, eastern Washington.

CONTENTS

INTRODUCTION

Timber management research in the mixed conifer forests of eastern Oregon and Washington has been under way for only about 10 years. During this period the results of studies on the silvics and silviculture of mixed conifer forests have been reported in a number of publications. This paper summarizes the available knowledge on timber management in these forests based on past research, work done in adjacent areas having similar forest types, and observations and experience of land managers. From this information, general guidelines and recommendations for silvicultural prescriptions have been developed.. Although much has been learned about the characteristics and management of these mixed conifer forests, much remains to be learned. Because of the complex nature of these forests and the relatively limited available knowledge, recommendations are often tentative.

This paper is intended as a guide for professional foresters and land managers who are responsible for prescribing and supervising the application of silvicultural treatments in mixed conifer forests. No attempt is made to discuss all possible silvicultural alternatives. Rather, the objective is to present a broad overview of the state of the art. Recommendations must be modified in response to local ecological, economic, and social conditions, and as additional facts and experience are accumulated.

GENERAL DESCRIPTION OF MIXED CONIFER FORESTS

The mixed conifer forests of eastern Oregon and Washington occupy a great variety of landforms (fig. 1). For purposes of this report, mixed conifer forests are considered to consist of all forests other than pure ponderosa pine,[1] pure lodgepole pine, or mixtures of ponderosa and lodgepole pines. Commercial mixed conifer stands east of the Cascade summit in Oregon and Washington occur within parts of the Okanogan Highlands, the Northern Cascades, the Southern Washington Cascades, the Blue Mountains, the High Cascades, the High Lava Plains, and the Basin and Range Physiographic Provinces (fig. 2). These mixed conifer forests contain a large number of species whose seedlings are less tolerant to drought than ponderosa pine and therefore occupy higher elevation sites where moisture is more readily available. Species common in these mixed conifer forests include Douglas-fir, ponderosa pine, western larch, lodgepole pine, grand fir, white fir, subalpine fir, western white pine, Engelmann spruce, Shasta red fir, mountain hemlock, western hemlock, and western red cedar.

---

[1]Scientific names of plants and animals mentioned are listed on page 69, appendix.

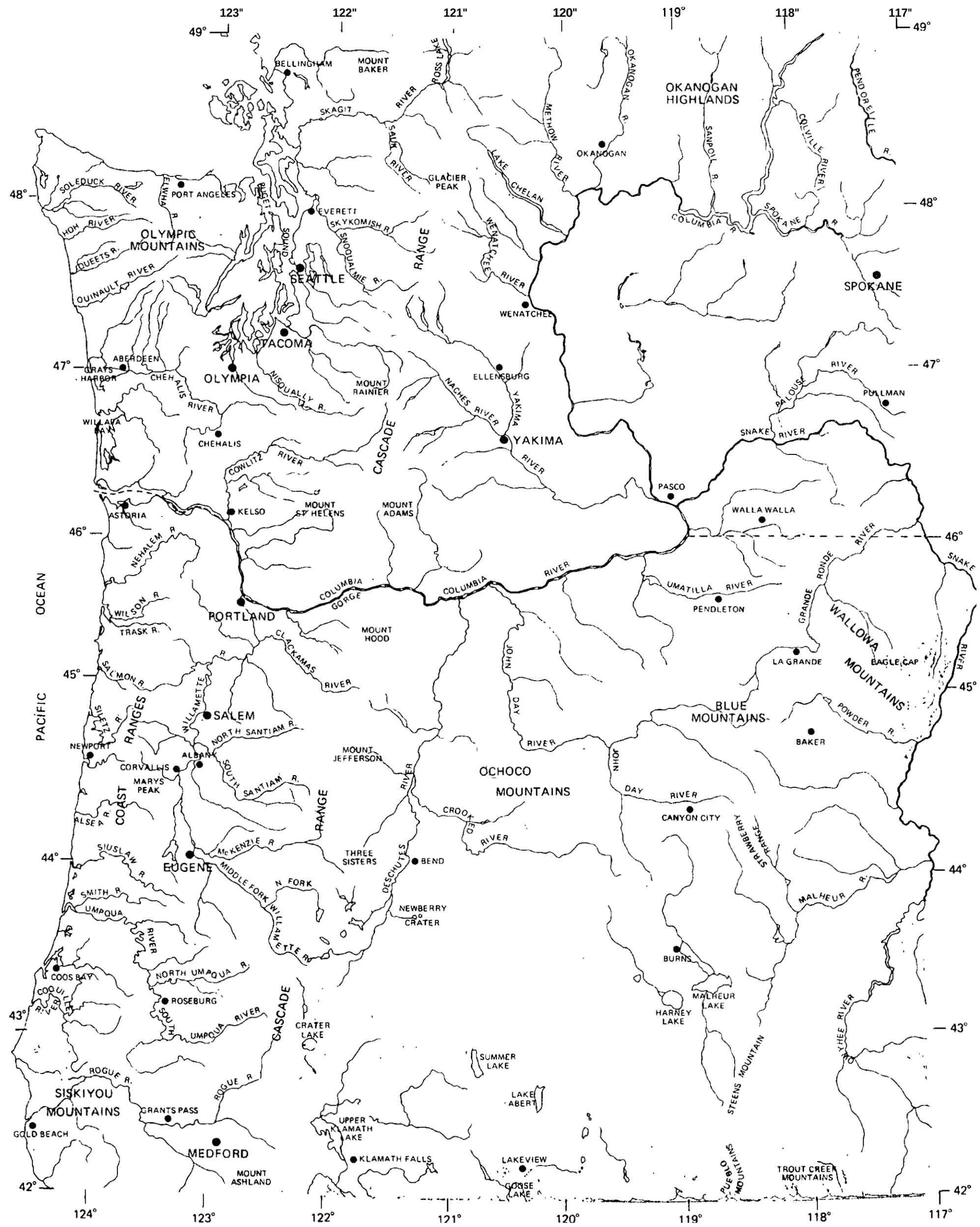


Figure 1.—Major topographic features and some cities and towns in Oregon and Washington. (Reproduced from Franklin and Dyrness 1973.)

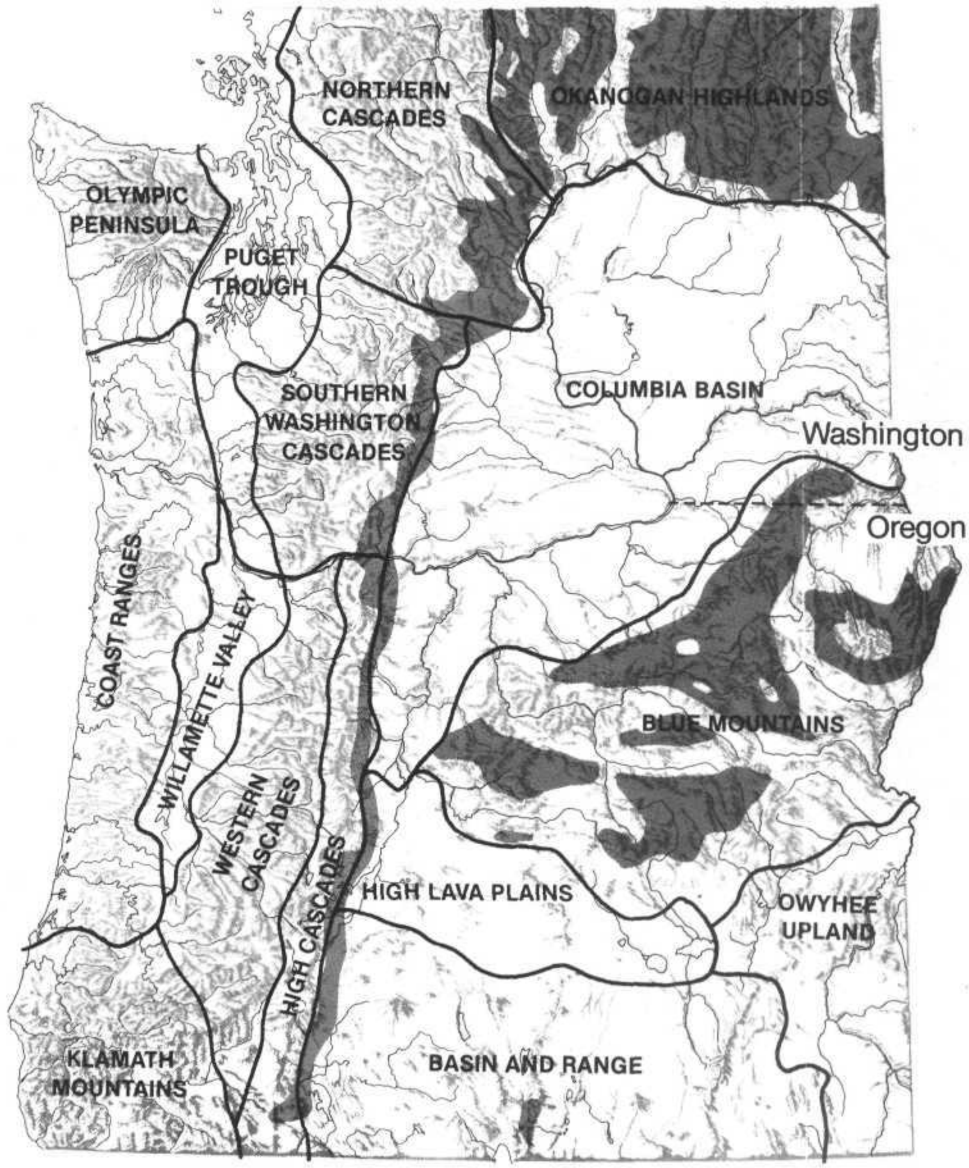


Figure 2.—Physiographic and geological provinces in Oregon and Washington. The distribution of mixed conifer forests is shown by the shaded area. (Adapted from Franklin and Dyrness 1973.)

Stand structure and species composition are extremely variable depending upon site, logging history, insect and disease attacks, and wildfire. Various combinations of species are found growing together in both even-aged and uneven-aged stands. As a result of past fires, many of these forests consist of a mosaic of even-aged stands (or at least two- or three-aged), with even-aged overstories and one or two age classes in the understory. Uneven-aged stands having a multi-storied structure are also common. At lower elevations, mixtures of ponderosa pine and Douglas-fir occur. Farther up the slope, larch and lodgepole pine, both seral[2] species in these forests, are found in pure or mixed stands as a result of fire or clearcutting. In many such stands, an understory of Douglas-fir or grand fir is common. At higher elevations, mountain hemlock and subalpine fir are the climax vegetation.

Lodgepole pine is seral in the forests of eastern Oregon and Washington except on the pumice plateau of central Oregon, where it is found in pure stands in the pine type and is considered an edaphic or topoedaphic climax[3] because of its ability to survive on more severe sites where there is little competition and temperature extremes are common. These climax lodgepole stands are not considered in this report.

ECOLOGICAL SETTING

Climate

Eastern Oregon and Washington have a more continental climate than areas west of the Cascade Range. Typical weather patterns consist of cold winters, hot and dry summers, and large diurnal temperature fluctuations. Precipitation is primarily cyclonic as a result of low-pressure systems from the Pacific Ocean but is much less than to the west because the area lies in the rain shadow of the Cascade Range. Much of the annual precipitation falls as snow and the frost-free season is relatively short. Elevation of the mountain areas within the region is the primary factor influencing local climate. Temperatures decrease and precipitation increases rapidly with increasing elevation. This, of course, has a profound effect on the vegetation. Species better adapted to a cold and moist environment are found at higher elevations while those more tolerant of warm and dry conditions become established at lower elevations.

---

[2]Species in the early or developmental stages of a plant community before the climax or equilibrium condition.

[3]Edaphic climax: a plant community that differs from the normal climatic climax because of abnormal soil conditions. Topoedaphic climax: a plant community that differs from the normal climatic climax because of abnormal soil conditions and special microclimates resulting from local topography.

Soils

In the Okanogan Highlands, deposits of glacial drift are widespread. In some of the main valleys, glaciolacustrine sediments form a series of terraces on valley walls. In mountainous'areas away from the major river valleys, forested soils derived from granitic parent material are Xerochrepts and Cryorthods. Soils at high elevations developing over glacial materials often have high volcanic ash content and are Vitrandepts or Cryandepts. Soils at lower elevations on terraces and flood plains along major rivers are usually coarse textured, well to excessively drained, and classified as Haploxerolls, Vitrandepts, Haplorthods, and Xeropsamments.

The Northern Cascades are characterized by extreme variability in parent materials, extensive glaciation, and steep slopes. Most of the forested soils east of the divide are Vitrandepts, Cryandepts, Cryorthods and Haplorthods with some Xerochrepts and Haploxerolls at lower elevations.

Andesite and basalt flows with associated breccias and tuffs dominate the Southern Washington Cascades Province. East of the Cascade crest, soils are largely Vitrandepts, Xerochrepts, Cryandepts, with Haploxeralfs and Haploxerolls at lower elevations. These soils, although derived primarily from andesite, sandstone, or glacial till, are also influenced to a considerable extent by volcanic ash or loess or both. Soil textures are often silt loams or loams.

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 ejected from Mount Mazama (Crater Lake) about 6,500 years ago. Subsequent erosion has largely removed the ash from south-facing slopes; however, other locations are typically mantled by the material. Many upland areas were covered by loess deposits. Forested soils developing on volcanic ash are almost completely restricted to broad ridge tops and north-facing slopes where the ash mantle varies from 2 to 3 feet. Most of these soils are Vitrandepts and Cryandepts. In ashless areas the soils are mostly Haploxerolls and Argixerolls.

The High Cascades Province is dominated by immature soils developed in volcanic ejecta and soils showing more profile development which are derived from glacially deposited materials. The forested soils of the northern section are dominated by Cryorthods and Cryumbrepts. The southern areas have extensive mantles of volcanic ejecta (pumice, cinders, and ash) and the soils are mostly Cryorthents and Cryandepts.

Mixed conifer forests occur in the western portion of the High Lava Plains Province adjacent to the High Cascades Province. Soils beneath these forests are developing from pumice and are classified as Cryorthents.

Commercial mixed conifer forests occur in the western portion of the Basin and Range Province and in the central portion of the Province in the Warner Mountains where the dominant soils are Cryoborolls. The immature soils in the western portion are strongly influenced by Mazama pumice north of the Sprague River and are Cryorthents and Cryoborolls.

Vegetation

The diversity of habitats in the mixed conifer forests of eastern Oregon and Washington is evident to even the casual observer, but only recently has the basic biological and ecological information needed to understand and classify the vegetational associations of these forests begun to accumulate. Natural vegetation can be classified and organized in many ways. Franklin and Dyrness (1973) have provided a detailed description of the plant geography and ecology of these complex, mixed conifer forests in their comprehensive account of the natural vegetation of Oregon and Washington. Our purpose here is to briefly describe the dominant vegetation in terms of timber or cover types, forest zones, and plant communities.

Timber or Cover Types.—Timber types simply classify existing forest vegetation in terms of predominant tree species with no implication as to whether the species are temporary or relatively stable. The principal mixed conifer forest cover types of eastern Oregon and Washington (Society of American Foresters 1980) are:

Type Number	Type
205	Mountain hemlock-subalpine fir
206	Engelmann spruce-subalpine fir
207	Red fir
210	Interior Douglas-fir
211	White fir
212	Western larch
213	Grand fir

Forest Zones.—Classification of forests by altitudinal-vegetation zones in mountainous regions is a common way of differentiating natural vegetation (Daubenmire 1943, 1946). Such zones have been based on climate, existing vegetation, and potential (climax) vegetation. The forest zones identified by Franklin and Dyrness (1973) are based on communities in which a single tree species is the major climax dominant. They point out some characteristics of this zonal scheme as follows:

1. Zones may occur as sequential belts on mountain slopes, but generally they interfinger, with each attaining its lower elevational limits in valleys and its highest limits on ridges.
2. There is a tendency for species or associations occupying modal sites in one zone to occur on moist, cool habitats in the adjacent warmer and drier zone and on warm, dry habitats in the adjacent cooler and moister zone.
3. Disturbance and the resulting seral vegetation may obscure zonal sequences. Pioneer species often range throughout several zones. Many of the seral dominants in a given zone tend to be climax species in adjacent warmer and drier zones.
4. Zonal schemes reflect plant responses to strong macroclimatic gradients in temperature and moisture. Unusual soil properties sometimes override climatic factors to severely modify zonation patterns. The pumice plateau region of central Oregon is an example of this condition.

The *Pseudotsuga menziesii* zone is the lowest elevational zone in the mixed conifer forests of eastern Oregon and Washington. It is well developed in most of eastern Washington at an elevation of 2,000 - 4,300 feet. In eastern Oregon it is sparse or absent except in parts of the Wallowa Mountains. Douglas-fir, ponderosa pine, lodgepole pine, and western larch are the major species (table 1). This zone is more mesic than those at lower elevations.

Table 1—Importance and ecological role of major tree species in representative forest zones and locales in eastern Oregon and Washington[1]

	Eastern Washington Cascade Range					Central Oregon Cascade Range					Ochoco and Blue Mountains		Southern Oregon Cascade Range		
Species	*Pinus ponderosa* Zone	*Pseudotsuga menziesii* Zone	*Abies grandis* Zone	*Tsuga heterophylla* Zone	*Abies lasiocarpa* Zone	*Juniperus occidentalis* Zone	*Pinus ponderosa* Zone	*Pseudotsuga menziesii* Zone	*Abies grandis*[2] Zone	*Tsuga mertensiana* Zone	*Pinus ponderosa* Zone	*Abies grandis*[2] Zone	*Pinus contorta* Zone	*Pinus ponderosa* Zone	*Abies concolor* Zone
Abies amabilis	—	—	—	—	c	—	—	—	—	c	—	—	—	—	—
Abies grandis or *concolor*	—	—	C	S	s	—	—	—	C	s	—	C	—	—	C
Abies lasiocarpa	—	—	—	s	C	—	—	—	s	C	—	—	—	—	—
Abies magnifica shastensis	—	—	—	—	—	—	—	—	—	—	—	—	—	—	s
Libocedrus decurrens	—	S	S	s	s	—	—	c	s	—	—	—	—	—	s
Larix occidentalis	—	S	S	s	s	—	—	s	s	—	—	S	—	—	—
Larix lyallii	—	—	—	—	s	—	—	—	—	—	—	—	—	—	—
Picea engelmannii	—	—	s	s	Sc	—	—	—	s	s	—	s	—	—	—
Pinus contorta	—	S	S	s	s	—	—	s	S	S	—	S	C	S	s
Pinus lambertiana	—	—	—	—	—	—	—	—	s	—	—	—	—	—	s
Pinus monticola	—	—	S	S	s	—	—	—	s	s	—	s	—	—	s
Pinus ponderosa	C	S	S	s	—	—	C	S	S	s	C	s	c	C	S
Juniperus occidentalis	—	—	—	—	—	C	s	s	—	—	s	—	—	s	—
Populus tremuloides	s	s	s	—	—	—	s	s	s	—	—	—	s	s	s
Pseudotsuga menziesii	—	C	S	S	s	—	—	C	S	s	—	Sc	—	—	—
Thuja plicata	—	—	—	sc	—	—	—	—	—	—	—	—	—	—	—
Tsuga heterophylla	—	—	—	C	s	—	—	—	—	—	—	—	—	—	—
Tsuga mertensiana	—	—	—	—	c	—	—	—	s	C	—	—	—	—	s

[1]C = major climax species, c = minor climax species, S = major serai species, and s = minor serai species.

[2]*Abies grandis-A. concolor* complex.

Source: Franklin and Dyrness (1973).

The ***Abies grandis*** zone is the most extensive midslope zone in the Cascade Range of Oregon and southern Washington and the Blue Mountains of eastern Oregon. It is generally found at 3,600 - 4,900 feet in the central Oregon Cascades, 4,900 - 6,500 feet in the Ochoco and Blue Mountains, and 5,400 - 6,500 feet in south-central Oregon. Principal tree species are grand fir or white fir,[4] ponderosa pine, lodgepole pine, western larch, and Douglas-fir. Climatic conditions are moderate with more precipitation and cooler temperatures than in lower zones.

The ***Tsuga heterophylla*** zone is an eastern extension of the coastal western hemlock zone and is found on the eastern slopes of the Cascades in Washington and northern Oregon at elevations between 2,600 and 3,900 feet. This zone also occurs in the mountains of the Okanogan Highlands. Major tree species, in addition to those in the ***Pseudotsuga menziesii*** and ***Abies grandis*** zones are western white pine, western red cedar, and western hemlock. This zone has the best tree-growing climatic regime of all the interior forest zones.

The subalpine forests of eastern Oregon and Washington are represented by the ***Abies lasiocarpa*** and ***Tsuga mertensiana*** zones. The ***Abies lasiocarpa*** zone is found on high secondary ranges extending east from the crest of the Washington Cascades, in the Okanogan Highlands, and in the Blue and Wallowa Mountains. The ***Tsuga mertensiana*** zone is the highest forested zone along the western slopes and crest of the Cascade Range but also extends east of the Cascade crest where it merges with the interior ***Abies lasiocarpa*** zone. Extensive mountain hemlock forests occur east of the Cascade crest in central and southern Oregon. Major species in these zones are subalpine fir, mountain hemlock, Engelmann spruce, and lodgepole pine. True firs are also common. These are the coolest and wettest of the forest zones with short, cool summers and long, cold winters. Much of the precipitation falls as snow which accumulates to depths of 26 feet and remains on the ground for 6 to 8 months of the year.

Habitat **Types or** Plant Communities.—Within each of the forest zones identified in the mixed conifer forests of eastern Oregon and Washington, there is a wide range of environmental conditions, and the response to a given silvicultural treatment may vary considerably within the same zone. Therefore, it is desirable to identify natural landscape units which are relatively uniform in biological and physical characteristics. In the western United States, identification of these relatively homogenous units has been accomplished in many areas by habitat types or plant communities. A habitat type is based on the potential climax vegetation in terms of the self-perpetuating tree species and the dominant understory species. It provides an ecologically sound integration of the various environmental factors as expressed in the climax vegetation. Thus, the land manager can have greater assurance that similar treatments on the same habitat type will give similar results.

---

[4]Grand fir and white fir form a continuously varying biological complex in eastern Oregon. For management purposes, grand and white fir can be treated alike.

Considerable progress has been made in identifying habitat types in the mixed conifer forests of eastern Oregon and Washington. In northern Idaho and northeastern Washington, Daubenmire and Daubenmire (1968) identified 21 habitat types: 6 in the ponderosa pine type and 15 in mixed conifer zones. In the Blue Mountains, Hall (1973) identified 45 plant communities, ranging from grass/sagebrush habitats to subalpine types, and gave estimates of site potential for range and timber management. Volland (1976) working in the central Oregon pumice zone, described 61 habitat types and also gave estimates of various characteristics of these communities which affect land management. And Hopkins (1979a, 1979b) identified plant communities in the Fremont and Winema National Forests in south-central Oregon.

Climax and Succession

In the absence of disturbance on mixed conifer sites, natural succession will result in the replacement of seral communities by the more shade tolerant climax species. These climax species will tend to persist until severe disturbance, such as fire, clearcutting, windthrow, or insects and diseases, creates conditions favorable for establishment of intolerant species. Thus, western larch and lodgepole pine, both seral species in the Abies ***grandis*** zone, are commonly found in even-aged stands resulting from fire or clearcutting. In many areas of the mixed conifer forests, severe disturbance can result in grass and shrub communities if tree regeneration is not established immediately. Gratkowski (1974) estimated that 1,482,600 acres of mixed conifer forest land is occupied by species such as snowbrush ceanothus, Sierra evergreen chinkapin, greenleaf manzanita, and willows. Once these species become dominant, conifers may be excluded for decades unless expensive measures are taken to reforest the site artificially.

The classical concept of succession as a more or less orderly process proceeding from less shade tolerant pioneer species to the more tolerant climax species is useful in looking at various plant communities and predicting changes that will result from management activities. In general, these successional changes do occur over much of the mixed conifer forests. The silviculturist should be aware, however, that exceptions also occur because of availability of seed or local site conditions. For example, because of an adequate seed supply, an intolerant and a tolerant species may invade a disturbed area simultaneously. Differences in tree size apparent many years later may be caused by differences in growth rates of the two species rather than later establishment of the more tolerant species.

Successional trends within forest zones and plant communities have important implications for forest management. Observations suggest the following order of shade tolerance, from most to least tolerant species: western hemlock ≈ western red cedar > mountain hemlock ≈ subalpine fir ≈ Engelmann spruce ≈ grand or white fir > Douglas-fir > western white pine ≈ ponderosa pine ≈ lodgepole pine > western larch. In order to successfully apply selected silvicultural systems, however, it is essential to realize that the successional role or relative tolerance of species differs from site to site. For example, Douglas-fir is the climax species in the *Pseudotsuga menziesii* zone but a seral species in the *Abies grandis* zone. Therefore, application of uneven-aged management (selection system) in the *Pseudotsuga menziesii* zone would tend to maintain Douglas-fir in the stand whereas it would be replaced by more tolerant species in the *Abies grandis* zone.

PRINCIPAL DAMAGING AGENTS

Insects

Mixed conifer forests are attacked by a large number of insect pests (Furniss and Carolin 1977). Those causing serious damage over large areas include the Douglas-fir beetle, the mountain pine beetle, the Douglas-fir tussock moth, the western spruce and Modoc budworms, the larch casebearer, the fir engraver, and the pine engraver.

The Douglas-fir beetle is the most damaging bark beetle pest of Douglas-fir throughout the range of this tree. Generally, it breeds in felled, damaged, or diseased trees, and large populations can kill many mature and overmature trees (Furniss and Orr 1970). When outbreaks occur, usually following blowdown or defoliation by other insects, nearly every Douglas-fir in a stand can be killed. Direct control of the beetle has seldom been attempted and is not recommended. Research with a pheromone, however, suggests a possible control measure for the future (Furniss et al. 1974). In interior forests, preventive control is obtained by thinning and harvesting.

The mountain pine beetle is the most destructive bark beetle in the western States. It attacks all pine species but causes most damage to overmature or overstocked stands of ponderosa and lodgepole pine and can be a serious problem in mixed conifer forests where these species are major components. Details of the life history of the mountain pine beetle and the damage it causes are given by Evenden et al. (1943) and McCambridge and Trostle (1972). During endemic infestations beetles favor weaker, less vigorous trees for attack, but no such selection occurs during epidemics. Attacks are recognized by pitch tubes that are usually heaviest along the main bole of the tree from the ground to midcrown. Sometimes a heavy flow of resin from the tree will prevent successful attacks by the beetle. Various methods to control epidemics have been attempted, such as felling and burning or peeling, and treating with oil or chemical sprays, but such measures are generally uneconomical and of limited usefulness because large areas are involved. Control by harvesting susceptible stands prior to epidemics and thinning overstocked young stands to maintain vigorous trees appear to be the most desirable methods of preventing outbreaks (Sartwell 1971, Sartwell and Stevens 1975).

Bark beetle epidemics characteristically do the most damage in unmanaged or overmature stands. Like fire and wind, they provide a natural means of liquidating such stands so they can be replaced with vigorous, second-growth stands. Bark beetle problems should diminish as old-growth stands are harvested and the stocking level of the replacement stands is controlled.

The Douglas-fir tussock moth is a major defoliator of east-side mixed conifer forests, showing equal preference for Douglas-fir, grand or white fir, and subalpine fir. It also attacks other species after the preferred hosts are consumed (Wickman et al. 1973a, 1973b). Epidemic populations usually develop explosively and then subside abruptly after about 3 years. Population collapse usually results from such factors as disease organisms, insect parasites, and bird predation. Defoliation by the tussock moth can result in tree mortality, top-killing, or weakening so the trees are killed by other insects. Mortality occurs as scattered single trees throughout the outbreak area or in patches that range in size from a few to several hundred acres (Wickman 1978). Scattered tree mortality has positive as well as negative effects, since the reduction in stand density results in'increased vigor and growth of the survivors and non-host trees.

Direct control is often needed to control tussock moth populations. Two microbial insecticides, ***Bacillus thuringiensis*** (B.t.) and a nucleopolyhedrosis virus (NPV), show promise. These agents are toxic to the tussock moth, but do not affect populations of beneficial insects, such as bees. Silvicultural control by manipulating the composition of species also seems promising. Because of the exclusion of fire and the harvesting of overstory ponderosa pine during the past 75 years, the proportion of true firs has increased greatly in many stands, and recent tussock moth outbreaks have occurred mostly in second-growth or understory stands of true fir. Maintaining pine on the more xeric sties by the use of prescribed fire could reduce the severity of further outbreaks (Williams et al. 1980). Detailed information on population dynamics and management of the tussock moth is given by Brookes et al. (1978).

The western spruce budworm is the most widespread and possibly the most destructive forest defoliator in western North America (Carolin and Honing 1972). It attacks spruce and western larch but shows a decided preference for Douglas-fir and true firs. Some epidemics subside naturally in a few years; others persist for as long as 20 years. The usual diet of the budworm larvae is the current year's foliage. Several years of defoliation can result in decreased growth, top-killing, and sometimes death of trees. In addition to feeding on foliage, the budworm severs the stem of the current year's terminal and lateral shoots of western larch and also causes damage to cones and seeds (Fellin and Schmidt 1973). Repeated severing of terminals and upper laterals produces crooked boles, deformed trees, and a considerable loss of height growth. Prompt thinning of young larch stands could reduce the incidence of budworm damage. Faster growing trees with large diameter shoots are severed less often than those with smaller shoots, and the more vigorous trees are better able to recover when budworm outbreaks subside. In the Warner Mountains of Oregon and California, sporadic outbreaks of the Modoc budworm follow a pattern similar to that of the western budworm.

The larch casebearer is the most serious pest of western larch. This defoliator, of European origin, was first discovered in the West in Idaho in 1957 (Denton 1979). Because no natural enemies were present when it was first introduced, the casebearer quickly spread throughout the range of larch and now is present in most larch stands in eastern Oregon and Washington. Typical effects of defoliation, such as growth reduction, loss of vigor, susceptibility to secondary insects, and occasional mortality, result from casebearer infestations. In addition, because of the shade intolerance of larch, this insect can seriously affect the fate of larch in mixed stands even if no mortality occurs. For larch to remain competitive in mixed stands, it must maintain a dominant position in the overstory. Repeated defoliation reduces vigor of the larch until it can no longer compete successfully with its more shade tolerant associates. Thus, even though the casebearer outbreak may subside, larch will eventually be eliminated from the stand once it loses its dominant position. The most promising means of containing the casebearer in the long run appears to be through biological control. A host-specific European parasite of the casebearer, *Agathis pumila* (Ratzeburg), was successfully introduced in western larch forests in 1960 (Denton 1972). Two other foreign parasitic wasps, *Chrysocharis laricinellae* (Ratzeburg), and *Dicladocerus westwoodii* (Westwood) were first released in 1972 and appear to be spreading (Ryan and Denton 1973). Control of the casebearer by these parasites is slow because host populations are large and widely dispersed.

The fir engraver beetle is a serious pest of true firs. It kills pole-sized to mature trees, and outbreaks often are associated with drought conditions (Ferrell 1978). Because of the sporadic nature of outbreaks and the prevalence of healthy engraver broods in living trees, direct control measures are impractical. As in the case of most beetles, the best insurance against outbreaks is to keep the trees in a vigorous, healthy condition by the proper control of stocking level and taking measures to assure stand sanitation.

The pine engraver beetle can be a serious pest of ponderosa and lodgepole pine, although outbreaks seldom last more than 1 year (Sartwell et al. 1971). Slash larger than 2 inches in diameter is generally the preferred host material for the beetle. When populations become too large for the available slash, the beetle attacks healthy living trees. Trees from 2 to 8 inches in diameter are most frequently killed, and top-killing of larger trees also occurs. The most practical way to prevent outbreaks of this beetle is by timely slash disposal and thinning of overstocked stands.

Diseases

Coniferous forests of eastern Oregon and Washington are subject to a multitude of diseases, both biotic and abiotic in nature (Hepting 1971). The most serious diseases of mixed conifer forests are trunk and root rots and dwarf mistletoes. Trunk and root rots are widespread throughout old-growth mixed conifer forests, especially in the true firs where nearly 40 percent of the volume is unmerchantable because of rot (Aho 1977). In addition to loss of volume, these rots increase the susceptibility of trees to windthrow and breakage. Aho (1971, 1977) has studied the fungi causing decay in grand fir and Engelmann spruce in the Blue Mountains and the relationship of decay to various external defect indicators, such as basal scars. Four fungi were responsible for a high proportion of infections and volume losses in grand fir. They were the Indian paint fungus, yellow pitted rot, mottled rot, and annosus root rot. By far the most damaging of these was the Indian paint fungus which alone, or associated with other fungi, accounted for 78 percent of the decay volume. Branches are apparently the major infection court for this fungus. Etheridge and Craig (1976) give a good review of the mode of infection of this fungus. The yellow pitted rot and mottled rot entered trees mainly through injuries and annosus root rot through the roots. A pathological rotation age of 125 years is suggested for grand fir.[5]

A large number of fungi were found to cause infections in spruce (Aho 1971). The three most damaging were red ring rot, red root and butt rot, and bleeding conk fungus. Aho (1966) has prepared guidelines for estimating the amount of defect in grand fir, Engelmann spruce, Douglas-fir, and western larch based on indicators such as tree age, basal injuries, and number of conks.

The laminated root rot and the shoestring root rot are also serious diseases in mixed conifer forests. The fungi which cause these diseases attack most coniferous species, but tree species vary in degree of susceptibility. Grand fir, Douglas-fir, and mountain hemlock are most susceptible to the laminated root rot (Filip and Schmitt 1979). Pines appear to suffer the most damage from the shoestring root rot. These two diseases are widespread throughout western coniferous forests, but control is expensive and should be considered only where the diseases are causing economic losses. Recommendations for control of laminated root rot are given by Hadfield and Johnson (1977) and for the shoestring root rot by Shaw and Roth (1978) and Roth and Rolph (1978). Avoiding the establishment of plantations on sites likely to have a high disease hazard, or removing the disease sources by thinning trees, uprooting stumps, and dislodging root remnants appear to be the most effective means of control.

---

[5] A pathological rotation is the age at which unacceptable losses from decay occur.

Decay should be reduced in the future as overmature, old-growth mixed conifer stands are replaced by vigorous, free-growing natural or planted young stands. Evidence to support this conclusion comes from a recent study where very little decay was found in large true firs that have been free-growing most of their lives.'

The importance of the Indian paint fungus and other fungi in suppressed advance true fir reproduction is not fully understood at this time. Aho and Hutchins (1977) feel that a potential decay problem exists in this reproduction because of the potential reactivation of dormant infections by injuries.

Dwarf mistletoes are found on nearly every species in mixed conifer forests. Most dwarf mistletoe species are host specific; that is, they occur on only one tree species. Some may be found on three or four different species in a genus, but only rarely do they cross infect from one conifer genus to another. The biology of dwarf mistletoes has been described by Hawksworth and Wiens (1972). Mistletoe infection reduces tree growth and seed production and lowers wood quality. Eventually, the tree will die if the entire crown becomes infected. Trees respond to infection by localized swelling of branches, but considerable swelling of the main stem occurs when the parasite infects the bole directly or grows into the trunk from an infected branch. These swellings may double the normal diameter of the bole and allow decay fungi to enter the tree through cracks in the bark caused by the swellings. Trees weakened by mistletoe are also more susceptible to attack by bark beetles.

Mistletoe infection occurs on all age and size classes of trees but is most damaging in young stands in their maximum growth period. Heavy infection of the understory by the overstory can result in a stand composed of deformed and stunted trees that never attain their growth potential and are unlikely to reach rotation age. Because of host specificity, however, there is less chance of the entire understory becoming infected in mixed stands than in pure stands.

Mistletoe control in mixed stands where only one tree species is infected can be accomplished by sanitation cuttings which favor the uninfected species. In stands where several species are heavily infected, clearcutting and establishing a new stand is the best way to eliminate the parasite. It may be possible to deal with light to moderate infections in the understory through release of these trees by overstory removal and thinning. Barrett and Roth[7] have shown that because of the greater height growth after release, ponderosa pine saplings are able to outgrow the mistletoe infection with diameter growth rates equal to those of uninfected trees.

'Data on file at Silviculture Laboratory, Pacific Northwest Forest and Range Experiment Station, Bend, Oregon.

[7] Barrett, James W., and Lewis F. Roth. Response of dwarf mistletoe infected pine saplings after thinning. [In preparation.]

Besides rots and dwarf mistletoe, a number of rusts cause significant damage to mixed conifer species. The most damaging is white pine blister rust. This disease is caused by a heteroecious rust fungi that requires an alternate host ***(Ribes)*** to complete its life cycle. It attacks nearly all soft pines but has been most destructive to eastern and western white pine; many stands have been severely damaged and some completely destroyed. Limited numbers of rust resistant western white pine seedlings are now available for reforestation as a result of genetic research conducted by the USDA Forest Service, Pacific Northwest Region's tree improvement center at Dorena, Oregon.

Bega (1978) has compiled an excellent manual for the identification of diseases of Pacific Coast conifers. It describes both biotic and abiotic diseases, and although written primarily for the Pacific Coast region, it should also be useful in the interior West. Another useful publication for identification of diseases and insects of coniferous forests has been prepared by Partridge et al. (1978).

Rodents and Birds

Rodents can cause significant mortality and damge in mixed conifer forests. Although damage can occur in areas of natural regeneration and seeded areas because of seed and seedling consumption, the most serious damage takes place in young plantations. Pocket gophers and porcupines cause most of the damage in plantations. Only minor damage is caused by other small mammals such as hares, rabbits, deer mice, and voles (Crouch 1969). In general, animal damage is more common on clearcuts than on partial cuts.

Pocket gophers can severely damage or completely destroy entire plantations, but, in general, less damage occurs in mixed conifer communities than in ponderosa and lodgepole pine communities (Volland 1974). Most of the damage is done in the winter or spring under the snowpack. Gophers commonly sever seedling roots and girdle or clip the stem. They can also burrow under the seedling and pull it partly or entirely into the ground (Barnes 1973). A variety of direct and indirect measures have been tried or proposed to control gophers. Direct measures include trapping, poisoning, flooding, fumigating, using repellents, and exclosing or caging (Crouch and Frank 1979). Indirect measures include habitat modification, such as eliminating the food supply with the use of herbicides (Crouch 1979).

Porcupines most often attack pole-size trees, but girdling of seedlings and saplings also occurs. Some trees are killed, and others suffer top damage resulting in stem deformation and **loss** of height growth. Porcupines have been controlled by hunting and trapping and placing strychnine-treated salt blocks in trees, high enough to prevent use by livestock and big game.

Birds do not cause significant damage in mixed conifer forests. They eat tree seed but not enough to affect natural regeneration. Birds have a more positive than negative effect, since they often help to prevent epidemics of harmful insects (Beebe 1974, Bruns 1960).

Livestock and Big Game

Damage to trees by livestock and big game is of greatest concern in young plantations. Heavy browsing of all species can occur in areas where sheep are numerous. Cattle cause seedling mortality and damage both by browsing and trampling. Most browsing of tree seedlings occurs in areas where forage is not adequate during the period of shoot growth or where cattle' concentrate. Generally, browsing damage by cattle is not serious on well managed ranges. Edgerton (1971) found that browsing damage on ponderosa pine seedlings in a mixed conifer clearcut in northeastern Oregon was light when the grazing season was properly timed. An abundance of preferred herbaceous forage was available when cattle began to graze in the spring, and the animals were removed by midsummer before forage was depleted or had become unpalatable. Trampling damage increases as livestock numbers increase and is most severe in areas where cattle concentrate near water or salt blocks.

Damage to seedlings by deer and elk is generally more common than livestock damage. In a survey of animal damage in Oregon and Washington National Forests, deer were found to be causing most problems because they browse during both dormant and growing seasons (Crouch 1969). Elk also cause considerable damage in some areas by both browsing and trampling. The amount of deer and elk damage to regeneration depends upon such factors as animal populations, availability of preferred forage species, and type of seasonal range. Damage is generally most severe to ponderosa pine on lower elevation winter ranges where animals are concentrated. It is sometimes difficult to identify the animal causing the damage. A guide to identifying wildlife by the type of injury caused has been prepared by Lawrence et al. (1961).

A number of methods are available for reducing damage caused by livestock and big game. Regulated hunting in reforestation areas can reduce deer and elk to reasonable numbers (Crouch 1976), but the cooperation and approval of State Wildlife Departments is needed for such hunts. Two chemical repellents provide some protection for seedlings from browsing by deer and elk: TMTD (tetramethylthiuram disulfide) and BGR (big game repellent). The active ingredient in BGR is putrified liquid egg, and it appears to be more effective than TMTD. It only gives about 2 months of protection, however, and cannot be stored for long periods (Rochelle et al. 1974). Entire plantations can be protected from deer, elk, and cattle by fences, but the cost is very high and can usually be justified only for high value plantations such as seed orchards. Plastic tubes or wire cages may also be used to protect individual seedlings (Larson et al. 1979). Deer and elk damage to regeneration can also be reduced by increasing the size of clearcuts. Units less than 40 acres are used more heavily by deer and elk than are larger units (Thomas et al. 1979b). Finally, seedling damage can be reduced by leaving enough slash on the area to act as a physical obstruction to large animals. This has the drawback, however, of providing cover for small mammals and increases the fire hazard.

Preventing or reducing animal damage by silvicultural treatments that do not create a favorable habitat for problem animals should be considered in plant communities where problems exist. For example, partial cutting rather than clearcutting can reduce the production of forbs and grasses. Direct control may still be needed but should be easier where habitat is less than ideal and animal populations are reduced. Control of animal damage can be difficult and expensive, especially if a number of different animals are present. A careful evaluation of which animals are causing problems is necessary before suitable methods to prevent or control damage are chosen. In many cases, the best results will be obtained by a combination of habitat modification and direct control.

Fire

Wildfire.—Fire is one of the primary natural forces in forested ecosystems and has had a major impact on vegetation patterns of mixed conifer forests. The role of wildfire in western forest ecosystems has been described by Daubenmire and Daubenmire 1968; Cooper 1961; Weaver 1961, 1974; Wellner 1970; Wagener 1961; Habeck and Mutch 1973; Heinselman 1978.

Before human activities had a significant impact on fire frequency, wildfires occurred in western mixed conifer forests at intervals ranging from 5 to 300 years. In lower elevation ponderosa pine and Douglas-fir communities, light to moderate surface fires occured at intervals of about 6 to 15 years. These light, frequent fires prevented excessive fuel accumulation, prevented true firs from invading, and thinned dense clumps of pine, thus avoiding stands stagnating from overstocking. This type of fire resulted in open, parklike stands which were typical of lower elevation communities. In contrast, the fire pattern in higher elevation communities was one of severe surface or crown fires at infrequent intervals of 100 to 300 years. These resulted in large, even-aged stands of seral species such as larch, lodgepole pine, and western white pine. These large, conflagration-type wildfires not only destroyed the standing timber but also caused soil erosion, stream sedimentation, lower water quality, and non-wettable soil. During one wildfire in the Oregon Cascades, a water repellent layer 1-9 inches thick, that formed in pumice soil on a severely burned site, persisted for 5 years (Dyrness 1976).

Fire suppression practiced during the past 60 years has had the most effect on fuels and vegetation in the lower elevation communities which had been subject to light, frequent fires.

Prescribed Fire.—Properly used, prescribed fire can be a useful silvicultural tool for managing interior mixed conifer forests. It is probably most useful in lower elevation pine and Douglas-fir communities to reestablish the natural cycle of light, frequent surface fires. The negative effects of some 60 years of fire exclusion in these communities are now readily apparent. Residues previously consumed have accumulated in large amounts, and dense, stagnated stands of advance reproduction have become established in the understory, adding to the fuel supply. In addition, ponderosa pine is gradually being replaced by the more shade-tolerant true firs in communities where pine is a seral species. The importance of restoring fire to mixed conifer communities and its potential for stand management has been recognized by Beaufait et al. 1975; Kilgore 1971, 1972; Kilgore and Briggs 1972; LeBarron 1957; Martin 1976; Norum 1977; and others.

Although the benefits of prescribed fire are now well recognized, reintroducing fire into ecosystems where it has been excluded for many years is difficult because of the large amount of fuel that has accumulated. Skillful application of prescribed burning techniques is required. Martin and Dell (1978) have developed guidelines for using prescribed burning in eastern Oregon and Washington to accomplish various management objectives. Common objectives are (1) reduce fire hazard, (2) prepare sites for natural regeneration or planting, (3) eliminate dense understories of shrubs and shade-tolerant tree species, (4) control diseases and insects, and *(5)* improve habitat for wildlife and livestock. In many cases, more than one objective can be attained by a single prescribed burn.

The use of prescribed fire as a silvicultural tool in the western United States is still relatively new. To develop better prescriptions, more information is needed about the response of various plant communities to fires of varying intensities, fuel consumptions, and burning conditions.

Wind and Snow

Windfall and windbreak along the boundaries of clearcuts and in partial cuttings can be a serious problem in mixed conifer stands of unmanaged old-growth. Trees in dense stands have not developed the windfirmness needed to resist wind stresses that result when the stand is opened up. Shallow-rooted species or a shallow rooting zone, such as bedrock near the surface of the soil, further compound this problem. And as noted, the presence of heart and root rots predisposes trees to wind damage. The chance of wind damage increases with greater amounts of mountain hemlock in the stand. In a survey of shelterwood units on the east-side of the Oregon Cascade Range, Seidel (1979c) found that an average of 2.4 trees per acre were blown down in a mountain hemlocklgrouse huckleberry community compared with 0.5 tree per acre in a mixed coniferlsnow brush-chinkapin type.

Alexander (1964) studied wind damage in Colorado and summarized his work in guidelines for locating cutting boundaries and for identifying topographic situations where blowdown is very high, above average, or below average. Although his work is specific for spruce-fir forests in the Rocky Mountains, it probably is applicable to many high elevation mixed conifer stands in eastern Oregon and Washington.

Alexander lists topographic situations associated with three wind damage categories:

Very high—

1. Ridgetops.
2. Saddles in ridges.
3. Moderate to steep middle south- and west-facing slopes not protected to the windward.
4. All upper south- and west-facing slopes.

Above average—

1. Valley bottoms parallel to the direction of prevailing winds.
2. Gentle middle south and west slopes not protected to the windward.
3. Moderate to steep middle, and all upper north- and east-facing slopes.
4. Moderate to steep middle south- and west-facing slopes protected by considerably higher ground not far to windward.

Below average—

1. Valley bottoms, except where parallel to the direction of prevailing winds, and flat areas.
2. All lower, and gentle middle north- and east-facing slopes.
3. All lower, and gentle middle south- and west-facing slopes that are protected from the wind by considerably higher ground not far to windward.

Recommendations for locating cutting boundaries, as summarized from Alexander (1964) by Jones (1974), are:

1. Protect the vulnerable downwind boundary from wind.
2. Do not locate boundaries where uncut stands will be exposed to winds funneling through exposed saddles to the south or west.
3. When the main drainage is a narrowing valley with steep sides, avoid locating boundaries on ridgetops or near saddles, especially ridgetops or secondary drainages downwind from and at right angles to the main drainage. Such ridgetops should either be cut or left uncut for at least 200 feet down on both sides.
4. So far as other considerations permit, lay out each unit so the maximum length of cutting boundary is parallel to the contours.
5. Irregular boundaries without sharp indentations, projections, or square corners will reduce blowdown.
6. Do not locate boundaries on poorly drained or shallow soils.
7. Locate boundaries where stand conditions favor windfirmness: (a) stands of sound trees, (b) immature stands, and (c) poorly stocked stands.

The importance of leaving sound dominant and codominant trees along clearcut boundaries and in shelterwood units was pointed out by Gordon (1973a). He suggests the following types of trees be cut:

1. Intermediate or suppressed crown classes.
2. Heavy leaners.
3. Trees with decay, as indicated by conks, and those with heavy dwarf mistletoe infestations.
4. Trees with large fire scars.
5. "Twinned trees"; that is, those with a fork near ground level resulting in two trees from the same root system.

Snow movement on steep slopes can cause stem deformities and breakage of seedlings and saplings (Leaphart et al. 1972). It often causes damage to lower elevation species, such as ponderosa pine, that are planted at higher elevations where they are not normally found (Seidel 1979b).

SOME SILVICAL CHARACTERISTICS

Seed Supply

An adequate supply of sound seed is one of the essential requirements for natural regeneration; the other two are a receptive seed bed and favorable environmental conditions. Western larch, mountain hemlock, and lodgepole pine are the three most prolific seed producers in mixed conifer forests, producing some seed almost every year. Lodgepole pine cones are mostly nonserotinous in the Oregon Cascades and the Blue Mountains (USDA Forest Service 1965). In the Cascade Range of Oregon and Washington, medium to heavy cone crops generally occur at 3- to 4-year intervals (Franklin 1968, Franklin et al. 1974). Because of the variety of species in mixed conifer forests, there is a greater chance of some seed being produced every year than in stands of only a single species.

Dispersion of coniferous seed is chiefly by wind, although rodents carry away some seed and bury it. Western larch and mountain hemlock both have light seeds (average 137,000 and 114,000 seeds per pound, respectively) which are carried long distances by the wind. In Montana, enough larch seed reached the center of a square 60-acre clearcut to establish a well-stocked stand on favorable seed beds (Schmidt et al. 1976), and in the Oregon Cascades, 1 - 2 pounds of mountain hemlock seed per acre were found at the middle of a 31-acre clearcut (Franklin and Smith 1974a). Seed disperal from clearcut edges typically follows a negative exponential curve with large amounts falling within 60 - 130 feet of the boundary and a pronounced decrease in seed density at greater distances from the timber edge (fig. 3).

Dispersal of large quantities of sound seed over long distances does not guarantee natural regeneration if environmental conditions are too severe or seed beds unsuitable. Examples are the seed dispersion patterns of western larch and mountain hemlock discussed previously. Large amounts of seed of both species were dispersed over clearcuts. Because larch is a seral species well adapted to invade disturbed areas, seedling establishment was successful. On the other hand, mountain hemlock regeneration was not because it generally requires some residual overstory for successful regeneration.

Germination and Seedling Survival

The rate of germination of viable seed of coniferous species varies considerably. Laboratory tests indicate that ponderosa pine and lodgepole pine seeds generally have the highest germination rate, ranging from 60 to 70 percent, whereas the true firs have the poorest rate, less than 50 percent (USDA Forest Service 1974).

Viable seeds normally germinate following snowmelt in June, but white fir seed has germinated as early as February in northern California on patches of bare ground (Gordon 1970). **Also,** seeds of white fir, red fir, and subalpine fir will germinate on, in, and beneath the snowpack (Gordon 1970, Franklin and Krueger 1968). Many potential seedlings die when the snow melts because the radicle dries out before it can penetrate the soil. Consequently, the weather conditions in the fall can have a significant effect on seedling establishment the following spring. Seeds that fall before a permanent snowpack develops have a much better chance of producing established seedlings than those that fall on the snowpack.

The first growing season atter germination is the most critical period for young seedlings; most of the mortality occurs during this time, although losses may be considerable during the first 5 years. The ability of seedlings to survive depends upon their tolerance of the stresses imposed by five primary variables: light, temperature, moisture, chemical factors, and physical factors. These primary variables are affected, in turn, by the many secondary variables, such as seed bed condition, understory vegetation, aspect, and slope.

Mineral soil is the most favorable seed bed for all coniferous species because it is a more stable source of moisture and is cooler than litter and duff layers (Seidel and Cooley 1974). Larch and lodgepole pine require exposed mineral soil for successful establishment. True firs also become established better on mineral soil, but they also survive in light litter and duff layers up to about $^{1}/2$-inch thick (Seidel 1979a).

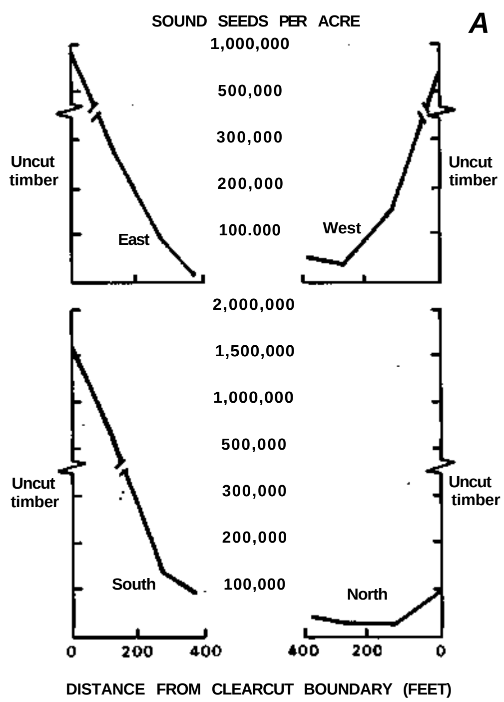
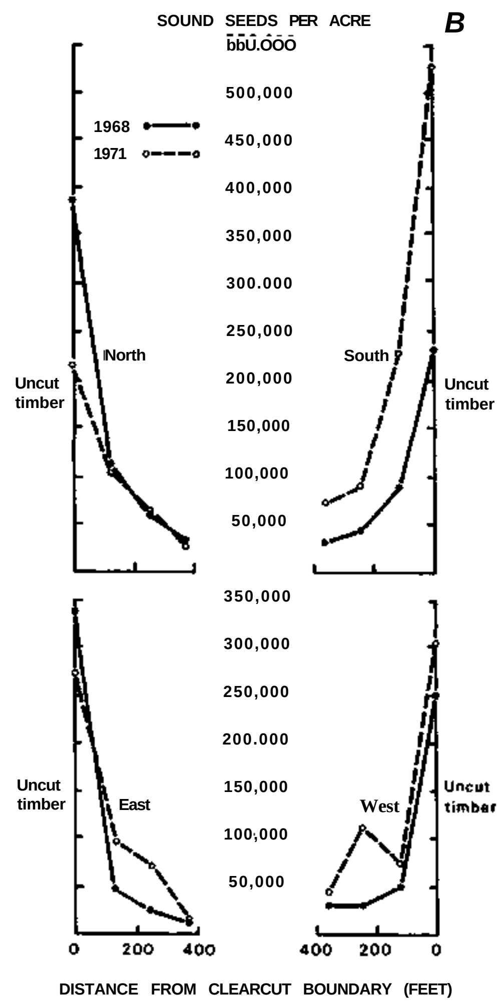


Figure 3.—Seedfall into clearcuts as related to distance from stand edge: *A,* mountain hemlock, 1968 cone crop; (Reproduced from Franklin and Smith 1974a, fig. 2); 8, white and Shasta red fir, 1968 and 1971 cone crops; (Reproduced from Franklin and Smith 1974b, fig. 2.)



On the east slopes of the Oregon Cascades, inadequate soil moisture is not generally a problem—providing competition from understory vegetation is not severe. In several studies of true fir regeneration in central Oregon, Seidel and Cooley (1974) found that soil moisture was always well above the “wilting point,” and seedling moisture stress (xylem pressure potential) was never less than – 15 bars throughout the summer. Fowells and Stark (1965) also reported that even during a 4-month drought, soil moisture was nearly always available to seedlings in the mixed conifer type of northern California. Seedlings avoid drought by rapid root growth so that root tips always stay ahead of the drying front in the soil. Root growth of true fir during the first growing season in central Oregon exceeds 6 inches and in northern California ranges from 6 to 12 inches (Gordon 1970).

Extremes in temperature cause considerable seedling mortality. Temperatures as high as 163°F can be reached at the soil surface (Seidel and Cooley 1974). Higher temperatures are reached on organic seed beds than on mineral soil. Injury to seedlings by direct freezing is most likely to occur in spring when they are still succulent, whereas damage from frost heaving occurs in fall when daytime temperatures are warm, temperatures at night are freezing, and soils are saturated with moisture. It is not extremes of temperature alone that result in seedling mortality but also the length of time seedlings are exposed to them. A series of “isosurvival curves” for grand fir seedlings were constructed for a central Oregon seed source (Seidel 1974a). The curves indicate the combinations of time-freezing temperature that result in equal survival. Extremes in temperature can be mitigated by partial shade from an overstory andlor by light amounts of slash which reduces radiation cooling and decreases solar insolation.

Seedling survival is reduced in severely burned areas because of decreased water infiltration into the soil and higher temperatures of the charcoal surface. In a study of regeneration in mixed conifer clearcuts in eastern Oregon, Seidel (1979b) found the pile-and-burn treatment was a strong negative factor in seedling establishment, in contrast to broadcast burning which had a small positive effect. Vogl and Ryder (1969) also attributed poor regeneration in a Montana study to conditions created by severe fire. Although seedling establishment may be reduced where piles of slash have been burned, the impact of this treatment on regeneration is small because slash piles generally occupy only a small part of the total reforestation area.

The amount of understory vegetation, especially grasses and sedges, has a strong influence on the success of natural regeneration. On eastern Oregon clearcuts and in the Cascade Range and the Blue Mountains, the presence of grasses and sedges was negatively correlated with seedling establishment (Seidel 1979b). After an area has been disturbed by logging and site preparation, the amount of tree regeneration depends to a large extent on how fast understory vegetation reinvades. Seed beds in shelterwood units in mixed coniferlsnowbrush-chinkapin and mountain hemlocklgrouse huckleberry communities of the eastern Oregon Cascades have remained receptive to seed for at least 5 years after a seed cut (Seidel 1979c).

To summarize, it appears that seed germination and seedling survival is enhanced by a mineral soil seed bed that has not been severely burned, by the absence of competing understory vegetation, and, for the more tolerant species, by light shade cast by slash or overstory. More detailed information on silvics of mixed conifer species can be found in "Silvics of forest trees of the United States" (USDA Forest Service 1965). Comparative autecological information for Northwestern tree species is given by Minore (1979).

SILVICULTURE AND MANAGEMENT

Silviculture is an attempt to manage forests by influencing ecological processes to attain specified objectives. Given sufficient time, nature will replace most forests in temperate climates following disturbances such as logging or fire, but the result may not be satisfactory to humans in terms of species composition or stand structure. Therefore, the basic justification for silvicultural manipulation of forests is an economic one—to speed up the regeneration process by planting or direct seeding, for example, or to shorten the rotation by controlling stocking level.

The primary objective of silvicultural prescriptions is timber management, and that will receive the major emphasis in the following discussions. Other multiple-use resources of the forest, such as water yields, wildlife, forage, and recreation, are also affected by silvicultural treatments. In many cases, one or more of these resources are compatible with timber goals such as the increase in water and forage yields associated with stocking level control.

Regeneration Systems

Because of the large number of species and stand conditions in mixed conifer forests of eastern Oregon and Washington, both even-aged and uneven-aged silvicultural systems can be used for their management. The complex nature of old-growth stands can result in considerable variation from acre to acre and may require a compromise between what is desirable and what is possible. On the other hand, the range of silvicultural systems available to the land manager enables him or her to better integrate silvicultural prescriptions with other resources.

Franklin and DeBell (1973) surveyed the effects of cutting methods on regeneration and concluded:

> Few situations require either extreme in treatment— uneven-age management using a selection system or even-aged management using large clearcuttings. On the other hand, either of these extremes could be applied much more widely to regenerate forests successfully if a type or species conversion is acceptable, as in the selection system, or a dependable technique for artificial regeneration is available, as in extensive clearcutting. On the majority of productive forest sites, factors other than ecological limitations of the species appear to be primary in the choice between uneven- and even-age management and among the several silvicultural systems that can be used to create even-age stands. These include: economic considerations, including efficiency in logging, growth rates, and costs and returns on investments; social considerations, such as the esthetics of cutover areas and effect on other resource values— soil, water quality, and wildlife habitat; physical considerations such as the terrain with its limitations on suitable logging methods; and other biological considerations such as presence or absence of damaging agents— dwarf mistletoe, large deer population, and some insects or fungi.

Even-Aged Management.—In mixed conifer stands where timber production is an important objective, the use of silvicultural systems which result in even-aged stands is recommended (Seidel 1973). Even-aged management is desirable to convert overmature, old-growth stands to vigorous, fast-growing, second-growth stands and to secure regeneration of the shade intolerant species. It also has an economic advantage as markets for smaller material increase and the removal of large volumes reduces logging costs by spreading fixed costs over a greater volume removed.

Clearcutting method.—The term "clearcutting" in the discussion that follows is used in the literal sense of the word; that is, removing essentially all trees from an area, followed by establishment of a new stand by either natural or artificial regeneration. Cuttings where all the overstory is removed leaving varying amounts of advance reproduction are the final cuts in the shelterwood system. Discussion of that system begins on p. 30.

Clearcutting has several advantages as a harvesting method in old-growth mixed conifer stands. It is the best way of quickly removing all trees in areas where heavy infestations of dwarf mistletoe exist in both overstory and understory or where heart rots are prevalent in the overstory. Since lateral movement of mistletoe is very slow (about one-half foot per year) from infected trees at the clearcut edge, the new stand will remain uninfected for long periods. Clearcutting allows regeneration to develop without suppression or possible damage from a residual overstory and eliminates the risk of blowdown in areas where probability of wind damage is high. It is well-suited for regeneration of seral species such as larch and lodgepole pine.

On the other hand, there are also disadvantages. Removing all trees on steep slopes can result in mass soil movement because reduced transpiration drain increases soil water content. Understory vegetation also develops rapidly on many clearcuts, requiring measures to reduce competition to tree regeneration. And animal damage to reproduction is often greater on clearcuts than in partial cuts.

Esthetic considerations are increasingly important in planning clearcuts as recreational use of forests rises. Clearcuts should be blended into the landscape by modifying boundaries and adjusting sizes to follow natural topographic and vegetative features.

A. Natural regeneration

Mixed conifer clearcuts can be adequately regenerated with natural reproduction if sufficient seed falls on receptive seed beds and microclimatic conditions are favorable for germination and survival. Clearcuts must be designed so seed can reach all parts. In a survey of clearcuts in the Oregon Cascades and Blue Mountains, Seidel (1979b) found that stocking was not affected within about 530 feet from the clearcut edge. In white fir-red fir stands in northern California, natural regeneration was better on 130- to 200-foot-wide clearcut strips than on those 333 feet wide (Gordon 1970). And in the intermountain region, seeding was effective from 265 to 660 feet from clearcut edges, depending upon the aspect (Roe et al. 1970). As might be expected, natural regeneration is better on strip and patch clearcuts than on larger, "staggered-setting" clearcuts of 40 acres or more (Franklin 1963). The probability of obtaining adequate natural regeneration in clearcuts is greatest on north and east aspects, and, because of the prevailing southwesterly winds, strips oriented in a NW-SE direction provide the best seed distribution and least chance of wind damage.

Although natural regeneration can effectively reforest mixed conifer clearcuts, there is no assurance it will occur quickly. If the seed bed is occupied by grasses and shrubs before a heavy seed year, the chance of tree seedlings becoming established is small. Grass competes heavily with tree seedlings for soil moisture. In the Oregon Cascade and Blue Mountain clearcuts, grass was negatively correlated with seedling establishment (Seidel 1979b). Shade-tolerant seedlings did become established under snowbrush and manzanita, but growth was slow. Therefore, because of the chance of losing the seed bed to grass andlor shrubs within a few years after clearcutting, natural regeneration seems best suited as a supplemental rather than primary method of reforesting mixed conifer clearcuts. Natural regeneration has the best chance of success on north and east aspects, at distances up to about 333 feet from a seed source, and where the stand at the clearcut edge contains larch andlor lodgepole pine seed trees.

B. Direct seeding

There have been no studies of direct seeding (broadcast or spot seeding) in mixed conifer forests of eastern Oregon and Washington. In general, however, direct seeding trials in the West have not been successful because of problems with seed predators, poor seed beds, or unfavorable environments. In a test in the western Cascades, stocking of seed spots was not satisfactory without protection by wire screens, even when repellent-treated seed was used on areas baited to control rodents (Franklin and Hoffman 1968). Of the mixed conifer species, western larch is one of the best adapted to direct seeding because its small seeds are not as subject to rodent depredation as are larger seeds (Shearer and Halvorson 1967). Because of these limitations, direct seeding is not recommended as a primary means of artificial regeneration but seems best suited for use (1) when suitable planting stock is not available to reforest large areas (e.g., after a large wildfire), (2) on rocky sites where planting is difficult, or (3) on sites where access is limited during the planting season. Even these uses of direct seeding are decreasing, however, because container-grown seedlings are used to supply planting stock for emergencies and to lengthen the planting season on high elevation sites.

C. Planting

All mixed conifer clearcuts should be planted, except where local experience shows that natural regeneration is sufficiently reliable to reforest the area in an acceptable period. Planting should be done immediately after logging and slash disposal operations are completed to establish a vigorous, fast-growing stand of trees before competing vegetation occupies the site. Seedlings planted on clearcuts are not subject to suppression from a residual overstory or to damage and mortality when the overstory is removed, as are seedlings planted in shelterwood units. Planting also offers the opportunity to control spacing and species composition, and size of clearcuts is not limited as with natural regeneration.

Establishing plantations is a complex and expensive operation. It involves many steps. These include obtaining correct seed source; producing vigorous nursery stock; proper lifting, handling, and storage of stock; careful planting; and controlling animal damage. Plantation failure can result if any one of these steps is not done correctly. Details of all the steps necessary for successful plantation establishment have been prepared by Cleary et al. (1978) and by Ronco (1972). The rest of this section summarizes some important factors.

1. Site preparation. Site preparation is a means of temporarily eliminating competing vegetation, thereby giving planted or natural tree regeneraiton a more favorable environment for establishment and growth. Site preparation can be accomplished by mechanical or chemical methods, or by using fire. Often a combination of these methods is more effective than a single method. Stewart (1978) has prepared an excellent review of the uses and limitations of various site preparation methods in Oregon. He describes methods suitable for harvested areas or burns, for poorly stocked existing plantations, and for brushfields.

The choice of a site preparation method in a given area depends upon seven factors: (1) the nature of existing ground cover, (2) physical site factors, (3) site preparation requirements, (4) available personnel and equipment, (5) external constraints, (6) environmental impacts, and (7) cost.

Sites occupied by dense, well-established stands of shrubs require more complete site preparation than those with only herbaceous plants. Physical factors such as slope, aspect, soil type, erosion potential, and access will influence the choice of site preparation method.

Site preparation required will depend on the vegetation succession expected after disturbance, regeneration methods and species available, and the severity of the environment in relation to the tree species chosen (Pfister 1973). For example, prescribed burning in a Douglas-fir/pinegrass plant community in eastern Washington will result in profuse development of grasses. Therefore, scarification or herbicides is preferred to eliminate root systems of these graminoid species. As knowledge of successional trends in plant communities increases, the silviculturist can choose site preparation methods that minimize establishment of unwanted species.

Species and size of planting stock should be matched to site preparation method. For example, shade tolerant species or large seedlings may reduce the degree of site preparation needed (Newton 1973). Therefore, reforestation plans should specify combinations of species and size classes that require minimum site preparation and investment.

Regardless of method, site preparation is expensive. If clearcuts are reforested immediately after harvest and slash disposal operations are completed, site preparation may not be necessary and these costs can be avoided. Finally, the land manager should be aware that reinvasion of planted clearcuts by shrubs may require one or more chemical or mechanical treatments to release the trees.

2. Species selection. It is important to select species that are native to the plant community. Planting off-site species can result in excessive mortality and damage from snow or ice. For example, on east-side Cascade clearcuts, ponderosa pine was planted on lower elevation clearcuts and some high elevation, mountain hemlock clearcuts. As a result — even though all areas had been planted at the same spacing (8 by 8 feet) — survival was decreased significantly at the higher elevations (fig. 4) (Seidel 1979b). In addition to greater mortality associated with higher elevation, there was a noticeable increase in the amount of snow damage (stem deformation and breakage) to the pine.

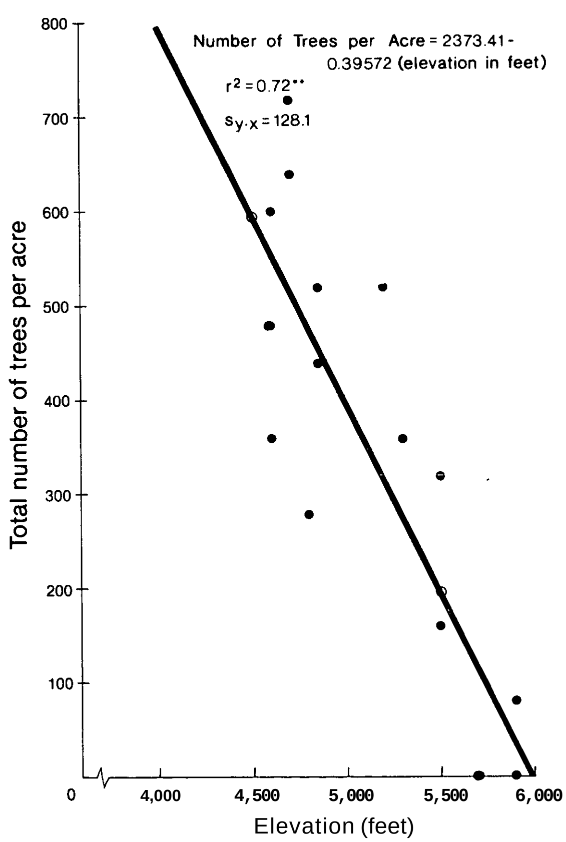


Figure 4.—On clearcuts in the eastern Cascade Range, the number of planted ponderosa pine decreased as elevation increased. (Adapted from Seidel 1979b.)

Ponderosa pine and Douglas-fir are good choices in clearcuts below about 5,300 feet. Douglas-fir should be considered for north and east slopes whereas ponderosa pine should be favored on warmer south and west aspects. In most of the clearcuts in the mixed conifer/snowbrush-chinkapin community in the Cascades, planted ponderosa pine becomes dominant because of its rapid growth (Seidel 1979b). In higher elevation clearcuts, lodgepole pine survives and grows well in mountain hemlock communities; in the Blue Mountains, lodgepole pine, larch, and Engelmann spruce are desirable species. Rust-resistant white pine is also suitable for mountain hemlock communities. The more shade tolerant spruce should be planted on north and east slopes. True firs (grand and Shasta red fir) have been planted on some mixed conifer clearcuts, but, in general, survival has not been as good as for the more seral species. Planting a number of species in mixed conifer clearcuts is recommended. This enables the silviculturist to match the species to site conditions it can best tolerate. In addition, establishing more than one species reduces the chance of losing the entire plantation to insects or diseases.

3. Planting stock. Both bare-root and container-grown planting stock are available. Each type has advantages and disadvantages. Some advantages of container-grown stock are: (1) faster production and more flexible growing schedules, (2) higher quality of some species, such as hemlock and true firs, (3) transplant shock is reduced because root systems are disturbed less, (4) extension of planting seasons, (5) easier planting in rocky soil, and (6) more adapatable to mechanization in nursery and field. Some disadvantages are: (1) higher production and transportation costs, (2) potting mix is subject to rapid moisture and nutrient losses, (3) smaller seedlings are more likely to be buried, overtopped by competing vegetation, or damaged by animals, and (4) greater potential for root binding or spiraling resulting in poor anchoring in the soil. In general, initial field performance of container-grown seedlings in the Pacific Northwest has been poorer than that of bare-root stock (Gutzwiler and Winjum 1974). Performance is quite variable, however, depending on species, site, and size of seedlings. Initial survival of ponderosa and lodgepole pine container-grown seedlings was lower than bare-root stock because of heavier animal damage on the smaller, less woody container-grown seedlings. It appears that the primary reliance should be on bare-root seedlings, with container-grown stock being used for special situations such as on rocky sites, or when true firs and hemlock are planted. In situations where field performance is about equal, the choice of stock will probably depend on relative costs, availability at specific times, speed and ease of planting, and type of planting equipment available.

Only healthy, vigorous planting stock should be used. Larger seedlings have an advantage on severe sites where vegetative competition, soil movement, frost heaving, or animal damage are problems. Size of seedlings will depend to a large extent on the inherent growth patterns of the species, but bare-root seedlings should have tops at least 4-5 inches long. Roots should not be shorter than 5-6 inches and should be compact, fibrous, and have several well developed lateral roots. The proper balance between shoot and root systems (shoot-root ratio) is more important than size of either shoots or roots. Survival of Douglas-fir planted in the eastern Washington Cascades was greater as the shoot-root ratio decreased (Lopushinsky and Beebe 1976). Shoot-root ratios in the 2.0 to 3.0 range (by weight) are considered acceptable, with ratios closer to 2.0 being the most desirable.

Selecting suitable planting stock on the basis of seedling age (1-0, 2-0, 1-1, 2-1) is not recommended because this system is too variable to accurately describe seedling characteristics. Seedling size depends upon environmental conditions and nursery practices, and therefore age alone cannot describe size of tops, roots, or the shoot-root ratio.

4. Storage. Seedlings should be lifted when dormant and stored so that seedling temperature is about 35°F. Storage up to 3 months is possible at this temperature. During shipment to the field, seedlings must be maintained at temperatures under 39°F with either refrigerated units or ice. Seedling storage in the field is more difficult because limited facilities make it hard to control temperature. Well insulated sheds cooled by ice or snow are suitable, and at high elevation sites, a pit or culvert snow cache will provide good storage (Dahlgreen et al. 1974). Field storage generally should not exceed 7 days.

5. Planting seasons. Spring planting immediately after snowmelt generally results in better survival than fall planting because soil moisture is at a maximum and new root growth quickly supplies water lost by transpiration. A study in northern Idaho showed that 1st-year survival of spring-planted Douglas-fir, Engelmann spruce, grand fir, and western larch seedlings was generally better than survival of fall plantings (Sinclair and Boyd 1973).

Fall planting may be necessary on high elevation sites, however, because the time between snowmelt in spring and the onset of very hot, dry weather may not be sufficient to complete the job. Fall planting is most likely to succeed if the ground is quickly covered by snow, since this protects seedlings from frost heaving and desiccating winds.

Planting should be temporarily suspended when high temperatures or wind velocities cause excessive water loss from seedlings. As a general rule, air temperature should be between 32° and 64°F and wind speed should be less than 20 miles per hour for planting seedlings without undue risk (Cleary 1971).

6. Spacing. The spacing interval selected for plantations depends upon a number of factors; the expected survival rate, future thinnings, and product objectives are the most important. Narrow spacings are indicated if low survival rates are anticipated, thinning is planned, and a market for small material is available or expected. On the other hand, wide spacings are suggested if anticipated survival is high, no thinnings are planned, and only a sawlog market exists. The species planted can also influence spacing. Wider spacing is indicated for faster-growing species. A reasonable range of spacings for mixed conifer stands ranges from 8 by 8 feet, 680 trees per acre, to 12 by 12 feet, 302 trees per acre. It is not necessary to maintain rigid spacing. Planting spots should take advantage of shade cast by stumps, logs, or slash where possible, especially when planting species such as the true firs or Engelmann spruce. Avoid planting in spots where skidding or slash disposal operations have buried organic matter in the soil and in areas with an extensive cover of sod-forming grasses.

7. Plantation protection. Planted seedlings must be protected from livestock, big game, and small mammals. Trampling by livestock can cause considerable damage, and fencing or adjustments in grazing allotments may be needed for several years. Control of pocket gophers and other small mammals should be undertaken when needed, following the guidelines given in the animal damage control handbook.*

Shelterwood method. —Use of the shelterwood method in mixed conifer forests of eastern Oregon and Washington has increased considerably during the past 15 years. There are advantages and disadvantages to using this regeneration method, as in all cutting methods, and these must be weighed in deciding what cutting method is suitable for a given area. The shelterwood method is well suited for moderating high and low temperatures or intense sunlight and thus enhances natural regeneration of more shade-tolerant species such as true fir (McDonald 1976a, 1976b). It slows the invasion of understory vegetation, leaving seed beds more receptive to tree seedling establishment, and it reduces competition. It reduces the chance of soil movement on steep slopes and decreases the probability of animal damage to regeneration. Perhaps the major reason why use of the shelterwood method has increased in high elevation mixed conifer forests is an esthetic one—harvested units look better.

The chief disadvantage of the shelterwood method in old-growth forests is the chance of losing the residual overstory by windthrow. This drawback will diminish as more second-growth stands are managed and trees become more windfirm. Other disadvantages are possible infection of the regeneration with dwarf mistletoe, and damage or loss to reproduction when the overstory is removed.

[8]USDA Forest Service Handbook 2609.22. Pacific Northwest Region, Portland, Oreg.

A. With advance reproduction

Many mixed conifer stands have a two-storied structure consisting of an overstory of larch or lodgepole pine and an understory of true fir. In this type of stand, the manager must decide if he or she wishes to manage the advance reproduction or destroy it and start over with natural regeneration. If the first alternative is selected, the reproduction method amounts essentially to the removal cuts of the shelterwood system.

To make this decision, it is necessary to evaluate the amount and condition of the advance reproduction. By today's standards, 400-500 well-distributed trees per acre appear to be sufficient after logging and slash disposal operations are completed.[9]

Based on the assumption that about one-half of the advance reproduction will be destroyed during the removal cuts, the understory should contain at least 800-1,000 trees per acre before logging. To be acceptable, advance reproduction must be of good form and have few injuries. Trees must be vigorous and have the potential for rapid growth when released (fig. 5). After

Figure 5.-- A vigorous, full-crowned grand fir sapling that grew rapidly after the overstory was removed. Ochoco National Forest, Oregon.

[9]USDA Forest Service Handbook 2409.26d, Silvicultural Examination and Prescription. Pacific Northwest Region, Portland, Oreg.

release, the growth response of suppressed advance reproduction is primarily a function of tree vigor—age is relatively unimportant. Suppressed seedlings and saplings will respond up to 80 years of age. In some cases growth response occurs immediately after release, and in others it is delayed for several years. In a study in the central Oregon Cascades, both diameter and height growth of suppressed 43-year-old grand fir and Shasta red fir advance reproduction increased two to three times above the pre-release rate after the lodgepole pine overstory was eliminated (Seidel 1977b). Most of these trees were fully crowned with more than 50 percent live crown. In northern Idaho, annual height growth of suppressed grand fir saplings following release by removing the overstory was two to three times greater than the growth rate before release, and increased growth began 2 years after release (Feryuson and Adams 1979). And in northern California, height growth of released suppressed white fir and red fir seedlings and saplings increased from about 0.1 foot per year to 0.6 foot per year; radial growth rate increased from 70-100 rings per inch to 7-12 rings (Gordon 1973b). In this study, diameter growth response occurred within 1-2 years after release, but increased height growth was not evident until the 5th year after release. These results suggest that a reasonable growth response cannot be expected unless the understory trees have a live crown covering at least 50 percent of the tree. Height growth after release is also related to height growth before release. In a study of suppressed grand fir in central Oregon, trees growing slowly before release usually grew slowly after release, and faster growing trees continued to grow at a faster rate (Seidel 1980a).

In addition to anticipated growth response of the advance reproduction after overstory removal, consideration should be given to the possibility that heart rots may cause future volume losses. The question of heart rotting fungi in true fir advance reproduction being reactivated by wounds has not been completely resolved. Recent work by Filip and Aho (1978) in the Fremont National Forest, Oregon, suggests, however, that under certain conditions a high risk exists that serious decay will develop in advance white fir regeneration. They concluded these conditions indicate high risk:

1. Overstory of white fir infected with Indian paint fungus.
2. Advance white fir regeneration that has been suppressed for over 50 years.
3. Advance white fir regeneration that has numerous wounds.
4. Advance white fire regeneration of low vigor because it is growing on a poor site.

If three or more of these conditions are present in a stand, the advance white fir regeneration has a high potential for developing serious decay. Advance reproduction of other species should be favored in such stands or the regeneration destroyed and new seedlings established.

When making decisions regarding advance true fir reproduction, it is important to consider both potential growth, as indicated by tree vigor, and the potential for decay. For example, on good sites the rapid growth of vigorous fir reproduction may compensate for loss by decay. If the decision is made to manage the advance reproduction, damage to the regeneration should be reduced as much as possible by careful logging practices (Gravelle 1977). If stocking permits, scarred trees should be removed in the first thinning.

If the advance reproduction consists chiefly of seedlings and saplings, the overstory may be removed in a single sale involving two- or three-stage logging. If the understory contains many pole-sized trees larger than 4 inches in diameter, consideration should be given to removing the overstory in several sales, provided windfall hazard is average. Removing about one-third of the overstory in each of three cuts at 5- to 10-year intervals should permit the pole-sized trees to develop windfirmness and prevent serious blowdown of the residual overstory.

After the final removal cut, areas should be evaluated for adequacy of stocking, and understocked holes about three-fourths of an acre or larger should be promptly planted with species native to the site. Landings to be retained for future silvicultural treatments or for wildlife openings should be seeded with forage species and others planted to trees.

When making overstory removal cuts, it is essential that the operator understand the need for saving the advance saplings and poles at each entry and make a conscientious effort to do so. This requires good communication between the sale administrator and the operator and close supervision by the administrator (see the discussion on logging considerations, page 39).

Another factor that should be considered when evaluating advance reproduction is a comparison of its height growth potential with that of seedlings planted in a clearcut. A potential height advantage for planted trees at some time in the future would be an indication that clearcutting and planting might be desirable, whereas greater height of the advance reproduction would suggest managing the existing regeneration.

To make such an evaluation, it is necessary to know the average height of planted seedlings and the advance reproduction and the average height growth rates of both. The manager can estimate from the following equation the annual growth rate required of planted seedlings to equal the height of the advance reproduction at the end of a given period. (Seidel 1980b):

$$A = \frac{B - E}{D} + C;$$

where

A = annual height growth of planted seedlings needed to equal height of advance reproduction at the end of a given period,
B = average height of advance reproduction after overstory removal,
C = average annual height growth of advance reproduction after release,
D = number of years in growth period, and
E = average height of planted seedlings.

B. Without advance reproduction

Use of the shelterwood method in old-growth mixed conifer stands where advance reproduction is lacking or where it is not of acceptable quality requires a residual overstory sufficient to provide seed and shelter over the entire area and a receptive seed bed. In addition, the risk of losing the overstory by windthrow must be considered.

In a survey of shelterwood units in the eastern Cascades, blowdown of the residual overstory was not severe—6 percent of the trees left after the seed cut were windthrown in a mixed conifer community, compared to a 16 percent loss in a mountain hemlock community (Seidel 1979c). Mountain hemlock is especially susceptible to blowdown because of its shallow root system, and extensive loss of this species can occur along clearcut edges and in shelterwood units (fig. 6). It should be discriminated against when marking seed cuts. This practice not only reduces the chance of blowdown but increases the chance of successful regeneration by providing more seed of species, such as the true firs, that regenerate better than mountain hemlock at lower stand densities. In situtations where risk of wind damage is very high, even light cuts may result in unacceptable blowdown. In these situations, the shelterwood method is not a suitable regeneration technique; the choice is limited to clearcutting and planting or no treatment.

Natural regeneration after seed cuts in both mixed conifer and mountain hemlock communities in the eastern Oregon Cascades has generally been good to excellent (Seidel 1979c). An average of 63 percent of milacre quadrats were stocked in both plant communities. Seedling density averaged 4,483 per acre in the mountain hemlock type and 2,968 in the mixed conifer. Over 90 percent of the seedlings in both types were of natural origin (fig. 7). And in the Blue Mountains, natural regeneration was also prolific following the seed cut in a mixed conifer community.[10] In general, shelterwood cutting is most useful for obtaining natural regeneration on south and west aspects.

The residual overstory after the seed cut should be only enough to provide adequate natural regeneration because damage to the reproduction during overstory removal and slash disposal is more likely as overstory density increases. A residual overstory of 60-80 square feet of basal area per acre is sufficient for adequate natural regeneration in both mixed conifer and mountain hemlock communities in the eastern Oregon Cascades, with the exception of pure mountain hemlock stands (Seidel 1979c). Natural regeneration of pure mountain hemlock apparently requires densities greater than 100 square feet of basal area per acre, but more research is needed on this species (Seidel and Cooley 1974).

---

[10]Data on file at Silviculture Laboratory, Pacific Northwest Forest and Range Experiment Station, Bend, Oregon.

Figure 6.—Blowdown of mountain hemlock after shelterwood cutting. Deschutes National Forest, Oregon.

Figure 7.—Five-year-old grand fir seedlings in shelterwood unit. Deschutes National Forest, Oregon.

Figure 8.—Shelterwood unit after the seed cut in a grand fir-Shasta red fir stand. Leave trees were marked. Deschutes National Forest, Oregon.

When marking a stand for a seed cut, it is important to mark the leave trees rather than the cut trees. Marking the leave trees focuses the marker's attention on the best trees in the stand. In addition, marking leave trees reduces the tendency to leave too dense an overstory which can occur if the cut trees are marked. Leave trees should be uniformly distributed over the unit. Leave trees should be dominants or codominants with long, full symmetrical crowns and free from insect or disease infestation (fig. 8). Such trees are the best seed producers and the most windfirm. In some mixed conifer stands, the best overstory trees have been cut (high-graded) leaving only poorer quality intermediates or codominants. The shelterwood system should not be used in this type of stand.

Figure 9.—Shelterwood unit 7 years after the seed cut in a mountain hemlock-grand fir stand. Note the absence of understory vegetation. Deschutes National Forest, Oregon.

The greatest chance of securing natural regeneration with the shelterwood method occurs when the seed cut coincides with a bumper seed crop. Natural regeneration typically occurs in "waves" which result from heavy seed fall on receptive seed beds. Although seed cuts made in heavy seed years provide ideal conditions for natural regeneration, adequate stocking can be obtained from several years of light to medium seed fall, provided the seed bed remains receptive. Several studies in the eastern Oregon Cascades have shown that the residual overstory tends to inhibit the invasion of competing understory vegetation for at least 5 years (Seidel 1979a, 1979c) (fig. 9). Williamson (1973) also reported satisfactory natural regeneration of Douglas-fir after several years of low seed fall. Therefore, it appears that although a heavy seed year immediately after the seed cut provides optimum conditions for establishment of natural regeneration, it is not essential to schedule seed cuts to coincide with heavy seed years.

As discussed previously, a mineral soil seed bed is the most favorable for seedling establishment. Seed per seedling ratios indicated the superiority of a mineral soil seed bed in a study of true fir natural regeneration after shelterwood cutting in the central Oregon Cascades (Seidel 1979a). Fewer sound seeds were needed to produce one seedling on plots where mineral soil was exposed (table 2). Although seedling establishment is better on mineral soil, complete removal of litter and duff layers is not necessary nor is it desirable. Exposure of only about 40-50 percent of the mineral soil is needed. This will result from logging and slash disposal operations.

Table 2—Sound seed per seedling ratio for grand fir and Shasta red fir by slash treatment and overstory density, based on 1974 seed year and 1975 seedling count[1]

Slash treatment	Overstory density		
	50 square feet per acre	90 square feet per acre	130 square feet per acre
		Grand fir	
None	38:1	63:1	43:1
Lop and scatter	49:1	55:1	43:1
Bulldoze	21:1	22:1	31:1
Crush	37:1	63:1	34:1
		Red fir	
None	6:1	16:1	7:1
Lop and scatter	6:1	11:1	8:1
Bulldoze	3:1	4:1	2:1
Crush	4:1	9:1	10:1

[1]Adapted from table 2, Seidel (1979a).

The shelterwood system is ideally suited for obtaining natural regeneration because it provides good distribution of seed over the area, ameliorates environmental extremes, and inhibits competing understory vegetation. For these reasons, natural regeneration should be relied on when using the shelterwood system. Planting should be only a means to raise stocking above minimum standards. The most efficient use of planting in the shelterwood system is to increase stocking if it is below minimum standards **after** removing the residual overstory. Planted seedlings are then not subject to loss or damage by logging operations as they are when planted before the overstory is removed.

Generally in east-side mixed conifer forests, planted seedlings do not need the protection of a shelterwood. Therefore, if local experience shows that shelterwood units do not regenerate naturally in an acceptable period, units should be clearcut and planted. An exception should be made in frost pockets where planted seedlings will not survive or grow without the thermal protection of some overstory. If natural regeneration does not occur in these areas, planting should be done before the overstory is removed.

Uneven-Aged Management.—As discussed previously, the choice of even-aged or uneven-aged management in the mixed conifer forests of eastern Oregon and Washington generally depends on factors other than ecology or silvical characteristics of the species. Under intensive forest management, even-aged systems are preferred to remove large volumes of defective trees, to maintain desired species in the stand, and for economic reasons. Uneven-aged management appears to be most suitable in areas of high recreational value — near campgrounds, for example — or where establishment of shade-tolerant species makes maintaining a single-storied, even-aged stand difficult and expensive. An example of this condition occurs in northeastern Washington where abundant natural regeneration of western hemlock and western red cedar can frustrate efforts to control the stocking level of even-aged stands.

Another use of uneven-aged management is in pure mountain hemlock stands where natural regeneration may be enhanced by the group-selection method. In the Cascades, natural regeneration of mountain hemlock characteristically occurs in small openings where several trees have fallen. Simulating this condition by harvesting groups of trees covering about one-fourth acre may result in an environment favorable for mountain hemlock regeneration. It should be recognized that although natural regeneration is favored by the group-selection method, growth of the regeneration may be suppressed by the mature trees surrounding these small openings. Because their roots extend into the openings, the surrounding trees can complete with seedlings for distances of 50-60 feet.[11] Thus growth of reproduction could be retarded over much of any opening less than an acre in size. Openings larger than 1 acre may not qualify as uneven-aged management.

A true single-tree selection method has never been applied to any mixed conifer community in eastern Oregon or Washington and probably has never been used in any Western forest type. To successfully regulate uneven-aged management using a single-tree selection system, three interrelated factors must be considered (Alexander and Edminster 1977a): (1) a maximum tree size goal, (2) stocking level (the residual growing stock that must be maintained to provide adequate growth and yield), and (3) a stand structure goal, in terms of diameter distribution, that will provide for regeneration, growth and development of the replacement trees. From these criteria, it can be seen that simply cutting scattered mature trees throughout a stand is not an application of the single-tree selection method because it does not control stand density nor does it regulate the stand structure.

Logging Considerations.—Increased use of the shelterwood method in mixed conifer forest types requires the skillful application of improved logging techniques designed to minimize damage to the residual overstory and the regeneration. In many mixed conifer stands, the seed cut has been completed and natural regeneration established; however, this is only half the reforestation job. Unless the residual overstory can be removed without unacceptable loss and damage to the regeneration, all the time and effort involved in securing regeneration will be wasted, and the area may as well have been clearcut and planted in the beginning.

---

[11] Personal communication from Philip McDonald, USDA Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, California. Based on response of regeneration in group-selection cuttings in west-side Sierra Nevada mixed conifer type in northern California.

Logging methods to reduce loss and damage to reproduction have been suggested by Gottfried and Jones (1975). They include:

1. Marking and clearing skid trails.—Skid trails should be marked on the ground and used for all cuts. Pushing tree-length windfalls out of trails does considerable damage to the reproduction. This can be avoided by sawing the blowdown into sections and pushing the sections into areas where they will cause the least damage.
2. Directional falling and variable log lengths.—Trees should be felled into openings in a herringbone pattern so logs can be pulled onto skid trails with the least disturbance. Where a strict herringbone pattern cannot be maintained, the trees should still be felled into openings. Trees laying at a poor angle for winching to skid trails should then be bucked into 16-foot logs rather than being skided in 32-foot logs. Tractors should stay on trails and back toward direction of fall.
3. Winching.—Restricting tractors to marked and pre-cleared skid trails requires more winching. Logs being winched sometimes catch on down material and drag it sideways, destroying and damaging regeneration. The swamper or choker setter can saw out sections that lie in the way, making winching easier and reducing damage.
4. Yarding unmerchantable material.—Moving unmerchantable logs to landings reduces the amount of slash that must be disposed of.
5. Season.—Logging on snow reduces root damage and destroys fewer trees. Logging operations should not be conducted, if possible, during spring when terminal shoots are tender and easily broken or when freezing conditions make stems brittle.

In addition to careful logging, good communication between the timber purchaser and the land owner or manager is the key to satisfactory logging. The best silvicultural prescription will not achieve its objectives if the logger does not understand what is expected of him and desire to accomplish these goals. Because many loggers have little experience with logging methods designed to save regeneration, brief training sessions for sawyers, skidders, swampers, and choker setters would probably help achieve the prescribed objectives.

Closely related to good communication is good sale administration. This requires close supervision of logging and incorporating standards in the contract which minimize damage.

Failure to attain silvicultural objectives may result from a poor prescription, poor marking, an inadequate contract, poor sale administration, or a careless logging job. If any of these jobs is not done properly, the results will likely be damaging to the residual overstory and the regeneration.

Slash Treatment.—Timber harvesting in old-growth mixed conifer stands produces considerable slash because of the large volume of defective material in the true firs. Utilizing residues is the best way to dispose of this material, but at the present time there is little demand for this residue. Using logging residues as fuel for electric generating plants appears to be promising but material less than 3 inches in diameter should not be removed from the harvested area because the foliage and smaller branches are rich with nutrients that can be returned to the soil.

Slash and its treatment can have both desirable and undesirable effects on timber management activities. Unfavorable effects of slash include these:

1. It increases the fire hazard when present in large volumes.
2. It provides breeding material for insects in some situations.
3. Heavy concentrations of slash provide cover for rodents.
4. It is a physical obstruction to planting.
5. In large quantities, it has the potential for creating a nitrogen deficiency in the soil. This is not likely to be serious, however, unless the slash is chipped and incorporated into the soil (Cochran 1968).

There are three important favorable effects:

1. Slash moderates extremes in microclimate at the soil surface thus improving conditions for seedling establishment (fig. 10).
2. As slash decomposes, nutrients are returned to the soil.
3. Decomposing woody residues provide important sites for nonsymbiotic nitrogen fixation and for ectomycorrhizal activity, particularly during dry periods or on dry sites (Harvey et al. 1979).

Slash can be treated in many ways. The method selected depends on factors such as the regeneration method (clearcut or shelterwood) and markets for residues. It is important to keep in mind that slash should be treated only to the extent necessary to satisfy land management goals. Complete slash disposal is neither necessary nor desirable.

Figure 10.—Natural grand fir regeneration established in the shade from slash. Deschutes National Forest, Oregon.

Clearcutting creates the largest amount of slash and also permits the greatest flexibility in choice of residue treatments (Seidel 1974b). Any method suitable for the terrain may be used since no constraints are imposed by residual overstory or reproduction. Slash may be treated by:

1. Broadcast burning.—Broadcast burning is inexpensive but requires skill and experience to attain the desired results (Martin 1976). It reduces the hazard of wildfire, and unburned bole sections provide shade over the area. In high elevation mixed conifer types, the time available for broadcast burning is limited because high fire danger in summer and early rain or snow in fall prevent burning. Broadcast burning after clearcutting can result in a large amount of woody vegetation, such as snowbrush and manzanita, because seed germination is stimulated by fire. It may be possible to reduce these woody species, however, by making one or more preharvest broadcast burns. Such burns could first cause the seed to germinate, then kill the resulting vegetation before it began to compete with seedlings planted after the harvest cut (Martin 1979). More information is needed on the effect of broadcast slash burning on understory vegetation in mixed conifer plant communities.

   Burning also results in a loss of nitrogen from residues because the nitrogen is volatilized by the fire. Although no information is available for the Pacific Northwest, studies in other regions show that this loss is compensated for by nitrogen fixation in the soil stimulated by increased nutrients in the ash (Jorgensen and Wells 1971).

2. Machine piling and burning.—This method is more expensive than broadcast burning, but it reduces the chance of fire escaping and increases the period during which burning can be done. It provides good seed bed scarification but may compact soil. It also tends to remove most of the slash, thus eliminating slash needed on clearcuts for seedling protection. Piling slash also removes nutrients from most of the area. On areas where slash piles have been burned, seedling establishment may be reduced because soil properties are impaired by extreme heat.

3. Crushing and shredding.—This treatment reduces fire hazard but may not clear an area sufficiently for planting. For best results, this treatment should be used in conjunction with tree-length logging to a 4-inch top diamater or yarding unmerchantable material, since larger material is not effectively broken. Machines commonly used for this type of slash treatment are the "Tomahawk,"[12] the "Marden Brushcutter," and "Tree Eater."

[12]Mention of trade names does not imply endorsement by the U.S. Department of Agriculture.

4. Burying.—Burying slash effectively clears an area and provides good seed bed scarification but may immobilize nitrogen in the soil, reducing growth of regeneration. It is probably best used in areas where esthetic considerations or smoke problems prevent other residue treatments. When slash is buried, an effort should'be made to replace upper soil horizons at the surface.

5. Chipping.—Chipping is expensive but speeds the return of nutrients to the soil by increasing decomposition rates. Chipping also lowers the fire hazard.

Treatment of residues resulting from the shelterwood system depends upon the stage of cutting. If advance reproduction is lacking or if it is infected by mistletoe, and the logging operation is a seed cut, then most methods of residue treatment are suitable, provided damage to the residual overstory is avoided. Care must be taken to pile residue far enough from residual trees to prevent scorching when piles are burned. Removing crown with top logs is one method of reducing slash. This method provides good seed bed scarification but has the disadvantage of removing the needles, twigs, and small branches that contain nutrients needed to maintain soil fertility.

Slash in a shelterwood system should also be treated in a way which causes the least damage to established reproduction. Falling trees into openings during logging will minimize damage to regeneration during slash piling operations. Using equipment other than tractors with brush blades can greatly reduce damage. Barrett et al. (1976) found that using a rubber-tired tractor equipped with a front-end grapple reduced damage to ponderosa pine advance reproduction. There was less damage because slash was lifted over the reproduction rather than being pushed through it. This method also has the advantage of not completely removing all slash, since smaller pieces fall through the forks of the grapple. Other ways to minimize damage to regeneration are to hand-pile and burn the slash or to lop and scatter it. Although hand treatment of slash is the most effective way to preserve the reproduction, labor costs are high and people willing to do the work may be difficult or impossible to find.

Slash treatment affects not only timber management but also has impacts on range management, wildlife, insects, diseases, and other forest resources. A systematic approach to residue management which integrates effects on these resources has been developed by Pierovich et al. (1975). In this approach, the land manager is referred to guideline statements that are stratified by type of ownership, management activity, geomorphic province, and species association.

In conclusion, there is a wide variety of possible slash treatment methods. From a silvicultural viewpoint, the method chosen should minimize damage to residual trees and regeneration and maintain soil fertility. This is best achieved by treating slash only to the extent necessary to reduce extreme fire hazards.

Growth and Yield of Managed Stands

Managed stands are those undergoing manipulation to meet some goal, usually to produce a "target" number of trees of a given species of defined diameter and height by a specific time. This goal is often attained through some combination of precommercial and commercial thinning and perhaps suppression of competing vegetation early in the life of the stand.

To define management goals and methods of attaining them in a particular stand, the manager needs the ability to assess site quality and predict tree development for that site. The simplest case confronting the land manager is an even-aged stand of a single species.

Even-Aged Stands.—Site index and height growth curves for Douglas-fir and white or grand fir in managed, even-aged mixed conifer stands are available (figs. 11 and 12) (Cochran 1979b, 1979c). The site index curves are used to forecast potential production from current height and age. Height growth curves are used to estimate height of the tallest trees and used in constructing yield tables (Curtis et al. 1974). Some information on net and gross yields for these species is also available (Cochran 1979a).

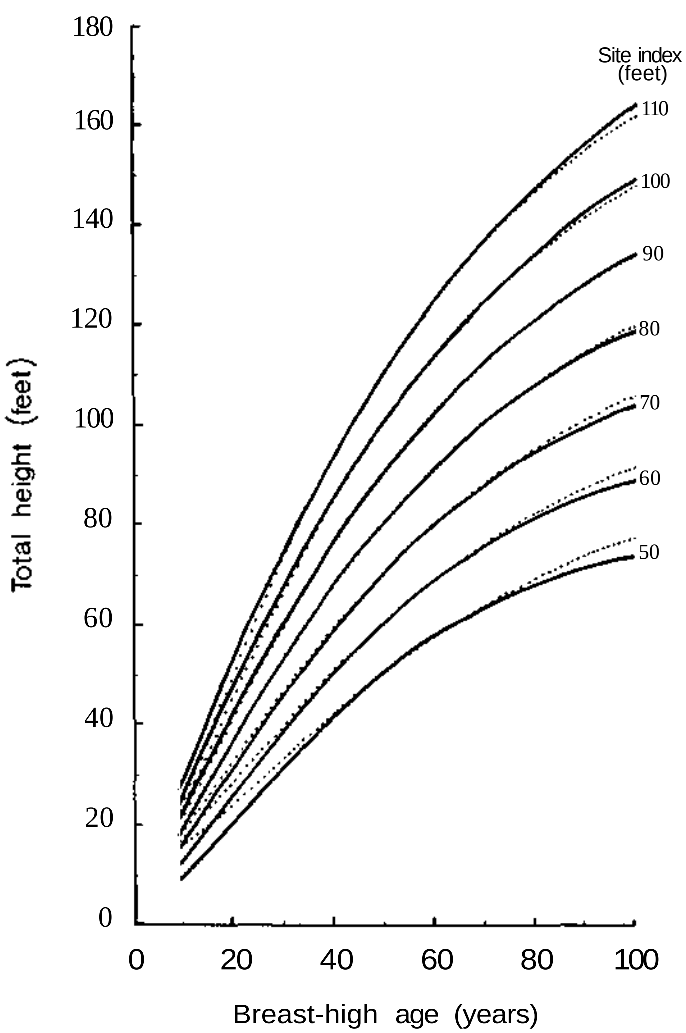


Figure 11.—Site index (solid lines) and height growth curves (dotted lines) for Douglas-fir in managed, even-aged stands east of the Cascades in Oregon and Washington. (Reproduced from Cochran 1979b.)

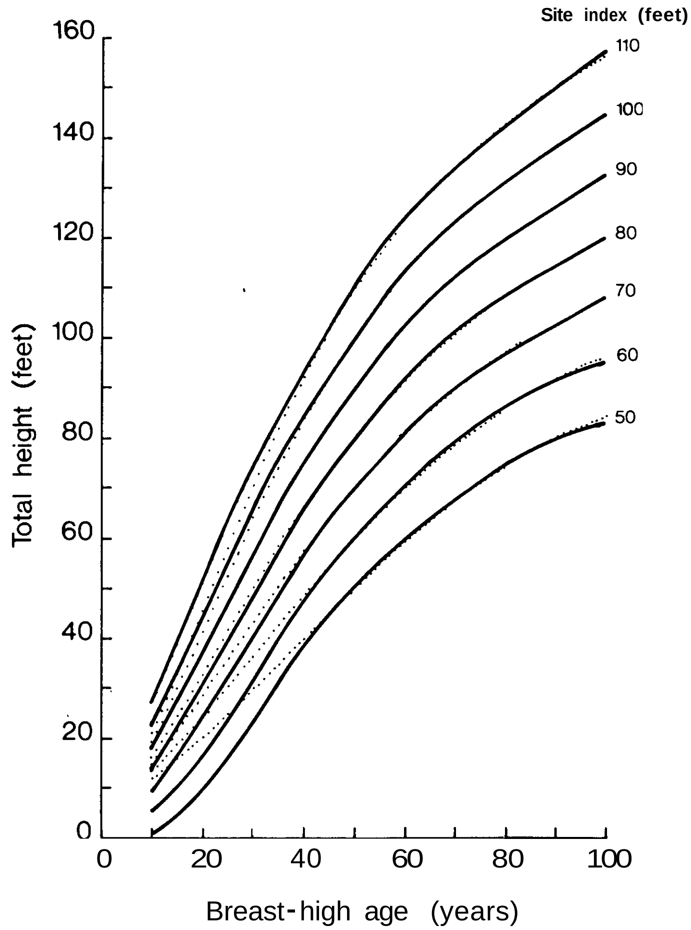


Figure 12.—Site index (solid lines) and height growth curves (dotted lines) for white or grand fir in managed, even-aged stands east of the Cascades in Oregon and Washington. (Reproduced from Cochran 1979c.)

For the range of site indexes, net basal area at 100 years varies from 149 to 322 square feet per acre for Douglas-fir and from 266 to 379 square feet per acre for white or grand fir. Net volumes at these ages and site indexes range from 3,378 to 16,605 cubic feet per acre for Douglas-fir and from 6,839 to 18,940 cubic feet per acre for white or grand fir. These net volume yields are about 76 percent of the gross volume yields for Douglas-fir and 59 to 71 percent of the gross volume yields for white or grand fir.

Except for Cochran's (1979b, 1979c) curves for Douglas-fir and grand (white) fir, Barrett's (1978) curves for ponderosa pine, and Dahms' (1964) curves for lodgepole pine, no site index curves or yield tables have been developed for the other mixed conifer species in eastern Oregon and Washington. The site index tables now used for Shasta red fir, western white pine, western larch, and Engelmann spruce are given in the silvicultural examination and prescription handbook (see footnote 9, p. 31).

The table for red fir is based on Schumacher's (1928) data collected in northern California; the white pine table is based on Haig's (1932) data collected in Idaho and Montana. The larch table, derived from data collected by Cummings (1937) in the intermountain region, is given in curve form by Schmidt et al. (1976). The spruce table is based on unpublished data collected in the intermountain region.

Site index and height growth curves for mountain hemlock are available for some plant communities (Johnson 1980). No other yield data are available, and use of western hemlock yield tables (Barnes 1962) may result in considerable overestimation of growth and yield (Herman and Franklin 1976). In pure mountain hemlock stands, we suggest using mountain hemlock site index curves and western hemlock yield tables, coupled with field checks, to determine the adjustment necessary for mountain hemlock yield in the area of interest. In mixed stands, site index curves and yield tables available for other species may also be used.

Intermediate cuttings (primarily thinnings) are essential in many mixed conifer types to maintain or improve growth and vigor. Timely thinnings result in (1) concentrating growth on fewer higher quality trees, (2) salvaging mortality, (3) maintaining vigorous trees that are more resistant to damaging agents such as insects, wind, and snow, and **(4)** reducing the amount of slash.

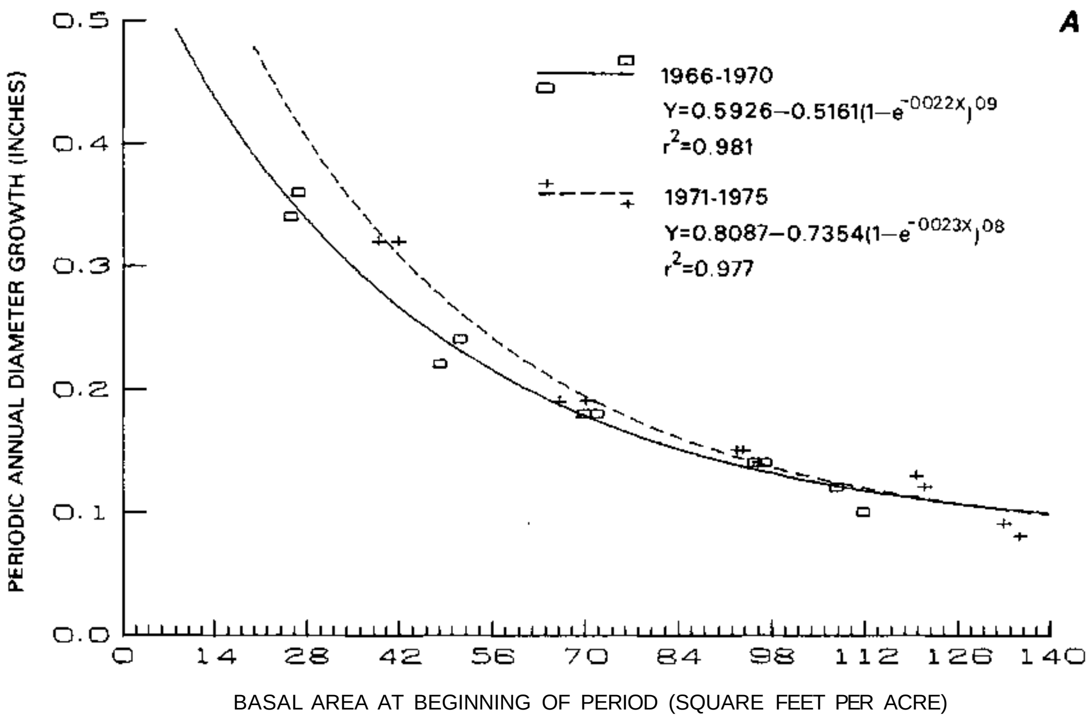
To plan a thinning program, the land manager must answer questions such as (1) when should thinning be done, (2) what type of thinning, and (3) what thinning intensity is needed? These questions are closely related, especially the timing and intensity of thinning.

The stands that benefit most from thinning are young, even-aged stands of seral species such as larch and lodgepole pine. Many naturally regenerated stands are overstocked and need an early precommercial thinning. For larch, the greatest gains occur when trees are about 10 years old and from 10 to 15 feet tall, before competition reduces crown size (Schmidt 1966). Other species also benefit from early precommercial thinning. Land managers should keep in mind that thinning young larch stands creates conditions favorable for the establishment of associated shade-tolerant species, so additional cleanings or weedings may be needed if a single-storied larch stand is desired.

The thinning method will depend to a large degree on stand structure and age. Generally, low thinning (thinning from below) is recommended in even-aged stands. These thinnings remove the suppressed and intermediate trees that are slower growing and less vigorous (fig. 13). Light crown thinning may be used with low thinning as the initial treatment in stands where the crown canopy is uniform in order to open up the canopy. Selection thinning (thinning from above) is not recommended because this leaves the smaller trees that are unable to respond quickly to the increased growing space. These trees are also more subject to mortality from wind and snow (Seidel 1975).

Figure 13.—An even-aged, 33-year-old western larch pole stand after it was thinned from below to a basal area of 50 square feet per acre. Wallowa-Whitman National Forest, Oregon. (Reproduced from Seidel 1977a.)

Thinning intensity (as well as timing) depends on many factors. These include (1) rotation age, (2) species, (3) expected growth rate, (4) present and future markets for small trees, (5) risk of damage to the stand, (6) schedule of future thinnings, and (7) multiple use considerations. The most important factor affecting the intensity of precommercial thinnings is the manager's estimate of tree size (d.b.h.) that will be merchantable in the future. By leaving a high stand density, the silviculturist is assuming that smaller trees will provide a commercial thinning in the future; conversely, leaving a stand of a low density implies that larger trees are needed for a commercial thinning. In other words, the larger the trees needed for a commercial thinning, the fewer that should be left after the precommercial thinning. After a stand has reached merchantable size, goals are to utilize mortality and maintain good volume and diameter growth. Obviously, it is not possible to maximize both diameter growth per tree and volume growth per acre because maximum diameter growth occurs at low stand densities while high densities result in maximum total volume (fig. 14) (Seidel 1977a). Thus, if the management objective is to obtain a relatively high volume per acre, stands should be thinned lightly. If, on the other hand, the aim is to shorten the rotation—sacrificing some volume growth—a heavier thinning is required.



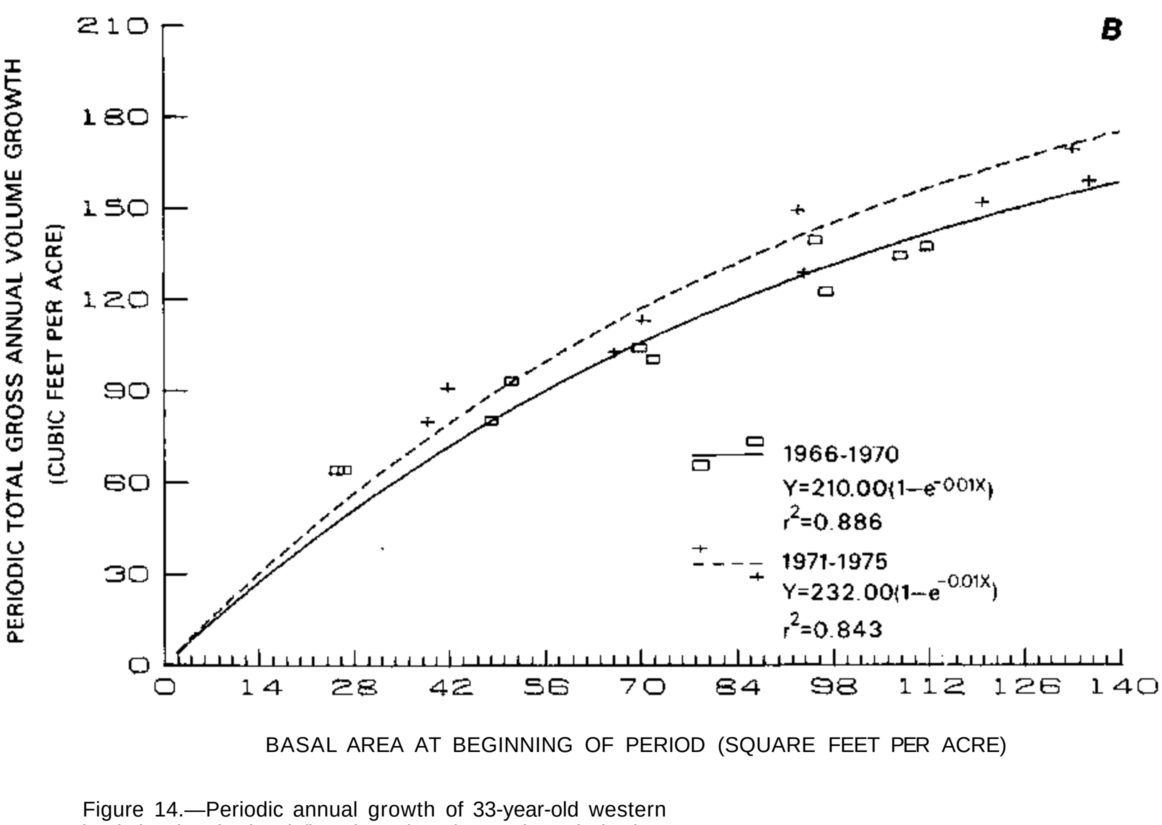


Figure 14.—Periodic annual growth of 33-year-old western larch by density level (basal area) and growth period, site index 80: *A,* Diameter growth; (Reproduced from Seidel 1977a, fig. 3); *B,* Cubic volume growth; (Reproduced from Seidel 1977a, fig. 8).

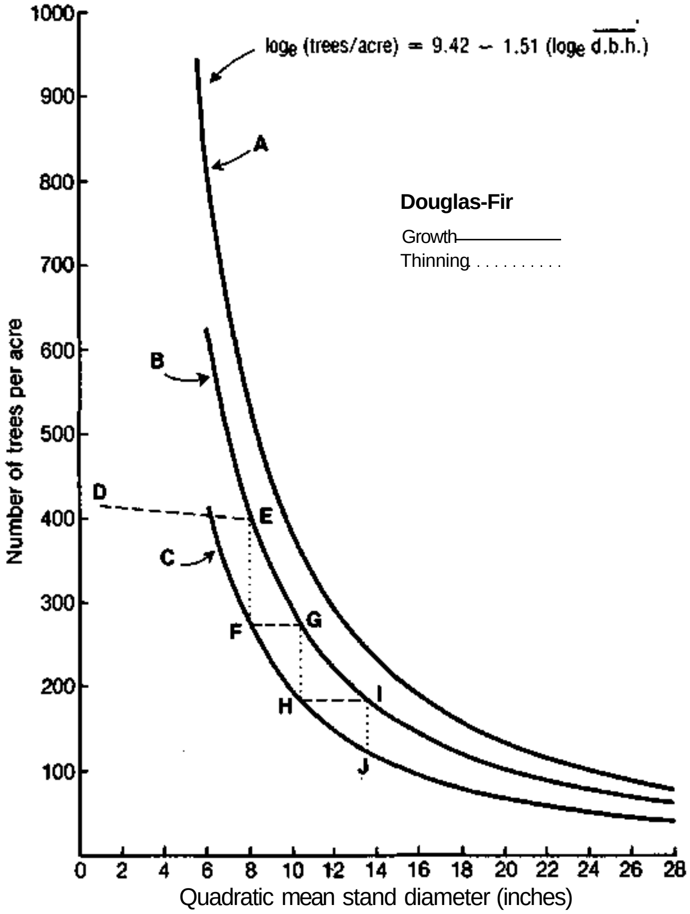


Figure 15.—Stocking level curves for managed, even-aged, east-side Douglas-fir with an illustration of a thinning regime beginning with a precommercial thinning at an average diameter of 1 inch and the first commercial thinning at 8 inches. Curve A represents full stocking, curve B represents the recommended maximum stocking level for managed stands, and curve C represents the recommended minimum stocking level after commercial thinning. Stand density should be regulated during the rotation by thinning to the C curve whenever the average stand diameter for a given number of trees reaches the B curve.

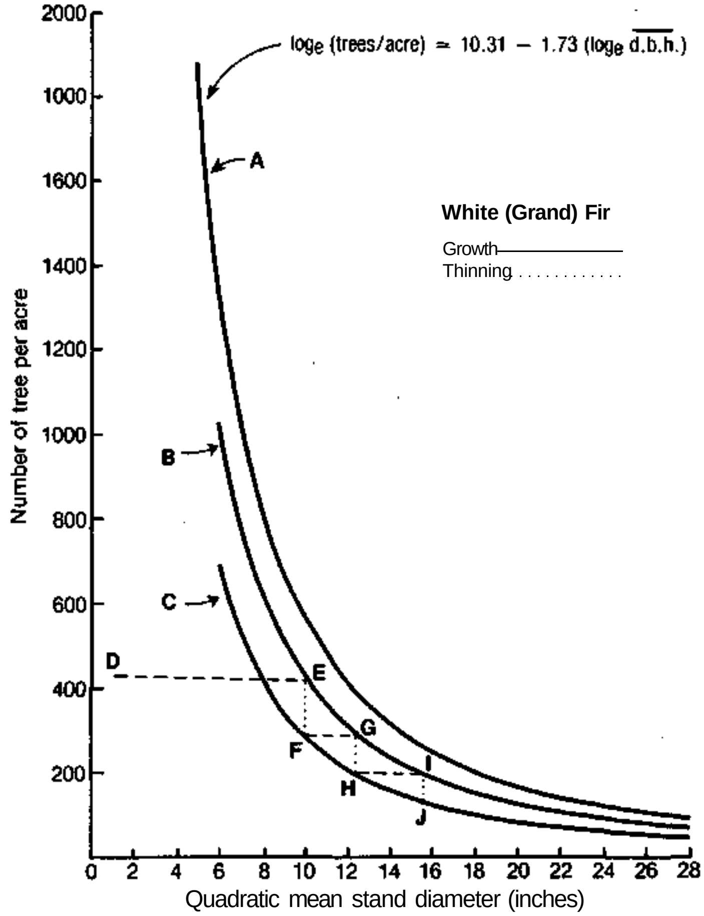


Figure 16.—Stocking level curves for managed, even-aged, east-side white or grand fir with an illustration of a thinning regime beginning with a precommercial thinning at an average diameter of 1 inch and the first commercial thinning at 10 inches. Curve A represents full stocking, curve B represents the recommended maximum stocking level for managed stands, and curve C represents the recommended minimum stocking level after commercial thinning. Stand density should be regulated during the rotation by thinning to the C curve whenever the average stand diameter for a given number of trees reaches the B curve.

Stocking level cures have been prepared for even-aged, east-side Douglas-fir (fig. 15) and white (grand) fir (fig. 16). For each set of curves, the upper curve A corresponds to the best fit of $\log_e$ (trees per acre) = a + b ($\log_e$ quadratic mean diameter) (Reineke 1933), and represents full stocking.[13] The middle curve B represents a stocking level equivalent to 75 percent of the upper curve. At or below this stocking level, suppression and suppression mortality should be minor. The lower curve C (67 percent of the middle curve) represents a stocking level that we believe is reasonable after commercial thinning, provided the thinning is mostly from below and vigorous trees are left. This level will concentrate most of the potential production on trees which eventually will be harvested in thinnings or harvest cuttings, provided no other damage not directly related to stand density occurs.

[13]Curves derived from data on file at the Silviculture Laboratory, Pacific Northwest Forest and Range Experiment Station, Bend, Oregon.

In using these curves, the manager should regulate stand density so it varies between the C- and B-level curves after the first commercial thinning. An example is given in figure 15. It assumes one precommercial thinning in a Douglas-fir stand at an average diameter of 1 inch and the first commercial thinning at 8 inches. The precommercial thinning would reduce the number of trees to about 415 per acre (point D) allowing for mortality of about 15 trees per acre before commercial entry. When the average diameter reaches 8 inches (E), the stand would be commercially thinned to about 270 trees per acre (F). Another commercial thinning would be indicated when the average diameter intersects the B curve at about 10.5 inches (G). In this thinning, the number of trees would be reduced to about 180 per acre (H). A third commercial thinning to about 125 trees per acre (J) is suggested at an average diameter of 13.5 inches.

A similar example is shown in figure 16 for a white (grand) fir stand. It assumes a precommercial thinning at a l-inch diameter and the first commercial thinning at 10 inches. These illustrations are only two of many possible thinning regimes. The number of trees left after a precommercial thinning depends mainly on the diameter of trees that will be merchantable in the commercial thinning. Therefore, if the first commercial thinning is possible when average diameter is 8 inches instead of 10 inches, for example, about 630 trees per acre should be left after precommercial thinning in a white fir stand. This is the number of trees at the point where the B curve intersects the average stand diameter that will support a commercial thinning, plus a small (2- to 4-percent) allowance for mortality. Site index and age are not given with the curves because diameter is more dependent on past stand history than age for any given site, and recommended stocking levels are largely independent of site.

For western white pine and western larch, we recommend stocking levels similar to Douglas-fir; Engelmann spruce stocking levels are thought to be very close to those for white (grand) fir.[14] For stands which are mixtures of several species, we suggest using a weighted average of the appropriate curves with the weights being the fraction of each species the manager wishes to retain after thinning. Note that the stocking level curves do not indicate rates of growth. Growth rates (Cochran 1979a) should be considered when making decisions concerning thinning, and economics may rule out any kind of thinning on poorer sites.

[14] Curve forms of log, (trees per acre) = a + b (log, quadratic mean diameter) were derived for western white pine, western larch, and Engelmann spruce from data collected in the Rocky Mountains. Curves for white pine and larch compare closely with eastern Oregon and Washington Douglas-fir, whereas curves for Engelmann spruce compare closely with grand fir data. We assume that the relative number of suppressed trees in normal stands of white pine, larch, and spruce are similar to Douglas-fir and white (grand) fir.

Silviculturists should keep in mind that acceptable stocking levels encompass a range of stand densities. Therefore it is not critical to maintain an exact stand density at any time in the rotation. The important point is to thin the stand sufficiently to prevent excessive competition which results in smaller crowns, loss of vigor, and reduced growth.

Uneven-Aged Stands.—In uneven-aged stands most trees undergo periods of suppression. Thus site index and height growth curves may have little meaning. Further, averages of age, basal area, and volume have no relationship to the site index, age, basal area, and volume relationships for managed, even-aged stands. One method of predicting growth and yield of these complex stands is to use a simulation model based on individual trees. At present two simulation models appear applicable to mixed conifer stands of uneven age. One of these models has been developed by Stage (1973), and other by Botkin et al. (1972).

These models have a set of functions that predict changes in individual tree diameters, heights, and crowns, with time, for specified stand conditions. Periodic mortality, scheduled harvest, and tree damage are also included. To use these models outside the areas where they were developed, the manager should define and plug individual functions into the desired model. For short-term projections, the models can be calibrated during stand examination. This calibration allows for raising or lowering projected growth rates by a factor equivalent to recent stand growth rate divided by predicted stand growth rate from the model.

To use Stage's prognosis model, the manager must supply:

1. Site characteristics: slope, aspect, elevation, habitat type.
2. Stand characteristics: density (crown competition factor, basal area, trees per acre), diameter distribution by species.
3. Tree characteristics: diameter, height, crown ratio, and species.

Use of the prognosis model ea'st of the Cascades in Oregon and Washington requires approximation of comparable habitat types plus the calibration features incorporated in the model.

A commitment to uneven-aged management requires stand treatments to create a distribution of age and size classes that will allow the desired level of periodic tree removal consistent with growth rates. As we discussed previously, the land manager must consider three factors for uneven-aged regulation: (1) a maximum tree size goal, (2) the residual basal area level that should be maintained, and (3) the stand structure or diameter distribution goal.

The most widely accepted procedure for establishing a diameter distribution goal is to utilize a quotient Q (Marquis 1977). Q is related to diameter class and the number of trees per unit area in a given class. A balanced diameter distribution implies that the number of trees in successive diameter classes follows a geometric series of the form M, MQ, MQ^2, MQ^3—where M is the number of trees in the largest diameter class. Q values (for 2-inch diameter classes) ranging from 1.3 to 2.0 have been recommended for various situations. Stands maintained at small Q values have a higher proportion of available growing space in large trees. These stands may require periodic removal of many small trees in the diameter class where unregulated growing stock crosses the threshold into the portion of the stand to be regulated (Alexander and Edminster 1977b).

The cutting cycle depends on growth rate, residual stocking levels selected, site quality, and the amount of merchantable volume left for cutting. The projected allowable cut is the difference between the residual goal and the estimated stocking (Marquis 1977). Curtis (1977) cites several references to short-term projections for uneven-aged stands and points out many difficulties involved in yield estimations. Some approximations of stocking levels, maximum tree sizes, cutting cycles, and even Q values for Douglas-fir and white or grand fir can be obtained from the stocking level curves for even-aged stands. Such approximations assume that uneven-aged stands are merely mixtures of components of even-aged stands. We have serious doubts about the validity of such estimates because when species are mixed on the same area the growth rates of various age classes probably differ from the growth rates of those same age classes and species in a pure, even-aged stand.

The application of uneven-aged silviculture and management is difficult because information on growth and regeneration in relation to stocking and stand structure is lacking: Until more data becomes available, the best summary of current applicability of uneven-aged silviculture and management in the West is found in the proceedings of a workshop on uneven-aged silviculture and management (USDA Forest Service 1977).

Multiple-Use Silviculture

In addition to their value as a source of timber for the wood-using industries of the area, the mixed conifer forests of eastern Oregon and Washington are of great importance in providing water, habitat for many species of wildlife, forage for livestock, and recreation opportunities. As population increases and more land is set aside for restricted use (i.e., Wilderness Areas), the pressure for multiple-use management on the remaining forests increases. It is important for land managers to realize that any alteration of forest habitats for silvicultural purposes also affects wildlife populations, water yields, and esthetic quality. Timber management is, in effect, management of wildlife, watersheds, and recreation. Fortunately, in most cases, timber management objectives can be compatible with multiple-use objectives.

Water.—Hydrologic studies of forested watersheds in the United States have all resulted in the conclusion that streamflow increases as stand density is reduced because of reduced transpirational drain on soil moisture. On one central Oregon watershed, Berndt and Swank (1970) reported an increase of 2.21 inches in the average annual water yield, which coincided approximately with the onset of heavy timber harvesting. They also found a decrease of 1.18 inches in average water yield 16 years later. They attributed this to increased stocking by second-growth stands and a reduction of timber harvest.

No studies of the effect of various cutting methods on water yield have been conducted on mixed conifer watersheds in eastern Oregon and Washington, but work in the Rocky Mountain subalpine forests has provided guidelines for improving water yield which may be useful in the eastern Oregon-Washington region (Leaf 1975). Patterns of optimum snow accumulation resulted from patch clearcutting when patches had a diameter 5-8 times the height of surrounding trees and were spaced about the same distance apart. Because of the more rapid snowmelt in the clearcuts, streamflow was increased in spring and early summer. Average annual water yields increased at least 2 inches when 40 percent of the watershed was clearcut in patches and 60 percent was left uncut; flood peaks were not significantly increased when not more than 50 percent of the watershed was clearcut.

Range and Wildlife.—Habitat for big game and domestic livestock in old-growth mixed conifer stands can be greatly improved by silvicultural practices which increase forage and provide adequate thermal and hiding cover. The cutting method which creates these conditions is the same as that which optimizes water yields—small patch clearcuts distributed throughout the uncut stand. The clearcuts provide palatable forage for deer, elk, and cattle, and the adjacent uncut stands provide cover. Partial cut stands are preferred least by deer and elk because they lack the volume and variety of forage in clearcuts and the cover of the uncut stands (Edgerton 1972). Recommendations for improving livestock utilization of mixed conifer forests are given by Hedrick et al. (1968).

Thomas et al. (1979b) recommend a ratio of 40-percent cover to 60-percent openings for deer and elk to optimize use of the maximum area on summer ranges in the Blue Mountains. A distance of 600-1,200 feet between openings is suggested as optimum requirement for cover. Size of the clearcuts should not exceed 40 acres since deer and elk will not forage over larger areas (Dealy 1975). Domestic livestock, however, will forage over openings of any size. Detailed information on the effect of timber management on deer and elk habitat in the Blue Mountains is given by Black et al. (1976) and Thomas et al. (1979b).

Timber management also affects the habitat of other wildlife species. After reviewing the effect of intensive forest management on birds, Thomas et al. (1975) concluded that present trends in timber management will lead to stand diversity resulting in a greater variety of bird species, except for those species adapted to old-growth and those requiring snags for nesting. Estimates of the number of snags needed to maintain populations of snag-dwelling species in the Blue Mountains have been prepared by Thomas et al. (1979a). To provide sufficient snags for these species, it may be necessary to retain snags that might otherwise be salvaged and to create snags by killing suitable trees. Longer rotations of selected trees or stands can also provide the larger diameter snags required by some species.

Recreation and Esthetics.—The scenic quality of forested landscapes is affected by timber management. In general, scenic quality is enhanced by variety and diversity in the landscape (USDA Forest Sevice 1973). Esthetic quality is usually highest in partially cut stands and lowest in clearcuts and uncut old-growth stands. The visual quality of clearcuts can be improved by irregular openings that have form and texture similar to the surrounding stands and thus complement the natural landscape (USDA Forest Service [In press]).

In areas of high recreational use near campgrounds and lakes, uneven-aged management (single-tree or group selection) can minimize the visual impact of logging and yet provide variety in stands.

The ephemeral quality of many landscapes in eastern Oregon and Washington can be greatly increased by maintaining or increasing the larch component of mixed conifer stands because of the fall color of larch.

RESEARCH NEEDS

Because of the multiple uses of mixed conifer forests, the most important need in research is to integrate silvicultural research with other disciplines in a holistic approach toward forest management. As more information is available from multidisciplinary research, land managers will be better able to predict the effects of silvicultural prescriptions not only on tree regeneration and growth but also on the probability of insect or disease attack, on soil nutrient balance, and on habitat for wildlife and domestic livestock. Specific problems that need attention are:

1. Response of suppressed true fir seedlings and saplings to release in various plant communities and the characteristics of trees that respond rapidly.
2. Reactivation of decay-causing fungi in suppressed true fir saplings wounded during overstory removal.
3. Use of uneven-aged management in plant communities where regeneration of shade-tolerant species is prolific. This involves the effect of stand structure and composition on the establishment, growth, and composition of regeneration, and the potential growth and yield under various stand structures.
4. Refinement of stocking-level curves for mixed species stands.
5. Development of site-index curves and yield tables for managed stands of Engelmann spruce, western white pine, and mountain hemlock.
6. Development of techniques to simulate the effects of thinning regimes on growth and yield in both even-aged and uneven-aged stands of mixed species.

7. Economic analyses of silvicultural and management alternatives.
8. Use of prescribed burning in mixed conifer communities and its effect on vegetation, soil nutrient status, insects, and disease.
9. The long-term effects of increased utilization of logging residues on nutrient balance of the soil and forest productivity.

METRIC EQUIVALENTS

1 inch = 2.54 centimeters
1 foot = 0.3048 meter
1 mile = 1.61 kilometers
1 acre = 0.4047 hectare
1 pound = 0.4536 kilogram
1 tree per acre = 2.47 trees per hectare
1 square foot per acre = 0.2296 square meter per hectare
1 cubic foot per acre = 0.0700 cubic meter per hectare
°C = 5/9 (°F −32)

LITERATURE CITED

Aho, Paul E.
1966. Defect estimation for grand fir, Engelmann spruce, Douglas-fir and western larch in the Blue Mountains of Oregon and Washington. USDA For. Serv. Pac. Northwest For. and Range Exp. Stn., 26 p., illus. Portland, Oreg.

Aho, Paul E.
1971. Decay of Engelmann spruce in the Blue Mountains of Oregon and Washington. USDA For. Serv. Res. Pap. PNW-116, 16 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Aho, Paul E.
1977. Decay of grand fir in the Blue Mountains of Oregon and Washington. USDA For. Sew. Res. Pap. PNW-229, 18 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Aho, Paul E., and Anita Hutchins.
1977. Micro-organisms from the pith regions of suppressed grand fir understory trees. USDA For. Sew. Res. Note PNW-299, 5 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Alexander, Robert R.
1964. Minimizing windfall around clear cuttings in spruce-fir forests. For. Sci. 10(2): 130-142, illus.

Alexander, Robert R., and Carleton B. Edminster.
1977a. Regulation and control under uneven-aged management. *In* Uneven-aged silviculture and management in the western United States. Proc. of In-Service Workshop, p. 118-131. Redding, California, Oct. 19-21, 1976. USDA For. Serv., Washington, D.C.

Alexander, Robert R., and Carleton B. Edminster.
1977b. Uneven-aged management of old growth spruce-fir forests: Cutting methods and stand structure goals for the initial entry. USDA For. Sew. Res. Pap. RM-186, 12 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Barnes, George H.
1962. Yield of even-aged stands of western hemlock. U.S. Dep. Agric. Tech. Bull. 1273, 52 p., illus.

Barnes, Victor G., Jr.
1973. Pocket gophers and reforestation in the Pacific Northwest: A problem analysis. U.S. Dep. Inter. Fish and Wildlife Serv. Spec. Sci. Rep. Wildl. 155. 18 p.

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., 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. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Beaufait, William R., Charles E. Hardy, and William C. Fischer.
1975. Broadcast burning in larch-fir clearcuts: The Miller Creek-Newman Ridge study. USDA For. Serv. Res. Pap. INT-175, 53 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Beebe, Spencer B.
1974. Relationships between insectivorous hole-nesting birds and forest management. Yale Univ. Sch. For. Environ. Study, New Haven, Conn. 49 p. [multilithed].

Bega, Robert V., Tech. Coord.
1978. Diseases of Pacific coast conifers. [U.S. Dep. Agric.] Agric. Handb. 521, 206 p., illus.

Berndt, H. W., and G. W. Swank.
1970. Forest land use and streamflow in central Oregon. USDA For. Serv. Res. Pap. PNW-93, 15 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Black, Hugh, Richard J. Scherzinger, and Jack Ward Thomas.
1976. Relationships of Rocky Mountain elk and Rocky Mountain mule deer habitat to timber management in the Blue Mountains of Oregon and Washington. *In* Proceedings of the elk-logging roads symposium, Moscow, Idaho, Dec. 16-17, 1975, p. 11-31, J. Peek, ed. Univ. Idaho, Moscow.

Botkin, D. B., J. F. Janak, and J. R. Wallis.
1972. Rationale, limitations, and assumptions of a northeastern forest growth simulator. J. Res. Develop. 16(2):101-116. IBM Corp.

Brookes, Martha H., R. W. Stark, and Robert W. Campbell, Eds.
1978. The Douglas-fir tussock moth: A synthesis. U.S. Dep. Agric. Tech. Bull. 1585, 331 p.

Bruns, Herbert.
1960. The economic importance of birds in forests. Bird Study 7(4):193-208.

Carolin, V. M., Jr., and F. W. Honing.
1972. Western spruce budworm. USDA For. Serv. For. Pest Leafl. 53 (rev.), 8 p.

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

Cleary, Brian, Robert D. Greaves, and Richard K. Hermann, Eds.
1978. Regenerating Oregon's forests—a guide for the regeneration forester. 287 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. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Cochran, P. H.
1979a. Gross yields for even-aged stands of Douglas-fir and white or grand fir east of the Cascades in Oregon and Washington. USDA For. Serv. Res. Pap. PNW-263, 17 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Cochran, P. H.
1979b. Site index and height growth curves for managed, even-aged stands of Douglas-fir east of the Cascades in Oregon and Washington. USDA For. Serv. Res. Pap. PNW-251, 16 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Cochran, P. H.
1979c. Site index and height growth curves for managed, even-aged stands of white or grand fir east of the Cascades in Oregon and Washington. USDA For. Serv. Res. Pap. PNW-252, 13 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Cooper, C. F.
1961. The ecology of fire. Sci. Am. 204(4):150-160.

Crouch, Glenn L.
1969. Animal damage to conifers on National Forests in the Pacific Northwest Region. USDA For. Serv. Resour. Bull. PNW-28, 13 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Crouch, Glenn L.
1976. Deer and reforestation in the Pacific Northwest. *In* Proceedings of the 7th vertebrate pest conference, Monterey, Calif., March 9-11, 1976, p. 298-301. Charles C. Siebe, ed., Univ. Calif., Davis.

Crouch, Glenn L.
1979. Atrazine improves survival and growth of ponderosa pine threatened by vegetative competition and pocket gophers. For. Sci. 25(1):99-111.

Crouch, Glenn L., and Larry R. Frank.
1979. Poisoning and trapping pocket gophers to protect conifers in northeastern Oregon. USDA For. Serv. Res. Pap. PNW-261, 8 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Cummings, L. J.
1937. Larch-Douglas-fir board foot yield tables. USDA For. Serv., Appl. For. Notes 78, 5 p. North Rocky Mt. For. and Range Exp. Stn., Missoula, Mont.

Curtis, Robert O.
1977. Growth and yield in uneven-aged stands. *In* Uneven-aged silviculture and management in the western United States. Proc. of In-Service Workshop, p. 81-97. Redding, Calif. Oct. 19-21, 1976. USDA For. Serv., Washington, D.C.

Curtis, Robert O., Donald J. DeMars, and Francis R. Herman.
1974. Which dependent variable in site index-height-age regressions? For. Sci. 20(1):74-87.

Dahlgreen, Allen K., Russell A. Ryker, and David L. Johnson.
1974. Snow cache seedling storage: Successful systems. USDA For. Serv. Gen. Tech. Rep. INT-17, 12 p., illus. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Dahms, Walter G.
1964. Gross and net yield tables for lodgepole pine. USDA For. Serv. Res. Pap. PNW-8, 14 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Daubenmire, R.
1943. Vegetational zones in the Rocky Mountains. Bot. Rev. 9(6):325-393.

Daubenmire, R.
1946. The life zone problem in the northern Intermountain Region. Northwest Sci. 20(2):28-38.

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

Dealy, J. Edward.
1975. Management of lodgepole pine ecosystems for range and wildlife. *In* Proceedings on management of lodgepole pine ecosystems symposium, Pullman, Wash., Oct. 9-11, 1973, p. 556-568. David M. Baumgartner, ed., Wash. State Univ. Coop. Ext. Serv., Pullman.

Denton, Robert E.
1972. Establishment of ***Agathis pumila*** (Ratz.) for control of larch casebearer and notes on native parasitism and predation in Idaho. USDA For. Serv. Res. Note INT-164, 6 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Denton, Robert E.
1979. Larch casebearer in western larch forests. USDA For. Serv. Gen. Tech. Rep. INT-55, 62 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Dyrness, C. T.
1976. Effect of wildfire on soil wettability in the high Cascades of Oregon. USDA For. Serv. Res. Pap. PNW-202, 18 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Edgerton, Paul J.
1971. The effect of cattle and big game grazing on a ponderosa pine plantation. USDA For. Serv. Res. Note PNW-172, 8 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Edgerton, Paul J.
1972. Big game use and habitat changes in a recently logged mixed conifer forest in northeastern Oregon. Proc. 52nd Annu. Conf. West. Assoc. State Game and Fish Comm. p. 239-246. Portland, Oreg.

Etheridge, D. E., and H. M. Craig.
1976. Factors influencing infection and initiation of decay by the Indian paint fungus ***(Echinodontium tinctorium)*** in western hemlock. Can. J. For. Res. 6(3):299-318.

Evenden, James C., W. D. Bedard, and G. R. Struble.
1943. The mountain pine beetle, an important enemy of western pines. U.S. Dep. Agric. Circ. 664, 25 p.

Fellin, D. G., and W. C. Schmidt.
1973. How does western spruce budworm affect western larch? USDA For. Serv. Gen. Tech. Rep. INT-7, 25 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Ferguson, Dennis E., and David L. Adams.
1979. Guidelines for releasing advance grand fir from overstory competition. For., Wildl. and Range Exp. Stn. Note 35, 3 p., Univ. Idaho, Moscow.

Ferrell, George T.
1978. Moisture stress threshold of susceptibility to fir engraver beetles in pole-size white firs. For. Sci. 24(2):85-92.

Filip, G. M., and P. E. Aho.
1978. Incidence of wounding and associated stain and decay in advanced white fir regeneration on the Fremont National Forest, Oregon. For. Insect and Dis. Manage. Rep. 22 p. USDA For. Serv., Pac. Northwest Reg., Portland, Oreg.

Filip, G. M., and C. L. Schmitt.
1979. Susceptibility of native conifers to laminated root rot east of the Cascade Range in Oregon and Washington. For. Sci. 25(2):261-265.

Fowells, H. A., and N. B. Stark.
1965. Natural regeneration in relation to environment in the mixed conifer type of California. USDA For. Serv. Res. Pap. PSW-24, 14 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Franklin, Jerry F.
1963. Natural regeneration of Douglas-fir and associated species using modified clear-cutting systems in the Oregon Cascades. USDA For. Serv. Res. Pap. PNW-3, 14 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Franklin, Jerry F.
1968. Cone production by upper-slope conifers. USDA For. Serv. Res. Pap. PNW-60, 21 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Franklin, Jerry F., Richard Carkin, and Jack Booth.
1974. Seeding habits of upper-slope tree species. I. A 12-year record of cone production. USDA For. Serv. Res. Note PNW-213, 12 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Franklin, Jerry F., and Dean S. DeBell.
1973. Effects of various harvesting methods on forest regeneration. ***In*** Symposium on Even-aged Management. Sch. For., Oreg. State Univ., Pap. 848, p. 29-57. Corvallis.

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

Franklin, Jerry F., and John Hoffman.
1968. Two tests of white pine, true fir, and Douglas-fir seedspotting in the Cascade Range. USDA For. Serv. Res. Note PNW-80, 11 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Franklin, Jerry F., and Kenneth W. Krueger.
1968. Germination of true fir and mountain hemlock seed on snow. J. For. 66(5):416-417.

Franklin, Jerry F., and Clark E. Smith.
1974a. Seeding habits of upper-slope tree species. II. Dispersal of a mountain hemlock seedcrop on a clearcut. USDA For. Sev. Res. Note PNW-214, 9 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Franklin, Jerry F., and Clark E. Smith.
1974b. Seeding habits of upper-slope tree species. III. Dispersal of white and Shasta red fir seeds on a clearcut. USDA For. Serv. Res. Note PNW-215, 9 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Furniss, M. M., G. E. Daterman, L. N. Kline, M. D. McGregor, G. C. Trostle, L. F. Pettinger, and J. A. Rudinsky.
1974. Effectiveness of the Douglas-fir beetle antiaggregative pheromone methylcyclohexenone at three concentrations and spacings around felled host trees. Can. Entomol. 106:381-392.

Furniss, M. M., and P. W. Orr.
1970. Douglas-fir beetle. USDA For. Serv. For. Pest Leafl. 5, 4 p.

Furniss, R. L., and V. M. Carolin.
1977. Western forest insects. USDA For. Serv. Misc. Publ. 1339, 654 p., illus.

Garrison, G. A., J. M. Skovlin, C. E. Poulton, and A. H. Winward
1976. Northwest plant names and symbols for ecosystem inventory and analysis. 4th ed. USDA For. Serv. Gen. Tech. Rep. PNW-46, 263 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Gordon, Donald T.
1970. Natural regeneration of white and red fir—influence of several factors. USDA For. Serv. Res. Pap. PSW-58, 32 p., illus. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Gordon, Donald T.
1973a. Damage from wind and other causes in mixed white fir-red fir stands adjacent to clearcuttings. USDA For. Serv. Res. Pap. PSW-90, 22 p., illus. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Gordon, Donald T.
1973b. Released advance reproduction of white and red fir—growth, damage, mortality. USDA For. Serv. Res. Pap. PSW-95, 12 p., illus. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Gottfried, Gerald J., and John R. Jones.
1975. Logging damage to advance regeneration on an Arizona mixed conifer watershed. USDA For. Serv. Res. Pap. RM-147, 20 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Gratkowski, H.
1974. Brushfield reclamation type conversion. *In* Environmental effects of forest residues management in the Pacific Northwest—A state-of-knowledge compendium. USDA For. Serv. Gen. Tech. Rep. PNW-24, p. I-1 through 1-31. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Gravelle, Paul.
1977. Growth response and logging damage to advanced regeneration following overstory removal: The present state of knowledge. Potlatch For. Tech. Pap. TP-77-3, 27 p. Potlatch Corp., Lewiston, Idaho.

Gutzwiler, J. R., and J. K. Winjum.
1974. Performance of containerized coniferous seedlings in recent forest regeneration trials in Oregon and Washington. *In* Proceedings of the North American containerized forest tree seedling symposium. R. W. Tinus, W. I. Stein, and W. E. Balmer, eds. Great Plains Agric. Counc. Publ. 68, p. 291-297.

Habeck, J. R., and R. W. Mutch.
1973. Fire-dependent forests in the northern Rocky Mountains. Q. Res. 3(3):408-424.

Hadfield, James S., and David W. Johnson.
1977. Laminated root rot—a guide for reducing and preventing losses in Oregon and Washington forests. USDA For. Serv. Pac. Northwest Reg., 16 p., illus.

Haig, Irvine T.
1932. Second-growth yield, stand, and volume tables for the western white pine type. U.S. Dep. Agric. Tech. Bull. 323, 67 p., illus.

Hall, Fredrick 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 Reg., Portland, Oreg.

Harvey, A. E., M. F. Jurgensen, and M. J. Larsen.
1979. Role of forest fuels in the biology and management of soil. USDA For. Serv. Gen. Tech. Rep. INT-65, 8 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Hawksworth, Frank G., and Delbert Wiens.
1972. Biology and classification of the dwarf mistletoes (Arceuthobium). U.S. Dep. Agric. Agric. Handb. 401, 234 p.

Hedrick, D. W., J. A. Young, J. A. B. McArthur, and R. F. Keniston.
1968. Effects of forest and grazing practices on mixed coniferous forest of northeastern Oregon. Agric. Exp. Stn., Tech. Bull. 103, 24 p. Oreg. State Univ., Corvallis.

Heinselman, Miron L.
1978. Fire in wilderness ecosystems. *In* Wilderness management. USDA For. Serv. Misc. Publ. 1365, p. 249-280.

Hepting, George H.
1971. Diseases of forest and shade trees of the United States. U.S. Dep. Agric. Agric. Handb. 386, 658 p.

Herman, Francis K., and Jerry F. Franklin.
1976. Errors from application of western hemlock site curves to mountain hemlock. USDA For. Serv. Res. Note PNW-276, 6 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Hopkins, William E.
1979a. Plant associations of the Fremont National Forest. USDA For. Serv. R-6 Ecol-79-004, 106 p. Pac. Northwest Reg., Portland, Oreg.

Hopkins, William E.
1979b. Plant associations of south Chiloquin and Klamath Ranger Districts, Winema National Forest. USDA For. Serv. R-6 Ecol-79-005, 96 p. Pac. Northwest Reg., Portland, Oreg.

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

Johnson, Gregory P.
1980. Site index equations for mountain hemlock on three habitat types in the central Oregon Cascades. M.S. thesis. Oreg. State Univ., Corvallis. 56 p.

Jones, John R.
1974. Silviculture of southwestern mixed conifers and aspen: The status of our knowledge. USDA For. Serv. Res. Pap. RM-122, 44 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Jorgensen, J. R., and C. G. Wells.
1971. Apparent nitrogen fixation in soil influenced by prescribed burning. Soil Sci. Soc. Am. Proc. 35(5):806-810.

Kilgore, B. M.
1971. The role of fire in managing red fir forests. Trans. 36th North Am. Wildl. and Nat. Resour. Conf., p. 405-416.

Kilgore, B. M.
1972. Impact of prescribed burning on a sequoia-mixed conifer forest. *In* Annual tall timbers fire ecology conf. proc., p. 345-375.

Kilgore, Bruce M., and George S. Briggs.
1972. Restoring fire to high elevation forests in California. J. For. 70(5):266-271, illus.

Larson, John E., Dan L. Campbell, James Evans, and Gerald D. Lindsey.
1979. Plastic tubes for protecting seedlings from browsing wildlife. USDA For. Serv. Equip. Dev. and Test Proj. Rep. 2217, 19 p. Equip. Develop. Center, Missoula, Mont.

Lawrence, W. H., N. B. Kverno, and H. D. Hartwell.
1961. Guide to wildlife feeding injuries on conifers in the Pacific Northwest. 44 p. West. For. and Conserv. Assoc., Portland, Oreg.

Leaf, Charles F.
1975. Watershed management in the Rocky Mountain subalpine zone: The status of our knowledge. USDA For. Serv. Res. Pap. RM-137, 31 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Leaphart, Charles D., R. D. Hungerford, and H. E. Johnson.
1972. Stem deformities in young trees caused by snowpack and its movement. USDA For. Serv. Res. Note INT-158, 10 p., illus. Intermt. For. and Range Exp. Stn., Ogden, Utah.

LeBarron, Russell K.
1957. Silvicultural possibilities of fire in northeastern Washington. J. For. 55(9):627-630.

Little, Elbert L., Jr.
1979. Checklist of United States trees (native and naturalized). U.S. Dep. Agric. Agric. Handb. 541, 375 p.

Lopushinsky, W., and T. Beebe.
1976. Relationship of shoot-root ratio to survival and growth of outplanted Douglas-fir and ponderosa pine seedlings. USDA For. Serv. Res. Note PNW-274, 7 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

McCambridge, William F., and Galen C. Trostle.
1972. The mountain pine beetle. USDA For. Serv. For. Pest Leafl. 2, 6 p.

McDonald, Philip M.
1976a. Forest regeneration and seedling growth from five cutting methods in north central California. USDA For. Serv. Res. Pap. PSW-115, 10 p., illus. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

McDonald, Philip M.
1976b. Shelterwood cutting in a young-growth mixed conifer stand in north central California. USDA For. Serv. Res. Pap. PSW-117, 16 p., illus. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Marquis, David A.
1977. Application of uneven-aged silviculture on public and private lands. *In* Uneven-aged silviculture and management in the western United States. USDA For. Serv. Proc. In-Service Workshop, p. 20-54. Oct. 1976, Redding, Calif.

Martin, Robert E.
1976. Prescribed burning for site preparation in the inland Northwest. *In* Tree planting in the inland Northwest, p. 134-156. Wash. State Univ., Pullman.

Martin, Robert E.
1979. Site preparation by fire [Abstr.]. Site preparation workshop of the Forestry Intensified Research Program, Medford, Oreg., Nov. 14-15, 1979. Oreg. State Univ., Corvallis.

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., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Minore, Don.
1979. Comparative autecological characteristics of Northwestern tree species —a literature review. USDA For. Serv. Gen. Tech. Rep. PNW-87, 72 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Newton, M.
1973. Environmental management for seedling establishment. For. Res. Lab., Sch. For., Oreg. State Univ., Corvallis. Res. Pap. 16, 5 p.

Norum, Rodney A.
1977. Preliminary guidelines for prescribed burning under standing timber in western larch/Douglas-fir forests. USDA For. Serv. Res. Note INT-229, 15 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Partridge, A. D., E. R. Canfield, and D. L. Kulhavy.
1978. Keys to major disease, insect, and related problems of forests in northern Idaho. For., Wild. and Range Exp. Stn. Contrib. 127, 100 p. Univ. of Idaho, Moscow.

Pfister, R. D.
1973. Habitat types and regeneration. Perm Assoc. Comm. Proc. 1972:120-125. West. For. and Conserv. Assoc., Portland, Oreg.

Pierovich, John M., Edward H. Clarke, Stewart G. Pickford, and Franklin R. Ward.
1975. Forest residues management guidelines for the Pacific Northwest. USDA For. Serv. Gen. Tech. Rep. PNW-33, 273 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Reineke, L. H.
1933. Perfecting a stand-density index for even-aged forests. J. Agric. Res. 46(7):627-638.

Rochelle, J. A., I. Guaditz, K. Oita, and J. H. K. Oh.
1974. New developments in big-game repellents. *In* Proceedings of wildlife and forest management in the Pacific Northwest symposium, Corvallis, Oreg., Sept. 11-12, 1973, p. 102-112. H. C. Black, ed., Sch. For., Oreg. State Univ., Corvallis.

Roe, Arthur L., Robert R. Alexander, and Milton D. Andrews.
1970. Engelmann spruce regeneration practices in the Rocky Mountains. U.S. Dep. Agric. Prod. Res. Rep. 115, 31 p.

Ronco, Frank.
1972. Planting Engelmann spruce. USDA For. Serv. Res. Pap. RM-89, 24 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Roth, L. F., and L. Rolph.
1978. Marking guides to reduce Armillaria root rot in ponderosa pine are effective. For. Sci. 24(4):451-454.

Ryan, R. B., and R. E. Denton.
1973. Initial releases of *Chrysocharis laricinellae* and *Dicladocerus westwoodii* for biological control of the larch casebearer in the western United States. USDA For. Serv. Res. Note PNW-200, 4 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Sartwell, Charles.
1971. Thinning ponderosa pine to prevent outbreaks of mountain pine beetle. *In* Proceedings of precommercial thinning of coastal and intermountain forests in the Pacific Northwest, Pullman, Wash., Feb. 3-4, 1971, p. 41-52. David M. Baumgartner, ed. Wash. State Univ., Pullman.

Sartwell, Charles, R. F. Schmitz, and W. J. Buckhorn.
1971. Pine engraver, *Ips pini,* in the western States. USDA For. Serv. For. Pest Leafl. 122, 5 p.

Sartwell, Charles, and Robert E. Stevens.
1975. Mountain pine beetle in ponderosa pine, prospects for silvicultural control in second-growth stands. J. For. 73(3):136-140.

Schmidt, Wyman C.
1966. Growth opportunities for young western larch. USDA For. Serv. Res. Note INT-50, 4 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Schmidt, Wyman C., Raymond C. Shearer, and Arthur L. Roe.
1976. Ecology and silviculture of western larch forests. U.S. Dep. Agric. Tech. Bull. 1520, 96 p.

Schumacher, Francis X.
1928. Yield, stand, and volume tables for red fir in California. Agric. Exp. Stn. Bull. 456, 26 p. Univ. Calif., Coll. Agric., Berkeley.

Seidel, K. W.
1973. Mixed pine-fir of eastern Oregon and Washington. In Silvicultural systems for the major forest types of the United States. U.S. Dep. Agric. Agric. Handb. 445, 124 p.

Seidel, K. W.
1974a. Freezing resistance of hardened and unhardened grand fir seedlings. Northwest Sci. 48(3):195-202.

Seidel, K. W.
1974b. Natural regeneration of east-side conifer forests. In Environmental effects of forest residues management in the Pacific Northwest—a state-of-knowledge compendium. USDA For. Serv. Gen. Tech. Rep. PNW-24, p. L-1 through L-25. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Seidel, K. W.
1975. Response of western larch to changes in stand density and structure. USDA For. Serv. Res. Note PNW-258, 11 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Seidel, K. W.
1977a. Levels-of-growing-stock study in thinned western larch pole stands in eastern Oregon. USDA For. Serv. Res. Pap. PNW-221, 14 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Seidel, K. W.
1977b. Suppressed grand fir and Shasta red fir respond well to release. USDA For. Serv. Res. Note PNW-228, 7 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Seidel, K. W.
1979a. Natural regeneration after shelterwood cutting in a grand fir-Shasta red fir stand in central Oregon. USDA For. Serv. Res. Pap. PNW-259, 23 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Seidel, K. W.
1979b. Regeneration in mixed conifer clearcuts in the Cascade Range and the Blue Mountains of eastern Oregon. USDA For. Serv. Res. Pap. PNW-248, 24 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Seidel, K. W.
1979c. Regeneration in mixed conifer shelterwood cuttings in the eastern Oregon Cascades. USDA For. Serv. Res. Pap. PNW-264, 29 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Seidel, K. W.
1980a. Diameter and height growth of suppressed grand fir saplings after overstory removal. USDA For. Serv. Res. Pap. PNW-275, 9 p. illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Seidel, K. W.
1980b. A guide for comparing height growth of advance reproduction and planted seedlings. USDA For. Serv. Res. Note PNW-360, 6 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Seidel, K. W., and R. Cooley.
1974. Natural reproduction of grand fir and mountain hemlock after shelterwood cutting in central Oregon. USDA For. Serv. Res. Note PNW-229, 10 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Shaw, C. G., III, and L. F. Roth.
1978. Control of *Armillaria* root rot in managed coniferous forests—a literature review. Eur. J. For. Pathol. 8(3):163-174.

Shearer, Raymond C., and Curtis H. Halvorson.
1967. Establishment of western larch by spring spot seeding. J. For. 65(3):188-193.

Sinclair, Clarence, and R. J. Boyd.
1973. Survival comparisons of three fall and spring plantings of four coniferous species in northern Idaho. USDA For. Serv. Res. Pap. INT-139, 20 p., illus. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Society of American Foresters.
1980. Forest cover types of the United States and Canada. F. H. Eyre, ed. 148 p. Washington, D.C.

Stage, Albert R.
1973. Prognosis model for stand development. USDA For. Serv. Res. Pap. INT-137, 32 p., illus. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Stewart, R. E.
1978. Site preparation, chap. 7. *In* Regenerating Oregon's forests—a guide for the regeneration forester, p. 93-129. Brian D. Cleary, Robert D. Greaves, and Richard K. Hermann, eds. Oreg. State Univ. Ext. Serv., Corvallis.

Thomas, Jack Ward, Glenn L. Crouch, Roger S. Bumstead, and Larry D. Bryant.
1975. Silvicultural options and habitat values in coniferous forests. *In* Proceedings of management of forest and range habitats for nongame birds symposium. D. R. Smith, ed. USDA For. Serv. Gen. Tech. Rep. WO-1, p. 272-287. Washington, D.C.

Thomas, Jack Ward, Ralph G. Anderson, Chris Maser, and Evelyn L. Bull.
1979a. Snags. *In* Wildlife habitats in managed forests. U.S. Dep. Agric. Agric. Handb. 553, p. 60-67. Washington, D.C.

Thomas, Jack Ward, Hugh Black, Jr., Richard J. Scherzinger, and Richard J. Pedersen.
1979b. Deer and elk. *In* Wildlife habitats in managed forests. U.S. Dep. Agric. Agric. Handb. 553, p. 104-127. Washington, D.C.

U.S. Department of Agriculture, Forest Service.
1965. Silvics of forest trees in the United States. H. E. Fowells, ed. U.S. Dep. Agric. Agric. Handb. 271, 762 p.

U.S. Department of Agriculture, Forest Service.
1973. National Forest landscape management, vol. 1. **U.S.** Dep. Agric. Agric. Handb. 434, 77 p.

U.S. Department of Agriculture, Forest Service
1974. Seeds of woody plants in the United States. C. ***S.*** Schopmeyer, tech. coord. U.S. Dep. Agric. Agric. Handb. 450, 883 p.

U.S. Department of Agriculture, Forest Service.
1977. Uneven-aged silviculture and management in the western United States. Proc. In-Service Workshop, 137 p. Oct. 1976, Redding, Calif.

U.S. Department of Agriculture, Forest Service.
[In press.] Timber, chap. **5.** *In* National Forest landscape management, vol. 2. U.S. Dep. Agric. Agric. Handb. 434.

Vogl, Richard J., and Calvin Ryder.
1969. Effects of slash burning on conifer reproduction in Montana's Mission Range. Northwest Sci. 43(3):135-147.

Volland, Leonard A.
1974. Relation of pocket gophers to plant communities in the pine region of central Oregon. *In* Proceedings of wildlife and forest management in the Pacific Northwest symposium, Corvallis, Oreg., Sept. 11-12, 1973, p. 149-166. H. C. Black, ed. Sch. For., Oreg. State Univ., Corvallis.

Volland, Leonard A.
1976. Plant communities of the central Oregon pumice zone. USDA For. Serv. R-6 Area Guide 4-2, 119 p. Pac. Northwest Reg., Portland, Oreg.

Wagener, W. W.
1961. Past fire incidence in Sierra Nevada forests. J. For. 59(10):739-748.

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

Weaver, H.
1974. Effects of fire on temperate forests: Western United States, chap. 9. *In:* Fire and ecosystems. T. T. Kozlowksi and C. E. Ahlgren, eds. p. 279-319. Academic Press, New York.

Wellner, Charles A.
1970. Fire history in the northern Rocky Mountains. *In* Proceedings on the role of fire in the Intermountain West symposium, Missoula, Montana, Oct. 27-29, 1970, p. 42-64. Intermt. Fire Res. Counc., and Univ. Mont., Missoula.

Wickman, Boyd E.
1978. **A** case study of a Douglas-fir tussock moth outbreak and stand conditions 10 years later. USDA For. Serv. Res. Pap. **PNW-244,** 22 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Wickman, Boyd E., Richard R. Mason, and C. G. Thompson.
1973a. Major outbreaks of the Douglas-fir tussock moth in Oregon and California. USDA For. Serv. Gen. Tech. Rep. PNW-5, 18 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Wickman, Boyd E., Galen C. Trostle, and Paul E. Buffam.
1973b. Douglas-fir tussock moth. USDA For. Serv. For. Pest Leafl. 86, 6 p.

Williams, Jerry T., Robert E. Martin, and Stewart G. Pickford.
1980. Silvicultural and fire management implications from a timber type evaluation of tussock moth outbreak areas. Proc. 6th Conf. Fire and For. Meteorolog., Seattle, Wash., April **22-24,** 1980, p. 191-196. Soc. Am. For., Washington, D.C.

Williamson, Richard **L.**
1973. Results of shelterwood harvesting of Douglas-fir in the Cascades of western Oregon. USDA For. Serv. Res. Pap. PNW-161, 13 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Appendix

Common and Scientific Names of Plants, Vertebrates, Insects, and Diseases[1]

PLANTS

Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco
Douglas-fir (Rocky Mountain)	*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco
Engelmann spruce	*Picea engelmannii* Parry ex Engelm.
Fir	
Grand fir	*Abies grandis* (Dougl. ex D. Don) Lindl.
Shasta red fir	*Abies magnifica* var. *shastensis* Lemm.
Subalpine fir	*Abies lasiocarpa* (Hook.) Nutt.
White fir	*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.
Greenleaf manzanita	*Arctostaphylos patula* Greene
Hemlock	
Mountain hemlock	*Tsuga mertensiana* (Bong.) Carr.
Western hemlock	*Tsuga heterophylla* (Raf.) Sarg.
Pine	
Lodgepole pine	*Pinus contorta* Dougl. ex Loud.
Ponderosa pine	*Pinus ponderosa* Dougl. ex Laws.
Western white pine	*Pinus monticola* Dougl. ex D. Don
Sierra evergreen chinkapin	*Casfanopsis sempervirens* (Kell.) Dudl.
Snowbrush ceanothus	*Ceanothus velutinus* Dougl. ex *Hook.*
Western larch	*Larix occidentalis* Nutt.
Western redcedar	*Thuja plicata* Donn ex D. Don
Willow	*Salix* spp.

INSECTS

Douglas-fir beetle	*Dendroctonus pseudotsugae* Hopkins
Mountain pine beetle	*Dendroctonus ponderosae* Hopkins
Douglas-fir tussock moth	*Orgyia pseudotsugata* (McDunnough)
Fir engraver	*Scolytus ventralis* LeConte
Pine engraver	*Ips pini* (Say)
Larch casebearer	*Coleophora laricella* (H*ubner)*
Spruce beetle	Dendroctonus rufipennis (Kirby)
Western spruce budworm	*Choristoneura occidentalis* Freeman
Modoc budworm	*Choristoneura viridis* Freeman
(no common name)	*Agathis pumila* (Ratzeburg)
(no common name)	*Chrysocharis laricinellae* (Ratzeburg)
(no common name)	*Dicladocerus westwoodii* Westwood

---

[1]Sources for nomenclature: trees, Little (1979); shrubs, Garrison, Skovlin, Poulton, and Winward (1976); insects, Furniss and Carolin (1977); and vertebrates, Ingles (1973). There is no standard reference for diseases.

DISEASES

Annosus root rot	***Fomitopsis (Fomes) annosa*** (Fr.) Karst.
Bleeding conk fungus	***Stereum sanguinolentum*** Alb. & Schw. ex Fr.
Dwarf mistletoe	***Arceuthobium*** spp.
Indian paint fungus	***Echinodontium tinctorium*** Ell. & Ev.
Laminated root rot	***Phellinus (Poria) weirii*** (Murr.) Gilb.
Mottled rot	***Pholiota*** spp.
Red ring rot	***Phellinus*** (Fomes) ***pini*** (Thore ex Fr.) Pilat
Red root and butt rot	***Polyporus tomentosus*** Fr. var. ***circinatus*** (Fr.)
Shoestring root rot	***Armillariella mellea*** (Fr.) Karst
White pine blister rust	***Cronartium ribicola*** Fisch.
Yellow pitted rot	***Hericium abietis*** (Weir ex Hubert) K. Harrison
(no common name)	***Bacillus thuringiensis*** Berliner

VERTEBRATES

Cattle	***Bos.*** spp.
Deer	***Odocoileus*** spp.
Deer mouse	***Peromyscus maniculatus*** (Wagner)
Elk	***Cervus*** spp.
Hare	***Lepus*** spp.
Pocket gopher	***Thomomys*** spp.
Porcupine	***Erethizon dorsatum*** (Linnaeus)
Rabbit	***Sylvilagus*** spp.
Sheep	***Ovis*** spp.
Voles	***Microtus*** spp.

Seidel, K. W., and P. H. Cochran.
1981. Silviculture of mixed conifer forests in eastern Oregon and Washington. USDA For. Serv. Gen. Tech. Rep. PNW-121, 70 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

The silviculture of mixed confier forests in eastern Oregon and Washington is described. Topics discussed include ecological setting, damaging agents, silviculture, and management. The relevant literature is presented, along with unpublished research, experience, and observations. Research needs are also proposed.

Keywords: Silviculture, mixed stands, coniferae, timber management, regeneration (stand), eastern Oregon, eastern Washington.

The Forest Service of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

The U.S. Department of Agriculture is an Equal Opportunity Employer. Applicants for all Department programs will be given equal consideration without regard to age, race, color, sex, religion, or national origin.

Pacific Northwest Forest and Range
Experiment Station
809 NE Sixth Avenue
Portland, Oregon 97232

GPO 994-672