United States
Department of
Agriculture

Forest
Service

Agriculture
Handbook
No. 445

# Silvicultural Systems for the Major Forest Types of the United States

## Selected Sections for North Central Idaho

## Acknowledgment

# Contents

# Introduction

The forests of the United States are coming under increasing pressure to provide more and better products and benefits for more and more people. This pressure has accelerated the development of procedures for multipurpose management planning to provide a mix of goods and services when and where they are needed. Forest culture, in turn, is being directed more toward the establishment and care of forests for a wide combination of uses. This trend requires an increasing flexibility in forest culture, and a knowledge of the silvicultural choices available for the important forest types of the United States. The purpose of this publication is to summarize the silvicultural systems that appear biologically feasible, on the basis of present knowledge, for each of 48 major forest types.

Great public interest focuses on the harvest cutting operation. However, in a well-managed forest, harvest cutting can be done only in the context of a complete system of forest culture. A system of forest culture must provide for harvesting, regenerating, and maintaining desired species of trees in a stand of suitable structure. This, in turn, can be done only through an orderly series of treatments. Each treatment must be performed on schedule for the system to attain specified objectives.

## Silvicultural Systems

The silvicultural systems discussed in this publication are selection, shelterwood, seed-tree, and clearcutting. These terms also refer to the method of harvest cutting that characterizes each system, but it is important for the forest manager to think in terms of a system of silviculture rather than only the method of harvest cutting.

The **selection system** involves the removal of mature and immature trees either singly or in groups at intervals. Regeneration is established almost continuously. The objective is maintenance of an uneven-aged stand, with trees of different ages or sizes intermingled singly or in groups. When properly applied, the system is esthetically pleasing, but is difficult to apply successfully in most forest types. The two types of selection are individual tree selection and group selection.

**Individual (single) tree selection** involves the removal of individual trees rather than groups of trees. In mixed stands it leads to an increase in the proportion of shade-tolerant species in the forest.

**Group selection** can be used to maintain a higher proportion of the less shade tolerant species in a mixture than individual tree selection. For this purpose larger harvest groups are more effective than smaller ones. In Eastern timber types, groups a fraction of an acre in size are generally suitable. In some Western timber types, where the stands are open or the trees are very tall, the groups may be as large as an acre or two. When groups are of maximum size, they resemble small clearcut patches. The group selection system is distinguished from clearcutting in that the intent of group selection is ultimately to create a balance of age or size classes in intimate mixture or in a mosaic of small contiguous groups throughout the forest.

The remaining silvicultural systems—shelterwood, seed-tree, and clearcutting— provide for even-aged management and result in stands of trees of about the same age. In each of these systems, it is important to plan the size, shape, and dispersion of the harvested areas to meet multiple-purpose management objectives.

In the **shelterwood system,** the mature stand is removed in a series of cuts. Regeneration of the new stand occurs under the cover of a partial forest canopy or shelterwood. A final harvest cut removes the shelterwood and permits the new stand to develop in the open as an even-aged stand. This system provides a continuing cover of either large or small trees. It is especially adapted to species or sites where shelter is needed for the new reproduction, or where the shelterwood gives the desired regeneration an advantage over undesired competing vegetation.

The **seed-tree system** involves harvesting nearly all the timber on a selected area in one cut. A few of the better trees of the desired species are left well distributed over the area to reseed naturally. When feasible, the seed trees are harvested after regeneration is established. This system applies mainly to conifers.

**Clearcutting** is the harvesting in one cut of all trees on an area for the purpose of creating a new, even-aged stand. The area harvested may be a patch, stand, or strip large enough to be mapped or recorded as a separate age class in planning for sustained yield under area regulation. Regeneration is obtained through natural seeding, through sprouting of trees that were in or under the cut stand, or through planting or direct seeding. This system requires careful location of boundaries to fit the landscape and appropriate cleanup of debris to improve the appearance of the harvested area. The absence of reserved trees on the clearcut area facilitates site preparation and other area-wide cultural treatments.

In past decades the silviculture of a number of mixed timber types was dictated by requirements for maintaining a high proportion of a single valuable species in the mixture, such as western white pine. Now, nearly all species are marketable, and silvicultural options that perpetuate any of these species are desirable as they result in additional species diversity.

Recent improvement in timber markets has coincided with greatly increased public interest in recreation, esthetics, wildlife, and other values of forests. In many places these nontimber values strongly influence the choice of silvicultural systems and cultural treatments such as site preparation and prescribed burning.

Perhaps the most important influences on the choice of silvicultural systems result from certain biological factors that silviculturists have learned about from long-term research and experience.

1

## Biological Factors Influencing the Choice of Silvicultural Systems

Biological factors frequently prevent the use of certain silvicultural systems. Some of the more common of these factors governing the choice of a silvicultural system recur in many of the timber types.

**Reproductive habits and requirements of the desired and competitive tree species** are among the most important factors influencing the choice of a silvicultural system. If forests are regenerated in the shade, the shade tolerant species will be favored and sooner or later will predominate. Fast-growing, shade-intolerant trees usually dominate stands regenerated in full light. The basic factors about requirements for regeneration and growth of the important forest trees of the United States are summarized in *Silvics of Forest Trees of the United States.*[1]

The choice of cultural measures and silvicultural systems must take the **requirements of wildlife** and their impact on forest vitality and reproduction into consideration. Browsing animals are favored by systems that provide clearings of appropriate size, shape, and dispersal for production and utilization of low browse. Squirrels are favored by systems or rotation lengths that result in abundant seed production and mature trees for nest sites. Consumption of seed by birds and rodents and damage to young trees by browsing and gnawing animals are serious enough in some timber types to influence the choice of silvicultural systems and cultural treatments.

**Hazards created by insects and diseases** are also important in the choice of silvicultural systems. When stands are heavily attacked by serious disease or insect pests, it may be necessary to remove the affected trees or the entire stand. Under other conditions, protecting against insects, such as infestations by pine shoot weevils, involves maintaining a canopy over the reproduction, as in the shelterwood system.

**Use of fire in forest culture** also may limit the choice of silvicultural systems. In a few forest types, periodic use of prescribed fire reduces hazardous accumulations of flammable debris and undesirable undergrowth. Periodic prescribed burning is adapted chiefly to even-aged stands, because the young regeneration present in all-aged stands is easily killed by fire. All-aged systems, on the other hand, leave less concentration of debris resulting from any one harvest cut and tend to make disposal of debris less essential.

**Climatic hazards** are another important element in the choice of a silvicultural system. For example, on sites subject to heavy frost near ground level, a new seedling crop must be started under a partial canopy of trees to protect the seedlings. On the other hand, certain mountain and coastal sites, subject to high wind velocities, should not be partially cut. Clearcutting is usually required on windy sites and in shallow-rooted forests on wet soils to avoid the risk of windthrow that occurs in partially cut stands.

Another serious constraint is imposed by the **size, age, and vigor of the trees in the existing stand**. A production forest composed wholly of trees of advanced age and declining vigor ordinarily requires a heavy harvest cut such as a clearcut, seed-tree, or shelterwood. Attempts to use the selection system in overmature even-aged stands have consistently resulted in high mortality among remaining trees. The selection system is better suited to stands composed of trees that vary considerably in age, size, and vigor.

Another natural factor in the choice of silvicultural systems is the **use of genetically improved trees** for the next crop. Improved strains of forest trees are coming out of the nurseries in increasing numbers, and superior trees of many important species will be produced in the future. With most species, the growth potential of these improved varieties can be realized only if they are planted and grown in properly cultured even-aged stands.

Of course, certain factors can lead to a decision that no harvest cutting should be done. They may include unstable soils unsuited for road construction, shallow soils or severe sites where a new crop cannot be started, or areas that have unique value in the untouched state.

Finally, the ultimate choice of the system for a particular tract involves analysis of various managerial constraints. These include availability of personnel, equipment, capital, and of markets for different classes of timber. These factors have an important bearing on the efficiency of operating under different silvicultural systems, but they vary so much with time and place that they are beyond the scope of this publication.

In the following pages experts briefly describe each major forest type as it occurs in the United States, the cultural requirements of the component species, the biological factors that control the choice of silvicultural options, and the silvicultural systems that are applicable.

An effort has been made to include metric equivalents of all English measurements in the text. This presents a variety of problems, especially in converting board feet to cubic feet and cubic meters. Board feet measurements based on various log rules have been converted, nonetheless, for the reader's convenience. These conversions should be viewed as estimates, however, rather than true measurements because of the assumptions involved in the conversion process.

The table of conversion factors for English to metric measurements begins on p. 186.

---

[1] Fowells, H. A., comp. Silvics of Forest Trees of the United States. Agric. Handb. 271. Washington, DC: U.S. Department of Agriculture; 1965. 762 p.

# Western Forest Cover Types

# Grand Fir, Douglas-Fir, and Associated Species (Eastern Oregon and Washington)

K. W. Seidel
*Pacific Northwest Forest and Range Experiment Station*

Tom Beebe
*Pacific Northwest Region*

The grand fir, Douglas-fir, and associated species type of eastern Oregon and Washington occupies about 6 million acres (2.4 million ha) on the east side of the Cascade Range and other ranges to the east.

The climax tree species in these forests are Rocky Mountain Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco), grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.), and white fir (*Abies concolor* (Gord. and Glend.) Lindl. ex Hildebr.). Both Douglas-fir and grand fir climax forests are found on the east slopes of the Washington Cascades south of the Entiat River. To the north, only Douglas-fir climax forests exist. In Oregon, the usual climax species is grand fir.[1]

Major pioneer species in these forests include Douglas-fir (a pioneer in grand fir forests), ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.), lodgepole pine (*P. contorta* Dougl. ex Loud.), and western larch (*Larix occidentalis* Nutt.). Other species occur in these forests only in minor quantities or in restricted habitats, such as streamside zones. These latter include nearly all of the tree species indigenous to eastern Oregon and Washington.

This forest cover type includes the northwesterly portion of the following Society of American Foresters forest cover types (7): interior Douglas-fir (210), white fir (211), western larch (212), and grand fir (213). It is found within the *Pseudotsuga menziesii* and *Abies grandis* Zones (11), which occupy a midslope position between the lower elevation *Pinus ponderosa* Zone and the high elevation *Abies-lasiocarpa* Zone.

Stand structure and species composition of the grand fir and Douglas-fir forests in eastern Oregon and Washington are extremely variable, depending upon site, logging history, insect attack, and wildfire. Both even- and uneven-aged stands occur. Typically, light-demanding species such as larch and pines become established in pure even-aged stands after severe disturbances from wildfire or blowdown, while the more shade tolerant true firs eventually form the climax vegetation after many years of stand stability.

Volcanic activity has played a major role in shaping much of the landscape. As a result, a great diversity in soils exists within this complex forest cover type. Many large areas in the Cascade Range and Blue Mountains are covered with deposits of pumice and volcanic ash that show little profile development because of their youth (11). Elevation is the primary factor influencing local climate. Average annual temperatures range from 42° to 50° F (5.6° to 10.0° C) and extremes are from about −45° to 110° F (−42.8° to 43.3° C). The frost-free season is relatively short and very irregular from year to year, with freezing temperatures occurring in any month of the year. Average annual precipitation ranges from about 15 inches (380 mm) at lower elevations to 50 inches (1270 mm) near the crest of the Cascade Range.

Seed production is generally adequate for natural regeneration with medium to heavy cone crops occurring at 3- to 4-year intervals (9). Species having small, light seeds such as western larch and lodgepole pine are the best seed producers, yielding some seed almost every year.

Heavier seeded species such as Douglas-fir and ponderosa pine have less frequent crops. Lighter crops of all species are especially subject to heavy insect and rodent depredations. Seed is dispersed chiefly by wind, although rodents carry away some seed and bury it. Much seed falls within 60 to 130 feet (18 to 40 m) of clearcut edges, with smaller amounts at greater distances.

Mineral soil is the most favorable seedbed for all coniferous species because it is a more stable source of water and is cooler than litter and duff (26). True firs become established better on mineral soil, but they also survive in light litter and duff layers up to about 0.5 inch (1.3 cm) deep (21). A mineral soil seedbed is more essential on south and west aspects.

Seedling mortality is generally greatest during the first growing season because of drought, temperature extremes, competing vegetation (especially grass), or animal damage. Temperature extremes can be mitigated by partial shade from an overstory or by light amounts of slash which reduce radiation cooling and decrease solar insolation. Severely burned seedbeds, such as areas where slash has been piled and burned, can also reduce seedling survival (22).

Seedlings of shade intolerant species such as western larch, lodgepole pine, and ponderosa pine grow rapidly in full sunlight and may reach a height of 4 feet (1.2 m) in 4 years (29). In contrast, height growth of the more shade tolerant true firs is slower initially, but they may eventually exceed the pioneer species in total height. Net volumes of even-aged stands of grand fir and Douglas-fir on high sites are impressive—yielding up to 18,940 cubic feet per acre (1326 m³/ha) at 100 years of age (4, 5, 6).

Mixed conifer forests are attacked by a large number of insects and diseases (12, 14). Insects causing serious damage over large areas include the western pine beetle (*Dendroctonus brevicomis* LeConte), the mountain pine beetle (*D. ponderosae* Hopkins), the Douglas-fir beetle (*D. pseudotsugae* Hopkins), the Douglas-fir tussock moth (*Orgyia pseudotsugata* (McDunnough)), the western spruce and Modoc budworms (*Choristoneura occidentalis* Freeman and *C. retiniana* (Walsingham)), and the larch casebearer (*Coleophora laricella* (Hubner)). The most practical silvicultural control to prevent bark beetle outbreaks is by harvesting susceptible overmature stands before epidemics and thinning overstocked young stands to maintain vigorous trees (19). The Douglas-fir tussock moth is a major defoliator of east-side mixed conifer forests, showing equal preference for Douglas-fir, grand fir, or white fir. It also attacks other species after the preferred hosts are consumed (31). It may be possible to reduce the severity of further outbreaks by maintaining pine on the more xeric sites

---

[1] Grand fir and white fir form a continuously varying biological complex in eastern Oregon and are treated alike for management purposes (11). Both species belong to the genus *Abies*. Members of this genus are collectively known as "true firs."

19

using prescribed fire (32). The larch casebearer is the most damaging defoliator of western larch. Some foreign parasitic wasps offer the best means of containing the casebearer (18).

The most serious diseases of mixed conifer forests are trunk and root rots and dwarf mistletoes (*Arceuthobium* spp.). The single most damaging pathogen in true firs is the Indian paint fungus (*Echinodontium tinctorium* (E. & E.) E. & E.). In the Blue Mountains, nearly 40 percent of the true fir old-growth volume is unmerchantable because of rot from this disease (1). In eastern Washington, an important fungal disease of Douglas-fir and true firs is shoestring root rot (*Armillariella mellea* (Vahl. ex Fr.) Karst.). Dwarf mistletoes are found on nearly every tree species in these coniferous forests. In most cases, these parasitic plants slow the growth of the host tree; but in the Douglas-fir forests of eastern Washington, an infestation is often fatal.

Fire is a primary natural force in forest ecosystems and has had a major impact on the forests in this type. Wildfire has influenced the age structure and species composition of the forest and produced a mosaic of even-aged stands intermixed with uneven-aged stands. It has also affected insect and disease populations, influenced nutrient cycles, and determined wildlife habitats (13, 30). Fire suppression during the past 70 years has drastically altered the natural ecological relationships resulting in large accumulations of residues and replacement of ponderosa pine by the shade tolerant true firs in communities where pine is a pioneer species. Properly used, prescribed fire can be a useful silvicultural tool for maintaining pioneer stands of ponderosa pine and other intolerant species, with a cycle of light, frequent, surface fires (16, 17).

Successional trends within the mixed conifer forest depend upon the shade tolerance of the species and have important implications for forest management. Observations suggest the following order of shade tolerance from most to least tolerant species: grand or white fir, Douglas-fir, ponderosa pine, lodgepole pine, western larch. In order to successfully apply selected silvicultural systems, 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 pioneer 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.

Because of the variety of species and stand conditions in this forest type, both even- and uneven-aged silvicultural systems can be used. In stands where timber production is an important objective, the use of an even-aged silvicultural system is recommended. 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. On the other hand, uneven-aged management is well suited where healthy uneven-aged stands exist or can be created in a reasonable time and conversion to more shade-tolerant species is not objectionable. Areas of high recreational or esthetic value such as near campgrounds and roadsides may be good choices for uneven-aged silviculture.

On the majority of productive forest sites in this type, the choice between even-aged and uneven-aged silvicultural systems depends primarily on factors other than the ecological limitations of the species (10). These factors include economic and social considerations, esthetics of cutover areas, and effect on soil, water, and wildlife habitat, limitations on suitable logging methods, and constraints imposed by insects, diseases, or potential animal damage.

The clearcutting method and the shelterwood method are recommended to create even-aged stands in this forest type (25). The seed tree method is not recommended because it does not commonly provide sufficient seed or protective overstory and the isolated trees are subject to windthrow.

Clearcutting is recommended as a harvesting method in old-growth mixed conifer stands where heavy infestations of dwarf mistletoe exist in both overstory and understory, or where rots are present. Clearcutting allows regeneration to develop without suppression or possible damage from a residual overstory and eliminates the risk of blowdown in areas where wind damage is common. It is well suited for regeneration of the pioneer tree species. On the other hand, there are also disadvantages. Understory vegetation such as greenleaf manzanita (*Arctostaphylos patula* Greene) and snowbrush (*Ceanothus velutinus* Dougl. ex Hook.) develops rapidly on many clearcuts, requiring measures to reduce competition to tree regeneration. Seedlings are subjected to greater temperature extremes resulting in frost damage or heat stress. And animal damage to reproduction is often greater on clearcuts than in partial cuts (3).

The primary application of clearcutting is for regeneration of mature stands on protected sites. Such sites are located generally on northwest to east aspects, where slopes range from 30 to 70 percent. Flatter uplands may also be suitable for clearcutting, especially in the more moderate environments of the grand fir climax forests. Here clearcutting often is limited to stands where medium- or fine-textured soils are generally over 30 inches (76 cm) deep and where insolation and frost are moderated by slope and aspect.

A mixture of planted species may be needed to resolve insect and disease problems common in single-species stands and to achieve full site utilization and wildlife and esthetic benefits. Planting should be done immediately after logging and slash disposal operations are completed, except where local experience shows that natural regeneration is sufficiently reliable to reforest the area in an acceptable period. Generally, natural regeneration is better on strip and patch clearcuts of 10 to 20 acres (4.0 to 8.1 ha) than on large clearcuts of 40 acres (16 ha) or more. The probability of obtaining adequate natural regeneration in clearcuts is greatest on northwest to east aspects; strips oriented perpendicular to the prevailing wind provide the best seed distribution and least chance of wind damage. No studies of direct seeding (broadcast or spot-seeding) in mixed conifer forests of eastern Oregon and Washington have been reported, and this practice is recommended only in more moderate environments where seed predators have been controlled and suitable seedbeds prepared.

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. It can also be used effectively with intolerant species by leaving fewer trees after the seed cut and removing them sooner after regeneration is established. It often slows the invasion of understory vegetation, thus leaving seedbeds more receptive to tree seedling establishment for a longer time. It reduces the chance of soil movement on steep slopes and decreases the probability of animal damage to regeneration. It also temporarily improves the visual quality of harvested units. 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.

Natural regeneration after shelterwood cutting, leaving a basal area of 60 to 80 square feet per acre (13.7 to 18.4 m²/ha) in the overstory, has generally been good to excellent in mixed conifer communities in the Oregon Cascades (23). Suitable seedbeds are provided by the logging and slash disposal if about 40 to 50 percent mineral soil is exposed. Because of the high probability of obtaining natural regeneration when using the shelterwood method, planting is generally not needed after the seed cut. The most efficient use of planting in these communities is to increase stocking if it is below minimum standards after removing the residual overstory.

On steeper ground in Washington and eastern Oregon, shelterwood cutting is usually recommended for the regeneration of mature stands growing on exposed sites. These are located generally on southeast to west aspects where slopes exceed 30 percent. Especially recommended for shelterwood regeneration are the harsher low-elevation Douglas-fir climax forests growing on exposed sites. Because of vegetative competition and irregular seed production, planting is usually necessary under such shelterwoods. The amount of shelter provided may vary according to the harshness of the site and the tolerance of the species planned for regeneration. Where no suitable shelter is available (due to root rot or other problems), small 8- to 12-acre (3.2 to 4.9 ha) clearcuts may provide the best alternative, especially when shaped so that trees on clearcut edges provide a maximum of shelter.

Site preparation is often a requirement of the regeneration process in Douglas-fir and grand fir forests. Although many species of shrubs, forbs, and grasses exist in these forests, the single most formidable competitor of planted seedlings is pinegrass (*Calamagrostis rubescens* Buckl.). The occupancy of a site by pinegrass is a slow process (generally 3 to 5 years after clearcutting), but once established, major site preparation efforts are required to obtain satisfactory survival of new conifer seedlings. Methods include tractor scarification (on flat ground), hand scalping, and hand or aerial herbicide treatment.

Many mixed conifer stands have suppressed true fir and Douglas-fir advance reproduction established in the understory. If sufficiently vigorous to respond rapidly to release, these trees can be used to form the new stand after the overstory is removed. Trees with live crown ratios of at least 50 percent have the best potential for rapid growth after release (20, 24). Although advance reproduction of released true fir can grow rapidly, there is a possibility that reactivation of dormant fungi by wounds may cause serious decay in the future (8).

Uneven-aged silviculture (single-tree and group selection) appears to be most suitable in those stands having a multi-storied or irregular structure and where dwarf mistletoe or heart rots are not major problems. The single-tree selection method provides maximum flexibility in choosing trees to cut or leave and favors the shade tolerant species. In group selection cutting, tree groups, ranging in size from a fraction up to about 1 acre (0.4 ha) are removed. The larger sized groups provide an opportunity for the shade intolerant species to be maintained in the stand, although growth of the regeneration may be suppressed by the mature trees surrounding these small openings. 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. Guidelines for the initiation of uneven-aged management in the Rocky Mountains may prove useful in eastern Oregon and Washington (2).

Thinnings are essential in many mixed conifer stands to maintain or improve growth and vigor. All species benefit from timely thinnings; but the highest priority for early precommercial thinnings should be given to overstocked stands of pioneer species such as larch, lodgepole pine, and ponderosa pine growing on good sites. Such thinnings should remove the smaller, slower growing trees, while maintaining a mixed species composition. The greatest gains from precommercial thinning occur when trees are about 10 to 15 feet tall (3.0 to 4.6 m), usually less than 20 years old, and before competition reduces crown size. The residual stocking depends on species and estimates of merchantable tree diameter but usually varies from 200 to 400 trees per acre (490 to 990 trees/ha).

In addition to their value as a source of timber, the mixed conifer forests in this type are of great importance in providing water, habitat for many species of wildlife, forage for livestock, and recreational opportunities. Fortunately, in most cases, timber management objectives can be a part of the multiple-use objectives.

Water yields from forested watersheds increase as a result of timber harvesting. Although no information is available for this forest cover type, work in the Rocky Mountains suggests that optimum snow accumulation may result from patch clearcutting when patches have a diameter 5 to 8 times the height of surrounding trees and are spaced about the same distance apart (15).

The habitat for big game and domestic livestock can be improved by the same cutting method which optimizes water yields—small patch clearcuts distributed throughout the mature stand (27). 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. Timber management also affects the habitat of other wildlife species. The 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 are available (28).

The esthetic value of these forests is often closely tied to the presence of scattered old-growth ponderosa pine, which can be maintained as a second age class in managed, young fir forests.

**Literature Cited**

1. Aho, Paul E. Decay of grand fir in the Blue Mountains of Oregon and Washington. Res. Pap. PNW-229. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1977. 18 p.
2. Alexander, Robert R.; Edminster, Carleton B. Uneven-aged management of old-growth spruce-fir forests: Cutting methods and stand structure goals for the initial entry. Res. Pap. RM-186. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1977. 12 p.
3. Barnes, Victor G., Jr. Pocket gophers and reforestation in the Pacific Northwest: A problem analysis. Special Scientific Rep.—Wildlife No. 155. Denver, CO: U.S. Department of Interior, U.S. Fish and Wildlife Service; 1973. 18 p.
4. Cochran, P. H. Gross yields for even-aged stands of Douglas-fir and white or grand fir east of the Cascades in Oregon and Washington. Res. Pap. PNW-263. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1979. 17 p.
5. Cochran, P. H. Site index and height growth curves for managed, even-aged stands of Douglas-fir east of the Cascades in Oregon and Washington. Res. Pap. PNW-251. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1979. 16 p.

6. Cochran, P. H. Site index and height growth curves for managed, even-aged stands of white or grand fir east of the Cascades in Oregon and Washington. Res. Pap. PNW–252. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1979. 13 p.

7. Eyre, F. H., ed. Forest cover types of the United States and Canada. Washington, DC: Society of American Foresters; 1980. 148 p.

8. Filip, G. M.; Aho, P. E. Incidence of wounding and associated stain and decay in advanced white fir regeneration on the Fremont National Forest, Oregon. Forest Insect and Disease Management Report, Region 6. Portland, OR: U.S. Department of Agriculture, Forest Service; 1978. 22 p.

9. Franklin, Jerry F. Cone production by upper-slope conifers. Res. Pap. PNW–60. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1968. 21 p.

10. Franklin, Jerry F.; DeBell, Dean S. Effects of various harvesting methods on forest regeneration. In: Even-aged management: Proceedings of the symposium. School of Forestry Pap. 843. Corvallis, OR: Oregon State University, 1973: 29–57.

11. Franklin, Jerry F.; Dyrness, C. T. Natural vegetation of Oregon and Washington. Gen. Tech. Rep. PNW–8. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1973. 417 p.

12. Furniss, R. L.; Carolin, V. M. Western forest insects. Misc. Publ. 1339. Washington, DC: U.S. Department of Agriculture; 1977. 654 p.

13. Heinselman, Miron L. Fire in wilderness ecosystems. In: Wilderness management. Misc. Publ. 1365. Washington, DC: U.S. Department of Agriculture; 1978: 249–280.

14. Hepting, George H. Diseases of forest and shade trees of the United States. Agric. Handb. 386. Washington, DC: U.S. Department of Agriculture; 1971. 658 p.

15. Leaf, Charles F. Watershed management in the Rocky Mountain subalpine zone: The status of our knowledge. Res. Pap. RM–137. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1975. 31 p.

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

17. Martin, Robert E.; Dell, John D. Planning for prescribed burning in the inland Northwest. Gen. Tech. Rep. PNW–76. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1978. 67 p.

18. Ryan, R. B.; Denton, R. E. Initial releases of *Chrysocharis laricinellae* and *Dicladocerus westwoodii* for biological control of the larch casebearer in the western United States. Res. Note PNW–200. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1973. 4 p.

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

20. Seidel, K. W. Suppressed grand fir and Shasta red fir respond well to release. Res. Note PNW–228. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1977. 7 p.

21. Seidel, K. W. Natural regeneration after shelterwood cutting in a grand fir–Shasta red fir stand in central Oregon. Res. Pap. PNW–259. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1979. 23 p.

22. Seidel, K. W. Regeneration in mixed conifer clearcuts in the Cascade Range and the Blue Mountains of eastern Oregon. Res. Pap. PNW–248. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1979. 24 p.

23. Seidel, K. W. Regeneration in mixed conifer shelterwood cuttings in the eastern Oregon Cascades. Res. Pap. PNW–264. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1979. 29 p.

24. Seidel, K. W. Diameter and height growth of suppressed grand fir saplings after overstory removal. Res. Pap. PNW–275. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1980. 9 p.

25. Seidel, K. W.; Cochran, P. H. Silviculture of mixed conifer forests in eastern Oregon and Washington. Gen. Tech. Rep. PNW–121. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1981. 70 p.

26. Seidel, K. W.; Cooley, R. Natural reproduction of grand fir and mountain hemlock after shelterwood cutting in central Oregon. Res. Note PNW-229. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1974. 10 p.

27. Thomas, Jack Ward; Black, Hugh, Jr.; Scherzinger, Richard J. [and others]. Deer and elk. In: Wildlife habitats in managed forests. Agric. Handb. 553. Washington, DC: U.S. Department of Agriculture; 1979: 104–127.

28. Thomas, Jack Ward; Anderson, Ralph G.; Maser, Chris [and others]. Snags. In: Wildlife habitats in managed forests. Agric. Handb. 553. Washington, DC: U.S. Department of Agriculture; 1979: 60–67.

29. U.S. Department of Agriculture, Forest Service. Silvics of forest trees of the United States. Agric. Handb. 271. Washington, DC: U.S. Department of Agriculture; 1965. 762 p.

30. Wellner, Charles A. Fire history in the northern Rocky Mountains. In: Proceedings on the role of fire in the Intermountain West symposium; 1970 October 27–29; Missoula, MT. Missoula, MT: University of Montana, Intermountain Fire Research Council; 1970: 42–64.

31. Wickman, Boyd E.; Mason, Richard R.; Thompson, C. G. Major outbreaks of the Douglas-fir tussock moth in Oregon and California. Gen. Tech. Rep. PNW–5. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1973. 18 p.

32. Williams, Jerry T.; Martin, Robert E.; Pickford, Stewart G. Silvicultural and fire management implications from a timber type evaluation of tussock moth outbreak areas. In: Proceedings of the 6th conference on fire and forest meteorology; 1980 April 22–24; Seattle, WA. Washington, DC: Society of American Foresters; 1980: 191–196.

# Ponderosa Pine and Rocky Mountain Douglas-fir

**Russell A. Ryker**
*Intermountain Forest and Range Experiment Station*

**Jack Losensky**
*Northern Region*

In the interior Northwest States of Montana, Idaho, and eastern Washington, ponderosa pine (*Pinus ponderosa* Dougl. ex Laws. var. *ponderosa*) and Rocky Mountain Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco) forests cover about 20 million acres (8 million ha). The two species occur together over an elevation range of about 4,000 feet (1220 m). Ponderosa pine is found from 1,000 to 6,000 feet (305 to 1830 m), and Douglas-fir from 1,800 to 8,000 feet (550 to 2440 m) (7). On the lower edge of its range, ponderosa pine is the climax tree species in the first forest zone above grasslands. Above this narrow zone, it is a topographic climax on steep southerly slopes or is a seral species on Douglas-fir and grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.) sites (11). With increasing elevation and precipitation, ponderosa pine gives way to Douglas-fir, which in turn gives way to grand fir on mid-elevations in northern Idaho and northwestern Montana and to subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) on higher elevations throughout the Northern Rocky Mountains.

These forests are represented by two Society of American Foresters forest cover types (5): Interior Ponderosa Pine (type 237) and Interior Douglas-fir (type 210). They include pure forests of ponderosa pine or Douglas-fir, or various mixtures of these two species and their major associates grand fir, western larch (*Larix occidentalis* Nutt.), and lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.). Timber productivity rates vary from 10 to more than 100 cubic feet per acre (0.7 to 7.0 m³/ha) per year, depending on site and stand conditions (9, 11, 14).

The distribution of ponderosa pine and Douglas-fir is strongly influenced by climate and available soil moisture. Ponderosa pine is not found in north-central and northeast Montana because of cold and windy conditions (1). Similarly, its distribution is limited in southwest and south-central Montana and central and eastern Idaho because of too little precipitation during May and June, a critical time for the survival of new seedlings (2). At higher elevations where moisture is adequate, the temperatures are too low. Though both species occur on a variety of soils, their distribution on drier sites is related to supplies of available soil moisture that, in turn, are related to soil texture and depth (7). Ponderosa pine extends into drier areas on sandy soils and along streams. Douglas-fir can be found on dry soils too, but only on higher elevations where temperatures are lower. Douglas-fir does not tolerate poorly drained soils or soils normally subjected to flooding during part of the year.

Precipitation ranges from about 14 inches (355 mm) on the lower ponderosa pine sites to 40 inches (1015 mm) on the higher elevations (7), but throughout the type July to August rainfall is deficient, often less than 1 inch (25 mm) (1, 5, 7). During the establishment of a new stand, the scant summer rainfall creates a need for protecting sites from the extremes of temperature and moisture losses that occur on exposed sites on southerly aspects.

Natural regeneration of ponderosa pine and Douglas-fir is sporadic. On the drier sites successful natural regeneration is thought to be the result of a chance combination of a good seed crop and favorable weather during the next growing season. Regeneration is enhanced by leaving enough trees to ameliorate temperature and moisture extremes in the openings, and to provide larger quantities of seed. On the driest sites, where ponderosa pine is the climax and only tree species, prompt natural regeneration is difficult to obtain no matter what cutting method is used, because the combination of good seed crops and moisture conditions favorable for seedling survival is infrequent. On more moist sites, ponderosa pine natural regeneration depends on timing the site preparation to coincide with a good seed crop. The number of seedlings can be increased by protecting the cone crop from tree squirrels and by reducing populations of seed-eating rodents (13).

Seed production directly influences regeneration and the cutting method that may be applied. Ponderosa pine is a poor seed producer west, and a fair producer east, of the Continental Divide in Montana. Most seed falls to the ground within 130 feet (39.6 m) of the parent tree. Douglas-fir is somewhat more prolific, and the effective dissemination distance is about twice that of ponderosa pine (7).

Prescribed fire and scarification are the methods most often used to create favorable conditions for regeneration. On the dry sites, it is imperative to control vegetation competing for the limited soil moisture. Seed germination and seedling establishment are best on mineral soil seedbeds; however, Douglas-fir can establish seedlings on litter if it is not more than 2 inches (5 cm) deep. Both species do well on burned seedbeds (6, 12, 15).

Planting of bareroot and container-grown trees has been widely used to reestablish ponderosa pine and Douglas-fir. Because of the low predictability of natural regeneration, these species are planted whenever prompt regeneration is needed. Successful planting requires good site preparation to control competing vegetation, and vigorous seedlings capable of initiating root growth soon after planting. Survival often depends on maintaining contact with the receding soil moisture level during summer drought.

New growth on young Douglas-fir trees is occasionally damaged by late-spring and late-summer frosts. Plantations established on high elevations with trees grown from seed collected at somewhat lower elevations are especially susceptible. Damage also occurs in some lower elevation valley bottoms that collect cold air when the protective cover of trees is removed. Ponderosa pine is seldom damaged by frost.

The potential of understory Douglas-fir to respond, grow, and become a vigorous forest once the overstory trees are cut, is most important in deciding on a cutting method. Some stands contain healthy understory trees that have large, vigorous crowns that enable them to grow rapidly once the overstory is removed. However, other mature stands contain small but old understory trees that have small crowns and do not possess the vigor to grow when released from competition. Many trees, though alive, are infected with dwarf mistletoe

53

or other diseases and are thus unsuitable for further management.

Ponderosa pine has excellent juvenile growth rates. Growth rates are generally slower for Douglas-fir. Young Douglas-fir trees appear to grow best with partial shade; whereas ponderosa pine requires full sunlight (7, 10).

Insects and disease can play a major role in establishment and development of trees in this forest type. Outbreaks of the western spruce budworm (*Choristoneura occidentalis* Freeman) have caused serious defoliation and growth loss of Douglas-fir. Heavy feeding by the budworm severely reduces seed production by Douglas-fir and is apparently responsible for regeneration failures in some areas (4). The Douglas-fir beetle (*Dendroctonus pseudotsugae* Hopkins) can cause serious losses. Old, dense stands containing a high proportion of Douglas-fir are most susceptible (8). The mountain pine beetle (*Dendroctonus ponderosae* Hopkins) is a primary killer of ponderosa pine trees. Group killing occurs in mature forests and in young over-stocked stands. The dwarf mistletoes (*Arceuthobium douglasii* Engelm. and *A. Campylopodum* Engelm.) are major enemies of Douglas-fir and of ponderosa pine in some areas. They infect trees of all ages, and although mortality is low, significant growth loss can occur along with lower lumber quality.

On Douglas-fir sites, fire has played an important role in the maintenance of seral stands of larch and pine (3). On the drier Douglas-fir sites, pure ponderosa stands were maintained by fire. On the more mesic sites within the range of western larch, the larch was favored as it is slightly more fire resistant than ponderosa pine and is less affected by crown scorch because it grows a new crop of needles each year. Though older Douglas-fir trees are also fire resistant, burning that destroys seedlings and saplings favors the aggressive pioneer species, larch and pine. On cooler sites lodgepole pine is the seral species maintained by fire. Although lodgepole pine can withstand light ground fire, it is generally considered susceptible to fire at all ages. It is, however, aggressive in reestablishment following a stand-destroying fire.

Depending on site and stand conditions, both even-aged and uneven-aged management systems are feasible. On dry climax ponderosa pine sites, prompt natural regeneration is difficult to obtain because of the need for the combination of good seed crops, good site preparation, and favorable weather during the first two growing seasons. Single tree and group selection cutting methods are usually prescribed. Site preparation in the openings should coincide with good seed crops. Heavy infections of dwarf mistletoe in many stands in Idaho and eastern Washington may limit the choice to clearcutting and planting in order to prevent infection of the regenerated stand. When ponderosa pine is managed in uneven-aged stands, low stand densities are needed to maintain reasonable individual-tree growth rates.

On moderate sites where Douglas-fir and ponderosa or lodgepole pine occur in mixture, group selection and shelterwood cutting methods are preferred, but the choice often depends on the amount of dwarf mistletoe. If a merchantable stand of ponderosa pine and Douglas-fir is vigorous and relatively free of dwarf mistletoe, these methods may be used. In stands where most of the Douglas-fir trees are badly infected with dwarf mistletoe and little mistletoe-free understory is present, a silviculturally satisfactory method is to clearcut the merchantable trees, dispose of remaining trees, prepare the site with mechanical equipment or fire, and establish a new stand by planting. In lightly infected stands, any partial cutting should be accompanied by cutting or killing infected trees.

On moist sites, Douglas-fir and ponderosa pine may occur in mixture with lodgepole pine, western larch, and grand fir. The seed tree, shelterwood, and clearcutting

methods are appropriate depending on insect and disease infestations and site and stand conditions. The shelterwood method is increasingly used in mature even-aged stands, but seed tree cutting is occasionally used, especially for regenerating western larch on northerly aspects. The clearcutting method is frequently used in overmature stands. Clearcutting is particularly useful in efforts to control insects and dwarf mistletoe. It also facilitates slash disposal and site preparation.

On higher elevation dry sites, Douglas-fir occurs in pure stands. The sites are severe, establishment of natural regeneration is slow, and juvenile growth rates are low. Often the Douglas-fir is heavily infected with dwarf mistletoe, and badly damaged by the western spruce budworm. If a merchantable stand is healthy and relatively free of dwarf mistletoe, a shelterwood or selection method of cutting may be used, but the regeneration period will be long. In stands heavily infected with dwarf mistletoe or badly damaged by the budworm, the only reasonable method is to clearcut if the timber is to be salvaged. However, clearcuts on these sites are difficult to regenerate even by planting.

The forests in this type are truly multiple-use forests. Some of the most important forest range for livestock found in the Northern Rocky Mountain region occurs in this forest type. Timber harvest and prescribed fire can significantly increase livestock and wildlife forage. Though this type is a low to moderate water producer, excessive soil disturbance can impact the many large streams flowing through the type, adversely affecting fish populations and increasing sedimentation in reservoirs. The majority of the present deer and elk winter range occurs in this type. Portions of the type are used by the grizzly bear and wolf. Because this forest type is located on lower elevations, esthetics and recreation must also be important management considerations.

## Literature Cited

1. Arno, Stephen F. Forest regions of Montana. Res. Pap. INT—218. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1979. 39 p.
2. Baker, F. S.; Korstian, Clarence F. Suitability of brush lands in the Intermountain Region for the growth of natural or planted western yellow pine forests. Tech. Bull. 256. Washington, DC: U.S. Department of Agriculture; 1931. 82 p.
3. Davis, Kathleen M.; Clayton, Bruce D.; Fisher, William C. Fire ecology of Lolo National Forest habitat types. Gen. Tech. Rep. INT—79. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1980. 77 p.
4. Dewey, Jerald E. Damage to Douglas-fir cones by *Choristoneura occidentalis*. J. Econ. Entomology 63(6): 1804—1806; 1970.
5. Eyre, F. H., ed. Forest cover types of the United States and Canada. Washington, DC: Society of American Foresters; 1980. 148 p.
6. Foiles, Marvin W.; Curtis, James D. Regeneration of ponderosa pine in the Northern Rocky Mountain region. Res. Pap. INT—145. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1973. 44 p.
7. Fowells, H. A., comp. Silvics of forest trees of the United States. Agric. Handb. 271. Washington, DC: U.S. Department of Agriculture; 1965. 762 p.
8. Furniss, Malcolm M.; Livingston, R. Ladd; McGregor, Mark D. Development of a stand susceptibility classification for Douglas-fir beetle. In: Proceedings, Hazard-rating systems in forest insect pest management symposium; 1980 July 31—August 1; Athens, GA. Gen. Tech. Rep. WO—27. Washington, DC: U.S. Department of Agriculture, Forest Service: 1981. 115—128.
9. Meyer, Walter H. Yield of evenaged stands of ponderosa pine. Agric. Handb. 630. Washington, DC: U.S. Department of Agriculture; 1938. 59 p.
10. Minore, Don. Comparative autecological characteristics of northwestern tree species—a literature review. Gen. Tech. Rep. PNW—87. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1979. 72 p.

11. Pfister, Robert D.; Kovalchik, Bernard L.; Arno, Stephen F.; Presby, Richard C. Forest habitat types of Montana. Gen Tech. Rep. INT—34. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1977. 174 p.

12. Ryker, Russell A. A survey of factors affecting regeneration of Rocky Mountain Douglas-fir. Res. Pap. INT—174. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1975. 19 p.

13. Shearer, Raymond C.; Schmidt, Wyman C. Natural regeneration in ponderosa pine forests of western Montana. Res. Pap. INT—86. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1970. 19 p.

14. Steele, Robert; Pfister, Robert D.; Ryker, Russell A.; Kittams, Jay A. Forest habitat types of central Idaho. Gen. Tech. Rep. INT—114. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1981. 137 p.

15. U.S. Department of Agriculture, Forest Service. The scientific base for silviculture and management decisions in the National Forest System: Selected papers. Washington, DC: U.S. Department of Agriculture, Forest Service; 1977. 59 p.

# Western Larch

**Wyman C. Schmidt and Raymond C. Shearer**
*Intermountain Forest and Range Experiment Station*

**John R. Naumann**
*Northern Region*

Western larch (*Larix occidentalis* Nutt.) grows in the upper Columbia River Basin, mostly in the Northern Rocky Mountains west of the Continental Divide. As a Society of American Foresters forest cover type (type 212) (3), it comprises a plurality of the stocking on nearly 3 million acres (1.2 million ha) and is an important stand component on additional millions of acres in most other forest cover types in northwestern Montana, northern and west-central Idaho, central and northeastern Oregon, central and eastern Washington, and southeastern British Columbia (8).

The western larch cover type usually occurs in mountain environments at elevations from about 2,000 to 5,500 feet (610 to 1675 m) in British Columbia— the northern part of its range—and up to 7,000 feet (2135 m) in south-central Idaho—the southern part of its range. It typically is found on north and east facing slopes, valley bottoms, and benches. However, in the mid-to-northern part of its range, particularly at higher elevations, larch can grow on all exposures.

The western larch type occurs on a wide variety of soils including deep, well-drained soils developed from glacial till of limestone, argillite, and quartzite bedrock of Precambrian origin; alluvium from the recent Tertiary; and lake sediments from the Pleistocene. Nearly all soils in the larch type have been influenced by volcanic ash deposits. Inceptisols and Alfisols comprise the bulk of the soils where this cover type predominates, but Spodosols also support some of the cover type at the cool-moist end of the type's environmental gradient.

Larch forests grow in relatively moist, cool conditions, with low growing-season temperatures limiting its upper elevational range, and deficient moisture its lower range. Mean annual temperature is about 44° F (6.7° C), with a range from about 37° to 52° F (2.8° to 11.1° C). Temperature extremes average as low as −35° F (−37.2° C) and as high as 105° F (40.6° C). During the May to August growing season temperatures average about 60° F (15.6° C) with July the warmest month. The frost-free period varies from about 60 to 160 days (usually early June to early September), but frosts may occur any month of the year.

Annual precipitation in the larch cover type ranges from about 18 to 50 inches (46 to 127 cm) with an average of 28 inches (71 cm) in the north to 32 inches (81 cm) in the south. About one-fifth of the moisture falls during the May to August period, most in May and June. July and August are characteristically hot and dry with low humidity and high evapo-transpiration rates under clear, sunny skies. Coastal maritime conditions influence this cover type even though much of it is 500 miles (805 km) inland, resulting in cloud cover much of the winter. Snow accounts for over one-half of the total annual precipitation and blankets most of the type from early November to late April (8).

Western larch is a long-lived seral species with a wide ecological amplitude (7). It grows in mixture with several other pioneer, subclimax, and climax species including ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) and Rocky Mountain Douglas-fir (*Pseudotsuga menziesii* var.

*glauca* (Beissn.) Franco) on the lower, warmer, and drier sites; grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.), western white pine (*Pinus monticola* Dougl. ex D. Don), western redcedar (*Thuja plicata* Donn. ex D. Don), and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) on moist sites; and Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), and mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.) on cool, moist locations (8).

Western larch can be regenerated quite easily by both natural and artificial methods. Good larch cone crops are produced at about 5-year intervals, with a ratio of about one good or fair crop produced for each poor crop (8). Occasionally, two good or up to four poor seed crops may occur consecutively. Dominant and codominant larch bear abundant cone crops throughout their crowns from about 40 through 500 years of age. The small seeds are usually dispersed by upslope thermal winds in late summer and fall; some seeds can be carried long distances (9). Most seeds fall near the edge of openings and decrease rapidly away from the source (9, 11). In years of good cone production, even the centers of clearcuts as large as 60 acres (24 ha) (800 feet (240 m) from the nearest seed source) receive seed for adequate stocking. Good cone crops average about 40 to 50 percent viable seed, but poor cone crops average less than 10 percent.

Burning or scarification is required to create favorable seedbed conditions for regeneration (7). Both the vegetative competition and duff layer must be reduced temporarily to promote early establishment of larch seedlings; otherwise, more shade tolerant species will dominate the new stand. Prescribed burning is preferred for site preparation and fuel reduction because little soil damage results (2), and larch seedlings grow best on burned seedbeds (8). More seedlings are established as the amount of soil exposed during site preparation increases and as the number of viable seed increases. Less bare soil is needed to achieve regeneration goals near a timber edge bordering a clearcut than near its center, or within shelterwood than with seed tree cuttings.

Western larch seeds germinate well when temperature and moisture are favorable (8). Natural stratification of larch seed during the winter prompts rapid and complete germination. Germination begins at snowmelt in late April on exposed low-elevation sites to mid-May or early June on sheltered north slopes at higher elevations (8). Larch seed germinates from a few days to 2 weeks before its associated tree species. Spring-sown larch seed without stratification has slow and incomplete germination, and some seeds germinate the next spring.

Aspect greatly influences seedling survival (8). Northwest to north to nearly east aspects, and gentle or flat topography provide the most favorable conditions for larch seedling survival. Seedling mortality begins at or soon after germination. Initially, fungi, rodents, and birds cause most loss. When the soil surface dries, particularly on unshaded south and west aspects, high temperatures at the soil-air interface cause heat girdling of new seedlings. Later, insuffi-

cient soil water may cause heavy drought losses. Frost heaving can kill young seedlings in the fall before snowfall and the next spring after snowmelt. Seedling mortality (usually caused by drought, frost heaving, and rodents) decreases the second and each successive year.

The natural regeneration principles just described apply equally to artificial regeneration, particularly direct seeding. Both broadcast and spot-seeding can be successful on well-prepared seedbeds, but should be limited to north and east exposures. Bare root and containerized seedlings can be successfully planted on sites that are adequately prepared. Planted larch survive best on well-drained soils and poorest on heavy soils. At higher elevations and south and west aspects, shade, such as that provided by logging debris, will increase plantation survival. Because larch seedlings break dormancy very early in the spring, and because survival is much better for stock that has not broken dormancy, fall lifting at the nursery, frozen winter storage, and cold field storage in the spring during outplanting is recommended.

Because western larch is the least shade tolerant conifer in the Northern Rockies (8), it requires nearly full sunlight for best development. Only in its early seedling stage can it tolerate any shade. In developing stands, it either dominates or loses vigor when overtopped, and dies if not released. Its widespread distribution has been attributed to frequent historic wildfire (13). Mature larch is well adapted to survive fire because of its thick and low-resin bark, its high and open branching habit, its low foliage flammability, and its low duff volume. However, fire normally kills most of the thin-barked seedlings and saplings. Scars on the survivors provide an entry for rot. Larch develops a deep and widespreading root system that makes it windfirm until root rots weaken the trees in old age. Snow and ice seldom damage larch because the needles are deciduous. However, wet snow in early fall or late spring can fall on a full complement of needles and cause severe bending in young trees and broken branches in older trees.

Growth patterns of the species that comprise the larch cover type are related to their shade tolerance (8). Larch and lodgepole pine are the least shade tolerant and, during the juvenile years, grow substantially faster than Douglas-fir, grand fir, and Engelmann spruce, their more tolerant associates. These species' differences ameliorate as the stands grow older, but larch normally retains the dominant position in the stand. Cultural practices improve and prolong growth if done before crown lengths and vigor are reduced. At age 100, larch heights range from 130 feet (40 m) on good sites to 65 feet (20 m) on poor sites. Diameter growth of western larch parallels height growth and is affected by many of the same factors. Larch has the potential for rapid diameter growth, but overstocking, insects, and dwarf mistletoe (*Arceuthobium laricis* (Piper) St. Johns) often decrease the potential. In fully stocked unmanaged stands basal area increases to about age 40, decelerates, and nearly levels off after age 100 when it has about 300 square feet per acre (68.9 m²/ha) on high-quality sites, and about 200 square feet per acre (45.9 m²/ha) on low-quality sites. Volume growth follows the same trend as basal area but peaks later. With full stocking, 7,765 cubic feet per acre (543.6 m³/ha) is a reasonable objective in 100 years on medium-quality sites (8). Intensive management using thinning and improvement cuttings should permit sawtimber production in 60 to 80 years (1).

Insects, disease, and other biological factors substantially reduce the growth potential for trees and stands in the larch cover type (8). The larch casebearer (*Coleophora laricella* (Hubner)), a larch defoliator, can reduce growth and cause occasional death, but weather factors and parasites appear to be limiting its damage potential. Western spruce

budworm (*Choristoneura occidentalis* Freeman) damages both shoots and cones, reducing height growth and seed production of larch. Other insects causing less extensive damage to larch are the larch sawfly (*Pristiphora erichsonii* (Hartig)), twolined larch sawfly (*Anoplonyx laricivorus* (Rohwer and Middleton)), larch budmoth (*Zeiraphera improbana* (Walker)), a western subspecies of the larch looper (*Semiothisa sexmaculata incolorata* (Dyar)), false hemlock looper (*Nepytia canosaria* (Walker)), Douglas-fir beetle (*Dendroctonus pseudotsugae* Hopkins), and the California fourspined ips (*Ips plastographus* (LeConte)). A cone maggot (*Hylemya* spp.) and a woolly adelgid (*Adelges* spp.) can cause high mortality of cones and seeds. Heavy infections of dwarf mistletoe kill treetops and reduce cone production, seed viability, wood quality, and height and diameter growth. Other damaging diseases are larch needle cast fungus (*Hypodermella laricis*, Tub.), quinine fungus (*Fomitopsis officinalis* (Vill. & Fr.) Bond & Sing.), and red ring rot (*Phellinus pini* (Thore) Pilat). Girdling and stripping of cambium by bears and squirrels can cause serious local problems.

The western larch cover type can easily be maintained by silviculture practices that parallel the natural processes, such as wildfire, which have perpetuated this cover type. Developing and maintaining a plurality or majority of western larch in a stand is effectively achieved by even-aged management systems. These systems, using shelterwood, seed tree, or clearcut cutting methods, best meet the regeneration requirements of this intolerant species. Western larch is difficult to maintain as a cover type with uneven-aged management systems. However, some larch can be regenerated with uneven-aged management systems if the growing stock levels of reserve stands are kept low and the site is prepared. Of the two uneven-aged systems, the group selection cutting method comes closest to satisfying the regeneration needs of western larch, but may not provide enough of this species in a stand over time to constitute a plurality of larch. The single tree selection cutting method provides the least favorable conditions for the establishment and development of western larch and tends to convert the cover type to the more shade-tolerant species. Also, dwarf mistletoe can become a significant problem using uneven-aged management methods but can be largely eliminated by using even-aged management methods.

The shelterwood cutting method is most effectively used on south and west aspects where some protection is needed for survival of new seedlings (8). Seeding or planting may be required in poor seed years to take advantage of mineral soil exposed by site preparation efforts. If associated species are retained with western larch in the overstory, the shelterwood cutting method increases species diversity in regenerated stands. Once regeneration is established, the overstory must be removed promptly to maintain environmental conditions that will retain western larch as a viable component in the new stand and prevent infection from possible sources of dwarf mistletoe from the overwood. Early removal of the reserve trees also results in the least amount of damage to the young stand. Shelterwood cutting may not be wise if overstory western larch are heavily infected with dwarf mistletoe or if adequate site preparation is seriously hampered by the residual trees retained for seed and shelter. While shelterwood cutting may sometimes be used primarily to meet multiple-resource needs, overwood densities must be lighter on less severe north and east aspects. The longer the overwood is retained for resource needs other than timber production, the less chance there is to perpetuate western larch as a cover type because the more tolerant trees will dominate.

Seed tree and clearcut harvest cutting methods generally utilize the same silvicultural principles and produce the same

results. The seed tree method provides a more uniform seed distribution and allows the retention of some mature trees for cavity-nesting birds and animals. Clearcutting offers the greatest choice and ease of site preparation and provides a favorable environment for the establishment of regeneration on all but hot and dry exposures. Here shelterwood cuttings might be more appropriate, but, if clearcutting is the only option, larch may have to be planted to maintain this species as a stand component.

Immature stands in the larch cover type respond rapidly and substantially to cultural practices, and there are nearly always enough conifer species present to mold a diversified stand. Early thinning should be the rule in this cover type. It prevents height suppression found in heavily overstocked stands, effectively concentrates diameter growth on the featured trees, and retains crowns on the shade-intolerant larch. Furthermore, thinning reduces overall water consumption, increases understory vegetation, and keeps the stand in a vigorous condition so that it is better able to recuperate after insect attacks (6).

Thinning stands 40- to 50-years old and older in the larch cover type is less effective than early thinning. At this age, the more tolerant Douglas-fir, Engelmann spruce, and grand fir are better able to capitalize on the increased growing space than are larch or lodgepole pine. Because larch crowns are so intolerant of shade, they are substantially shortened in heavily overstocked stands, and they respond more slowly than their associates that retain fuller crowns. As a result, moderately overstocked stands respond more rapidly than heavily overstocked stands.

Selection of species to feature in stand culture should be based on knowledge of the productivity of species within the different ecological habitat types that make up the larch cover type. On nearly all habitat types larch should be one of the featured species. Species diversity can be maintained by thinning and other intermediate cuttings. This capitalizes on the rapid juvenile growth of larch, retains those species that reach their greatest potential at a later age, and provides some insurance against host-specific insect and disease attacks.

The western larch type occupies lands that produce a wide variety of forest resources. Western larch is a premier species for the production of plywood, lumber, and wood fiber for pulp and paper products.

Even-aged management methods generally give forest managers the flexibility they need to enhance or maintain forage production for wildlife and livestock, water quality and yield, wood production, and esthetics (10). Forage production for big game, such as elk, moose, and deer, is high with even-aged silviculture systems, but excessive size openings can reduce visual and thermal cover and discourage use by these animals. Uneven-aged management is sometimes used to maintain specific habitat conditions for certain timber, wildlife, water quality, and esthetic situations. Special management considerations are often needed; for example, cavity-nesting animals and birds prefer old, broken-topped larch, and some should be retained in harvested areas to provide that habitat (4, 12).

Several rare and endangered species that live in this cover type include grizzly bear, grey wolves, bald eagles, and peregrine falcons. For grizzly bear habitat, size of openings and retention of forbs and berry-producing plants are important considerations. Grey wolf habitat is benefitted by practices that favor deer and elk—the wolf's food source. Habitat for eagles and falcons is influenced by site-specific considerations rather than broad management strategies applied to favor the larch cover type.

Water quality is seldom affected by careful harvest cutting, site preparation, or stand culture. However, care must be taken in the design, construction, and maintenance of access roads because they are the greatest potential source of soil movement. Water yields are moderate in this cover type in relation to other cover types in the Northern Rockies. Water yields are increased by harvest cutting and thinning in direct relation to the amount of forest removed. However, rapid tree and understory vegetation development soon ameliorates these increases (5).

Fall and spring coloration of larch, a deciduous conifer, adds unique esthetic diversity to areas where it is perpetuated in this cover type. The effect of silviculture systems on the visual resource depends upon the objectives established for an area. Viewing requirements can be satisfied if harvest cuttings are carefully shaped, residues properly managed, and tolerant understories retained in some foreground views.

## Literature Cited

1. Adams, David L. The Northern Rocky Mountain Region. In: Barret, John W., ed. Regional silviculture of the United States. New York: John Wiley; 1980: 341−389.
2. DeByle, Norbert V. Clearcutting and fire in the larch/Douglas-fir forests of western Montana—a multifaceted research summary. Gen. Tech. Rep. INT−99. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1981. 73 p.
3. Eyre, F. H., ed. Forest cover types of the United States and Canada. Washington, DC: Society of American Foresters; 1980. 148 p.
4. McClelland, B. R.; Frissell, S. S.; Fischer, W. L.; Halvorson, C. H. Habitat management for hole-nesting birds in forests of western larch and Douglas-fir. J. For. 77(8): 480−483; 1979.
5. Newman, Howard C.; Schmidt, Wyman C. Silviculture and residue treatments affect water used by a larch/fir forest. In: Proceedings, Symposium on environmental consequences of timber harvesting in Rocky Mountain coniferous forests. Gen. Tech. Rep. INT−90. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1980: 75−110.
6. Schmidt, Wyman C. Some biological and physical responses to forest density. In: Proceedings, Eighth World Forestry Congress; 1978 October 16−28; Jakarta. Forestry for Quality of Life 25(2): 1−11; 1978.
7. Schmidt, Wyman C.; Shearer, Raymond C. Western larch. In: Silvicultural systems for the major forest types of the United States. Agric. Handb. 445. Washington, DC: U.S. Department of Agriculture; 1973: 37−38.
8. Schmidt, Wyman C.; Shearer, Raymond C.; Roe, Arthur L. Ecology and silviculture of western larch forests. Tech. Bull. 1520. Washington, DC: U.S. Department of Agriculture; 1976. 96 p.
9. Shearer, Raymond C. Regeneration establishment in response to harvesting and residue management in western larch−Douglas-fir forest. In: Environmental consequences of timber harvesting in Rocky Mountain coniferous forests. Gen. Tech. Rep. INT−90. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1980: 249−269.
10. Shearer, Raymond C. Silvicultural systems in western larch forests. J. For. 69(10): 732−735; 1971.
11. Shearer, Raymond C. Silviculture. In: DeByle, Norbert V., ed. Clearcutting and fire in the larch/Douglas-fir forests of western Montana—a multifaceted research summary. Gen. Tech. Rep. INT−99. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1981: 27−31.
12. Thomas, Jack Ward; Miller, Rodney J.; Black, Hugh; Rodiek, Jon E.; [and others]. Guidelines for maintaining and enhancing wildlife habitat in forest management in the Blue Mountains of Oregon and Washington. Trans. North Am. Wildl. Nat. Resource. Conf. 41: 452−476; 1976.
13. Wellner, Charles A. Fire history in the Northern Rocky Mountains. In: The role of fire in the Intermountain West, Symposium; 1970 October 27−29, Missoula, MT. Missoula, MT: University of Montana, Intermountain Fire Research Council; 1970: 42−64.

# Engelmann Spruce – Subalpine Fir

Robert R. Alexander
*Rocky Mountain Forest and Range Experiment Station*

Orville Engelby
*Intermountain Region*

The Engelmann spruce–subalpine fir type, Society of American Foresters forest cover type 206, occupies about 10 million acres (4 million ha) in the western United States. These forests grow on areas of moderate to high timber production potential. They are also important water yielding areas, and they provide habitat for a wide variety of wildlife, forage for livestock, and recreational opportunities and scenic beauty. Much land now covered by seral tree species such as lodgepole pine (*Pinus contorta* Dougl. ex Loud.) and other vegetation also has the potential to grow spruce and fir (4, 7).

Spruce–fir forests are widely distributed. In the Pacific Northwest, the type is found along the crest and east slope of the Cascade Mountains of Washington and Oregon to Mt. Shasta in California. In the Rocky Mountains, it ranges from Idaho and Montana and adjacent mountains of eastern Washington and Oregon; then south through the high mountains of Utah, Wyoming, Colorado, New Mexico, and northern Arizona (1, 2, 7).

Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) are the only tree species common throughout the type, but their proportions and site preferences vary. In the Rocky Mountains of Idaho and Montana and associated ranges, and in the Pacific Northwest, the spruce element of the type usually occupies moist sites at lower elevations (2,000 to 6,000 ft (610 to 1830 m)), stream bottoms, and basins characterized by slow drainage and accumulation of cold air. The subalpine fir element extends above the spruce–fir zone, and at timberline (8,000 to 11,000 ft (2440 to 3350 m)) may form pure stands that are either seral or climax. More often, subalpine fir is found at timberline in association with subalpine larch (*Larix lyallii* Parl.), whitebark pine (*Pinus albicaulis* Engelm.), and mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.) where it may be replaced by the mountain hemlock type. South of Montana and Idaho in the Rocky Mountains and associated ranges, the spruce–fir type makes up the timberline forests (9,500 to 12,000 ft (2895 to 3655 m)). In Colorado, Wyoming, and Utah, both spruce and fir are characteristically present, but subalpine fir rarely predominates at timberline. In the Rocky Mountains of Arizona and New Mexico, spruce extends above subalpine and cork-bark fir (*Abies lasiocarpa* var. *arizonica* (Merriam) Lemm.), forming nearly pure stands at timberline (7).

The spruce–fir type grows in a humid climate with long, cold winters and short, cool summers. It occupies the highest, coldest, and wettest forested continental climate in the western United States, characterized by heavy snowfall (150 to 400+ inches (3810 to 10 160 mm)), and temperature extremes of more than $-50°$ F ($-45.6°$ C) to above $90°$ F ($32.2°$ C). The range of mean annual temperatures is narrow considering the wide distribution of the type. Average annual temperatures are near freezing ($30°$ to $35°$ F ($-1.1°$ to $1.7°$ C)), and frost can occur any month of the year. Average precipitation exceeds 24 inches (610 mm) annually, with little or no seasonal moisture deficiencies. Summer is the driest season in the Cascades and in the Rocky Mountains

west of the Continental Divide to southern Colorado. The northern Rocky Mountains east of the divide, and the mountains in southwestern Colorado, in southern Utah, and in New Mexico and northern Arizona receive considerable summer rainfall (1, 2).

Engelmann spruce, which is the most valuable timber species of the type, is frequently difficult to regenerate either naturally or artificially, particularly in openings at high elevations, lower latitudes, and on southerly aspects. While spruce is restricted to cold, humid habitats, solar radiation is high at elevations where spruce grows in the Rocky Mountains. Newly germinated and planted seedlings are not resistant to drought or heat girdling; in the central and southern Rocky Mountains, spruces planted in the open are also frequently killed by solarization (light injury). Mountain pocket gophers periodically cause heavy mortality to natural and planted spruces, and trampling damage can be severe if livestock are not excluded from newly regenerated areas (3, 10).

Spruce reproduces best in partial shade and on protected sites, and many old-growth forests have an understory of advanced reproduction, some of which is spruce. If logging damage to established regeneration is controlled, these stands may be managed by removing the overstory and releasing the advanced growth (3, 4, 9). Where seral species are part of the original overstory, and a seed source and suitable seedbed conditions exist, they may regenerate after the overstory is removed, thus providing an opportunity for mixed species management in the replacement stand.

In stands without advanced growth, spruce regenerates from seed provided there is a dependable seed supply, at least 40 percent of the seedbeds are exposed mineral soil, and environmental conditions are favorable (3, 11). Shade and other forms of site protection are especially important to early survival and growth because they lower temperatures, thereby reducing moisture losses from soil and seedlings.

Engelmann spruce is a moderate seed producer, with good crops occurring about every 2 to 5 years. The amount of seed produced is in direct proportion to the basal area of dominant and codominant spruces of the seed source. Spruce seed is light and dispersed by wind or gravity, but usually less than 10 percent of the seedfall is dispersed beyond 300 feet (91 m) from the windward source, except in years of bumper seed crops when about 5 to 10 percent of the seedfall may be dispersed as far as 600 feet (183 m) (1, 11). In the Rocky Mountains, the maximum size opening likely to restock naturally on shaded mineral soil seedbeds on north slopes, is 400 to 500 feet (122 to 152 m) wide, and it will require at least 20,000 sound seeds per acre (49 420/ha) to produce 1,000 first-year seedlings per acre (2470/ha). On south slopes, the maximum size opening is only 100 to 200 feet (30.5 to 61.0 m) wide, and it will require at least 100,000 sound seeds per acre (247 100/ha) to produce 1,000 first-year seedlings per acre (2470/ha). Moreover, adequate stocking will usually require more than one good seed year. On unshaded and unprepared seedbeds, openings 50 to 100 feet (15.2 to 30.5 m) wide will restock on north

slopes, but will require a number of good seed years. On south slopes under similar conditions, few seedlings survive in openings. If openings larger than these are cut, the area beyond effective seeding distance must be planted (3, 10, 11).

Partial cutting is more likely to result in evenly distributed natural reproduction than clearcutting, but it may favor fir and other more tolerant associates over spruce. While spruce can be sucessfully regenerated artificially, planting has been used primarily to fill in gaps where natural regeneration has failed, or to regenerate burns or large areas clearcut to control insects (4).

At high elevations, the early growth of naturally established spruce and fir is very slow. Trees typically reach 4 to 5 feet (1.2 to 1.5 m) in height in the open or under a light overstory in about 20 years, and under a moderate overstory shade in about 40 years. Severe suppression of seedling growth does occur at low light levels. Trees may be 80 to 100 years old and only 3 to 5 feet (0.9 to 1.5 m) tall under a very dense overstory. At lower elevations growth is considerably faster. For example, planted trees in the northern Rocky Mountain and Intermountain Regions may reach 4 to 5 feet (1.2 to 1.5 m) in the open in 10 years or less. Once trees reach this size with sufficient space to grow, their growth rate will equal or exceed that of their common associates, even after long periods of suppression (9). Spruce is long-lived and has the capacity to make good growth at advanced ages. If given sufficient space, it will continue to grow steadily in diameter for 300 years, long after the growth of most common associates slows down. Subalpine firs older than 250 years are rare (1, 2).

Where Engelmann spruce and subalpine fir form the spruce−fir type, and mountain hemlock and other true firs are limited in number or absent, spruce is rated shade tolerant and subalpine fir as very shade tolerant. They are definitely more shade tolerant than such common associates as Rocky Mountain Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Biessn.) Franco), western larch (*Larix occidentalis* Nutt.), lodgepole pine, and quaking aspen (*Populus tremuloides* Michx.) (7).

The type forms either climax or long-lived seral forest vegetation throughout much of its range. In the Rocky Mountains south of Montana and Idaho, spruce and fir are considered climax species and occur as codominants or in nearly pure stands of one or the other. In the Rocky Mountains of Montana and Idaho, and in Utah, eastern Oregon, and Washington, subalpine fir is the major climax species. Spruce may occur as a climax, but more often it is a persistent long-lived seral species. Pure stands of either species may be found, however (7).

Although spruce−fir forests form climax or near climax vegetation associations, they differ from most climax forests in that stands are not generally all-aged. Differences in stand characteristics complicate the selection of silvicultural systems and cutting methods needed to convert old-growth forests to managed stands. Some stands are clearly single- or two-storied, indicating that spruce−fir forests can be successfully grown under even-aged management. Other stands are three- to multi-storied, indicating that these forests can also be successfully grown under uneven-aged management (3, 5, 8).

Where the type is the climax forest, it is not easily displaced by other vegetation, but fire, logging, and insects have played an important part in the sucessional status and composition of spruce−fir forests. Complete removal of the stand results in such drastic environmental changes that spruce and fir are usually replaced by lodgepole pine (the most ubiquitous and conspicuous of the several seral conifer-

ous species that initially replace spruce−fir), aspen, or shrub−forb−grass communities unless sites are prepared and planted to spruce (7, 11). The harshness of the site, severity of disturbance, and the kind of vegetation initially occupying the site usually determines the length of time required to return to a spruce−fir forest. It may vary from a few decades on cutover, protected sites initially occupied by lodgepole pine or aspen, to as many as 300 years or more on high altitude burns where grass is the replacement community (1, 2). Another feature of the spruce−fir forests is the imbalance in age-class distribution. More stands are in old-growth sawtimber than in pole or seedling and sapling stands (3).

Windfall is a common cause of mortality after any kind of initial cutting in old-growth spruce−fir forests, but partial cutting increases the risk because the entire stand is opened up. Windfall is usually less around clearcut openings because only the boundaries between cut and leave units are exposed, but losses can be substantial if no special effort is made to locate windfirm cutting unit boundaries. While the tendency of spruce and fir to windthrow is usually attributed to a shallow root system, the development of the roots varies with soil and stand conditions. Regardless of the kind or intensity of cutting, or soil and stand conditions, windthrow is greater on ridgetops, saddles in ridges and upper slopes, and on upwind aspects than on other topographic exposures (3).

Spruce beetle (*Dendroctonus rufipennis* (Kirby)) is the most serious insect pest attacking old-growth Engelmann spruce (12). Outbreaks have been largely associated with extensive windthrow. They have also started in cull material left after logging, and high beetle populations have built up in scattered trees windthrown after heavy partial cutting where a cool shaded situation is maintained (3, 12). Subalpine fir is attacked by several insect pests including bark beetles and western spruce budworm in the Rocky Mountains, but the most destructive insect is the balsam woolly adelgid (*Adelges piceae* (Ratzeburg)), introduced from Europe, which has virtually eliminated subalpine fir from some stands in the Pacific Northwest. Wood rot is common in subalpine fir, especially in residual trees damaged in partial cutting or older than 100 years (2).

Both even- and uneven-aged silvicultural systems can be used in spruce−fir forests, but not all cutting methods under each system are applicable in every stand nor will every cutting method meet specific management objectives. Spruce−fir forests are harvested by clearcutting, shelterwood, and selection cutting. Because of susceptibility to windthrow, the seed-tree method is not suitable as a regeneration method. Shelterwood can be standard, modified, or simulated. Modified shelterwood delays the final harvest until the replacement stand is tall enough to provide a forested aspect (at least 4 to 6 ft (1.2 to 1.8 m)). Simulated shelterwood removes the overstory from a naturally established manageable stand of advanced reproduction. Selection cutting removes trees singly, in groups of a fraction of an acre up to 2.0 acres (0.8 ha), or in a combination of individual tree and group removal (4).

In old-growth spruce−fir forests, if the harvest is primarily for timber production including the salvage of decadent stands, and the risks of windfall and/or spruce beetle attack are high, there is little choice but to clearcut the area and start a new stand. If management considerations preclude clearcutting, these stands must usually be left uncut, running the risk of the loss of most of the merchantable sized trees (3).

If windfall and spruce beetle problems are not limiting, and management objectives include maintenance of high forests or the combination of openings and high forests, a shelterwood method can be used in single- , two- , and even

three-storied stands, and a selection system in multi-storied stands if trees are uniformly spaced. Group selection with openings of a fraction of an acre up to 2 acres (0.8 ha), or clearcutting in small (3 to 5 acre (1.2 to 2.0 ha)) patches should be used in stands where trees are clumpy, groupy, or patchy to take advantage of the natural arrangement of trees (3). The initial entry into any old-growth stand under any partial cutting method should be light to minimize windfall losses.

In uncut old-growth spruce—fir forests, current average annual increment will vary from a net loss due to mortality up to 200 board feet (fbm) (Scribner Decimal C Log Rule) (40 ft$^3$)$^1$ per acre (2.8 m$^3$/ha), depending upon the age and vigor of the stand. All harvest cutting methods will salvage mortality, but none of the partial cutting methods are likely to significantly increase increment on residual trees. However, few old-growth stands will be managed solely for their timber resource. Manipulation of vegetation for esthetics, recreation, wildlife habitat and forage, and water production will require a combination of cutting methods within constraints imposed by stand conditions, silvical characteristics, windfall risk, and spruce beetle populations (1, 3). While no spruce—fir stands have been under management for a long period of time, the probable growth responses to different stand parameters can be estimated by using the Rocky Mountain Yield simulation program (RMYLD) (6). In managed even-aged stands, simulations indicate that with prompt restocking to 600 to 800 stems per acre (1480 to 1975 trees/ha), followed by periodic thinnings beginning at age 30 years to maintain proper growing stock levels (GSL), growth and yield and tree sizes can be substantially increased compared with unmanaged stands, and time required to produce high volumes and large sizes reduced. Stands managed at growing stock levels considered optimum for timber production appear to be most productive with a 140- to 160-year rotation. For example, at GSLs 140 to 180, gross mean annual increment is estimated to vary from 40 cubic feet per acre (2.8 m$^3$/ha) on site index 50 lands (base age 100 years) to 140 cubic feet per acre (9.8 m$^3$/ha) on site index 100 lands (6). In mixed stands, early thinning should favor spruce, Douglas-fir, and lodgepole pine over subalpine fir. Intermediate thinnings should favor spruce and Douglas-fir over lodgepole pine. These potential timber yields can be realized by either a clearcut or two-cut-shelterwood option, but total yields are likely to be less under a three-cut or modified shelterwood. Any increases in yields resulting from reduction in rotation length under a simulated shelterwood are likely to be offset by the higher proportion of fir in the replacement stand. Comparable growth rates and yields should be possible under either individual tree or group selection alternatives, but some reduction in total yield may also occur under individual-tree selection if the proportion of fir is high (4).

In spruce—fir forests, where 90 to 95 percent of annual streamflow (12 to 15 inches (305 to 380 mm)) results from melting snow, water production may be increased by clearcutting openings in the canopy. Size and arrangement of openings is critical. Largest increases in streamflow (2.0+ inches (51 mm)) result when 30 to 40 percent of a drainage is harvested in small patches (3 to 5 acres (1.2 to 2.0 ha)) dispersed over the entire watershed (13). With this pattern, more snow accumulates in the openings than in adjacent uncut stands. Cutting openings larger than 5 acres (2.0 ha) may be less efficient in increasing streamflow because, as opening size

increases, wind can scour deposited snow causing it to evaporate into the air or blow into adjacent uncut stands where consumptive use and recharge requirements are higher. Group selection cutting can be nearly as favorable for water production as clearcutting in small patches, but only if openings are near the maximum size of 2 acres (0.8 ha). Increase in water available for streamflow under individual tree selection will be small because consumptive use and recharge requirements will still be high, and the snow deposition pattern will be about the same as in an uncut stand. Standard and modified shelterwood cutting results in increases similar to individual tree selection as long as the overstory remains. After final harvest under any shelterwood alternative, water yield will increase to the level obtained under patch clearcutting, but the interval of increased water yield will be less (4). In managed stands, if water production is the primary goal from stand initiation to final harvest, spruce—fir stands must be maintained at low GSLs (40 or less), where timber production will be only about half of the maximum potential (6).

Spruce—fir forests are summer habitat for big game animals. Clearcutting and group selection result in the largest increases in quantity and quality of forage, but game animal use may be limited by the amount of cover available. Openings 2 to 20 acres (0.8 to 8.1 ha) are used more by big game animals in the Rocky Mountains than larger or smaller openings. Small openings provide little difference in stand structure, and large openings (more than 40 acres (16 ha)) can cause radical alteration of the microenvironment, often making tree regeneration difficult. As trees grow into seedling and sapling size (about 20 years), forage production in openings diminishes but cover increases. Shelterwood cutting provides less forage for big game than cutting methods that create openings and less cover than the uncut forest. These reductions vary with the density of the overstory and length of time it is retained. Individual tree selection provides forage and cover comparable to uncut forests, thus maintaining one kind of habitat at the expense of creating differences in stand structure (4). In managed stands, a combination of cutting methods, growing stock levels, and age classes are needed to create cover and forage necessary to maintain game animal populations, but may result in a reduction in timber production.

The relationship of cutting methods in spruce—fir forests to specific nongame animal habitat requirements is largely unexplored, but it is possible to estimate some of the probable effects. Group selection and clearcuts that create small, dispersed openings in old-growth forests provide a wide range of habitats for birds and small mammals by increasing the area supporting nontree vegetation and length of edge between dissimilar vegetation types while at the same time providing cover. Shelterwood cutting provides a variety of habitats attractive to species that forage in stands with widely spaced trees, but not to those that require closed forests or fully open plant communities. Under this cutting method, trees are still available for nesting, denning, and feeding until final harvest, when plans should require retention of some snags and live trees with cavities. Enthusiasm for increasing animal diversity by providing habitat diversity within a treatment area should be tempered with caution. Managers should maintain some old-growth timber for species that nest or den in large snags or live trees, feed largely on tree seeds, or require large acreages of continuous mature forest cover. Because most species have a minimum habitat size below which they cannot exist, providing small patches of all ages and stand structures can result in reduction of the number of species present in a given treatment area. Individual tree selection provides the least difference in horizontal

---

$^1$ Cubic foot and metric conversions of measurements expressed in board feet should be viewed as estimates because of the assumptions involved in the conversion process.

stand structure, and favors species associated with uncut forests and those that require stands with multi-storied structure. However, snags and live trees with cavities can be retained under any cutting method (2).

Much grazing land lies adjacent to or intermingled with high elevation spruce—fir forests. Under a mature canopy, forage production for livestock is low and may not be readily accessible. The quantity and quality of forage increases in proportion to the amount of canopy removed. Utilization of available forage is usually greater in large clearcut areas (more than 40 acres (16 ha)) because forage is more accessible to livestock. Forage production in managed stands can be maintained only by frequent thinnings and intermediate cuts that maintain low growing stock levels (GSL 40 to 60) (4, 6).

Spruce—fir forests provide a variety of recreation opportunities. Clearcutting has the greatest visual impact, and individual tree selection the least. However, variety typical of forests at the highest elevations—whose texture is broken by natural opening—is preferred to the monotony of vast, unbroken forest landscapes at middle and lower elevations. To enhance amenity values, openings cut for timber and water production and wildlife habitat improvement should be a repetition of natural shapes, visually tied together to create a balanced and unified pattern that will complement the landscape. This is especially important for openings in the middleground and background seen from a distance. Modified shelterwood or individual tree selection can be used to retain a landscape in foregrounds, or small clearcut openings can be used to create variety. Individual tree selection, group selection, and modified shelterwood cutting are appropriate in high-use recreation areas, travel influence zones, scenic-view areas, and lands adjacent to ski runs—and also near support facilities and subdivision developments where permanent forest cover is desired (4).

## Literature Cited

1. Alexander, Robert R. Silvical characteristics of Engelmann spruce. Stn. Pap. 31. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1958. 20 p.

2. Alexander, Robert R. Silvical characteristics of subalpine fir. Stn. Pap. 32. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1958. 15 p.

3. Alexander, Robert R. Silviculture of subalpine forests in the central and southern Rocky Mountains: The status of our knowledge. Res. Pap. RM—121. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1974. 88 p.

4. Alexander, Robert R. Cutting methods in relation to resource use in central Rocky Mountain spruce—fir forests. J. For. 75(7): 395—400; 1977.

5. Alexander, Robert R.; Edminster, Carleton B. Uneven-aged management of old-growth spruce—fir forests: Cutting methods and stand structure goals for the initial entry. Res. Pap. RM—186. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1977. 12 p.

6. Alexander, Robert R.; Edminster, Carleton B. Management of spruce—fir in even-aged stands in the central Rocky Mountains. Res. Pap. RM—217. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1980. 14 p.

7. Eyre, F. H., ed. Forest cover types of the United States and Canada. Washington, DC: Society of American Foresters; 1980. 148 p.

8. Hanley, Donald P.; Schmidt, Wyman C.; Blake, George M. Stand structure and successional status of two spruce—fir forests in southern Utah. Res. Pap. INT—76. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1975. 16 p.

9. McCaughey, Ward W.; Schmidt, Wyman C. Understory tree release following harvest cutting in spruce—fir forests in the Intermountain west. Res. Pap. INT—285. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1982. 19 p.

10. Noble, Daniel L.; Alexander, Robert R. Environmental factors affecting natural regeneration of Engelmann spruce in the central Rocky Mountains. For. Sci. 23(4): 420—429; 1977.

11. Roe, Arthur L.; Alexander, Robert R.; Andrews, Milton D. Engelmann spruce regeneration practices in the Rocky Mountains. Prod. Res. Rep. 115. Washington, DC: U.S. Department of Agriculture; 1970. 32 p.

12. Schmid, J. M.; Frye, R. H. Spruce beetle in the Rockies. Gen. Tech. Rep. RM—49. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1977. 38 p.

13. Troendle, Charles A.; Leaf, Charles F. Effects of timber harvesting in the snow zone on volume and timing of water yield. In: David A. Baumgartner, ed. and comp. Proceedings, Interior West Watershed Symposium; 1980 April 8—10; Spokane, WA. Pullman, WA: Cooperative Extension, Washington State University; 1981: 231—243.

# Lodgepole Pine

**Robert R. Alexander**
*Rocky Mountain Forest and Range Experiment Station*

**James E. Lotan**
*Intermountain Forest and Range Experiment Station*

**Milo J. Larson**
*Rocky Mountain Region*

**Leonard A. Volland**
*Pacific Northwest Region*

Lodgepole pine, Society of American Foresters forest cover type 218, occupies about 13 million acres (5.3 million ha) in the Rocky Mountain and Pacific Coast regions. It commonly is found in pure or nearly pure stands, but in mixed stands lodgepole pine may comprise only a plurality of stocking (6). The timber potential ranges from extremely poor to very good. These forests also provide watershed protection, streamflow, forage and cover for wildlife and livestock, recreational opportunities, and scenic beauty. Many of the areas occupied by long-lived seral lodgepole pine stands have the potential for growing other species (1, 6).

Lodgepole pine (*Pinus contorta* Dougl. ex Loud.) is one of the most widespread species in the western United States. It has a remarkable ecological amplitude, growing in many different environments. In the Rocky Mountains, extensive stands occur from Montana, Idaho, adjacent eastern Washington and Oregon, south through Utah and Wyoming to southern Colorado. In the Pacific Coast region, lodgepole pine grows throughout the Cascades of Washington and Oregon, south to the mountains of northern California, and extensively in the Sierra Nevada Mountains (6, 8, 10).

East of the Continental Divide in Montana, and in Wyoming and Colorado, it grows at elevations between 6,000 and 11,500 feet (1830 to 3500 m). Its most common associates are Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), and interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Biessn.) Franco). West of the divide in the Rocky Mountains, and in the Pacific Coast region, the inland form occurs from 1,500 to above 9,000 feet elevation (460 to 2740 m), where it may be either seral to other indigenous tree species or a topo-edaphic climax in some situations (6, 10).

Because of its wide distribution, lodgepole pine grows in a variety of climatic situations. In general, the climate can be characterized by heavy winter snowfall (120 to 250 inches (3050 to 6350 mm)) at higher elevations and temperature extremes of $-50°$ F ($-45.6°$ C) at high elevations to above $100°$ F ($37.8°$ C) at lower elevations in the interior West. Average annual temperatures are near freezing ($32°$ to $35°$ F ($0°$ to $1.7°$ C)), and frost can occur any month of the year at high elevations. Average precipitation usually exceeds 18 inches (455 mm) annually but may be as low as 12 inches (305 mm) in low elevation interior forests. Total precipitation decreases from west to east, and it is likely to be deficient for short periods during the growing season west of the Continental Divide. Summer is the driest season west of the divide, while east of the divide, the Rocky Mountains from Montana to Colorado receive more summer precipitation (1, 8, 10).

Lodgepole pine is usually not difficult to regenerate either naturally or artificially. It reproduces naturally from seed, and initial establishment is usually very good providing that seedbeds and soil and environmental conditions are favorable. Although germination is best on bare mineral soil in full sunlight, first-year seedlings are not always resistant to drought and heat girdling on hot, dry sites, or to radiation frost damage or frost heaving in many other situations. On south slopes and at low elevations in the interior West, and in many situations in the Pacific Northwest, light overstory shade benefits initial establishment by reducing daytime temperatures and conserving moisture loss from soil and seedlings. Shade also reduces losses from radiation frost, but overhead shade has little beneficial effect on frost heaving. Moreover, prolonged overstory shade reduces the growth and vigor of lodgepole pine seedlings (1, 8, 10).

Lodgepole pine is a prolific seed producer; good crops are borne every 1 to 3 years with light crops intervening. Occasional failures do occur, however, so that seed supply cannot be taken for granted. Lodgepole pine varies greatly in its cone habit. Nonserotinous (open) cones are common in Pacific Coast populations. Although the serotinous (closed) cone habit is widespread in the Rocky Mountains, there are many stands, particularly in the northern Rocky Mountains, where less than half of the trees bear serotinous cones. It cannot be assumed that the cone habit is open or closed; each stand must be examined.

The cone habit of lodgepole pine has considerable ecological and silvicultural significance. Large quantities of seed are stored in closed cones for long periods of time and are available for regenerating a new stand. This characteristic is responsible for the ability of lodgepole pine to regenerate after fire or cutting. These stands are often so dense that most common associates are at least initially excluded (8, 10).

In stands with largely nonserotinous habit, cones open when mature and the light seed is shed from standing trees. Dispersal is by wind and gravity, but only about 10 to 30 percent of the seedfall at timber edge is dispersed into openings as far as 66 feet (20.1 m), and sufficient seed to restock cutovers is usually not dispersed more than 150 to 220 feet (45.7 to 67.1 m). The maximum size opening likely to restock is about 300 to 400 feet (91.4 to 121.9 m) wide, and it will require at least 50,000 to 100,000 sound seeds per acre (123 500 to 247 100/ha) to produce 1,000 first-year seedlings per acre (2470/ ha) on mineral soil seedbeds with favorable environmental conditions (1). If larger openings are cut, the area beyond effective seeding distance usually will have to be planted. There are some exceptions to the size of opening likely to restock naturally, however; for example, in the intermountain region, much larger openings cut for mountain pine beetle control have restocked, but this circumstance is not the normal occurrence in stands with nonserotinous cones. Seedfall from nonserotinous cones is also important as a means of restocking lodgepole pine along road cuts and other rights-of-way as well as maintaining lodgepole pine in mixed stands (1, 8, 10).

In stands with a large proportion of serotinous cones, seed dispersal is from cones attached to the logging slash and cones knocked from the slash and scattered on the forest floor. Maximum seed release usually takes place the first year as soon as temperatures are high enough to open the cones. Successful natural regeneration is generally a one-shot opportunity. How the slash is handled in seedbed preparation and/or disposal is important because the seed supply is in the

slash-borne cones. There is considerable choice in the size and shape of openings that will restock in these stands (1, 8, 10).

The early growth of lodgepole pine is related to stand density, overstory shade, and competing vegetation. In fully-stocked stands in the absence of overstory shade and competing understory vegetation, lodgepole pine will initially outgrow most of its common associates. It will reach 4 to 5 feet (1.2 to 1.5 m) in height in about 5 to 15 years and 15 to 25 feet (4.6 to 7.6 m) in 20 to 25 years. In severely overstocked stands, under a dense overstory or in the presence of severe vegetative competition, both diameter and height growth are severely suppressed. Lodgepole pine is not as long lived as some common associates. At low elevations in northern Idaho and in the Pacific Northwest, stands begin to deteriorate in about 100 years, and elsewhere in the Rocky Mountains in 200 to 300 years. However, in the Sierra Nevada Mountains, some stands may persist for 400 years (8, 10).

Lodgepole pine is very shade intolerant, more so than any common associate except western larch (*Larix occidentalis* Nutt.). In spite of this shade intolerance, it does not thin itself well when established in overly dense stands as commonly occurs. Thus, too many trees persist for long periods of time (up to 100 years), and artificial thinning is required if these stands are to produce usable wood products (1, 8, 10).

Throughout much of its range lodgepole pine is an aggressive pioneer onto sites disturbed by fire, logging, or overgrazing. It plays a minor seral role when a component of stands with a mixed overstory composition, and it is usually replaced by more tolerant associates in 50 to 100 years. It is dominant seral when it is the principal overstory component of stands with a vigorous understory of more tolerant associates that will ultimately replace lodgepole pine in 100 to 200 years (7, 10). Where lodgepole pine stands are the result of catastrophic fires, it is persistent seral because there is no seed source for the normal replacement species. Where lodgepole pine is the only available species capable of growing in a particular environment, it is a self perpetuating climax (1, 10).

The lodgepole pine type is generally considered to be a pure, even-aged, single-storied, overly dense forest, varying in age from place to place but uniform in age within any given stand. This is true only where favorable fire, seed, and climatic conditions once combined to produce a large number of seedlings at one time. However, lodgepole pine may occur in virtually any age or stand configuration as a result of meadow invasion, past silvicultural treatments, scattered trees that produced seed for subsequent stand development, or the gradual deterioration of even-aged, old-growth stands (1).

In mixed stands at higher elevations, the overstory can be pure lodgepole pine, or lodgepole pine, Engelmann spruce, subalpine fir, whitebark pine (*Pinus albicaulis* Engelm.), or mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.), and at low elevations, lodgepole pine, western white pine (*Pinus monticola* Dougl. ex D. Don), ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.), western larch, Douglas-fir, grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.), or western redcedar (*Thuja plicata* Donn ex. D. Don). The climax or more tolerant species are generally in the understory. Advanced reproduction of associated species will respond to release when the overstory is removed (1, 6).

Lodgepole pine is susceptible to windthrow after cutting. Partial cutting increases the risk because the entire stand is opened up, whereas only the boundaries between cut and leave units are vulnerable after clearcutting. Losses can be substantial after clearcutting, however, if no special effort is made to locate windfirm boundaries. While the tendency to windthrow is frequently attributed to a shallow root system, the development of the root system varies with soil and stand conditions. Regardless of how stands are cut or the soil and stand conditions, the risk of blowdown is greater on some topographic exposures than others (1).

Mountain pine beetle (*Dendroctonus ponderosae* Hopkins) is the most serious insect pest of lodgepole pine. In the Rocky Mountains, stands most susceptible are over 80 years of age, on good sites, with a low enough density that a substantial number of trees are 12 inches (30 cm) in diameter at breast height (d.b.h.) and larger, with phloem thickness of at least 0.1 inches (2.5 mm), at elevations where temperatures are high enough for brood development. Generally Rocky Mountain stands with trees less than 14 inches (36 cm) d.b.h. will not support an attack, and trees smaller than 6 inches (15 cm) d.b.h. are not usually killed (4, 5). However, these limits change with elevation and latitude. For example, at low elevations on good sites mountain pine beetle is able to maintain epidemic populations in trees smaller than 14 inches (36 cm) d.b.h. The pine engraver (*Ips pini* (Say.)) is a potentially dangerous pest; populations build up in logging slash or fire-scorched trees and emerge to attack and weaken or kill trees (10). The lodgepole needleminer (*Coleotechnites milleri* (Busck)) is a serious pest in the Sierra Nevada mountains (9).

Dwarf mistletoe (*Arceuthobium americanum* Nutt. ex Engelm.) is the most serious disease affecting lodgepole pine, with over 50 percent of the stands in the Rocky Mountains infected to some degree. The disease reduces diameter and height growth, seed production, and vigor. The mortality rate depends largely on the age of the host when attacked. Dwarf mistletoe is most damaging in stands partially opened up by cutting, bark beetles, or windthrow, and of least consequence on regenerated burns following catastrophic fires (1, 8, 10). Stem cankers caused by rust fungi also attack lodgepole pine. Comandra rust (*Cronartium commadrae* Pk.) and western gall rust (*Peridermium harknessii* J. P. Moore) are the most serious in terms of growth and mortality losses (1, 8, 10).

Although an even-aged silvicultural system is preferred for lodgepole pine, both even-aged and uneven-aged systems can be used to regenerate lodgepole pine. But, not all cutting methods under each system are applicable in every stand. Moreover, some cutting methods cannot be used in lodgepole pine forests under most circumstances. The only uneven-aged method of cutting that can be used is group selection, and then only where management objectives include the combination of small openings and high forests, and mountain pine beetle and dwarf mistletoe problems are minimal (2). Individual tree selection should not be used to perpetuate lodgepole pine. The even-aged methods include clearcutting and shelterwood cutting. Seed-tree cutting is usually not applicable as a regeneration method because of susceptibility of residual trees to windthrow. Shelterwood cutting can be standard, modified, or simulated. Modified shelterwood delays the final harvest until the understory is large enough (at least 4 to 6 feet (1.2 to 1.8 m)) to provide a forested appearance, and is applicable only in areas where timber production is not the primary concern and dwarf mistletoe infection is low. Simulated shelterwood removes a pine overstory from an established and manageable stand of advanced reproduction of more tolerant associates (1, 7, 8).

In overmature old-growth stands of lodgepole pine heavily infected with dwarf mistletoe and where the risks of windthrow and mountain pine beetle attacks are high, there is little choice but to clearcut the area and start a new stand. Where dwarf mistletoe control is a primary consideration,

64

there is no advantage to cutting openings larger than 20 to 40 acres (8.1 to 16.2 ha) to reduce the proportion of perimeter to opening. Small patch clearcuts can be used to create a mosaic of different size and age classes where the probability of mountain pine beetle attack is high. Openings larger than 40 acres (16.2 ha) may have to be cut in stands actually sustaining a beetle attack. If management considerations preclude clearcutting, the alternatives are limited. Stands can be left uncut, running the risk of the loss of the merchantable stand to bark beetles and dwarf mistletoe. Partial cutting that removes the trees 10 inches (25 cm) and larger at d.b.h. will help in regulating losses to mountain pine beetle in stands with a good stocking of trees in the small diameter classes, but may leave a dwarf mistletoe infected stand or a stand with limited future economic options (1, 4, 5).

When management considerations include the combination of high forests and openings, and/or when sites are difficult to regenerate, a mix of standard two-step shelterwood, simulated shelterwood, and group selection methods can be used so long as windfall, mountain pine beetle, and dwarf mistletoe problems are not limiting.

In unmanaged, overmature stands, current average annual growth will vary from a net loss due to mortality up to 40 board feet (fbm) (Scribner Decimal C Log Rule) (8.0 cubic feet)[1] per acre (0.6 m³/ha) to yields of about 2,400 to 3,200 cubic feet per acre (168.0 to 224.0 m³/ha). Partial cutting may prevent mortality in these stands, but it is not likely to increase growth of residual trees. In unmanaged, thrifty stands less than 150 years old, average annual increment may be as high as 150 fbm (30 cubic feet) per acre (2.1 m³/ha), and the potential for maintaining this growth is high under a two-cut shelterwood (1, 7, 10).

Many second-growth stands of lodgepole pine, originated after fires or cutting, are overly dense and in need of thinning before stagnation occurs. Age and level of thinning depends upon density, site quality, and management objectives. Stands older than 60 to 70 years with 2,000 to 3,000 stems per acre (4940 to 7410/ha) are not likely to respond sufficiently to produce usable products in a reasonable amount of time. Stands with more than 4,000 stems per acre (9880/ha) should be thinned no later than age 30 years (1, 3, 8).

While no lodgepole pine stands have been under management for a long period of time, the probable growth responses to different stand parameters can be estimated by using the Rocky Mountain Yield Simulation program (RMYLD) (3). In managed stands, simulations indicate that with prompt restocking to 800 to 1,200 stems per acre (1980 to 2970/ha) followed by periodic thinnings beginning at age 30 years to maintain proper growing stock levels (GSL), growth and yield and tree sizes can be substantially increased, while reducing the time required to produce high volumes and large sizes. Stands managed at growing stock levels considered optimum for timber production in the Rocky Mountains are most productive with 80- to 120-year rotations. For example, at GSLs 140 to 160, gross mean annual increment is estimated to vary from about 45 cubic feet per acre (3.2 m³/ha) on site index 50 lands (base age 100 years) to 105 cubic feet per acre (7.4 m³/ha) on site index 80 lands (3). In some Pacific Northwest environments, maximum timber production occurs at lower stem densities. Mean annual increment will vary from less than 20 cubic feet per acre (1.4 m³/ha) on site index 50 lands to 80 cubic feet per acre (5.6 m³/ha) on site index 85 to 90 lands.

Highest potential timber yields can be realized under a clearcutting or a two-cut shelterwood option, providing that the final harvest with a shelterwood is made within 5 years after regeneration is established. Comparable growth rates can be achieved with group selection only if the openings are near the maximum size (2 acres (0.8 ha)). Total yields will be less under a modified or three-cut shelterwood. Under simulated shelterwood, yield increases resulting from reduction in rotation length will be offset by the slower growth of tolerant species in the replacement stand. Yields will be considerably less under group selection in situations where lodgepole pine is difficult to maintain and very small openings are cut.

In high elevation lodgepole pine forests, the proportion of water yielded to precipitation is high because of the cold climate, short growing season, and accumulation of overwinter snowpack. Approximately 90 to 95 percent of the water available for streamflow comes from snowmelt. The most efficient timber harvest pattern for increasing water yield (2.0 + inches (50.8 + mm)) in old-growth forests is to clearcut about 30 to 40 percent of a drainage in small irregular-shaped patches about 5 to 8 times tree height in diameter (3 to 5 acres (1.2 to 2.0 ha)) interspersed with uncut patches of about the same size. With this pattern, more snow accumulates in the opening than in adjacent uncut stands. Openings larger than 8 tree heights wide may be less efficient in increasing streamflow because, as size of opening increases, wind can scour deposited snow causing it to evaporate into the air or blow it into adjacent stands where autumn recharge requirements and evapotranspiration during the growing season are greater. Group selection cutting can be nearly as favorable for water production as patch clearcutting, but only if openings are near the maximum size. Standard and modified shelterwood result in small increases as long as the overstory remains. After final harvest under any shelterwood alternative, water yield will increase to the level obtained under patch clearcutting, but the interval of increased water yield will be less. If water production is the primary goal in stands managed from initiation to final harvest, lodgepole pine stands must be maintained at low GSL (40 or less). At these growing stock levels, timber production may be only about half of the maximum potential (3, 11).

Understory vegetation in lodgepole pine forests is potentially important as forage for big game and livestock, but production varies widely. In dense stands, there is little or no understory vegetation. As the overstory decreases, forage production increases, reaching maximum in recently clearcut openings or burns. Forage production, changes in species composition, and palatability vary considerably, depending upon the plant community and successsional stage. The increase in forage production in openings usually persists for about 10 to 20 years before competition from tree reproduction begins to reduce understory vigor and composition. It can be maintained only by frequent thinnings and intermediate cuts that keep growing stock levels low (3, 8).

Biotic diversity is generally low in old-growth lodgepole pine stands, but these forests provide habitat for a variety of game and nongame animals. Openings created by clearcutting and group selection can greatly benefit big game if a balance between forage and cover is maintained. Dispersed openings 2 to 20 acres (0.8 to 8.1 ha) are used more by big game than are larger or smaller openings. Small openings provide little difference in stand structure or forage, and large openings (more than 40 acres (16 ha)) can cause radical alteration in habitat, especially if coupled with extensive site preparation and tree planting. As trees grow to seedling and sapling size, forage production in openings decreases, but cover increases until it reaches maximum in immature to mature stands,

---

[1] Cubic foot and metric conversions of measurements expressed in board feet should be viewed as estimates because of the assumptions involved in the conversion process.

depending upon location (3). Shelterwood cutting provides less forage for big game than cutting methods that create openings, and less cover than the uncut forest. In managed stands, a combination of cutting methods, growing stock levels, and age classes provide forage openings and hiding cover necessary to maintain game animal populations (2).

Clearcutting and group selection create small dispersed openings (2 to 5 acres (0.8 to 2.0 ha)) and provide a wide range of habitats for birds and small mammals. The area supporting nontree vegetation and length of edge between dissimilar stand conditions are increased while at the same time providing cover. Shelterwood cutting provides a variety of habitats attractive to nongame species that forage in stands of widely spaced trees, but not those that require closed forests or fully open plant communities. Under this cutting method, trees are still available for nesting, denning, and feeding until final harvest, when consideration should be given to leaving some of the snags and trees with cavities. Attempts to increase animal diversity through stand structure modification should be tempered with caution. Managers should maintain areas of old-growth for species that nest, den, or feed in snags or large live trees or require large areas of mature forest cover. Most nongame species have a minimum habitat size below which they cannot exist. Small patches of varying ages and structures and all-aged stands may reduce the number of species.

Lodgepole pine forests provide a variety of recreational opportunities. Clearcutting has the greatest visual impact, and partial cutting methods the least. However, the variety typical of forests at high elevations—whose texture is broken by natural openings—is preferred to the monotony of vast, unbroken forest landscapes common to lodgepole pine forests. To enhance amenity values, harvested openings should emulate natural shapes. These openings should be visually blended to create a balanced and unified pattern that will complement the landscape. This is especially important for openings in the middleground and background seen from a distance. Modified shelterwood can be used to retain a landscape in foregrounds, or small clearcut openings can be used to create variety. Group selection and modified shelterwood cutting are appropriate in high-use recreation areas, travel influence zones, scenic-view areas, lands adjacent to ski run

support facilities, and subdivision developments where permanent forest cover is desired (2, 3).

## Literature Cited

1. Alexander, Robert R. Silviculture of subalpine forests in the central and southern Rocky Mountains: The status of our knowledge. Res. Pap. RM-121. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1974. 88 p.
2. Alexander, Robert R. Partial cutting in old-growth lodgepole pine. Res. Pap. RM-136. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1975. 17 p.
3. Alexander, Robert R.; Edminster, Carleton B. Management of lodgepole pine in even-aged stands in the central Rocky Mountains. Res. Pap. RM-229. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1981. 11 p.
4. Amman, Gene D.; McGregor, Mark D.; Cahill, Donn B.; Klein, William H. Guidelines for reducing losses of lodgepole pine to the mountain pine beetle in unmanaged stands in the Rocky Mountains. Gen. Tech. Rep. INT-36. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1977. 19 p.
5. Cole, Walter E.; Amman, Gene D. Mountain pine beetle dynamics in lodgepole pine forests Part I: Course of an infestation. Gen. Tech. Rep. INT-89. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1980. 56 p.
6. Eyre, F. H., ed. Forest cover types of the United States and Canada. Washington, DC: Society of American Foresters; 1980. 148 p.
7. Lotan, James E.; Cochran, P. E.; Frykman, Joel L. Lodgepole pine. In: Choices in silviculture for American Forests. Washington, DC: Society of American Foresters; 1981: 46-53.
8. Lotan, James E.; Perry, David A. Ecology and regeneration of lodgepole pine. Agric. Handb. 606. Washington, DC: U.S. Department of Agriculture; 1983. In press.
9. Struble, George R. Biology, ecology and control of the lodgepole needle miner. Tech. Bull. No. 1458. Washington, DC: U.S. Department of Agriculture; 1972. 38 p.
10. Tackle, David. Silvics of lodgepole pine. Misc. Pub. No. 19. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1961. 24 p.
11. Troendle, Charles A.; Leaf, Charles F. Effects of timber harvesting in the snow zone on volume and timing of water yield. In: Baumgartner, David A., ed., comp. Proceedings, Interior West Watershed Symposium; 1980 April 8-10; Spokane, WA. Pullman, WA: Cooperative Extension, Washington State University; 1981: 231-243.

# Mixed Conifers, Western White Pine, and Western Redcedar

**Russell T. Graham and Charles A. Wellner (retired)**
*Intermountain Forest and Range Experiment Station*

**Roger Ward**
*Northern Region*

The mixed conifer, western white pine, and western redcedar forest cover types listed by the Society of American Foresters (2), types 215 and 228, occupy about 5 million acres (2.0 million ha) in the Northern Rocky Mountains. The type is found in western Montana, northern Idaho, eastern Washington, northeastern Oregon, and adjacent parts of British Columbia. Topography is characterized by massive mountains with deep V- and round-bottomed valleys. Elevations vary from 1,500 feet (460 m) to 6,000 feet (1830 m). Stream erosion in addition to mountain and continental glaciation has shaped the landscape of the area. Soil depths range from 4 inches (10 cm) to 90 inches (229 cm) and have developed from a variety of base rocks; including granite, basalt, and sedimentary. Soils of the region are Inceptisols capped with a layer of loess; soils are frequently covered by layers of volcanic ash.

The climate is characterized by dry summers with the majority of the precipitation falling during the fall, winter, and spring (6). Precipitation averages between 28 inches (710 mm) and 60 inches (1525 mm). Snowfall averages 103 inches (2600 mm) with totals up to 244 inches (6200 mm) recorded at higher elevations. Temperatures average between 40° and 50° F (4.4° to 10.0° C) with lows of −40° F (−40° C) and highs of 107° F (41.7° C) recorded. Below-freezing temperatures may occur in any month. Because of local topographic features, frost pockets are common. Although frost damage is usually limited to young trees, sudden drops in temperature occasionally cause damage to mature trees. Wind velocities are generally low, but occasional high winds can cause extensive windthrow. The dry summers frequently result in drought damage to both natural and artificial regeneration.

The mixed conifer, western white pine, and western redcedar cover types include those areas where western white pine (*Pinus monticola* Dougl. ex D. Don) is a major seral species. Numerous cover types recognized by the Society of American Foresters are included (2). The more important species that occur include grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.), subalpine fir (*A. lasiocarpa* (Hook. Nutt.), western white pine, lodgepole pine (*Pinus contorta* Dougl. ex Loud.), ponderosa pine (*P. ponderosa* Dougl. ex Laws. var. *ponderosa*), western larch (*Larix occidentalis* Nutt.), western redcedar (*Thuja plicata* Donn ex D. Don), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), and Engelmann spruce (*Picea engelmannii* Parry ex Engelm.). The type includes the *Tsuga heterophylla* and *Thuja plicata* habitat type series, and those portions of the *Abies grandis*, *Abies lasiocarpa*, and *Tsuga mertensiana* series where western white pine grows (1). The tree species occurring in the type have a wide range of shade tolerance (6) and vary in drought tolerance and frost resistance (8).

Species in the type vary widely in seed production and dissemination. Western redcedar and western hemlock produce larger and more frequent seed crops than most of their associated species (6). The interval between good seed crops in western larch is highly variable and is often greater than 10

years. The remaining tree species usually produce good seed crops at intervals less than 5 years. Wind plays a major role in seed dissemination. Only lodgepole pine exhibits cone serotiny, and it is variable within the type. Seedling germination, survival, and initial growth also vary by species. Bare mineral soil and burned-over mineral soil tend to favor germination of the tree species. Western hemlock and western redcedar usually have high germination rates; Douglas-fir, ponderosa pine, western white pine, and lodgepole pine have intermediate rates; and western larch and grand fir have low rates. Western hemlock, mountain hemlock, western redcedar and subalpine fir occasionally reproduce vegetatively. This regeneration is as important as reproduction from seed in high-density western redcedar stands (8).

For species in the type, response to release after periods of crowding or suppression is directly related to the length and vigor of the crown. Generally, shade-tolerant species respond well to release after suppression and intolerant species respond poorly. Lodgepole pine, which often regenerates prolifically, is prone to stagnation early in its development, making later release cuttings ineffective.

Much of the type has higher-than-average potentials for timber production compared to other types in the Rocky Mountains. In fully stocked, even-aged stands at culmination, mean annual increment can reach 150 cubic feet per acre (10.5 m³/ha) per year with an average potential of 80 cubic feet per acre (5.6 m³/ha) per year (5). Actual growth falls below the potential because of losses due to diseases, insects, and weather. Depending on site quality, stand density, species composition, and objectives of management, rotation lengths range from 50 to over 150 years. On an excellent site at age 50 years, 4,830 cubic feet per acre (338.1 m³/ha) is the expected yield in fully stocked normal stands and at age 150 the expected yield is 18,100 cubic feet per acre (1267.0 m³/ha) (5).

Forest insects are a major factor in management (4). Western hemlock and western redcedar are the most resistant to insect attack. All sizes of grand fir and subalpine fir are subject to damage by the Douglas-fir tussock moth (*Orgyia pseudotsugata* (McDunnough)) and western spruce budworm (*Choristoneura occidentalis* Freeman). Subalpine fir is often killed by *Dryocoetes* spp. throughout the type. The spruce budworm also affects cone production of Douglas-fir, grand fir, and western larch. Grand fir is often damaged by the fir engravers (*Scolytus* spp.). The introduced pest, larch casebearer (*Coleophora laricella* (Hubner)), defoliates western larch trees causing growth reduction; this affects their rapid growth advantage over slower growing competitors. It may partially account for poor seed production. Most often mature lodgepole, ponderosa, and western white pine, are often heavily damaged by the mountain pine beetle (*Dendroctonus pseudotsugae* Hopkins).

A number of diseases cause serious damage (7). The most devastating is white pine blister rust (*Cronartium ribicola* Fisch.), which has caused extensive mortality in all sizes and ages of western white pine. Because tree-breeding

programs have developed western white pine resistant to blister rust, and because the level of natural resistance in young stands is steadily increasing, western white pine is manageable. The dwarf mistletoes (*Arceuthobium* spp.) occur on lodgepole pine, ponderosa pine, western larch, and Douglas-fir, causing considerable growth loss. Other than heart rots, western hemlock, western redcedar, and grand fir have minimal disease problems. Root diseases, especially *Armillariella mellea* (Vahl. ex Fr.) Karst., *Phellinus weirii* (Murr.) Gilb., and *Heterobasidium annosum* (Fr.) Bref., attack all tree species in the type and are most damaging to Douglas-fir and grand fir on drier sites. The pines and western larch show some tolerance to root diseases; conversion to these species is a preferred alternative in stands with root disease problems. Diseases cause growth reduction and mortality, interfere with cone production, and cause infected trees to be more susceptible to attack by other damaging agents. When young, all species of the type are easily killed by fire. However, mature and overmature trees exhibit differences in fire resistance by species (8). Western larch, ponderosa pine, and Douglas-fir, are the most fire resistant species. Grand fir, lodgepole pine, western white pine, and western redcedar are intermediate in tolerance to fire damage, and the remaining species are very susceptible. Historically, seral species such as western white pine, lodgepole pine, and western larch have regenerated as a result of fire. Fire is a useful tool for slash disposal and site preparation.

Management of the type has become more responsive to nontimber uses and values. Silvicultural treatments give consideration to watershed conditions, wildlife habitat, forage for livestock, esthetic values, and rare animals and plants, as well as timber production. Providing for nontimber uses and values usually requires a reduction in timber production.

Choice of a silvicultural system in the type depends on objectives of management, stand conditions, species requirements (3), and other forest uses. Although even- and uneven-aged silvicultural systems are used, even-aged systems have the widest application. Even-aged management is more applicable when regeneration of the shade-intolerant species is desired. Uneven-aged management is applicable where a continuous forest cover is desired (9) and the preferred species are shade tolerant.

Single tree selection, though little used to date, could be a useful method in certain situations in the type. This regeneration method will create stands with high proportions of shade-tolerant species. Individual tree selection is applicable in stands that may require continuous forest cover such as along stream courses or in sensitive viewing areas. Individual tree selection is best applied in stands that already have several age classes, resulting from past natural or cultural activities. The group selection method has advantages for certain situations. It provides conditions for incorporation of intermediate and shade-intolerant species in selection stands. Slash disposal can be accomplished by broadcast burning, hand work, or mechanical means. The smaller the opening, the larger the proportion of regeneration from tolerant species. Planting of the site with improved stock is possible, if desired. The method can be used to favor elk and deer use or where snowmelt needs to be carefully controlled. Group selection can, to some extent, reduce disease problems by species conversion. Although site preparation and slash disposal can be achieved using group selection, the costs are greater, and the risks of using fire are much greater, than with the clearcut system.

Both individual and group selection methods are difficult to apply in forests which have resulted from fire and tend to be more even-aged than all-aged. The methods do not

necessarily preclude the need for stocking control in the smaller diameter classes to meet the desired stand structure. Both the individual and group selection methods require more planning, are silviculturally difficult to apply, are more expensive, and are more difficult to regulate than even-aged methods.

The shelterwood regeneration method is applicable on all aspects and slopes, but is especially suited to the steep, dry slopes in the type. Overwood densities used in the method range from 15 to 40 trees per acre (37 to 90/ha). Cool, moist slopes need less shelter to achieve regeneration. The greater the number of trees left in the overwood, the greater will be the proportion and number of tolerant species regenerated. Because of the wide range of fire resistance of the species present, slash disposal and site preparation may be difficult and expensive. Vigorous trees should be left in the overwood to withstand the shock of release and act as good seed producers. When an adequate amount of regeneration is achieved, the overstory should be removed promptly. The shelterwood method offers a gradual regeneration period in areas sensitive because of recreation or esthetic values. Stocking control is frequently needed to maintain desired number of trees and the desired species composition. As with all even-aged methods, stocking control should be delayed until dominance is well expressed and the young stand is tall enough to minimize ingrowth of tolerant species.

The seed-tree method can be applied on all slopes and aspects, but best results are achieved on northerly aspects. As in the shelterwood method vigorous, wind-firm trees should be left as seed trees. Four to six trees per acre (10 to 15/ha) are adequate for seed production for the species in the type. If possible, site preparation should coincide with a seed crop in the overstory. The seed trees should be removed as soon as possible after regeneration. Again, stocking control is usually needed to maintain the desired number and species composition in the regenerated stand. The seed-tree method is better than shelterwood for increasing forage for livestock, and for grazing and browsing by big game.

The clearcut regeneration method is the easiest to apply in the type and is often the most applicable. It is well suited for species conversion when required because of disease or insect problems. Also, planting of improved stock from breeding programs is facilitated by the clearcut method. Disposal of fuels and site preparation can be accomplished by broadcast burning or by mechanical means on suitable slopes. Even without an overstory seed source, small, patch clearcut units on flats and northerly aspects can be regenerated by seed from surrounding uncut stands. Thinning or release treatments may be needed as the stand develops. Clearcutting is used on all slopes and aspects, but southerly slopes, especially steep slopes, are usually difficult to regenerate either artificially or naturally. These slopes are prone to heavy brush development and animal damage to regeneration. In addition, surface temperature and available soil moisture tend to be more critical. These factors make other regeneration methods preferred. If clearcutting is used on such slopes cutting unit should be small (2 to 5 acres or 0.8 to 2.0 ha) to provide as much protection as possible for regeneration. If progressive clear-strip cuttings are used, they should be limited to no wider than one tree height and oriented to provide maximum protection from the elements. Clearcutting provides the most latitude for watershed manipulation and for forage production for both livestock and big game, but has disadvantages, especially in terms of esthetics.

Intermediate cuttings are being used more often as part of the even-aged system. Commercial thinnings are used frequently, and salvage cutting can utilize trees that are seriously damaged. Liberation cuttings are often used to

release advance regeneration of shade-tolerant species. Intermediate cutting should be planned carefully so they are not dysgenic nor develop stands dominated by undesirable trees.

The western white pine and associated species cover type has a wide range of commercial species that offer much latitude in the silvicultural system used. The seral species offer fast growth for quality lumber and fiber production, while the tolerant species offer opportunities for timber management where other uses require a continuous forest cover. All recognized silvicultural systems and methods have applicability in the type, but the local management objectives, site factors, and feasibility of the treatment must be considered for each stand.

**Literature Cited**

1. Daubenmire, R.; Daubenmire, Jean B. Forest vegetation of eastern Washington and northern Idaho. Tech. Bull. 60. Pullman, WA: Washington State University Agricultural Experiment Station; 1968. 104 p.

2. Eyre, F. H., ed. Forest cover types of the United States and Canada. Washington, DC: Society of American Foresters; 1980. 148 p.

3. Fowells, H. A., comp. Silvics of forest trees of the United States. Agric. Handb. 271. Washington, DC: U.S. Department of Agriculture; 1965. 762 p.

4. Furniss, R. L.; Carolin, V. M. Western forest insects. Misc. Pub. 1339. Washington, DC: U.S. Department of Agriculture; 1977. 654 p.

5. Haig, Irvine T. Second-growth yield, stand, and volume tables for the western white pine type. Tech. Bull. 323. Washington, DC: U.S. Department of Agriculture; 1932. 68 p.

6. Haig, Irvine T.; Davis, Kenneth P.; Weidman, Robert H. Natural regeneration in the western white pine type. Tech. Bull. 767. Washington, DC: U.S. Department of Agriculture; 1941. 99 p.

7. Hepting, George H. Diseases of forest and shade trees of the United States. Agric. Handb. 386. Washington, DC: U.S. Department of Agriculture; 1971. 658 p.

8. Minore, Don. Comparative autecological characteristics of northwestern tree species—a literature review. Gen. Tech. Rep. PNW-87. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1979. 72 p.

9. U.S. Department of Agriculture, Forest Service. Uneven-aged silviculture and management in the United States: A combined proceedings of two In Service Workshops; 1975 July; Morgantown, WV; 1976 October; Redding, CA. Washington, DC: U.S. Department of Agriculture, Forest Service; 1978. 234 p.