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Silvicultural Systems for the Major Forest Types of the United States

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The current trend toward the establishment and care of forests for a wide combination of uses requires flexibility in forest culture and a knowledge of the silvicultural choices available to the resource manager. This publication summarizes the silvicultural systems that appear biologically feasible, on the basis of present knowledge, for each of 48 major forest types in the United States. Supporting information is given on the occurrence of the 48 forest types, the cultural requirements of the component species, and the biological factors that control the choice of silvicultural options.

Keywords: Silviculture, forest types, species, multiple use.

Cover photo: The results of uneven-aged management in Douglas-fir using the group selection cutting method on Mt. Baker National Forest, Wash. **F-437586.**

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The handbook is a compilation of 48 individual manuscripts written by research foresters at U.S. Department of Agriculture Forest Service Experiment Stations in collaboration with foresters from State and Private Forestry, from the National Forest System, and from academia. Individual manuscripts were reviewed for technical accuracy and completeness by technically competent experts from forest industry, State forestry organizations, and the university community.

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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.

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

Western Hemlock – Sitka Spruce

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The western hemlock–Sitka spruce forest type (2), as recognized by the Society of American Foresters (type 225), is composed of stands in which western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and Sitka spruce (*Picea sitchensis* (Bong.) Carr.) comprise a majority of the stocking. Also included at various locations may be small admixtures of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.), Pacific silver fir (*Abies amabilis* Dougl. ex Forbes), western redcedar (*Thuja plicata* Donn ex D. Don), Alaska-cedar (*Chamaecyparis nootkatensis* (D. Don) Spach), mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.), red alder (*Alnus rubra* Bong.), black cottonwood (*Populus trichocarpa* Torr. and Gray), vine maple (*Acer circinatum* Pursh), and bigleaf maple (*Acer macrophyllum* (Pursh)) (2).

Tree species within the type change with latitude. Douglas-fir is an important associate in Oregon and Washington; Western redcedar is important in British Columbia and extends into southeast Alaska. Pacific silver fir becomes an associate north of the Columbia River and extends north through British Columbia and into Alaska. Alaska-cedar and mountain hemlock become associates north of central Vancouver Island. Shore pine (*Pinus contorta* Dougl. ex Loud. var. *contorta*) is an associate on some sites from Oregon to Alaska. Red alder and black cottonwood are important hardwood associates in seral stands throughout the range; bigleaf maple is common only in the southern latitudes of the type.

The type occupies a coastal strip 2,000 miles (3220 km) long from southern Oregon to south central Alaska (11). Its greatest extent is in southeast Alaska where it reaches a width of 130 miles (210 km) including a narrow mainland strip and offshore islands.

Northwestward, along the Gulf of Alaska, the type narrows greatly, limited by steep mountains and glaciers, widening again to include islands within Prince William Sound. In British Columbia, the Queen Charlotte Islands lie entirely within the type, and a narrow strip extends along the mainland and on the west coast of Vancouver Island with stringers along major streams. In Washington and Oregon, the type occupies a narrow coastal strip and extends inland along streams and rivers.

The type occurs at sea level throughout its range, extending to elevations of 3,000 feet (910 m) in British Columbia and southeast Alaska. North and west from southeast Alaska, upper limits gradually lower to 1,500 feet (460 m) around Prince William Sound. Toward the south the type reaches elevations of 1,800 feet (550 m) along the Oregon coast, and as high as 3,000 feet (910 m) in especially moist situations on the Olympic Peninsula, Wash. (11).

Soils vary by latitude. In the Coast Ranges of Oregon and Washington, Inceptisols and Ultisols are the most widespread. Northward through British Columbia and Alaska, Spodosols and Histosols are more prevalent. Throughout the type, Entisols are found along streams.

From the Olympic Peninsula northward, glaciation has affected soil development. Soils tend to be less well developed northward. In Alaska, most Spodosols have low clay content; colloidal organic and iron compounds are the main source of cation exchange and water retention. They have relatively high moisture retention capacity and relatively high rates of water transmission. A substantial proportion of nutrients is concentrated in the surface organic layers. Even in the deeper soils, tree rooting is generally shallow, and, therefore, destruction or serious disturbance of the upper soil layers is likely to have adverse effects on tree growth (11).

The type is confined to an area of maritime climate with abundant moisture throughout the year, relatively mild winter temperatures, and cool summers. Lack of a pronounced summer drought is an important factor affecting vegetation. Length of growing season and total solar energy received during the growing season decrease northward and account for much of the variation in productivity, soil development, and species composition within the type (3).

Total annual precipitation tends to be high throughout the type, apparently little influenced by latitude; 60 to 150 inches (1525 to 3810 mm) is common with up to 300 inches (7620 mm) in some localities. Local topography greatly influences precipitation. Average depth of snowfall during the winter decreases southward, ranging from 134 inches (3400 mm) at Cordova, Alaska, to 5 inches (125 mm) at Otis, Oreg. Summer precipitation tends to be greater toward the north. Along the southern Alaska coast, frequent cloudiness, light summer drizzle, and fog are common. Toward the south where summer precipitation is less frequent, damp maritime air helps to maintain moist conditions.

Storm winds often sweep in from the Pacific Ocean during the fall and winter, causing frequent wind damage. In Oregon and Washington, the greatest damage is from south and southwest winds of approaching storms. Gale-force winds are most common in October and November. In southeast Alaska the most damaging winds are from the southeast and occur most frequently from September through November. Management strategies have been developed to reduce wind damage in the forest, such as selecting windfirm cutting boundaries, shaping cutting units to minimize the length of cutting boundaries exposed to storm winds, and laying out cutting strips perpendicular to prevailing storm winds with progressive cutting of strips toward the wind (11).

Both western hemlock and Sitka spruce are prolific seed producers. In Oregon and Washington, both species produce some seed most years with heavy crops every 3 to 4 years. In Alaska, a heavy crop occurs every 5 to 8 years. The seed is small and is carried long distances by the wind. Western hemlock is an especially heavy seed producer, and even relatively poor seed crops usually produce enough seed to insure natural restocking (16). Seed production generally is adequate for establishment of regeneration even on large clearcuts, so few areas fail to regenerate from lack of seed. Failures more often are due to competing vegetation (11).

Western hemlock and Sitka spruce seed will germinate and seedlings will grow on both organic and mineral soil seedbeds. Establishment and subsequent growth, however, are better on soils with a high percentage of organic matter. In Alaska, soils stripped of surface organic material may be unsuitable because underlying soil horizons contain few nutrients to support growth. Exposure of mineral soil also provides a good seedbed for red alder and brush species, which compete with conifers (6).

Shade improves seedling establishment where low moisture or high temperature is limiting. Both duff-covered soil and rotten wood can be good seedbeds under light shade, but too much shade can prevent seedling establishment. Toward the south, exposed organic seedbeds tend to dry out more readily and few seedlings become established on them. On the other hand, soils are deeper and better developed than in Alaska and have more nutrients available in lower soil horizons to support good tree growth (11).

Western hemlock is more tolerant of shade than is Sitka spruce and dominates reproduction in old-growth forests (4). Both species are capable of rapid growth increases if shade is removed.

Soil and ground water conditions are important in determining the success of tree species. Lodgepole pine (*Pinus contorta* var. *latifolia*.), Douglas-fir, and red alder roots can grow in soils with high bulk densities. These soils prohibit the growth of Sitka spruce, western redcedar, and western hemlock. Pacific silver fir ranks between these two groups (9). Red alder, western redcedar, Sitka spruce, and western hemlock are more tolerant of high water tables than is Douglas-fir (8).

Western hemlock–Sitka spruce is one of the world's most productive forest types. Yield tables are available for unthinned even-aged stands of mixed hemlock and spruce in Oregon, Washington, and Alaska. They show that many stands in the southern part of the type's range produce over 200 cubic feet of wood per acre per year (14 m^3/ha/yr) (1, 7, 12). Productivity decreases with increasing latitude (3). Stand volumes can be impressive. One plot in a 147-year-old stand in coastal Oregon contained, on an area basis, 76 spruce and 13 hemlock per acre (188 spruce and 32 hemlock/ha). Total volume was 34,000 cubic feet per acre (2380 m^3/ha). Spruce averaged 210 feet (64 m) in height and 34 inches (86.4 cm) in diameter at breast height (d.b.h.) (4).

Even-aged management is practiced throughout the western hemlock–Sitka spruce type. The optimum rotation age for management of hemlock–spruce depends on the objectives of the landowner. Many hemlock–spruce forests on industrial lands are managed on an economic rotation that varies from about 40 years in accessible, intensively managed areas, to well over 100 years in less accessible areas.

The white pine weevil (*Pissodes strobi* (Peck)) is the most serious enemy of young Sitka spruce in Oregon, Washington, and British Columbia. It is not a problem on the Queen Charlotte Islands nor in southeast Alaska. Within its range, the weevil is more damaging to widely spaced trees on drier sites located inland. Close spacing and the planting of Sitka spruce in small blocks offers the most practical means of minimizing damage in plantations (5). Weevil damage limits the suitability of many sites for future management of Sitka spruce.

The western blackheaded budworm (*Acleris gloverana* (Walsingham)) is an important defoliator of western hemlock and Sitka spruce in coastal forests of Oregon, Washington, British Columbia, and Alaska. Another defoliator, the hemlock sawfly (*Neodiprion tsugae* Middleton), attacks western hemlock. In this order, these are the two most destructive forest insects in coastal Alaska. Other defoliators include the western hemlock looper (*Lambdina fiscellaria lugubrosa* (Hulst)), and the Saddleback looper (*Ectropis crepuscularia* (Denis and Schiffermuller)) (5).

The thin bark and shallow roots of hemlock and spruce make them particularly susceptible to logging injury, which leads to decay, especially in hemlock. Losses from decay fungi are high, especially in the old-growth forests of Alaska. Conversion from old to young growth has great potential for reducing decay, but root rots that reduce growth and vigor then become important. Spread of *Heterobasidium annosum* (Fr.) Bref. from old stumps to new seedlings can lead to damage in hemlock plantations. Extent of damage is correlated with frequency and intensity of thinnings (13). Hemlock dwarf mistletoe (*Arceuthobium tsugense* (Rosend.) G. N. Jones), an important disease of western hemlock, can best be controlled by clearcutting (11).

Fire danger is of less concern here than in drier forest types. The greater concern is in the southern part of the range, particularly inland in the transition zone toward hemlock or Douglas-fir forests. Slash burning to reduce fire hazard has been common wherever conditions were dry enough to permit burning, but the trend now is away from slash burning. Fire does not play an important role in the management of coastal Alaska's forests, and slash burning has not been practiced there (6).

Regeneration of hemlock–spruce forests can be attained with any silvicultural system or combination. The choice depends on profit to the landowner and the need to integrate timber harvest with other forest values.

Clearcutting is by far the most common silvicultural system used in harvesting western hemlock–Sitka spruce stands (11). It is recommended where timber production is the primary use. Logging costs are lower than with other systems. Exposure to the sun raises soil temperature, which speeds decomposition of mor, thereby improving the productivity of northern sites. Clearcutting favors regeneration of Sitka spruce by destroying advance hemlock regeneration and by creating more favorable conditions for post-logging reproduction of spruce. Eliminating residual overstory trees infected with dwarf mistletoe prevents infection of western hemlock in the new stand. Clearcutting also facilitates residue management and fire protection and eliminates the risk of blowdown in residual stands. The chance of blowdown along cutting boundaries is increased but can be reduced through proper design of cutting units.

Natural seedfall is generally adequate for regeneration, and most young stands are dense. Direct seeding has been done to supplement a poor seed crop, alter species composition, or regenerate areas left without a natural seed source, but is not effective if regeneration failures are caused by competing vegetation. Restrictions on use of rodent control chemicals, high cost of seed, and development of improved nursery and planting techniques have made planting a better regeneration method (11).

Planting is often done to reduce the time required for natural regeneration on problem sites, to increase the percentage of Sitka spruce in stands, or to replace Sitka spruce with Douglas-fir in areas subject to weevil damage. Handplanting is required because hillsides usually are too steep for machine planting; flat bottomland is too wet; and where old-growth stands are logged, heavy logging residues create obstacles, even if broadcast burning is done. Both bare-root and container-grown stock are used. Where animal damage is a problem, measures such as use of plastic mesh tubes, chemical repellants, and modification of animal habitat may be necessary to protect seedlings (11).

Clearcutting may be less esthetic than other harvesting systems, although size, shape, and arrangement of clearcuts can be altered to reduce the visual effect. On National Forests in Alaska, openings are limited to 100 acres (40 ha) or less except under specific circumstances. After clearcutting, several years may elapse before the site is again fully utilized for timber production, and competing vegetation tends to take over the site more quickly than with the shelterwood or selection systems. In extensive swampy areas, clearcutting may reduce transpiration enough to cause an undesirable rise in the water table. In the northern portions of the hemlock–spruce type where winter snows are deep, clearcutting extensive areas of old growth can impair the quality of deer habitat (14).

Hemlock and spruce lend themselves to shelterwood cutting because both species can become established under a suitable forest canopy. Shelterwood cuttings resemble heavy thinnings, and use of this method logically follows a series of commercial thinnings in immature stands.

The shelterwood system may be preferable to clearcutting where it is essential to maintain a continuous tree cover, to reduce visual change, to reduce erosion, or to minimize encroachment of unwanted intolerant vegetation. Shade can be controlled, thus providing some control of species composition in the regenerating stand. In order of decreasing shade, seedlings of western hemlock, Sitka spruce, Douglas-fir, and red alder are able to become established (10). Logging costs are higher with shelterwood cutting because several entries are made into the stand. There is increased danger of wind damage to the residual stand. Overstocking of western hemlock regeneration can be expected, and growth rate of seedlings is slower under shade (11). The system is not appropriate for stands infected with dwarf mistletoe or for old-growth stands where trees are large and defective.

The selection system has not been tested in the western hemlock–Sitka spruce type, but in theory it appears to have merit. With the selection system, a high uneven-aged forest cover could be maintained, resulting in less visual change and greater stability of environmental conditions. It may have application in scenic areas where both forest cover and commercial timber production are desired, and may be a useful system for maintaining good deer habitat in the northern portion of the type. The system might be used to discriminate against unwanted intolerant plant species by restricting the size of openings.

Disadvantages of the selection system are that frequent entries must be made into the stand to remove trees individually or in small groups, thus increasing logging costs and the chance of logging damage. Risk of wind damage also increases. A more extensive road system needs to be maintained to secure the same volume of timber as obtained by use of other systems, and this could result in increased erosion. It would be the least desirable system where timber production is a major goal.

Converting older, even-aged stands with trees of fairly uniform, large diameters, or stands having several age classes to uneven-aged stands with a progression of diameter classes, would be a lengthy process. The selection system would not be desirable for hemlock stands infected with hemlock dwarf mistletoe.

The seed-tree system offers little advantage for use in hemlock–spruce forests. Overdense regeneration usually occurs even without seed trees; and on problem sites, additional seed offers no guarantee of regeneration success. Exposed trees tend to blow down, and it is costly to harvest them at a later date. From the standpoint of wildlife management, the seed-tree system might be used to provide snags for nesting or perching sites. Selection of seed trees could be based on their suitability for wildlife habitat as well as for seed production (11).

Both hemlock and spruce respond well to release, and growth rates increase immediately after thinning (15). Early precommercial thinning is recommended where stands are overdense. Height growth of Sitka spruce and western hemlock are nearly equal during the period of most rapid growth, but spruce grows more rapidly in diameter. Consequently, thinning from below tends to favor spruce.

Commercial thinning is becoming more common, but conventional logging methods have not proved satisfactory, and economics has limited thinning opportunities in hemlock. Cable yarding is often preferable to use of tracked or wheeled vehicles and is the only practical means on steep slopes. In Alaska, commercial thinning has been limited because of the predominance of old-growth stands, poor accessibility, and limited markets for small material.

Multiple use management of resources is practiced to various degrees in the western hemlock–Sitka spruce type depending on forest ownership, suitability of the land, and relative demands for various resources. Timber is a major resource; recreation, scenery, wildlife, and fish are important resources as well. Hemlock–spruce forests provide habitat for game and nongame animals and watershed protection for spawning and rearing habitat for anadromous fish. They provide recreational opportunities and scenery rarely found in any other forest type.

Clearcutting will doubtless continue to be by far the most economical and practical silvicultural system for use where timber production is a major objective of management. The shelterwood and selection systems could become more widely used in situations where the use or protection of other resources is paramount.

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Pacific Douglas-Fir

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Pacific Douglas-fir (type 229), with associated species, is one of the world's most productive forest cover types listed by the Society of American Foresters (5). This type generally is restricted in the United States to areas west of the Cascade Range in Washington and Oregon, but it also is found on a more limited area in northwestern California—in total, about 17 million acres (6.9 million ha).

Coast Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) (24), requires moderate temperatures and moisture regimes, as shown by its common presence on southerly slopes in the northern portion of its range and on northerly slopes in the southern part. The species thrives on a variety of soils, but grows poorly on shallow soils and over high water tables (26).

Almost pure stands of coast Douglas-fir are more common in the central portion of its range than toward the periphery. The principal associates, western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and western redcedar (*Thuja plicata* Donn ex. D. Don), appear more frequently in the west and north; true firs and mountain hemlock are more abundant at higher elevations (6). To the south the type merges into the mixed conifers and hardwoods of southwest Oregon and northern California and has a rather discreet western boundary there with the redwood type.

The type occupies a mild and humid climate with dry summers. Average annual temperatures vary from 45° to 55° F (7.2° to 12.8° C), with extremes from about 110° to −30° F (43.3° to −34.4° C) (6). Annual precipitation ranges from about 35 to over 200 inches (890 to more than 5080 mm) per year—much of that at higher elevations as snow. Elevations occupied by the type range from sea level to about 1,500 feet (460 m) in the northern part of the range; to about 6,000 feet (1830 m) in the southern part.

Coast Douglas-fir is usually a subclimax species. Left untouched, old-growth stands usually are succeeded by more shade-tolerant species, especially western hemlock, unless natural catastrophes such as wildfires and windthrow intervene. Douglas-fir is called a fire species because wildfire often will not kill thick-barked old-growth trees and fire has frequently been involved in its natural regeneration. Fire may stimulate seed production, cause the release of seed from cones, eliminate thin-barked competitors, and create suitable seedbeds. Historically, wildfires have burned large areas, giving rise to extensive even-aged stands.

Natural reproduction of Douglas-fir and its principal associates is through wind-disseminated seed. Douglas-fir seed production is irregular, but a light crop or better can be expected about 2 years out of 3 in the central portion of the range (18), and less frequently in the southern portion (34). Seed can be disseminated over a wide range of distances, depending on stand height and wind velocity (8, 15). Germination and survival are best on mineral soil seedbeds, but are possible on seedbeds of organic matter if temperature and moisture regimes are suitable (18). Temperatures are usually too high on sunlit seedbeds of organic matter (35). Reproduction is usually scantier where slash is heavier (2). Therefore, slash burning under typical old-growth harvest conditions results in better natural restocking of Douglas-fir than no burning.

Both western hemlock and western redcedar are more prolific seed producers than Douglas-fir (10, 49). These species prefer mineral soil seedbeds, too, but their seeds germinate and seedlings survive better on duff and rotten wood than do those of Douglas-fir. If slash is not burned, seedlings of western hemlock and western redcedar are more likely to predominate than if slash is burned.

Douglas-fir is medium in shade tolerance and much less tolerant than its principal associates (30). Young Douglas-fir seedlings require about one-third of full sunlight to achieve maximum photosynthesis under optimum temperature and moisture conditions (21). Light requirements are probably greater under the usual moisture stress of growing season field conditions. Western hemlock can germinate and survive at about 2 percent of full sunlight, compared to Douglas-fir, which requires at least 5 percent (18, 46, 50). On severe sites where regeneration of Douglas-fir is difficult, approximately 50 percent shade produces the best survival and reasonable growth of seedlings (18, 40, 48). Once Douglas-fir and western hemlock are well established, height growth increases with increasing light (42, 50).

Soil surface temperatures above about 140° F (60° C) can be lethal to very young Douglas-fir seedlings, and such temperatures are common during the middays of late spring and summer on south slopes (11, 14, 35). Where lethally high temperatures can be expected, shade benefits survival of seedlings (27, 48). Such benefits also extend to more mesic sites (16). These temperature relations are probably the principal reason why most clearcuts that have not restocked naturally in a satisfactory length of time have failed to do so, and why planting of seedlings is a standard practice. Predation of seeds and seedlings by birds, rodents, and other animals, and competing vegetation are also frequently listed as causes of regeneration failures.

The principal associates of coast Douglas-fir are much more tolerant of flooding and high water tables than is Douglas-fir, to the practical exclusion of Douglas-fir on such sites (26). Conversely, Douglas-fir tolerates drought much better than western hemlock (4).

Productivity of a coast Douglas-fir site depends, in part, on the genetic makeup of the trees. The use of local strains is essential for planting stock because of their adaptation to environmental conditions, though cautious genetic manipulation should improve yields somewhat (36). In the same vein, promoting both natural and artificial regeneration could uphold genetic diversity (44). Such practices should decrease the chances of lower-than-expected yields caused by the use of offsite seed sources.

Controlled burning is a principal tool of forest land managers within this type for preventing wildfire through hazardous fuel reduction, controlling undesirable species, and clearing harvested sites of debris for regeneration. Fire, however, may decrease site productivity through loss of nitrogen and through leaching of soil cations and surface erosion (31, 33). No significant differences between burned and unburned forest soils in short-term growth of seedlings and in organic matter, total N, P, K, Ca, permeability, and wettability were found 25 years after broadcast burning on the western flanks of the Cascade Range (20, 43).

Douglas-fir is remarkably free of pests during the juvenile stages, though browsing of foliage by various animals—principally deer, elk, mountain beaver, snowshoe hare, and various rabbits—can be a serious problem locally (3). As stands mature, they become increasingly vulnerable to root pathogens, the Douglas-fir beetle (*Dendroctonus pseudotsugae* Hopkins), and snow and ice breakage. Mortality and loss of production caused by these agents is much reduced if stands are maintained in a vigorous condition by thinning (47).

Extensive trials some 30 years ago clearly showed that the selection method used in uneven-aged management cannot be applied successfully to old-growth coast Douglas-fir (19). Slash disposal was difficult because there was risk of killing standing trees, mortality in residual stands was high, and insufficient light was provided for Douglas-fir reproduction. The result was that stands were converted to more shade-tolerant and less valuable species (18, 32). The uneven-aged system may have limited applicability where resource values other than timber production justify higher costs, changes in species composition, and stand structure or stand conditions associated with uneven-aged stands. Use of the selection method of cutting may be possible without species conversion in small portions of the Douglas-fir range—in ecosystems where Douglas-fir is a climax species. These ecosystems generally occur in topographic rain shadows such as the east side of Vancouver Island where soil and climate characteristics lead to droughty, but not xeric, soil conditions. No recorded trials of individual tree selection with all size classes represented have been designed and implemented for a significant period in the Pacific Douglas-fir type.

The medium shade tolerance of coast Douglas-fir, and the much greater tolerance of its principal associates, justify the use of even-aged silviculture.

Among the even-aged regeneration methods, the only one not appropriate for old-growth Douglas-fir is the seed-tree method. Seed trees are too isolated and, thus, susceptible to windthrow (17). The method should be appropriate in young-growth stands that have been thinned throughout their lives, with consequent increased wind firmness of individual trees. Clearcutting is by far the most common and successful reproduction method for coastal Douglas-fir—successful in that logging is most efficient and artificial regeneration practices usually result in good survival and growth of seedlings. Most seedling failures after clearcutting are caused by temperature extremes (16), with lesser amounts by drought and competing vegetation. Shelterwood overstories, together with site preparation, can be expected to mitigate such extremes. Artificial regeneration after clearcutting may fail frequently enough on some southerly slopes and on gentle terrain in the midportion of the range of the species, and increasingly on similar slopes toward the southern part of the range, to suggest use of the shelterwood method. The choice of which method to use should be based on evidence about which one would provide adequate regeneration at most reasonable cost.

Shelterwood harvesting in the Pacific Douglas-fir type, with appropriate overstory characteristics and site preparation, can insure adequate regeneration where evidence suggests that regeneration after clearcutting will fail (48). This evidence includes survey data on regeneration success in nearby existing clearcut areas of similar soil, slope, aspect, and elevation. Lesser vegetation and soils descriptions are available as regeneration guidelines for some areas (29). Financial considerations necessarily influence the choice since any reproduction method could be made to work anywhere if costs were no object.

Practices that aid regeneration and incur costs above those arising under patch clearcutting include making clearcuts smaller or in narrow strips, eliminating concentrations of slash, controlling brush, and providing artificial shade (7, 9, 22, 23, 27, 28, 41). Eliminating concentrations of slash and controlling brush often are accomplished together as part of site preparation. Burning, either broadcast or of piles, is the usual method. Yarding of unmerchantable material greatly reduces the need for burning and should practically eliminate hard-burn areas, including those areas where burning is necessary for fire control or site preparation.

Under shelterwood harvesting, practices that aid regeneration and also incur costs are the shelterwood operation itself, which is more expensive to lay out and log than a clearcut, and site preparation, which can be accomplished in the same manner as in clearcuts. Several precautions should be observed when using the shelterwood method within the Pacific Douglas-fir type:

- The largest, most vigorous, and best formed individuals of desirable species should be retained until the final cutting (37), unless some individual other trees are retained as future habitat for cavity-nesting birds.
- Overstories should be sufficiently dense to provide appropriate microclimate modification and resist windthrow and dessication (48).
- Site preparation should expose mineral seedbed (39).
- Overstories should be removed when seedlings are sufficiently dense and well established, but while still low and limber. Doing so avoids much regeneration mortality caused by overstory removal and relieves seedlings from the substantial competition offered by the overstory.

If these precautions are observed, conditions for natural regeneration under shelterwood (except on high-site, brush-threat areas) are favorable.

The method is reliable and avoids the cost of planting which may compensate for increased harvest and administrative costs. Since the seed providers in the overstory survived to maturity in the presence of whatever pests or hostile environmental conditions pertain to the site, the resultant natural regeneration should show similar adaption (36).

Coast Douglas-fir seedlings become established slowly, requiring 5 to 10 years to reach breast height. Once regeneration is established, growth is rapid on good sites, ranging up to about 300 cubic feet per acre per year (21.0 m^3/ha/year). Mature yields above age 100 can be more than 17,500 cubic feet per acre (1225.0 m^3/ha) (25). Conventional rotation lengths normally vary between 50 and 100 years, with final harvest yields in natural stands on average sites from about 5,000 to 14,500 cubic feet per acre (350.0 to 1015.0 m^3/ha). Initial spacing and subsequent growing stock control with fertilization are required for optimum yields in terms of tree size and fiber production. Yields under growing stock control and fertilization will generally range about 30 to 50 percent greater than natural yields.

The foregoing suggests that clearcutting and shelterwood will be the principal regeneration methods for the Pacific Douglas-fir type. That these methods will differ significantly in their impacts on water, fish, wildlife, rare and endangered species, or recreation is unlikely. Any shelterwood stand open enough to promote establishment of coast Douglas-fir seedlings will generally support the same species of lesser vegetation as clearcuts do, except for the very shade intolerant red alder, with quantities and nutrients somewhat reduced because of competition from the overstory. Even clearcutting does not seem to have significant and adverse impacts on streamflows (12, 13).

Clearcut areas provide forage for big game and habitat for other species of wildlife including birds that utilize plant communities containing predominantly pioneer plant species. Hiding and thermal cover provided by uncut or maturing stands are equally important to wildlife. The size and distribution of clearcut and uncut areas influence the quality of wildlife habitat (45).

Size, shape, and viewer position in relation to both clearcut and shelterwood units largely determine the visual acceptability of regeneration methods to achieve landscape management objectives. Rotation lengths of 250 or more years can provide the large-diameter trees that are specified in many "foreground" visual resource management plans in the Pacific Douglas-fir forest type (1).

Modifications of the even-aged silvicultural systems are options for this type that may be considered where management for esthetic, watershed, or wildlife objectives require a continuous high canopy or one with small gaps. These options also may provide some opportunity to manage for specific requirements of identified threatened, rare, or endangered species of plants or animals. Smaller clearcuts and shelterwood stands adjacent to streams will inhibit stream bank and sheet erosion into streams and mitigate the rise in stream temperature that would otherwise occur under large clearcuts.

The opportunities to utilize modifications of silvicultural systems within the Pacific Douglas-fir type are limited by willingness to accept yield reductions, increased costs, and species conversion, as well as by physical and biological limitations. The presence of potentially competitive vegetation capable of preventing the establishment of desired vegetation limits the choice of silvicultural systems. The use of chemicals to control the competing vegetation is hindered by the existence of residual trees on an area being reforested, especially on steep and rough topography.

The choice of specific silvicultural systems to achieve multiple-use management objectives influences costs of layout and administration or supervision of harvest operations. The primary factors contributing to increased operational costs are: increasing the variety of log sizes being harvested; increasing the numbers of residual trees in any partial cut; increasing the volume removed; and increasing the complexity of designating residual trees. The following comparisons are between clearcutting and partial cutting within the Pacific Douglas-fir type using current Forest Service appraisal and logging system guidelines. The estimated range of increased costs, relative to clearcutting, for preparation and harvest on slopes less than 30 percent is 6 percent for shelterwood to 10 percent for selection cutting. Similarly the range on slopes exceeding 30 percent is estimated to be 20 to 30 percent. Partial cutting becomes increasingly costly with longer yarding distances and steeper terrain.

Within the Pacific Douglas-fir type, partial cutting or clearcuts as small as 10 acres (4 ha) may require 7.5 miles of road per mile^2 (4.7 km/km^2) of land whereas block clearcuts of 100 acres (40.5 ha) may require only 6.3 miles of road per mile^2 (3.9 km/km^2) (38). Any method of harvesting that retains a portion of the timber stand requires an increased area of land to provide a similar volume of timber for harvest. This in turn requires a more rapid development of the ultimate road network; an increase in miles of road use and maintenance, with consequent erosion and siltation of streams; and a temporary decrease in cover for wildlife.

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True Fir–Hemlock

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The true fir–hemlock (*Abies–Tsuga*) type is a diverse collection of montane and subalpine forests found on the middle and upper slopes of the entire Cascade Range, on higher peaks in the northern Coast Ranges of Oregon and Washington, and throughout the Olympic Mountains in Washington. It covers at least 4 million acres (1.6 million ha) over a broad spectrum of environmental conditions and incorporates many species and stand conditions (3). These forests belong mainly to Society of American Foresters forest cover types 226 (Coastal True Fir–Hemlock) and 205 (Mountain Hemlock) (2) and occur within the Pasific Silver Fir and Mountain Hemlock Zones (5). The majority of true fir–hemlock forest are old growth, which often influences the choice of silvicultural systems.

True fir–hemlock forests can be stratified into four major geographic groups (3). One group is forests overwhelmingly dominated by Pacific silver fir (*Abies amabilis* (Dougl.) ex Forbes) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) that occur in the Olympic Mountains (except for the northeast corner) and western slopes of the Northern Cascades. Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and western redcedar (*Thuja plicata* Donn ex D. Don) are associated at lower and mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.) and Alaska-cedar (*Chamaecyparis nootkatensis* (D. Don) Spach) at higher elevations. A second group is mixed forests dominated by Pacific silver fir, western hemlock, noble fir (*Abies procera* Rehd.), and Douglas-fir with associated western redcedar, Alaska-cedar, and western white pine (*Pinus monticola* Dougl. ex D. Don) that characterize the western two-thirds of the Cascade Range from about 44° to 47.5° N. Another group is mixed forests with significant representation of interior species, such as lodgepole pine (*Pinus contorta* Dougl. ex Loud.), Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.), and western larch (*Larix occidentalis* Nutt.), that occur on the eastern slopes of the Washington Cascade Range and in Oregon's High Cascades north of about 44° N. Douglas-fir, western white pine, western and mountain hemlocks, and noble and Pacific silver firs remain major species in this region. A fourth group is mountain hemlock forests in the southern Oregon Cascade Range that have Shasta red fir (*Abies magnifica* A. Murr. var. *shastensis* Lemm.) and lodgepole pine as major associates. The Shasta red fir forests of the southern Cascade Range and Klamath Mountains with their associated grand fir, Douglas-fir, western white pine, and mountain hemlock resemble the California true fir types more closely that the true fir–hemlock types discussed in this section. Readers are referred to the "Red Fir–White Fir" section of this handbook for a discussion of relevant sivicultural systems.

More than 50 true fir–hemlock habitat types are recognized indicating the wide range of environmental variability. Elevations range from about 3,500 to 6,000 feet (1075 to 1825 m) in central Oregon to 2,500 to 5,000 feet (750 to 1525 m) in northern Washington, although true fir–hemlock forests may occur as low as 1,000 feet (300 m) in cold valley bottoms. Topography is typically gentle in the High Cascades and moderate to very steep in the Western and Northern Cascades, Coast Ranges, and Olympic Mountains (3). Soils are generally coarse textured, youthful, and most frequently developed in colluvium, volcanic tephra, or glacial till. Mor layers are typical but range widely in thickness, being best developed in the Northern Cascades.

Climatic conditions can be characterized as cool, wet, and snowy; but specifics vary with elevation, latitude, and location in the various mountain ranges. Temperature decreases and precipitation increases with increases in elevation and latitude; eastern slopes of mountain ranges have drier and more continental temperature regimes than the western slopes, since winter storms come from the west and southwest. Summers are generally cool, but winter temperatures are moderate for a subalpine region—subfreezing daytime maxima are not common. Frosty areas are particularly common and severe in the gentle topography of the High Cascades due to reradiation and poor air drainage but are also encountered throughout the type. Precipitation generally exceeds 80 inches (2030 mm) and can be over 200 inches (5080 mm) annually. Much of it occurs as snow which forms deep, heavy, snowpacks 2 to 20 feet (0.6 to 6 m) in depth, depending on elevation and aspect. These snowpacks are present for 3 to 8 months and prevent extensive soil freezing. Periods of dryness may occur during the summer but generally do not result in high plant moisture stresses. Clouds are common throughout the year and may cause abundant fog drip in mature forests. Strong southwest to west winds are associated with winter storms, and strong dry east winds occur occasionally throughout the year.

The most characteristic and widespread species are Pacific silver fir, western hemlock, mountain hemlock, Douglas-fir, and noble fir. Important constituents do vary widely on both a large geographic scale (as indicated above) and locally. Mixed stands of three to five species are most common, but almost any species can dominate or form local pure stands. Douglas-fir, noble fir, western larch, and the pines are the most shade intolerant species and often function as pioneers following major disturbances. Pacific silver fir and western hemlock are very shade tolerant. The relative importance of the two species as climax species varies with increasing elevation favoring Pacific silver fir dominance over the western hemlock.

Natural regeneration of trees in true fir–hemlock forest is almost exclusively by seed. Some seed is produced almost every year because stands are mixed and species vary in their patterns of seed production (6). Many species produce medium or better crops every 2 or 3 years, but Douglas-fir produces less frequently and the pines at more frequent intervals. Seed dissemination is by wind with the bulk of the seed falling within one tree height of its source. The shade intolerant species prefer mineral soil seedbeds while the tolerant species also utilize organic seedbeds. Seed germination varies widely with species, the true firs generally having low viability. Survival rates of seedlings differ markedly with year, habitat type, and other factors. Mortality of germinants can be extremely high with thousands of seeds necessary to produce a single established seedling. Vegetative competition (from sedges, shrubs, and beargrass (*Xerophyllum tenax*)), pocket gophers, and frost can be important factors reducing survival of both planted and natural trees. Once established, noble fir, Douglas-fir, western white pine, and shade intolerant associates require substantial light for best development; these species are generally not able to recover following suppression. Pacific silver fir and western hemlock can establish themselves in heavy shade, and suppressed seedlings of these species often do recover and grow normally following release.

Growth rates are highly variable between sites and between species on the same site. In general, trees initially grow slowly but sustain their growth into the second and even third centuries. When more typically low-elevation species (Douglas-fir and western hemlock) occur in the true fir–hemlock type, they consistently show slower juvenile growth but more sustained growth than at lower elevations (1). Noble fir site indices of 60 to 160 feet (18 to 49 m) at 100 years illustrates the range in productivity (11). Mean annual growth of stands can be in excess of 250 cubic feet per acre (17.5 m^3/ha) at culmination on the best sites although much lower values are typical and many sites produce 50 cubic feet per acre (3.5 m^3/ha) or less. Stand growth slows later in true fir–hemlock stands than in lower elevation forests; culmination of mean annual increment is at about 125 years in unmanaged stands on noble fir site class II.

Numerous insects and diseases affect true fir–hemlock forests (7, 10). Bark beetles such as mountain pine beetle (*Dendroctonus ponderosae* Hopkins) affect the pines, and the silver fir beetle (*Pseudohylesinus sericeus* (Mannerheim)) and *P. tsugae*) affects true firs and hemlocks. Both insects sometimes cause epidemic losses. The exotic balsam woolly adelgid (*Adelges piceae* Ratzeburg) is a serious pest of Pacific silver and subalpine fir, especially on better sites where it can limit their management potential (13). Dwarf mistletoes (*Arceuthobium* spp.) are sometimes problems especially in western hemlock; mistletoe limits the potential use of advance regeneration on some sites. White pine blister rust (*Cronartium ribicola* J. C. Fisch.) seriously limits the management potential of western white pine by killing large numbers of seedlings, saplings, and poles; development of rust-resistant planting stock should make it possible to again utilize western white pine on the many sites where it demonstrates a superior growth rate. Trunk rots are common in old-growth stands; true firs and hemlocks have low resistance to rots once infected. Laminated root rot (*Phellinus weirii* (Murr.) Gilb.) is the most serious root pathogen and causes extensive mortality in mountain hemlock forests in the high Cascades.

Fire is a significant factor in true fir–hemlock forests. Sites have burned catastrophically at natural fire intervals of 100 to 400 years or more depending upon habitat type and geographic location (8, 9). Forests located on high ridges and along the crest of the Cascade Range have especially high fire risk particularly during times of dry east winds. Prescribed fire is an important management tool to dispose of slash accumulations, which can be very large after cutting virgin stands, and to prepare the site for planting. True fir–hemlock forests may be more susceptible to misuse of fire than many other types, however, because of high proportions of nutrients found in surface organic layers on the predominantly young soils, predominance of thin-barked species, and importance of advanced regeneration.

True fir–hemlock forests can probably be managed either under even-aged or uneven-aged systems depending on species composition, health of stand, topography, and management objectives, although silvicultural trials of systems are far from complete. Where the more light-demanding species predominate or are desired, an even-aged system is indicated. If shade-tolerant species are the more important, then either even-aged or uneven-aged management is possible provided the stand is not defective and topography is favorable. Thus, the choice of silvicultural systems depends on many factors including site, species, stand condition, and objectives. Careful choice of species for management is especially important on true fir–hemlock sites because of the large local variations in environment and the large number of potential species. Mixed stands reduce the risk of catastrophic loss due to environmental or biological agents and may maximize productivity.

Small clearcuts of less than 20 acres (8.0 ha) and shelterwood cuttings are the most consistently successful systems for even-aged management. Noble fir, Douglas-fir, western white pine, Shasta red fir, and other shade intolerant species are well suited to both methods. The choice of species may depend upon whether natural or artificial regeneration is desired; the choice may be further influenced by lack of dependable methods for artificial regeneration of some species on some sites. A two-stage shelterwood cutting is the most dependable method and is particularly indicated on severe sites, such as frost pockets, and when reliance is to be placed on natural regeneration. Small clearcuts are a little riskier for securing natural regeneration but are more suitable on average sites which can be artificially regenerated. Natural seedlings typically volunteer on such small clearcuts producing stands with a mixture of species (12). Clearcutting is typically less expensive than shelterwood cutting and is easier to use on steep or wet ground. Shelterwood cutting creates more favorable environmental conditions for seedling establishment, and species can be favored through the selection of leave trees and preparation of seedbeds. Clearcuts should be avoided in situations where they could produce frost pockets. Strip clearcuts would appear a likely alternative to small clearcuts, but results have often been unacceptable to date. An untested possibility for regeneration cutting on very severe sites is group selection, even for the less shade-tolerant species.

Larger clearcuts of more than 20 acres (8.0 ha) are appropriate where available techniques have proven dependable for artificial regeneration of the desired species or, sufficient good quality advance reproduction of acceptable species can be preserved during logging and slash disposal. Clearcutting with heavy reliance on residual advance regeneration is a recommended alternative in many areas and has been effective on many ownerships in the Washington Cascade Range. The forester needs to be aware of potential problems with large clearcuts followed by broadcast burning of slash as indicated by past experience. Such procedures aggravate moisture and temperature extremes, minimize natural seedfall, destroy advance regeneration, volatilize nitrogen, and sometimes result in brush problems. Furthermore, the selection of potential species is limited since dependable stock or planting techniques or both are not yet available for many upper-slope species. Regeneration failures with large clearcuts have been more common in the High Cascades and near the upper limits of continuous forest. Advance regeneration, especially of true firs, responds well to release and can serve as insurance against reforestation failures even when planting is planned.

Selection is an alternative silvicultural system for extremely severe sites, such as those found at the upper edge of closed forest, or where management objectives call for maintenance of a continuous forest cover, as in heavily used recreation areas. Conceptually, group selection should work with less shade-tolerant species and single tree selection for species such as Pacific silver fir and western hemlock. Selection systems have not been tested, however, and have little application to steep slopes where damage to residual stems and soils during harvest operations would be severe.

Seed source and genetic variation are important considerations in regeneration programs reflecting high levels of genecological variability in many species and wide environmental differences in local site conditions. Selection and testing for genetic improvement of growth rates is currently underway on public and private forest lands for Douglas-fir, noble fir, Pacific silver fir, and western white pine. Western white pine trees resistant to white pine blister rust have been identified and their progeny are being used in reforestation programs.

There is very little documented experience in thinning true fir—hemlock stands. Intermediate cuttings should consider compositional as well as growth objectives, for example, maintenance of species mixtures, especially in the face of varying growth rates that tend to cause species stratification by size classes. In general, desirable stocking levels have not been determined; but they are expected to involve higher densities than those established for Douglas-fir stands on comparable sites; this is based on comparisons between normally stocked stands of true firs and Douglas-fir (4). Precommercial thinning is judged the most important type of intermediate cutting, especially on low site stands that tend to stagnate. Commercial thinning opportunities are limited by the thin bark and high damage susceptibility of many upper-slope species and their patterns of sustained growth. Similarly, sanitation cuttings should be avoided because of the potential for damaging the residual stand.

The potential for fertilization is essentially unknown. Soils are typically low in nitrogen and, sometimes, phosphorus. Responses have been reported from fertilized western hemlock and Pacific silver fir (14).

The true fir—hemlock type is well represented in reserved (National Park and Wilderness) lands and is, therefore, not endangered. No animal species are known to be solely dependent on the type for their existence although it is important to a great variety of wildlife.

Since true fir—hemlock forests occupy the upper slopes of mountain ranges, watershed and recreational values are major management considerations. The forests are sites for winter snowpack accumulations, and disturbances can affect water yields and quality. Recreational activities as varied as downhill skiing and wilderness backpacking are common in true fir—hemlock forests. Huckleberry picking is an historic and valued recreational use of cutover and burned forests of this type. Wildlife and livestock use are also important locally in interspersed meadows and as temporary range following forest disturbance. No-cutting options can be considered on true fir—hemlock sites with low productivity (despite significant standing crops) or with severe regeneration problems, and high non-timber values.

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Northwestern Ponderosa Pine and Associated Species

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The ponderosa pine type (Society of American Foresters forest cover type 237) occupies about 7 million acres (2.8 million ha) in eastern Oregon and Washington (10). Additional areas of similar forest occur in northeastern California. Gentle rolling hills, flat river bottoms, and steep slopes are all vegetated by ponderosa pine, especially at intermediate elevations from about 4,000 to 6,000 feet (1220 to 1830 m) in southern Oregon, but lowering to about 2,000 feet (610 m) in eastern Washington. Stands are frequently interspersed with islands of nonforest type and can also be islands in the grasslands.

Soils are quite varied with many of them the result of volcanism. Pumice, ash, cinder, and basalt-derived soils, usually with poorly differentiated horizons, have developed over buried soils. Other soils are derived from granitic or serpentine bases. Sedimentary rocks also account for some soils.

The climate is modified maritime, the result of the barrier to marine air masses provided by the Cascade Range. The area has warm dry summers and cold wet winters with much of the precipitation falling as snow. Growing season temperatures average between 62° to 70° F (16.7° to 21.1° C); but the daily range of temperature can be as much as 54° F (30° C), and frost can occur any night of the year in many areas. Summers are especially sunny; winters have intermittent periods of sunshine and clouds. Precipitation ranges from about 10 to 30 inches (250 to 760 mm), with only 2 to 6 inches (50 to 150 mm) falling during the growing season. Humidity is generally quite low, especially in summer.

Lodgepole pine (*Pinus contorta* Dougl. ex Loud.), western juniper (*Juniperus occidentalis* Hook.), and western larch (*Larix occidentalis* Nutt.) are common intolerant associates of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.), although ponderosa pine has no prevalent associate on the lowest, driest sites in Washington. The first two species may be killed by light fires, but the latter may be more resistant to fire than ponderosa pine as it becomes older.

Other associates of ponderosa pine in the area, in order of increasing tolerance and decreasing fire resistance are Jeffrey pine (*Pinus jeffreyi* Grev. & Balf.), an important associate in northern California; sugar pine (*Pinus lambertiana* Dougl.); Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco); incense-cedar (*Libocedrus decurrens* Torr.); western white pine (*Pinus monticola* Dougl. ex D. Don); and true firs (*Abies grandis* (Dougl. ex D. Don) Lindl.) and (*A. concolor* (Gord. & Glend.) Lindl. ex Hildebr.). Lack of disturbance such as fire on sites capable of supporting the more tolerant trees gradually converts the site to those species.

Artificial regeneration of ponderosa pine is generally by machine planting, although hand planting by auger and hoe are practiced (7) where obstacles or steep slopes are present. Adequate site preparation is necessary because of competing shrub and herbaceous species. Direct seeding is seldom used.

Good seed crops of 200,000 seeds per acre (494 200 seeds/ha) can be expected once every 4 or 5 years, although these years are not regularly periodic (9). Dissemination is primarily by wind and by small mammals who cache the seed. Poor seed years generally have a lower percent of sound seed; occasionally almost no seed is produced in the Northwest, perhaps because frost damages the conelets (9, 17). Barrett (2) reported little ponderosa pine seed disseminated more than 100 feet (30.8 m) from the seed source; but in strong prevailing winds, seeds can be blown 528 feet (161 m) into a clearcut. Mineral soil is considered best for seedling establishment. On many sites, this is needed in combination with a shelterwood of 10 to 15 trees per acre (25 to 37/ha) to reduce heat and frost damage. Survival of seedlings depends on a combination of factors: availability of sound seed, good seedbed, adequate moisture, and protection from frost, animals, disease, and fire. If any of these is unfavorable, survival will be poor (8).

Ponderosa pine is generally considered a shade intolerant tree, probably being more tolerant than western juniper, about the same as lodgepole pine and western larch, and less tolerant than all its other tree associates. Established seedlings and saplings are able to survive shade and root competition from overstory ponderosa pine. Once established, ponderosa pine is able to withstand the annual summer drought, often surviving where the more tolerant mesic species succumb. It also survives well through periodic droughts, although it is somewhat more susceptible to insect attack during dry periods.

Except where growing on very shallow soils, or when a stand is opened up in a shelterwood or seedtree cut, ponderosa pine is fairly resistant to uprooting by wind. Older trees often break from wind damage when previously weakened by fire scars or decay.

Snow can be damaging to ponderosa pine seedlings or saplings when they are established on upper slopes where snowpack is heavy. The overwinter compaction and slippage of the snow will cause bending or breakage of the young trees.

Ponderosa pine is able to recover from severe suppression at least to an age of 80 years. Removal of overstory, control of shrubs, and thinning to a stocking level that will produce a marketable product will allow rapid growth (3, 4, 14). Suppressed saplings are generally thinned to 150 to 200 trees per acre (370 to 490/ha) after overstory harvest and frequently will respond and grow at diameter growth rates of 2.5 to 3.0 inches (6.4 to 7.6 cm) per decade. Further reduction to only 60 trees per acre (148/ha) and control of shrubs can promote diameter growth rates to as much as 5 or 6 inches (12.7 or 15.2 cm) per decade on some sites. Height growth can also be substantially increased by thinning in these suppressed stands (3, 4).

Height and diameter growth of ponderosa pine will continue to respond to release for at least 16 years following treatment. Natural stands often grow many years to reach breast height (4.5 ft or 1.37 m) because of overstory presence, and understory vegetation competition. Frequently, many years are required for roots to reach more moist or fertile substrata in the soil.

Annual growth rates may vary from 10 cubic feet per acre (0.7 m^3/ha) on sites near the desert fringe to 80 cubic feet per acre (5.6 m^3/ha) on better pine climax types. On true fir–Douglas-fir habitat types, where ponderosa is present but not climax, annual yields commonly vary from 50 cubic feet per acre (3.5 m^3/ha) to 150 cubic feet per acre (10.5 m^3/ha). Stocking capacity is a major factor in yields along with site index and management practices such as thinning, vegetation control, and amount of overstory retained (6, 11).

Culmination of mean annual increment (MAI) (rotation age) varies from 80 to 140 years depending on site quality and silvicultural treatment. Ponderosa pine is sometimes allowed to grow to 200 years or older in visually sensitive areas on public lands without an appreciable reduction in MAI. Yield tables for natural unmanaged fully stocked stands (13) and a first approximation (16) for managed stands are available, but actual yield tables are commonly developed for each local situation due to the large variation in site, stocking capacity, and management objectives.

Insects have been a major problem in the management of ponderosa pine and probably will continue to be so. In contrast, diseases have been a relatively minor problem; but the future may see an increase in such problems.

The major problem insects are three species of bark beetles: western pine beetle (*Dendroctonus brevicomis* LeConte), mountain pine beetle (*Dendroctonus ponderosae* Hopkins), and pine engraver (*Ips pini* (Say)). Each insect attacks a different size class, but all are favored by trees under stress either from being overmature or overstocked. With intensive management, the risk of damage is greatly reduced.

Other insects that have potential for damage are red turpentine beetle (*Dendroctonus valens* LeConte), western pine shoot borer (*Eucosma sonomana* Kearfott), and pine butterfly (*Neophasia menapia* (Felder and Felder)).

In some stands, western dwarf mistletoe (*Arceuthobium campylopodum* Engelm.) can cause loss of growth and poor form in ponderosa pine in this region. Recent evidence, however, suggests that on better sites, young moderately infected trees can be managed.[1] Overstory trees having mistletoe must be harvested and the young infected trees thinned to a spacing that will promote at least 10 inches (25 cm) or more of leader growth per year. This eventually confines most infections to the lower part of the crown. Infected trees grow at acceptable rates and eventually produce merchantable trees. This practice frequently reduces the necessity for clearcutting and planting areas infested with mistletoe.

Armillaria root rot (*Armillariellia mellea* (Vahl. ex Fr.) Karst.) has infected ponderosa pine stands over a long period of time. It spreads primarily by black stringlike rhizomorphs from root to root. At present the recommended control is to remove infected stumps and surrounding trees and roots to prevent spread (15). Annosus root rot (*Heterobasidium annosum* (Fr.) Bref.) may become a problem in the future as ponderosa pine is more intensively managed.

Protection from wildfire can be achieved through mechanical methods or prescribed fire. Crushing or chipping increases fuel density thus reducing fire spread. Piling, followed by pile burning of natural or activity fuels, is often used to reduce the amount of fuel. These practices are usually done in conjunction with cultural practices.

One of the best ways of protecting ponderosa pine forests from wildfire, and to obtain other benefits, is judicious use of prescribed fire (12). Ponderosa pine, throughout its life, is one of the more resistant trees to fire. It is more resistant than any of its associates in the Northwest except for western larch. Historically, fires occurred as frequently as once every 5 years in lower, drier pine sites with the period between fires increasing as precipitation and altitude increase and as temperature decreases. Exclusion of wildfire in many areas has led to dangerous fuel complexes and an increase in tolerant species. Use of prescribed fire can be a cost effective method of reducing these fuel complexes, controlling undesirable species, and preparing the forest for other cultural practices after the burn.

Today both even-aged and uneven-aged silvicultural systems are used in ponderosa pine management. If a young even-aged stand is left from previous cutting practices, it is perpetuated. If an uneven-aged structure exists a choice usually exists for even-aged or uneven-aged management. Even-aged systems are popular because they are simpler to apply and more growth information exists for determining present and future cuts. Uneven-aged systems are sometimes preferred for esthetics along roadways, in recreation areas, and for wildlife habitat. It should not be inferred that the uneven-aged system is necessarily preferable to even-aged silviculture for achieving wildlife, recreation, and visual objectives. Both can have a place in accomplishing these objectives and are sometimes used alternately to give the forest viewer variety.

Single-tree selection is generally used where esthetic considerations are of major concern along highways. Group selection of pine is appropriate in some areas where esthetics are important, in lower, drier sites, or for special wildlife considerations. Timber production can probably be maintained at an acceptable level in such situations if proper stocking-level control is maintained in the smaller trees.

Clearcutting of units as large as 20 or 40 acres (8 or 16 ha) in size will reduce costs of logging, slash disposal, site preparation, and planting. An exception might be where seedling establishment and growth is hindered by edaphic conditions or animal pests. Clearcutting allows complete removal of trees infested with insects or disease and planting with genetically improved stock. A major disadvantage with clearcutting is unsightliness until trees are well established. To temper this disadvantage, clearcuts frequently are irregular in shape and simulate natural stand losses from fire, windthrow, or insects.

In multiple-storied stands, overstory removal or harvesting of the overstory, while saving enough understory to provide a satisfactory new stand, is frequently applied (5) and is simply the final removal cut of a natural shelterwood. Many older ponderosa pine stands have a dense understory that responds well to release (4). Saving and thinning the understory avoids the costs, problems, and uncertainties of site preparation and planting, saves several years in the next rotation, and reduces the period of unsightliness.

The seed-tree method has some of the advantages and disadvantages of clearcutting. Four to eight high-quality seed trees are left per acre (10 to 20/ha), and cutting and site preparation should preferably be done as a good seed crop matures to provide rapid regeneration. Seed trees are harvested once the new seedlings are established and a foot (0.3 m) or so in height. In some cases, one or more of the seed trees per acre (2 or more per ha) may be left for wildlife habitat. The method is not used extensively in the region but has been moderately successful on the perimeter of the Columbia Basin.

The shelterwood method removes the old stand in two or more cuttings. Usually 10 to 15 high-quality trees are left per acre (25 to 37/ha) to furnish seed and shelter for the new

[1] Barrett, James W.; Roth, Lewis F. Response of dwarf mistletoe infected ponderosa pine saplings after thinning. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1982. (Manuscript in preparation)

stand (6). Areas are planted if natural regeneration does not occur in a designated period of time. Ordinarily, the shelter trees are removed once the new stand is 1 or 2 feet (0.3 or 0.6 m) high. The shelterwood system is successful on many ponderosa pine sites. It provides a tree cover at all times and can be applied in three or four cuts where special consideration is being given to other resource objectives.

Intermediate cuttings made between regeneration and final harvest are usually necessary to keep the stand growing at desirable rates. In uneven-aged management, improvement cuttings are frequently necessary to regulate species composition and age class distribution and to sanitize insect- or disease-infested trees. The same may be true using even-aged management, but usually the intermediate cuttings thin the stand to an optimum density that will keep diameter and height growth at desirable rates, provide early return on invested capital, and maximize yields during the last few decades of the rotation. Precommercial thinnings are made from below, removing the smaller, less desirable trees from the stand. Later commercial thinnings retain the best trees.

Ponderosa pine stands commonly reproduce prolifically during good seed years when climatic conditions are just right and dense thickets develop. Early thinning is necessary to avoid stagnation. Trees are spaced far enough apart so they will produce a salable tree before another thinning is needed.

Brush species such as greenleaf manzanita (*Arctostaphylos patula* Greene), snowbrush (*Ceanothus velutinus* Dougl. ex Hook.), antelope bitterbrush (*Purshia tridentata* Pursh DC.), and golden chinkapin (*Castanopsis chrysophylla* (Dougl.) A. DC.) are significant competitors with ponderosa pine from seedling stage until the stand averages about 10 inches (25 cm) in diameter. Recent unpublished results from the Pringle Falls spacing study in Oregon's Deschutes National Forest indicate that tree volume growth losses from shrubs during this period can range from about 25 percent at commonly used tree spacings of around 15 feet (4.6 m) to 50 percent at wider spacings, sometimes used to promote rapid growth to sawlog-sized trees. Shrub control in thinned natural stands and plantations is recommended as soon as potential crop trees can be identified. An additional shrub treatment before trees reach sawlog size may be necessary.

The ponderosa pine forest has great potential for multiple use and is often managed for several purposes. These forests, while not high in production of wood, are excellent for accessibility, for recreation, and for providing habitat for a wide variety of wildlife.

Range management is often practiced in the ponderosa pine forest where livestock can complement timber management by reducing growth of competitive species and reduce fuel accumulation. Prescribed burning is often helpful in increasing the palatability and quantity of forage.

Water and fish are generally not major concerns in ponderosa pine management. Leaving trees along stream and lake edges can be important in keeping water temperature down, but protection of riparian zones is more a function of controlling livestock.

Controlling shrubs or tree stocking in pine stands can contribute significantly to groundwater (1).

A wide variety of game and nongame wildlife use one or more ponderosa pine communities and structures during their life cycles. Some wildlife have rather narrow requirements while others flourish under a wide range of conditions, and changing the stand structure can favor one life form over the other (18).

Rare and endangered species may have specific requirements in a rather restricted geographic area. For this purpose, through the planning processes now in effect, rare and endangered species must be considered before treatment can be made in any area.

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

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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 m^3/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."

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 m^2/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 multistoried 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.

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Mixed Conifers of Southwestern Oregon

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Mixed conifer forests occupy about 4 million acres (1.6 million ha), or nearly half the area of southwestern Oregon. They extend from the Calapooya Mountains (43° 30′ N.) south into northwestern California and from the western slopes of the Cascade Range (122° 20′ W.) to the Pacific Ocean, but are discontinuous and heterogeneous. Society of American Foresters forest cover types 231 (Port Orford-cedar), 234 (Douglas-fir–tanoak–madrone), and 244 (Pacific ponderosa pine–Douglas-fir) are present (4). Less defined forest types and nonforest inclusions of grass, brush, or agricultural land are common, however, and species composition varies with local physiography, soil, and climate.

The physiography of southwestern Oregon is complex and varied. Mountains create differing combinations of elevation, soil parent material, and weather that are considered here as seven subregions: the Oregon Coast Ranges in Coos, Curry, and western Douglas Counties; the western Siskiyous in southern Josephine County; the eastern Siskiyous in southern Jackson County; the southern Cascades in eastern Douglas and Jackson Counties; a pumice plateau where ancient Mt. Mazama deposited a deep, level layer of pumice in the Cascades; the Calapooya Mountains in northern Douglas County; and a central valley-ridge complex in southern Douglas, northern Josephine, and northern Jackson Counties. Mixed conifer forests occur in all seven subregions.

Topography is steep and broken in the Coast Ranges, Siskiyous, and central valley-ridge complex, with the most dissected terrain occurring in the Siskiyous. Slopes are less steep in the southern Cascades, Calapooya Mountains, and pumice plateau.

Relatively uniform soils derived from Mazama pumice characterize the pumice plateau. Soils derived from andesitic tuffs, basalt, and breccias are common in the southern Cascades. Elsewhere, the rocks and soils underlying mixed conifer forests in southwestern Oregon are complex and heterogeneous; with andesite, basalt, conglomerate, granite, sandstone, mica schist, shale, and ultramafic parent materials that are extensively folded, faulted, and metamorphosed (12, 14).

Mixed conifer stands occur at elevations as low as 500 feet (150 m) in the Coast Ranges, but are absent below 3,500 feet (1065 m) in the Cascade Range in southern Jackson County. Upper elevation limits are about 4,000 feet (1220 m) near the coast and about 6,000 feet (1830 m) in the southern Cascades. Average low temperatures recorded at representative weather stations in the mixed conifer forest from June 1973 through February 1981 ranged from −2° F (−18.9 C) in the southern Cascades to 21° F (−6.1° C) in the Coast Ranges (17). The greatest range in high temperatures occurred in the central valley-ridge complex, where average high temperatures ranged from 91° to 106° F (32.8° to 41.1° C).

The average frost-free period ranges from 50 (southern Cascades) to 207 days (Coast Ranges). Annual precipitation varies from 70 to 150 inches (1778 to 3810 mm) in the Coast Ranges to about 25 inches (635 mm) in the eastern Siskiyous. Most of this precipitation is winter rain, but 50 to 90 inches (1270 to 2286 mm) of snowfall occur at elevations above 4,000 feet (1219 m). Hot, dry summers are common throughout southwestern Oregon, and summer drought conditions are most severe in the eastern Siskiyous.

The mixed conifer forests of southwestern Oregon vary in composition, but two or more of the following major species are always present: Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*), incense-cedar (*Libocedrus decurrens* Torr.), sugar pine (*Pinus lambertiana* Dougl.), white fir (*Abies concolor* var. *lowiana* (Gord.) Lemm.), and ponderosa pine (*Pinus ponderosa* Dougl. ex Laws. var. *ponderosa*).

Several minor species are also present. Western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) occurs on cool moist sites in the Calapooyas, Coast Ranges, central valley-ridge, western Siskiyous, and northern portion of the southern Cascade subregions. Grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.) replaces white fir in the Calapooya, Coast Ranges, and central valley-ridge subregions. Elsewhere grand fir often hybridizes with white fir and forms intermediate populations (7). Jeffrey pine (*Pinus jeffreyi* Grev. & Balf.) grows on ultramafic soils in the Siskiyous and central valley-ridge complex. Port Orford-cedar (*Chamaecyparis lawsoniana* (A. Murr.) Parl.) also grows on ultramafic soils and along drainages where atmospheric moisture is high in the western Siskiyous, but it is most important in the Coast Ranges. Knobcone pine (*Pinus attenuata* Lemm.) sometimes occupies recent burns in the western subregions. Western redcedar (*Thuja plicata* Donn ex D. Don) grows on moist stream bottoms in the Coast Ranges, western Siskiyous, Calapooya, and central valley-ridge subregions. Pacific yew (*Taxus brevifolia* Nutt.) is occasionally present in the understory on moist sites throughout southwestern Oregon. Hardwoods often associated with mixed conifers include Pacific madrone (*Arbutus menziesii* Pursh), giant chinkapin (*Castanopsis chrysophylla* (Dougl.) A. DC.), California black oak (*Quercus kelloggii* Newb.), Oregon white oak (*Quercus garryana* Dougl. ex Hook.), canyon live oak (*Quercus chrysolepis* Liebm.), California-laurel (*Umbellularia californica* (Hook. & Arn.) Nutt.), tanoak (*Lithocarpus densiflorus* (Hook. & Arn.) Rehd.), bigleaf maple (*Acer macrophyllum* Pursh), and vine maple (*Acer circinatum* Pursh).

Natural conifer reproduction is common but erratic in southwestern Oregon. The most shade-tolerant species (e.g., western hemlock, western redcedar, white fir, and grand fir) tend to have seed crops more often than less tolerant species (e.g., Douglas-fir and ponderosa pine). Western hemlock, western redcedar, and Port Orford-cedar produce the largest seed crops, followed in descending order by Douglas-fir and Jeffrey pine, ponderosa pine, sugar pine, and white fir (15). Mineral soil benefits the germination and survival of all species; western hemlock and western redcedar are more successful than other conifers on organic seedbeds. Burned seedbeds amplify unfavorable temperature extremes; but they tend to favor Douglas-fir, grand fir, and ponderosa pine over other conifer species.

Two-year-old seedlings at least 5 inches (13 cm) tall are recommended as Douglas-fir planting stock (3, 20). Bareroot seedlings with a minimum diameter of 0.16 inches (4 mm) are usually used, and shoot/root ratios of 2.0 or less benefit survival. One-year-old containerized seedlings may be more successful on steep slopes with shallow skeletal soils, however; where the seedlings often have to be protected from downslope debris movement (10). Ponderosa pine seedlings are frequently planted in frost pockets. More sugar pine stock probably will be planted as blister-rust-resistant seedlings become more available. Conifer seedlings of all species survive and grow most successfully on north and east aspects in the absence of vegetative competition. South and west aspects with shallow soils, grass and brush competition, or sprouting madrone, maple and other hardwood trees tend to hinder and delay conifer reproduction.

Competition from annual and perennial grasses hinders conifer reproduction throughout southwestern Oregon. Brush competition from *Arctostaphylos, Ceanothus, Rhus,* and *Rubus* species is most serious in the Coast Ranges, western Siskiyous and Calapooya Mountains. Drought adversely impacts survival of seedlings in the eastern Siskiyous and central valley-ridge complex. Pocket gophers and frost seriously limit conifer regeneration in the southern Cascade and pumice plateau subregions.

The silvical characteristics of major southwestern Oregon conifer species differ greatly. Ponderosa pine is frost- and drought resistant and intolerant of shade. Incense-cedar is less frost- and drought-resistant but, like the faster-growing Douglas-fir and sugar pine, grows well in partial shade. Douglas-fir is less frost- and drought-resistant than incense-cedar, more drought-resistant and slower growing than sugar pine. White fir is more tolerant of shade and less drought-resistant than other major conifer species (15). It endures suppression and recovers well when released.

No growth and yield data are available for managed mixed-conifer stands in southwestern Oregon. Information derived from an inventory of existing natural stands indicates that site quality and yields are low, however; the average site index for mixed conifers on the Rogue River National Forest is 110 at age 100. Empirical net yields of unmanaged natural stands range from 23,170 board feet (fbm) (Scribner Decimal C) or 4,634 cubic feet[1] per acre (324.4 m^3/ha) at age 90 to 44,925 fbm or 8,985 cubic feet per acre (629.0 m^3/ha) at age 320 when very low site lands and badly damaged stands are excluded from the inventory data.[2]

Douglas-fir seedlings are often badly damaged by deer and elk. Older Douglas-firs are attacked by Douglas-fir beetles (*Dendroctonus pseudotsugae* Hopkins) and the flatheaded fir borer (*Melanophila drummondi* (Kirby)) throughout southwestern Oregon. They are seriously infected with dwarf mistletoe (*Arceuthobium douglasii* Engelm.) in the Siskiyous and southern Cascades (5, 9). Poria root rot (*Phellinus weirii* (Murr.) Gilb.) also is a serious Douglas-fir pathogen. White pine blister rust (*Cronartium ribicola* J. C. Fisch.) limited the management of sugar pine for many years, but rust-resistant sugar pine races have recently been identified and propagated (13). Unfortunately, no root-rot resistant races of Port Orford-cedar have been found, and the root rot caused by *Phytophthora lateralis* Tuck. & J. A. Milb. can be limited only by sanitation measures such as the prohibition of road building and avoidance of drainage areas.

Fire danger is highest in the southern Cascade and eastern Siskiyou subregions, lowest in the Coast Ranges and western Siskiyous (8). Throughout southwestern Oregon, fires in the past tended to perpetuate seral species such as Douglas-fir, ponderosa pine, Pacific madrone, and incense-cedar. Under modern fire prevention practices, however, natural stands are slowly converting to more shade-tolerant species such as white fir, Port Orford-cedar, and tanoak (1).

The slash resulting from clearcutting is often broadcast-burned. Slash in shelterwood stands also may be broadcast-burned, but it is often piled and burned to minimize overstory damage. Broadcast-burning lowers the fire hazard, eliminates physical obstructions, eradicates mistletoe present on advance regeneration, and creates favorable mineral-soil seedbeds (16). Although this promotes a more diverse blend of species in subsequent stands, repeated slash burning may deplete the nutrient capital, destroy advanced conifer regeneration, stimulate the germination or sprouting of some brush species, and, at some sites, create microsites subject to erosion and high soil surface temperatures.

Soil, climate, and topography are more important than species composition in determining silvicultural practices in southwestern Oregon; and no single silvicultural system is applicable throughout the mixed conifer forests. Even-age management seems necessary if the present species composition of most mixed conifer stands is to be maintained. Uneven-age silviculture probably should be limited to situations where a mixture of tolerant species is desirable or to open-grown stands on poor sites.

Clearcutting creates severe environments for conifer seedlings on south and west aspects with shallow soils and on flat or concave topography above 3,000 feet (914 m) in the eastern Siskiyous, pumice plateau, southern Cascade, and central valley-ridge subregions. Adequate site preparation, high quality planting stock, proper planting techniques, and careful timing are essential for prompt seedling establishment on shallow soils in these subregions; frost-tolerant species are often required on flat topography at high elevations. Clearcutting should also be used with extreme care on any topography above 4,500 feet (1372 m) in the western Siskiyous (19). Elsewhere, clearcutting usually creates favorable environments for conifer regeneration when competing vegetation is adequately controlled. Recommended control methods include the application of low volatile esters of 2,4-D for shrubs and weed trees (6), late autumn atrazine treatments for grass (2), and chemical desiccation followed by prescribed burning for established brushfields (11). The edge effects created by clearcutting are often beneficial for wildlife.

Seed-tree cutting is appropriate on some north slopes where competing vegetation is not a problem, but natural regeneration may be delayed until a seed crop occurs. The seed trees do not provide adequate shade or frost protection on severe sites in the Siskiyous, southern Cascades, pumice plateau, and central valley-ridge subregions; and they provide little wildlife cover. Seed trees are often windthrown in the Coast Ranges.

Shelterwood stands are damaged less than seed trees by storm winds, but are sometimes windthrown on exposed sites. They provide seedling protection on hot dry slopes and in frost pockets. Although adequate natural regeneration occurs if the soil is scarified in many shelterwood stands, underplanting is necessary on some sites. Overstory requirements vary with slope, aspect, tree size, species, and crown form. On severe sites, residual basal areas of up to 180 square feet per acre (41.32 m^2/ha) may be required (18), but 40 to 100 square feet per acre (9.18 to 22.96 m^2/ha) are often

[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.

[2] Rogue River National Forest Timber Management Plan. Appendix 1979: 70–71.

adequate in the southern Cascade, pumice plateau, Calapooya, and central valley-ridge subregions. Dense brush understories usually make shelterwood cutting impractical in the Coast Ranges and western Siskiyous. Steep slopes limit its use in the eastern Siskiyous. Wherever shelterwood cutting is practiced, details such as the timing and direction of felling for overstory removal and road layout should be planned in advance, before the shelterwood is established. Overstory densities that exceed shelter requirements should be avoided to minimize the seedling damage that occurs during felling and yarding operations.

Group selection is often appropriate where mixed conifer stands must be maintained with minimal disruption, but it should be avoided where frost is a problem—openings created by group selection may trap cold air. The smaller openings created by single-tree selection do not form frost pockets, and single-tree selection provides an opportunity to leave hardwood species desirable for wildlife. Shade-tolerant species are favored, however, and single-tree selection may eventually result in a change of forest type. Both selection methods are best applied on gentle slopes with good logging access and little brush competition—conditions most often found in the southern Cascade and pumice plateau subregions. Both methods should be avoided in mistletoe-infected stands because they tend to perpetuate the infection.

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Red Alder

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Red alder (*Alnus rubra* Bong.) is the most widely distributed hardwood type in the coastal Pacific Northwest, occupying more than 3 million acres (1.2 million ha) of commercial forest land in Oregon and Washington. This type is identical to Society of American Foresters cover type 221 of the same name (4). The type is found from southern California to southeastern Alaska, but stands seldom occur east of the Cascade Range or the Sierra Nevadas. Red alder stands grow on a wide range of soil and site conditions, varying from well-drained gravels and sands to poorly drained clays and organic soils (17). Because red alder can tolerate poorly drained conditions and some flooding in the growing season, it prevails on soils of restricted internal drainage, along streams, and on swampy or marshy areas. The most productive stands are usually found on deep, well-drained loams or sandy loams derived from marine sediments or alluvium; some very good stands also grow on residual or colluvial soils of volcanic origin. Rapidly growing red alder stands occur on hillsides as well as along streams at elevations below 1,500 feet (460 m) in coastal areas of northern Oregon, Washington, and British Columbia. At mid-elevations in the Cascade Range, stands of commercial dimensions are limited mainly to stream bottom sites.

Climate in the type's range is humid or superhumid, with most precipitation occurring as rain during winter. Summers are cool and dry, sometimes with considerable morning fog. Annual precipitation and temperature extremes are 16 to 220 inches (405 to 5590 mm) and −22° to 115° F (−30.0° to 46.1° C), respectively. Most stands, however, are found where annual precipitation exceeds 40 inches (1015 mm) and winter temperatures are relatively mild.

Red alder occurs in both pure and mixed stands. Common tree associates include coast Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), western redcedar (*Thuja plicata* Donn ex D. Don), Sitka spruce (*Picea sitchensis* (Bong.) Carr.), black cottonwood (*Populus trichocarpa* Torr. & Gray), bigleaf maple (*Acer macrophyllum* Pursh), and willow (*Salix* spp).

Red alder regenerates most commonly by natural seeding. It has also been established by direct seeding and planting in several research and pilot-scale trials (17). Survival of both bare-root and container seedlings has been excellent (3). Red alder will sprout vigorously from the stump when young and has been repeatedly coppiced on short cycles (6). Stumps of pole- and sawlog-size trees may sprout, but sprouts rarely persist.

Individual trees reach sexual maturity at 3 to 4 years, and most dominant trees in a stand will begin to produce seed at 6 to 8 years (11). Red alder is a prolific seeder, with moderate seed crops produced almost annually. Bumper crops occur at 3- to 5-year intervals, and seed crop failure is unusual. Seed dispersal begins soon after ripening in late summer, but most seeds are shed during fall and winter. Dissemination is primarily by wind, and sufficient seed for natural regeneration is usually present throughout the species' range (17).

Germination and early growth is best on moist mineral soil and in full sunlight. The species is a common pioneer on landings, skidtrails, road cuts, and other areas where mineral soil has been freshly exposed. Seeds will also germinate on soil organic horizons and on rock-surfaced logging roads, but the newly developing roots must quickly penetrate a moist, nutritious substrate if the seedlings are to survive. Some early mortality has been observed after girdling by meadow mice or cutting by mountain beaver, but its extent is unknown.

Red alder is moderately intolerant of shade. Seedlings will survive in partial shade for several years, but full sunlight is required for normal development. Compared with most of its associates, red alder is relatively tolerant of flooding and salinity. Windthrow is not common except along exposed cutting boundaries or where root systems have been undermined by flooding or erosion. Mortality, stem breakage, and other top damage have been observed in natural stands after ice storms and unseasonable frosts (3, 17).

Red alder is the only commercial tree species native to western North America that fixes atmospheric nitrogen symbiotically in its root nodules; both content and availability of nitrogen are increased in soils beneath red alder stands. Accretion rates varying from about 40 to more than 300 pounds of nitrogen per acre (45 to 335 kg/ha) per year have been reported for alder stands of 50 years and less (12, 13). Soil organic matter is higher and bulk density is lower in red alder stands than in conifer stands of comparable history (12). Red alder has therefore been proposed for site improvement purposes, either by itself or in crop rotations and mixtures with other species.

Young stands of red alder may be very dense, having more than 100,000 stems per acre (247 100 stems/ha) at 1 and 2 years (2). Self-thinning or suppression-related mortality begins at an early age in such stands, but they remain too dense for optimum growth without management. Spacing control or thinning in previously unmanaged stands is effective in stimulating growth if done before age 15 to 20. Thinning in overly dense, older stands can salvage mortality but is of questionable value for increasing growth on selected crop trees (10, 15).

Young alder trees grow rapidly. On favorable sites, seedlings grow 3 feet (0.9 m) or more in the first year; they may attain 30 feet (9.1 m) by age 5 and more than 80 feet (24.4 m) by age 30 (16). Good growth rates are maintained from establishment to at least age 25; during this period, growth of red alder surpasses that of any conifer or other hardwood species in the Pacific Northwest, with the exception of black cottonwood on its best sites. Growth thereafter slows, and the decrease begins earlier and is greater on poor than on good sites.

Growth and yield information is available for natural, unmanaged stands of red alder (1, 2, 10, 13, 14, 16). On well-stocked sites of the highest quality, mean annual increment (total stem) may approach 150 cubic feet per acre (10.5 m^3/ha) for 20- to 40-year rotations; a comparable value for sites of average quality is 120 cubic feet per acre (8.4 m^3/ha).

Projections based on early performance of experimental plantings, results of thinning trials, and gains obtained with spacing control of other species suggest that yields of managed red alder stands will be much higher than natural stands (2). For example, coppice stands can be grown on cutting cycles of 2 or more years, and pulpwood-size (6-inch (15 cm) diameter at breast height (d.b.h.)) trees can be produced in 10 to 15 years on good sites. Sawlog- and veneer log-size trees (12-inch (30 cm) d.b.h.) can probably be grown in 25 to 35 years on such sites. Annual total stem yields are estimated at 170 to 210 cubic feet per acre (11.9 to 14.7 m^3/ha). Rotations longer than 40 years are not recommended for timber production because of increased disease problems and reduced growth of red alder at older ages (3, 13, 17).

Young, vigorous stands of red alder appear relatively free from serious insect and disease problems, but such pests could become more evident or serious as the species becomes more widely managed (17). Insect damage observed in alder stands include twig girdling by flatheaded borers, defoliation by tent caterpillars and sawflies, and infestation by bark beetles. Red alder is susceptible to several canker-causing fungi and foliage and catkin diseases, but none have significant economic importance. A white heart rot is the major cause of defect in older trees, and many other fungi species have been identified on alder as secondary invaders of dead or dying tissues. Red alder is resistant to laminated root rot (*Phellinus weirii* (Murr.) Gilb.), and therefore is a suitable, non-susceptible species for growing on sites severely infested with the fungus (5).

Fire rarely damages red alder stands—in fact, the species has been planted as a fire break (17). The low fire hazard is due to scarcity of flammable understory and organic debris in closed alder stands and because natural alder stands commonly occur on wet sites. Fire may be an important site preparation tool in red alder management. Dense understories of shrub species develop in older, unmanaged red alder stands with less than full stocking, particularly on the more productive sites. Such shrub species may take over the site following harvest and thereby prevent successful regeneration of alder or other commercial tree species, unless special site preparation measures are taken. Tractor scarification is rather expensive and is inappropriate on many red alder sites because of steep terrain or excessive soil moisture. Broadcast burning is usually difficult because of moist conditions, green underbrush, and the non-resinous, light slash of such stands (17). Coupled with preparatory applications of herbicides and/or desiccants, however, broadcast burning can be a suitable method for ameliorating the brush encroachment problem following harvest cuts on such sites (9).

Although natural stands of red alder occupy about 15 percent of commercial forest lands in western Oregon and western Washington, foresters have had little experience in managing the species. Historically, red alder has been regarded primarily as a weed species limiting production of more highly valued conifers. Stumpage values for red alder are very low; available supplies far exceed present demand (7). There is growing interest, however, in regeneration and management of red alder because of its rapid juvenile growth and ability to fix atmospheric nitrogen and improve other chemical and physical properties of soils. Recent expansions in use of the species in solid wood, paper, and other reconstituted fiber products as well as recognition of its potential contributions in multiple-use situations have also aided the developing interest in red alder management. Because of the dearth of operational experience with the species, present management recommendations are based primarily on extrapolation of results from limited research trials as well as management experience with other species having similar biological traits.

Silvical characteristics and regeneration requirements of red alder mandate a silvicultural system adapted to even-aged management, specifically, clearcutting, seedtree, or shelterwood. Of the three, clearcutting provides the greatest flexibility in use of site preparation techniques to control brush and to expose mineral soil. Natural seeding from adjacent uncut stands, direct seeding, and planting of container or bare-root seedlings have all resulted in satisfactory establishment of new alder stands in clearcut areas (3, 17). Stocking in naturally established stands, however, is commonly either clumpy with much unoccupied growing space or extremely dense. Thus, planting may be preferable in situations where red alder is managed primarily for wood production. In most cases, clearcutting is probably the most effective silvicultural system, followed, if necessary, by scarification or some other form of site preparation. Clearcutting is also the appropriate method to use in short-rotation management systems for fiber and energy production (2, 6).

No attempts to reproduce red alder by the seedtree method have been documented. Only in rare cases does seed supply limit natural regeneration of red alder after clearcutting; seedbed condition is more likely to be the limiting factor. Leaving a few seed trees per acre, however, might provide a more uniform distribution of seedlings where cutting units are exceptionally large or where there are few adjacent uncut red alders.

The shelterwood system might also be used to regenerate red alder, but there is little documented information to recommend it. Seed is usually produced every year, and established seedlings grow best in full sunlight. Moreover, juvenile growth rate of red alder is so rapid that, even in areas of high esthetic value, the overstory would probably have to be removed in less than 2 years; excessive damage to the young reproduction would otherwise be expected.

Because red alder can become established naturally in abundance, precommercial thinning will probably be an essential feature of management programs—especially those that entail natural regeneration. There are several reports of enhanced growth of the species following early spacing control (10, 15); such cutting also provides opportunities to favor stems of superior form. Uniform spacing may also reduce the sweep or lean characteristic of red alder in unmanaged, irregularly spaced stands (2).

Maintenance of the red alder type is no problem; the estimated acreage occupied by red alder in western Oregon and western Washington has more than tripled in the past quarter century. Recent emphasis on conversion of red alder stands to conifers, however, has resulted in an unbalanced distribution of age classes in some areas. Individual alder stands begin to break up by age 60 to 70; intact stands more than 80 years old are rare. Much evidence points to maximum rotation ages of 40 years or less if wood production is the primary objective of management.

Mixed stands of red alder and other species are more common than pure red alder stands in many parts of the species range. These mixtures are both even- and uneven-aged, and may include most of the previously listed associated tree species. There is no specific management experience and little research data for most of these mixtures; the intention of most forest owners and managers is to convert such stands to pure conifers after harvest of the existing stands. There are some exceptions, however, and interest in mixed-species management has increased substantially in the last decade. For example, mixed stands of Douglas-fir and red alder have been established on an experimental basis and such mixtures are now being considered for limited operational use on some nitrogen-deficient soils. Interplanting alder seedlings in a 4-year-old Douglas-fir plantation at a ratio of nearly two alders to one Douglas-fir, increased soil nitrogen and soil organic matter and lowered bulk density (12); it also enhanced growth of Douglas-fir (8). Similar benefits might be obtained with a lower ratio of red alder to Douglas-fir. Mixed red alder–Douglas-fir stands are prescribed on the Siuslaw National Forest for soils that are low in nitrogen but are otherwise productive (site index class II). Current management plans for these sites call for leaving some naturally established red alder when Douglas-fir plantations are precommercially thinned at about age 10 (14). The red alder will be removed in a commercial thinning at about age 40. It is assumed that nitrogen accumulated in the soil during the period of alder's occupancy will enhance Douglas-fir growth in the remaining years of the conifer rotation.

Red alder stands can be established and managed for purposes other than, or in addition to, wood production. Because of the species' tolerance of poor drainage and flooding, alder is sometimes recommended for management in riparian zones. It can be especially useful in the amelioration of coal mine spoils, landslides, and other eroded or low fertility areas. Although red alder is not a preferred browse species, its presence in pure stands, small clumps or stringers, and mixed stands within extensive conifer forests provides edges and adds structural diversity; it may therefore be used to enhance the forest habitat for many wildlife species. Esthetically, red alder stands provide variety in a landscape covered mainly by stands of conifers, and its rapid juvenile growth rate permits its use where rapidly established tree cover is desired for protection or enhancement of visual resources.

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Southwestern Oregon-Northern California Hardwoods

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Hardwoods are abundant or predominate from southern Coos and Douglas Counties, Oreg., southward through the Klamath Mountains and Coast Range to Monterey County, Calif. They extend even farther south in the Coast Range and eastward into the southern Cascades and northern Sierra Nevada, but become disjunct. Elements of the Society of American Foresters Douglas-Fir–Tanoak–Pacific Madrone (type 234), California Black Oak (type 246), Canyon Live Oak (type 249), and Oregon White Oak (type 233) forest cover types are included in this composite hardwood type.

The climate of southwestern Oregon and northern California seasonally ranges from cool and moist to hot and dry. In the Coast Range of California and southwestern Oregon, temperatures average 41° to 50° F (5.0° to 10.0° C) in January and 57° to 73° F (13.9° to 22.8° C) in July. Average annual precipitation varies between 34 and 83 inches (865 and 2110 mm). Fog sometimes is a moderating influence in the Coast Range. Number of days free of killing frost ranges from 204 to 338 (4, 14).

In the interior mountains (interior Coast Range, Klamath Mountains, southern Cascades and northern Sierra Nevada), average January temperatures range from 33° to 41° F (0.6° to 5.0° C) and average July temperatures from 62° to 75° F (16.6° to 23.9° C). Average annual precipitation varies between 30 and 68 inches (760 and 1730 mm). Number of frost-free days ranges from 116 to 240 (3, 15).

Geology of the region is complex with volcanic, sedimentary, and metamorphosed rocks. All aspects are represented in topography that often is steep, rugged, and dissected by streams. Hardwood species are especially prevalent on the warmer and drier south and west aspects, but often are present on north and east aspects as well. They also are abundant in the transition zone between the mountains and the foothills, and frequently dominate the low rolling foothills as well. The elevational range of the mixed-hardwood forest in the Coast Range is from 40 to 4,000 feet (10 to 1220 m). In the interior mountains, most of the hardwood species can be found within the 580- to 4,700-foot (175- to 1430-m) elevational range.

Soils within the region reflect the effects of a wide range of local climate, geology, parent material, and topography interacting over a long time. They range from deep, moist, fertile alluvium to shallow skeletal soils characterized by coarse texture, excessive drainage, and relative infertility. Most hardwood species tend to inhabit well-drained or droughty soils.

Tanoak (*Lithocarpus densiflorus* (Hook. & Arn.) Rehd.) and Pacific madrone (*Arbutus menziesii* Pursh) are the most abundant hardwoods in the Coast Range and western Klamath Mountains. Other hardwoods throughout southwestern Oregon and northern California are California black oak (*Quercus kelloggii* Newb.), canyon live oak (*Q. chrysolepis* Liebm.), Oregon white oak (*Q. garryana* Dougl. ex Hook.), bigleaf maple (*Acer macrophyllum* Pursh), California-laurel (*Umbellularia californica* (Hook. & Arn.) Nutt.), and, to a lesser extent, giant chinkapin (*Castanopsis chrysophylla* (Dougl.) A. DC.).

Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) often is associated with these hardwood species and may be abundant. Incense-cedar (*Libocedrus decurrens* Torr.) and ponderosa pine (*Pinus ponderosa* Dougl. ex Laws. var. *ponderosa*) also are common conifer associates except on the western slopes of the Coast Range. Redwood (*Sequoia sempervirens* (D. Don) Endl.) and Port Orford-cedar (*Chamaecyparis lawsoniana* (A. Murr.) Parl.) are locally abundant in the Coast Range. California white fir (*Abies concolor* var. *lowiana* (Gord.) Lemm.) and sugar pine (*P. lambertiana* Dougl.) are less abundant associates in the mixed-hardwood forests.

Not all of the hardwood species grow together at a given location. Four or more species may be found in mixture, but two or three species are more common. Pure stands of one species occasionally clothe a hillside or occupy favorable sites. Hardwoods may cover large areas of more than 100 acres (40 ha). They also can be found as single trees, but more commonly as groups covering from 0.2 to 10 acres (0.1 to 4.0 ha). Old-growth conifer stands sometimes contain pure Douglas-fir that forms a solid canopy. At other locations, however, Douglas-fir is part of a ragged overstory with intervening spaces occupied by hardwoods. Sometimes only scattered remnants of Douglas-fir are present, and the remainder of the stand is comprised of hardwoods. Two-storied stands are common in the Coast Range and west-facing slopes of interior mountains, with Douglas-fir above tanoak, or Pacific madrone, or both. Sometimes a dense brush layer forms beneath the trees in more open stands (12).

Steep, rocky slopes may be covered with scattered Douglas-firs and more numerous canyon live oaks. Canyon live oak also forms pure stands, as it tends to become concentrated in steep, rocky areas with low incidence of fire (9). Pacific madrone, canyon live oak, California black oak, and Oregon white oak are abundant on drier areas. Oregon white oak, in groups or as single trees, often forms a scattered fringe between grassland and forest. Giant chinkapin and California-laurel are common associates of tanoak in more mesic locales. California black oak, more so than other hardwoods, grows on a wide range of forest soils, from those that are deep and fertile to others that are shallow and impoverished. Bigleaf maple generally is limited to moist sites in California, but grows in both moist and dry environments in the Klamath Mountains of Oregon (6).

Most of the hardwood species of southwestern Oregon and northern California have a scrubby variety. On poor sites, this variety prevails. On slightly better sites, taller poorly formed trees occupy a large but unknown percentage of the total land area. The scrubby stands, although noncommercial, are valuable for wildlife habitat and watershed protection.

Most hardwood stands are even aged but, occasionally, two or three age classes may be present. The tendency to be even aged is a consequence of the species' ability to sprout after major disturbances. Almost all hardwood species of southwestern Oregon and northern California depend primarily on fire, logging, blow-down, insect devastation, or mass soil movement to eliminate or reduce greatly the taller conifers, freeing the hardwoods to dominate.

Without exception, the hardwood species are vigorous, prolific sprouters. They may produce 20 to 40, or occasionally even 60 sprouts per stump. In Humboldt and Trinity Counties, Calif., 3-year-old sprouts of Pacific madrone averaged 10.1 feet (3.1 m), Oregon white oak 9.2 feet (2.8 m), tanoak 6.8 feet (2.1 m), and bigleaf maple 12.8 feet (3.9 m) in height (10). Ten-year-old madrone sprouts averaged 22.2 feet (6.8 m), tanoak 19.0 feet (5.8 m), and California black oak 19.7 feet (6.0 m) in the northern Sierra Nevada (1). At this location, tanoak and madrone sprouts grew more than 5 feet (1.5 m) the first year. Sprouting is a valuable regeneration mode for keeping a species in place, while acorns and other seeds, carried far and wide by a host of disseminators, are valuable for extending the species into new areas.

Some seed may be available almost every year (4, 13), but large crops are produced by most hardwoods every 2 to 3 years. Seed crop frequency may be slightly greater for California-laurel and Pacific madrone, however, and bigleaf maple produces large seed crops almost every year.

Seed crops can be large. Tanoak acorns from 18- to 24-inch (46- to 61-cm) diameter trees in Trinity County, Calif., numbered 78,000 to more than 91,000 per acre (193 000 to 225 000/ha) and were 49 percent sound (11). A 15.7-inch (40-cm) diameter Pacific madrone in the northern Sierra Nevada produced 2.15 million seed in a light seed year (4). Most seeds produced, however, quickly lose viability or are eaten by rodents, birds, and deer. California black oak acorns, for example, had severely withered cotyledons 9 days after falling on ground exposed to bright sunlight; acorns exposed to subfreezing temperatures had gravish cotyledons and were not viable (3). Inability to find a single seed in the spring, even after a bumper seed crop, is commonplace—all have been consumed or carried off.

Acorns of the oaks and tanoak, the nuts of giant chinkapin, nutlets of California-laurel, and fruits of madrone are relatively large, heavy, colorful, and probably nutritious. These attributes enhance collection and dissemination by birds and animals. Without such dissemination, the seeds fall mostly beneath tree crowns, often into inhospitable environments.

Loose, moist mineral soil or soil covered by sufficient leaves and litter to keep the seeds moist, insulate them from high and low temperatures, and hide them from consumers, are the best seedbeds for acorn- and nut-producing species. Califoria-laurel seeds need to be covered either by ground disturbance or from silt deposited by high water (13). Partially shaded mineral soil is the best seedbed for Pacific madrone because damping-off fungi and invertebrates in organic material decimate the population of tiny seedlings (4).

Seeds of southwestern Oregon-northern California hardwoods germinate at extremely variable rates. Trials have been few, however, and germination media and laboratory environments have been significantly different (1, 13). In the only documented trial, 94 percent of Pacific madrone seed germinated. Rates for other hardwoods are as follows: tanoak, 19 to 78 percent; California black oak, 63 to 95 percent; giant chinkapin, 14 to 53 percent; California-laurel, 20 to 82 percent; canyon live oak, 56 to 75 percent; Oregon white oak, 77 to 100 percent; and bigleaf maple, 32 to 90 percent (13).

Hardwood seedling survival varies with species' tolerance and amount of shade. Survival of California black oak seedlings (65 percent after 7 years) was better than tanoak seedling survival (30 percent after 10 years) when both were seeded in open northern Sierra Nevada plantations. In a shady hardwood forest nearby, however, 10- to 15-year-old tanoak seedlings and seedling-sprouts numbered 10,280 per acre (25 400/ha). Only a few small California black oak seedlings were present, however, because the environment was too shady for seeding establishment (1).

Pacific madrone seedlings become established and survive moderately well on partially shaded mineral soil in 3- to 4-year-old clearcuttings (4).

Only 2 percent of 829 Pacific madrone seedlings survived the first growing season in a central California coast study (7). No quantitative survival data are available for other hardwoods, but several observations suggest species differences. Oregon white oak reproduces in its own shade and in open stands, but cannot tolerate conifer overtopping (15). Giant chinkapin may be limited to relatively open stand conditions in moist environments, but seedlings become increasingly competitive on dry, nutritionally poor sites (5). Canyon live oak seedlings grow under overstories or on shaded overstory fringes (17), but the seedlings of California-laurel (14) and bigleaf maple (7) probably are the most shade tolerant.

Although their seedlings become established in shade, the tolerance of most hardwoods is not well defined. Tanoak, California-laurel, bigleaf maple, and giant chinkapin appear to be more tolerant than Douglas-fir, and Douglas-fir seems to be more tolerant than Oregon white oak or canyon live oak (4, 15). Canyon live oak may be slightly more tolerant than Pacific madrone. California black oak is relatively intolerant (3).

High water tables are lethal to nearly all of these hardwoods. Oregon white oak may be the exception (4). California-laurel (14) and bigleaf maple (6) survive temporary flooding. All of the hardwoods are adapted to periods of drought and the evergreen species, in particular, are able to minimize drought effects. All are windfirm except possibly California-laurel (14). Unusually heavy snow loads, however, can cause local damage.

Artificial regeneration of most of these hardwood species has not been reported. Only two trials with California black oak and one with tanoak are known. Direct seeding of California black oak acorns can be successful if competing vegetation and pocket gophers are controlled (3). In contrast, direct seeding of tanoak in the northern Sierra Nevada indicated little promise (1). Limited outplantings of tanoak and California black oak plug-seedlings in the northern Sierra Nevada showed no gain over direct seeding (1).

Hardwood seedlings grow slowly. A 5-year-old tree may be only a few inches tall. Fertilizer (16-20-0) applied each year significantly improves height of California black oak and tanoak seedlings (3). Shoot growth does not accelerate until root capacity is extensive enough for the seedling to obtain adequate moisture. Fertilizer probably promotes growth of feeder roots that aid in gathering moisture.

Diameter growth rates of trees vary with species, stand density, and quality of site. In typically dense natural stands, dominant and codominant trees, 60 to 80 years old, usually grow at 12 to 15 rings per inch (5 to 6 rings/cm). These data hold for Pacific madrone, California-laurel, and giant chinkapin in northern California. More open-grown stands of Oregon white oak and canyon live oak grow at about the same rate—the effect of lower stand density probably being offset by lower site quality. Tanoaks grow slightly faster, averaging 8 to 13 rings per inch (3 to 5 rings/cm) (11). Diameter growth of more open-grown trees is greater than that of trees in closed stands, and thrifty California black oaks may attain 3 rings per inch (1 ring/cm) (3). Height growth rates are poorly documented but appear to be fairly rapid in the sapling and pole stages, and slow after trees reach maturity.

Rotation age presently is not known for the hardwoods of southwestern Oregon and northern California. Presence of heart rot could influence rotation age. Incidence of incipient heart rot in California black oak increases rapidly after 110 years and could determine rotation age for wood products (3), but not for acorn production, wildlife benefits, or other uses.

Yields have not been determined for managed hardwood stands; even unmanaged stand data are scarce. Natural stands of mixed hardwoods in the northern Sierra Nevada consist of many stems (659/acre or 1628/ha) greater than 2 inches (5 cm) in diameter at breast height (d.b.h.) and contain 4,090 cubic feet of solid wood per acre (286.3 m^3/ha) (2). An average 70-year-old black oak stand in northern California contains slightly more than 5,845 cubic feet per acre (409.2 m^3/ha) (1). Comparable information for southwestern Oregon is not available.

Many insects feed on hardwood species, but few kill healthy trees. Local infestations of the western oak looper (*Lambdina fiscellaria somniaria* (Hulst)), California oakworm (*Phryganidia californica* Packard), Pacific oak twig girdler (*Agrilus angelicus* Horn), and fruittree leafroller (*Archips argyrospila* (Walker)), are common. Damage is unsightly, but short-lived. Insects often destroy entire acorn crops of the oaks and tanoak. The filbertworm (*Melissopus latiferreanus* (Walsingham)) may affect chinkapin seed production (5), but no serious damage to developing seed crops of California-laurel (14) or bigleaf maple (6) has been reported. The extent of damage to seed crops of Pacific madrone is unknown.

Few fungi kill the hardwoods, but tanoak, California black oak, and several other species are susceptible to heart rots, such as *Laetiporus sulphureus* (Bull. ex Fr.) Bond & Sing., *Inonotus dryadeus* (Pers. ex Fr.) Murr., and *I. dryophilus* (Berk.), Murr. and root rots, especially *Armillariellia mellea* (Vahl. ex Fr.) Karst. (3, 4, 11, 14, 15). A bleeding canker (*Phytophthora cactorum* Leb. & Cohn Schr.) is a damaging pest of Pacific madrone (4).

One means for virtually eliminating heart rot in young hardwood stands in Oregon and California is to leave a stump less than 8 inches (20 cm) tall, a practice that promotes sprouting from the root crown. Sprouts from root crowns have an extremely low incidence of rot bridging from stump to pith of sprouts. Stool sprouts, which arise at or near the top of higher stumps, almost always are rotten and, also, are susceptible to breakage by wind and snow (1). Once a stand has been clearcut, slash disposal by broadcast burning promotes root crown sprouts by removing accumulations of slash from around the root crowns and by killing aboveground portions of stumps.

Slash in partially cut hardwood stands should be lopped and scattered or piled. Prescribed burning is not recommended. The bark of most hardwood species provides little insulation from fire. Cambium is killed easily by small amounts of radiant heat, and long vertical bole wounds are common after fire.

Uneven-aged management of hardwood stands is not practical in open stands like those of Oregon white oak or Pacific madrone in the foothills, or in closed forest stands where a mixture of species with differing shade tolerances is present. The primary reason is that in stands of species having mixed tolerances, uneven-aged management usually promotes eventual conversion to the most shade-tolerant species. An additional reason, at least in present stands, is that seldom are enough age classes present to qualify for this form of management. Leaving a fairly dense shelterwood (removal of 40 to 60 percent of original 207.3 square feet per acre (47.6 m^2/ha) of basal area) also appeared to be impractical in mixed California black oak–tanoak–Pacific madrone stands in the northern Sierra Nevada (1). Form and growth of 10-year-old sprouts of these three species were markedly poorer in the shelterwood cutting than in a clearcutting. Because sprouts are a principal mode of hardwood reproduction, and most hardwood stands today are even-aged, clearcut harvesting and manipulation of the sprout stands are suggested for present and future operations. Also, the natural mixture of hardwood species should be preserved. Some evidence from northern Sierra Nevada stands suggests that greater volume growth is obtainable from thinned stands of several species than from stands of a single species.

Establishment of plantations in clearcuttings is possible for California black oak (3), and probably for Oregon white oak and canyon live oak. Whether California-laurel, bigleaf maple, Pacific madrone, or giant chinkapin can be established in this manner is not presently known. Tanoak probably cannot be consistently propagated from acorns in clearcuttings, at least not in the northern Sierra Nevada, without extensive artificial shading.

After establishment and development, managed stands from seed where stocking is controlled may differ appreciably from the present sprout stands in their response to manipulation. Straighter trees, faster growth rates, lower incidence of heart rot, and a shorter rotation age are likely.

Management guidelines for the hardwood stands of southwestern Oregon and northern California differ as the environments affecting the species differ. Environments can be described broadly as woodland, hardwood type, and hardwood element within a conifer type. A similar grouping with management guidelines for California black oak in the Sierra Nevada is available (16).

Management of hardwoods in woodlands is influenced by their location near cities and farms. Stands generally are tucked away in corners of fields, along streams, or on steep ground. Management for wood products, such as fenceposts and fuelwood often is incidental to other values such as esthetics, shade for livestock, and food and shelter for wildlife. Increased management for fuel and fiber in the future is likely. An intensive program of stand management and utilization has the best chance of being applied successfully and should be developed where hardwoods are numerous and where wood volumes are high. Well-stocked stands often are found at lower elevations, where they form part of the winter range for wildlife species. The forest manager, therefore, has an opportunity to manage for increased wildlife habitat as well as for wood production.

Hardwoods growing within a conifer forest give the forest increased diversity and an improved yield of both amenities and commodities. The hardwoods often grow in aggregations, the size of which varies inversely to site quality. Large stands of hardwoods on poorer sites should remain natural at least until uses for them are well defined. Management of hardwood aggregations is useful because specific treatments can be applied to discrete parts of the stand.

On high-quality sites, continued absence of disturbance will allow conifers to overtop hardwoods. Stand manipulation will be necessary to maintain a constant proportion of groups of well-developed hardwoods.

On medium-quality sites where young conifers and hardwood sprouts intermingle, opportunities are available to simultaneously manage both kinds of trees with the proper spacing of hardwoods above, sheltering the younger conifers below. The conifers, in turn, reduce epicormic branching by shading the hardwood boles. Together they constitute a habitat conducive to a large and varied population of wildlife. Eventually, both contribute to the harvest of timber and other wood products.

Stand management information is limited to the results of a single study in the northern Sierra Nevada in which a stand of California black oak, tanoak, and Pacific madrone trees was thinned (2). Where 34 to 55 percent of original basal area (198 ft^2/acre or 45.5 m^2/ha) remained, total diameter growth was 0.6 to 1.6 inches (1.5 to 4.1 cm) per tree after 8 years. Diameter growth was consistently best for trees in the dominant crown class, decreased successively through the codominant and intermediate classes, and was poorest in the suppressed class on both thinned and unthinned plots (2). Eight-year volume growth indicated that stands of black oak, tanoak, and Pacific madrone thinned to 102 and 125 square feet per acre (23.4 and 28.7 m^2/ha) yield about 85 cubic feet per acre (6.0 m^3/ha) per year. California black oak appears to grow better at stand densities below 125 square feet per acre (28.7 m^2/ha) and tanoak and Pacific madrone at stand densities above 102 square feet per acre (23.4 m^2/ha). Relatively dense stocking, whether from natural sprout stands or stands artificially established from seed, is recommended. Such stands produce better formed stems, fewer forks, and less epicormic branching.

Native Oregon and California hardwoods are valuable for wildlife, esthetics, recreation, wood products, and watershed protection (8, 9). In a world of seemingly insatiable needs for fuel and fiber, hardwoods also have high potential for increased use as wood products, pulp, and energy (9).

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Interior Alaska White Spruce – Hardwoods

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The interior Alaska white spruce–hardwood forest complex is the western extension of the boreal forest zone which spans Canada. In Alaska, these forests, also referred to as taiga, are composed of the following Society of American Foresters forest cover types (1): White Spruce (type 201), White Spruce–Aspen (type 251), White Spruce–Birch (type 202), Paper Birch (type 252), Aspen (type 217), and Balsam Poplar (type 203). The Black Spruce–White Spruce (type 253) and Black Spruce–Paper Birch (type 254) types may intergrade with the white spruce–hardwood complex on some sites. This complex covers approximately 22.5 million acres (9.1 million ha) of commercial forest land.

The northern extent of this forest complex is the Brooks Range with the exception of isolated balsam poplar stands farther north. These boreal forest types extend south to the coast in the Kenai Peninsula-Cook Inlet region. East of Cook Inlet, they extend to the Kenai-Chugach Mountains while the western most forests occur on the Seward Peninsula and lower Yukon River (9, 11). Forests in this region extend from sea level to a maximum treeline elevation of 3,000 feet (915 m).

Soil parent materials vary greatly, including alluvial deposits along the major rivers, loess deposits (mainly in the unglaciated portions of the interior), various types of glacial deposits, lacustrine deposits and various bedrock types. Spodosols are common south of the Alaska Range, with Inceptisols occurring north of the Range. Entisols predominate on floodplain sites. Although organic layer development is a prominent feature of these northern forests, Histosols are not common.

A unique feature of the soils is the presence of permafrost. However, permafrost is not continuous in the region and is absent from the most productive forest sites (e.g., southfacing upland and floodplain sites in particular). The occurrence of permafrost and depth of the active layer (i.e., annual depth of thaw) may be closely related to organic layer development (8).

Three broad climatic zones occur in the boreal forest area. These are the Arctic, Continental, and Transitional. Temperature extremes vary from −75° to 100° F (−59.4° to 37.8° C.) The duration of the frost-free period is normally 90 to 110 days (5). The warmest summer temperatures normally occur in the central to eastern interior region with decreasing maxima to the south, north, and west. The reverse is true in winter when the Transitional Zone has the mildest temperatures.

Annual precipitation varies from 8 inches (205 mm) at Fort Yukon to 32 inches (815 mm) on the Kenai Peninsula. The probability of precipitation is generally greatest from June through September. Annual snowfall varies from 50 to 100 inches (1270 to 2540 cm) (5).

Maximum day length (hours of sun at summer solstice) during the growing season varies from 17 hours at 60° N. to 24 hours north of the Arctic Circle. There is a 24-hour light period throughout most of this area, if twilight is considered. Day length at winter solstice varies from 0 to 6 hours (5).

The major species in this forest complex include white spruce (*Picea glauca* (Moench) Voss), paper birch (*Betula papyrifera* Marsh.), trembling aspen (*Populus tremuloides* Michx.), balsam poplar (*Populus balsamifera* L.), and black cottonwood (*Populus trichocarpa* Torr. & Gray). Hybrids between Sitka spruce (*Picea sitchensis* (Bong.) Carr.) and white spruce, and between black cottonwood and balsam poplar occur in the southern portion of the range in Alaska. Thinleaf alder (*Alnus tenuifolia* Nutt.), feltleaf willow (*Salix alaxensis* (Anderss.) Cov.), Scouler willow (*Salix scoulerana* Barratt ex Hook.), and Bebb willow (*Salix bebbiana* Sarg.) are species normally classified as shrubs, but they do attain tree size and are common in the early stages of forest development. Black spruce and tamarack (*Larix laricina* (Du Roi) K. Koch) are associated on some sites (9, 10).

Natural regeneration has been relied upon to restock burns and harvested areas. Planting has been conducted on a trial basis in interior Alaska, but at present it does not contribute significantly to reforestation.

Good to excellent seed crops occur at 1- to 3-year intervals for the hardwood species (6, 16). Occurrence of white spruce cone and seed crops is more erratic, good to excellent crops can occur at 2-year intervals or they can be separated by 10 to 12 years (14, 18). Cold summer temperatures at the time of seed formation can retard seed maturation and result in seed crops of poor quality. This can occur in years of excellent cone production and thus excellent cone crops do not necessarily mean excellent seed years. Immature seed may have most consequence at higher latitudes above the Arctic Circle and higher elevations (1,950 ft or 595 m) (15).

Wind is the primary seed dispersal agent for these boreal forest species. Maximum dispersal distance is greatest for *Populus* spp. followed by paper birch and white spruce. Secondary dispersal is accomplished by water, animals, and by gravity or wind movement over snow. This may be important in redistribution of seeds. *Populus* spp. seeds are dispersed in June and July and must germinate within several weeks to a month or die (6). Birch and white spruce seeds are dispersed in the fall and winter; germination can begin soon after snow melt and be completed by late June if temperature and moisture are adequate. If conditions are limiting, germination may be delayed until late summer or, in some cases, until the following summer (6, 16, 18).

In harvested or burned forest areas, mineral soil seedbeds appear to provide the best conditions for germination and early establishment. This is particularly true for the small seeds of aspen, balsam poplar, and black cottonwood. White spruce and birch, to a lesser degree, are able to germinate and become established on shallow organic layers and mixed mineral soil-organic matter seedbeds. In undisturbed natural forests, rotted wood provides good conditions for spruce germination and seedling establishment (6, 14).

Scarification also benefits seedling growth and survival. The benefits, however, are not always as clear as they are for germination. Examples of significant variation in response to seedling growth on scarified surfaces have been observed (14). In prescribing scarification, particular attention must be given to extent of scarified areas, depth, soil type, and overall site productivity. These variables can have a differential effect on stocking levels and growth rates of different species.

All of the hardwood species have the capacity to reproduce vigorously by vegetative means. Aspen stand formation depends on the distribution of the root systems of trees present prior to disturbance. These stands tend to have relatively uniform distribution of individual stems (6). Birch reproduces vegetatively by stump sprouting, and the stands formed usually consist of groups of stems arising from stumps of the previous trees. Birch begins to lose its ability to sprout at age 60. Balsam poplar and black cottonwood reproduce vegetatively by stump sprouting, root suckering, or by rooting and growth of broken, buried stem or branch segments (19). White spruce has the capacity to layer. This process appears to be an important way of maintaining stands near treeline but has little importance in recovery from disturbances such as fire or logging.

The hardwoods are early successional species and have the characteristics normally attributed to these species (e.g., rapid juvenile growth, relatively high light requirement, short life span, and eventual replacement by more tolerant, longer lived species). Aspen and birch are the most common upland hardwoods. Birch frequently occupies cooler and moister sites than aspen, although they occur in mixed stands. Balsam poplar and black cottonwood form relatively large stands adjacent to rivers and generally are of minor importance on uplands. These floodplain species tolerate flooding, and their ability to regenerate from buried branch and stem segments makes them well adapted to these sites.

White spruce is more tolerant than the hardwoods and eventually replaces them, frequently at stand ages of 80 to 100 years if the spruce becomes established at the time of stand formation. Replacement by spruce may require a much longer period if invasion occurs gradually due to a lack of adequate seed or seedbed conditions. White spruce tolerates moderate levels of flooding and silt deposition. Trees suppressed for up to 150 years have shown the ability to grow rapidly following release.

Rotation age will vary with species and the desired product. In interior Alaska, 130 years is used by the Alaska Department of Natural Resources in calculating the allowable cut for sawlog production in unmanaged stands of white spruce which have been regenerated naturally (13). Growth and yield data for white spruce suggests that small-to-medium sized sawlogs can be produced in 70 to 90 years on good sites with more intensive management (2). Alaska's Department of Natural Resources has used 70 years for calculating the allowable cut of hardwoods in the Fairbanks District (13).

Mean annual increment of unmanaged white spruce stands on moderate to good sites varies from 30 to 50 cubic feet per acre (2.1 to 3.5 m^3/ha). For aspen, mean annual increment may be as high as 80 cubic feet per acre (5.6 m^3/ha) on good sites, while birch on good sites is somewhat less productive (48 ft^3/acre or 3.4 m^3/ha) (2, 3). Mean annual increment of balsam poplar may attain 100 cubic feet per acre (7.0 m^3/ha). Average volumes being harvested on commercial forest land in the Fairbanks area are 15,000 to 19,000 fbm (Scribner Decimal C Log Rule) or 3,000 to 3,800 cubic feet[1] per acre (210.0 to 266.0 m^3/ha); volumes up to 30,000 board feet (fbm) or 6,000 cubic feet per acre (420.0 m^3/ha) have been measured.

The most serious insect pest is the spruce beetle (*Dendroctonus rufipennis* (Kirby)). During the past decade, this species has caused significant mortality over an area in excess of 500,000 acres (202 340 ha) in the Kenai Peninsula-Cook Inlet area. Other bark beetles are important causes of mortality north of the Alaska Range. A key factor in keeping these insects at acceptable population levels is good sanitation following harvesting (4).

The most noticeable insect pests of hardwoods are defoliators. Epidemics of the large aspen tortrix (*Choristoneura conflictana* (Walker)), whose host tree is aspen, and the spearmarked black moth (*Rheumaptera hastata* (Linnaeus)), whose host tree is paper birch, have occurred in the last 15 years in interior Alaska. These epidemics were controlled by natural processes, and little tree mortality was observed (4).

Cone and seed insects significantly damage white spruce seed crops during some years in local areas. Although they may not have a significant impact on natural reproduction, they can greatly reduce the quantity and quality of seed available for collection (4).

The impact of diseases on forest growth and development is poorly known. Various species of heart and root rotting fungi affect white spruce and the hardwoods; these are particularly noticeable in the overmature hardwood stands. Spruce needle rust (*Chrysomyxa ledicola* Lagh.) and spruce cone rust (*C. pirolata* Wint. ex Rabh.) affect white spruce over large areas with the latter making collection of high-quality seed difficult in some years (4).

Large and small mammals can have an impact on selected portions of the tree or, more significantly, on stand composition and early growth. Red squirrels are capable of harvesting the majority of cones produced in moderate-to-good cone years. During periods of high population density, the snowshoe hare significantly slows stand growth and development by browsing at intensities approaching 100 percent (12).

Fire has played an important role in forest development. Fire intervals are estimated to range from less than 50 to more than 200 years. None of these species is resistant to fire; and in most cases, trees are killed by fires of light-to-moderate intensity. Pure spruce forests are more flammable than hardwoods because of the greater accumulation of cured fuels, and crown and foliage characteristics. Because of varying species mixtures and site conditions there are generally significant unburned areas within the perimeter of any burn. Site conditions, species composition, proximity to a seed source, fire intensity, and postfire residual organic layer depths determine the rate of recovery following fire.

Fire has not been used as a management tool in Alaska. It has been used successfully, however, in adjacent western Canada. The main objectives in prescribing fire would be for fuel reduction and site preparation following harvesting.

Forest management and silviculture are in a very early stage of development in these subarctic forests, and little Alaskan experience exists upon which to make recommendations. The trends to date appear to follow those which exist for these species in other parts of their range. That is, even-aged management will predominate. Under natural conditions, however, white spruce may occur in multiple-aged stands and land managers may desire to maintain this condition.

Clearcutting is the only silvicultural practice currently applied. The species managed under this system are able to regenerate in the open conditions created by clearcutting. Both an adequate seed source and a mineral soil seedbed within 300 feet (91 m) of a source of seeds must be present to

[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.

attain acceptable levels of white spruce stocking. An adequate mineral soil seedbed is not usually created by harvesting and is normally accomplished by scarification. Because the quality of the seedbed in terms of germination and seedling survival deteriorates with time, seedbed preparation should coincide with good to excellent seed crops, where possible.

In aspen and birch stands, clearcutting is generally followed by vigorous vegetative reproduction. Provided preharvest stand density is adequate, aspen vegetative reproduction produces high stocking levels within 2 years. Aspen appears to respond most vigorously when the organic mat is disturbed but not completely removed and the root systems remain intact. Vegetative reproduction cannot be relied on, however, for high levels of birch stocking. High levels of birch stocking require attention to seed source proximity and seedbed conditions (6). Mature to overmature balsam poplar and black cottonwood stands do not always attain high stocking levels as a result of vegetative reproduction (19). Again, some degree of organic matter disturbance appears to improve stocking levels for these species.

The shelterwood system has been applied only on an experimental basis in white spruce. The results in terms of stocking have been good. This system is a viable option to clearcutting as a way of creating even-aged stands and perhaps a superior method where esthetic considerations are important. Hardwood regeneration has also been abundant under the open stand conditions created in the shelterwood (17).

Group selection appears to be an option for landowners that wish to maintain a multiple-aged forest condition. Abundant white spruce and birch regeneration has been observed in small forest openings no larger than 0.75 acre (0.3 ha) in size created by harvesting and seed bed preparation (15).

All species in this complex tend to have shallow root systems and are vulnerable to logging damage and windthrow. Silvicultural systems should attempt to minimize windthrow and maintain an adequate seed supply during the regeneration period. In addition, these species tend to have relatively thin bark and are susceptible to mechanical damage during harvesting. Limited application of the shelterwood system on upland sites in the Fairbanks area has shown that loss of residual trees can be minimal.

Management of sapling- and pole-sized stands has received little attention. White spruce can respond immediately to cultural practices such as thinning and fertilization (7). Thinning is currently being conducted on a limited operational scale in white spruce and birch stands on upland sites in the Tanana Valley.

The combined research and operational experience to date suggests that the major concern in maintaining this complex is achieving adequate stocking of white spruce. Vegetative reproduction will generally maintain some level of stocking of hardwoods; however, unless particular attention is given to proximity of seed source, site, and seedbed conditions, white spruce importance will decline. If the land manager wants to maintain a high level of white spruce stocking and it is not possible to address these factors, artificial regeneration must be used.

The white spruce–hardwood forests of Alaska provide a multitude of products and amenities. Past fires have created a mosaic of forest conditions that provide wildlife habitat, recreational opportunity, and a diversity of commercial and non-commercial forest products. Watershed values and stream habitat are an important resource. Interior watersheds are large with a majority of the area extending beyond the forested zone. Silvicultural activities will probably have little effect on the major river systems, such as the Tanana and Yukon, but might affect tributaries where the majority of fish spawning takes place. Watershed studies are in their infancy in this region.

Properly applied silvicultural practices and fire management can maintain the forest diversity needed to provide the range of products and amenities available in the natural forest. In populated areas, the recommended silvicultural practices offer the best means of maintaining diversity.

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Redwood

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The range of redwood (*Sequoia sempervirens* (D. Don) Endl.) encompasses a narrow strip of land 450 miles (724 km) long and 5 to 35 miles (8 to 56 km) wide, along the central and north coast of California and extending into extreme southwestern Oregon (21).

Within this range, redwood trees now grow, or could grow, on an estimated 1.6 million acres (647 500 ha). On this land, 643,000 acres (260 210 ha) comprise the commercial redwood forest type, Society of American Foresters Forest Cover type 232, which consists of more than 50 percent redwood stocking (10). The remainder of the area contains parks, other forest types including redwood, and recently logged redwood type (8). The old-growth redwood, much of which is in State and National Parks, occupies less than 200,000 acres (80 940 ha). The old growth in commercial forests will be harvested within the next few decades.

Climate in the redwood region is mild and humid, with winter rains and summer fogs. Major associated conifers are Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), Sitka spruce (*Picea sitchensis* (Bong.) Carr.), grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), and Port Orford-cedar (*Chamaecyparis lawsoniana* (A. Murr.) Parl.). Hardwood associates include red alder (*Alnus rubra* Bong.), Pacific madrone (*Arbutus menziesii* Pursh), and tanoak (*Lithocarpus densiflorus* (Hook. & Arn.) Rehd.). Redwood changes to Douglas-fir–Tanoak–Pacific Madrone (type 234) along the eastern fringes of its range and at higher elevations. The topography, ranging from near sea level to an elevation of about 2,500 feet (760 m), is often broken and moderate to steep. Redwood grows principally on loam and clay-loam soils (13). A common characteristic is that these soils are deep and have moderate to high moisture-storage capacity.

Various habitat classifications have been proposed for redwood. One is based on soil moisture, soil nutrients, light, and temperature (24). Another relies on herbaceous plants as indicators (1). Easily recognized broad habitat differences exist between the alluvial flat and slope redwoods. The almost pure, world-renowned groves of large trees, most of which are in State and National Parks, are mainly on alluvial flats. Redwood on slopes seldom forms pure, extensive stands.

The alluvial-flat stands develop in an environment that includes periodic fires and floods. Such an environment favors redwood because, unlike its associates, redwood can maintain itself when subjected to low- or high-intensity fire and severe flooding. The thick bark of redwood protects it from low-intensity fires. After high-intensity fires, redwood produces a new crown from the sprouting of dormant buds along the bole and new individuals from root crown sprouts around the stump. When redwood is buried beneath sediments carried by floods, its feeder roots turn negatively geotropic and grow upwards into the sediments. Later, its supporting roots are replaced by new ones developed adventitiously higher up the stem (22).

Although redwood seedlings sometimes become established under overstory canopies, they are scarce on undisturbed seedbeds in timber stands. This scarcity may be because of destruction by root rot and damping-off fungi (9). Juvenile growth is best in full sunlight, but redwood grows satisfactorily in moderate shade and will persist in heavy shade. New redwood seedlings require more moisture for survival than do seedlings of most associated species (12). Potential moisture stresses caused by low humidity, high air temperatures, wind, or low soil water, therefore, deter redwood establishment and growth.

Redwood has the capacity to sprout from stumps and root crowns in any season of the year within 2 or 3 weeks after harvesting. These sprouts originate from both dormant and adventitious buds. Those that originate below the soil surface are generally favored for tree crops because they are more firmly rooted and durable. Sprouts originating from the sides and top of stumps often are destroyed by strong wind. Sprouting capacity is related to variables associated with tree size or age. Stumps of small, young trees sprout more often than those of large, old trees (19).

Seed production by redwood and associates is fairly regular (3, 5). Proportion of sound redwood seed is low (less than 15 percent), but germination of sound seed is excellent. Mineral soil is the best seedbed for establishment because seeds germinate rapidly and losses from fungi are few. Although many redwood stumps sprout, the spacing of stumps is such that resulting tree reproduction is apt to be poorly distributed, especially in old-growth stands where stumps are widely spaced. Additional seedling regeneration, therefore, is needed to complete a full stand. The associated species, notably Douglas-fir, supplement the natural stocking of redwood seedlings in proportion to the seed sources available.

Prompt regeneration of conifers requires that other vegetation not gain control of the site. In the northern part of the redwood range, red alder and several shrub species may dominate severely disturbed sites. Tanoak, Pacific madrone, and blueblossom ceanothus (*Ceanothus thyrsiflorus* Eschsch.) are potential threats if these species are present in significant amounts before cutting. Blueblossom is especially aggressive in the southern redwoods, and slash burning usually will greatly increase the shrub cover by stimulating seed germination (4).

Controlling competing vegetation in newly established stands of redwoods is simple on fairly level topography, but difficult on steep lands because of inaccessibility and tight constraints on aerial application of phenoxy herbicides or, in some instances, the outright banning of their use by county ordinance. Redwood shows great sensitivity to phenoxy herbicides at all seasons of the year because of its indeterminate growth habit and lack of protective bud scales. In spite of this sensitivity, successful release operations of sapling redwood by aerial application of phenoxys have been made. Redwood trees injured by the chemical recover in a year, and the result is a net benefit from release.

Release of redwood has been done by other conventional techniques, including basal spray, frilling and herbicide application (hack and squirt), and manual release, with and without applying herbicide to cut stumps. Manual release is most effective when competing brush is nonsprouting or only a weak sprouter, such as blueblossom and red alder.

Redwood sprouts have an advantage over other young conifers in competing with hardwoods and brush. Height growth often exceeds 4 feet (1.2 m) a year on stems that reach 5 inches (13 cm) diameter at breast height (d.b.h.) in 6 to 8 years. Seedlings of redwood and associated conifers, however, will die or become seriously suppressed by many competing species if not released within a few years after establishment.

Redwood is extremely long lived (more than 2,000 years), and the old-growth stands differ greatly from the young-growth stands in their structure and management needs. Management of these two stand types, therefore, is discussed separately. Old growth is now almost exhausted on commercial ownerships, and interest is greater in young-growth management than in old-growth management. Because redwood reproduces by sprouting and seeding, can be planted successfully on many sites, and grows well in full light and partial shade, both even-aged and uneven-aged silvicultural systems can be used to manage redwood stands.

In old-growth stands 600 to 1,200 years old, clearcutting, seed-tree cutting, and shelterwood cutting resulted in even-aged stands as a result of sprout and seedling regeneration (7). In clearcuttings that exceed 30 to 40 acres (12 to 16 ha), even with those having surrounding seed sources, however, some supplemental seeding or planting is needed in central positions of the cut area where seed distribution may be inadequate. Seeding or planting is needed 1 to 2 years after harvesting, while the site is still favorable for seedling establishment. Once seedlings are established, seed trees or shelterwood trees are cut and this logging may reduce stocking of small seedlings as much as 25 percent because of logging damage. Sprouting of cut trees, however, will replace some seedling losses.

Gradual harvesting of virgin old-growth redwood by the selection system is practiced in some situations where a continuous forest cover is desired and the landowner wishes to promote an uneven-aged stand structure. It is generally best, however, to first convert old-growth redwood to young-growth stands by an even-aged silvicultural system, and then to develop the desired uneven-aged stand structure by manipulation of the young-growth stands. This procedure is recommended because any silvicultural system that requires multiple harvest entries into stands of large, old-growth trees will result in some destruction of young growing stock. Regeneration cuttings that minimize harvest entries, such as clearcutting, seed-tree cuttings, or two-cut shelterwood cuttings, therefore, should be favored over three-cut shelterwood cuttings or selection cuttings (7).

Tall, old-growth conifers in virgin redwood stands are particularly susceptible to windthrow after harvest by partial cutting (2). The leeward edges of clearcuts also are highly susceptible to windfall. Associated conifers are less windfirm than redwood, but loss of valuable old-growth redwoods is often serious. These large trees may have a value of $20,000 to $50,000 each on the stump. Any partial cutting or exposure of a stand edge will upset the balance required for windfirmness that uncut stands usually have. Storms that cause windfall come mainly from the south and to a lesser extent from the southwest and southeast during the winter season. The necessary combination of wet soil and strong wind makes time of occurrence unpredictable. Windfall losses along the leeward edges of clearcuts can be lessened by planning clearcuts with a minimum of edge exposed to storm winds.

Fire has a moderate ecological role in old-growth redwood forests under park management, principally in altering conditions for major associated species (23). Light ground fires favor western hemlock regeneration, but eliminate older hemlock. Relatively hot fires appear essential for the establishment of Douglas-fir trees in discrete age classes. In no observed instance has a natural redwood stand been decimated by fire on the coastal side of the redwood type, but inland, as fire frequency and intensity increase and environmental conditions become harsher, redwood is replaced by other species.

Many mixed old-growth–young-growth stands have developed after partial cuttings by tractor logging since the mid-1930's (11). Most of these were partial cuttings that high-graded the stands. A mixture of stump sprouts, Douglas-fir seedlings, and hardwoods dominated the understory. In these stands the objective should be overstory removal with minimum disturbance to the young growth, and control of hardwoods. This technique will result in uneven-aged young stands, with two or more age classes.

After harvest, some areas may require seeding or planting to supplement natural regeneration. Direct seeding of Douglas-fir, with some redwood, spruce, and Port Orford-cedar, has been done successfully in redwood cut blocks, but overly dense young stands often develop after seeding. Planting of either containerized or bareroot seedlings is the preferred method of artificial regeneration. Both redwood and Douglas-fir can be planted successfully if proper technique is used and animal damage is not severe. Douglas-fir is more susceptible to browsing damage than redwood, and sometimes needs to be protected from browsing animals. Planting densities of 400 to 500 seedlings per acre (990 to 1240/ha) provide adequate stocking.

Young-growth redwood, comprised of well-stocked stands up to 130 years old, are capable of yielding more than 200,000 fbm (International one-quarter-inch) or 40,000 cubic feet[1] per acre (2800 m^3/ha) in 100 years on many sites. Yields at 100 years are expected to range from 56,000 fbm (11,200 cubic feet) per acre (784 m^3/ha) on low sites to 350,000 fbm (70,000 cubic feet) per acre (4900 m^3/ha) on high sites (18). Although this yield provides valuable commercial products, it is not as highly prized as old-growth yield.

Site curves and conversions from various Douglas-fir site indices to young-growth redwood site indices have been developed (14, 17, 25). Recently, a computerized stand growth model was developed, based on projections of density-dependent tree growth for young-growth redwood and associated conifers in northwestern California (15). The model has been available for less than 1 year. Validation and testing of the model are not yet complete.

A combination of reliable sprout regeneration and heavy seeding will provide an overabundance of young trees in many redwood stands of average and above average quality. In the absence of heavy seeding, young-growth redwood develops into irregular stands, with dense clumps of sprouts (more than 40/clump in many instances) separated by openings that are generally occupied by tanoak or other brush. It is common to have five to eight sprouts in a clump develop into good sawtimber trees, though they may be only 2 to 4 feet (0.6 to 1.2 m) apart. It has been found that 5-year-old sprouts from old-growth stumps more than double in diameter after 5 years when thinned to two sprouts per stump, and increase by one-half when thinned to five sprouts per stump (6).

Early control of growing stock (age 10 to 20 years) in overdense stands is necessary. The need differs somewhat for

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

stands established after old-growth removal and those originating after young-growth harvests. Many more sprouting stumps are found in harvested young-growth than in harvested old-growth.

Rapid initial height and diameter growth of redwood sprouts and open-grown Douglas-fir make it vital that precommercial thinning be done early in the stand's development if the objective is to optimize lumber and veneer production. Many of these stands show remarkable cubic foot growth in an unthinned condition because of the large number of stems that become established. Unless thinning is done early, however, much of this potential is expended on trees that will not be marketable, or that will stagnate or die. Precommercial thinning in redwood and associated conifers must deal with a wide range of stand conditions because of the extreme differences in early growth rate between trees of sprout origin and trees of seedling origin.

We know of no published guidelines for precommercial thinning of redwood and associated conifers. Guidelines for use in Douglas-fir stands in the Pacific Northwest often are adapted for use in the redwood region (20). Precommercial thinning should be done when leave trees are 10 to 15 feet (3.0 to 4.6 m) tall and about 15 years old. Because trees must be of sawtimber size in most stands before commercial thinnings can be made, only 200 to 290 trees per acre (490 to 720/ha) should be left. In some parts of the redwood region, markets are developing for small diameter posts. With this product in mind, stands can be thinned somewhat later than age 15. When thinning redwood, it is not desirable to thin sprout clumps to one stem; several sprouts in a clump can grow into valuable crop trees. Conventional spacing guidelines can be used between clumps.

Many of the young-growth redwood stands established after harvest of old growth will need commercial thinning one or more times before they are ready for the regeneration cut at age 50 to 90 years, if an even-aged silvicultural system is used. These short rotations are economic rotations. Culmination of mean annual increment does not occur until after age 100. Several of these stands, now well stocked, originated after early clearcutting and were not given a precommercial thinning. On recent thinnings that removed 25, 50, and 75 percent of the basal area in 40-year-old stands, most redwood stumps sprouted (16). In the two heaviest thinnings, it appears that sprouts will develop as a new age class. With light thinning (25 percent removal), sprouts develop weakly, and few of them will survive as future crop trees. Seedlings of redwood and associated species germinate also on disturbed surfaces after heavy thinning. Moderate to severe competition from other vegetation, especially in the more northerly areas, often causes heavy mortality, but many seedlings survive as advance reproduction.

Commercial thinning guidelines for redwood have not been established through experimentation. Thinning must not be heavy, or, because of sprouting, an uneven-aged stand will result. Many commercial operations leave about 70 percent of the volume (50 percent of the trees). In terms of basal area, residual stands will range from 160 to 220 square feet per acre (36.7 to 50.5 m^2/ha). Thinning is generally from below, but some dominants and codominants must be cut to provide release. As with precommercial thinning, sprout clumps should not be thinned to one stem.

Individual tree selection and group selection, by coppice regeneration, can be used in young-growth stands. Uneven-aged stands can be maintained by removing selected redwood and fostering the development of smaller sprouts and natural seedlings. Careful logging is necessary to minimize destruction of advance regeneration. This method has yet to be tested in controlled experiments, but is being used operationally in several stands in the redwood region.

Redwood is remarkably free of serious pests. Insect and disease considerations do not dictate forest management strategies. Bark stripping by the American black bear has become a serious problem in some parts of the redwood region. Trees 10 to 30 years old and 6 to 10 inches (15 to 25 cm) in diameter are damaged most, and many may be girdled. Control is by hunting or live trapping and removing animals. Wood rats often injure trees, from seedlings and sprouts to mature trees. But they seldom do sufficient damage to warrant control measures.

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Red Fir and White Fir

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More than 4 million acres (1.6 million ha) of commercial forest land at the higher elevations in California and southern Oregon are dominated by two forest types—Red Fir, Society of American Foresters type 207, and White Fir, type 211 (1, 7). On the basis of current environmental and biological information, silvicultural practices for the two types are generally the same. For this reason, they will be discussed separately only when differences are silviculturally significant.

California white fir (*Abies concolor* var. *lowiana* (Gord.) Lemm.) forms extensive, pure, or nearly pure, stands in a relatively narrow band above the Sierra Nevada Mixed Conifer (type 243) and below the California red fir (*Abies magnifica* A. Murr.) forests. Elevational ranges are from 4,590 to 5,900 feet (1400 to 1800 m) in the Siskiyou Mountains and southern Cascades of Oregon (2), and from 4,500 to 5,500 feet (1370 to 1675 m) in the Klamath Mountains and interior Coast Ranges of California, as far south as Lake County. Minimum and maximum elevations increase toward the south and the type lies between 6,000 feet (1830 m) and 7,000 feet (2135 m) in various mountain ranges of southern California (11). Pure stands of limited extent are found east of the Sierra Nevada, and in the Warner Mountains. In the Sierra Nevada, white fir occupies thousands of acres that were logged and burned during the last century (1).

California red fir, including its commonly recognized variety Shasta red fir (*A. magnifica* var. *shastensis* Lemm.), and lodgepole pine (*Pinus contorta* Dougl. ex Loud.) are the dominant forest cover (types 207 and 218) at elevations above the white fir forests. Lower elevational limits for red fir begin at 5,300 feet (1615 m) in the Siskiyou Mountains of Oregon, and increase southward through the Cascades, rising to 7,000 feet (2135 m) in the southern Sierra Nevada of California (11). In California's Coast Ranges the red fir type occurs from 4,600 to 6,000 feet (1400 to 1830 m) in elevation (11). Red fir is not found in the Warner Mountains of California or south of Lake County in the Coast Ranges.

Between the elevational levels where red fir and white fir form nearly pure stands, the species are found in mixture, with either one dominant. Throughout their ranges, except at their northern limits in Oregon (1), these true firs form climax forests (1, 2). Both species appear to merge with similar but separate species at the northern end of their ranges. White fir merges with grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.) and red fir with noble fir (*Abies procera* Rehd.) (6, 17).

The two firs grow on soils that have developed on a variety of parent materials: volcanic and glacial deposits of recent origin; unmetamorphosed granitic, basic igneous, and sediments; and sedimentary, volcanic, and igneous material of various compositions and degrees of metamorphism. Most of the soils are young, have poorly developed profiles, and are cold, with mean annual temperatures from 32° to 50° F (0.0° to 10.0° C).[1]

Upland meadows are scattered throughout the true fir forests and Sierra lodgepole pine (*Pinus contorta* var. *murrayana* (Grev. & Balf.) Engelm.) is a common associate surrounding these meadows.

Climate of the true fir zone is relatively mild for high-elevation forests and can be classified as cool to cold and moist, with daily extremes only occasionally exceeding 90° F (32.2° C) or falling below −20° F (−28.9° C) (7, 8). Precipitation is between 30 and 70 inches (760 to 1780 mm) per year with more than 80 percent as snow. Snowpacks can exceed 13 feet (4.0 m) frequently and 20 feet (6.1 m) occasionally in the Sierra Nevada and 7 feet (2.1 m) in Oregon.[1] Almost all precipitation falls between October and May. Scattered thunderstorms between May and October seldom deliver enough water to significantly affect soil moisture.

Winds are generally westerly to southwesterly, and vary locally depending on terrain. Because true fir forests are located at high elevations and on young, generally shallow soils, they are susceptible to damage, especially on exposed ridges. Windthrow and stem breakage are common in closed, old-growth stands. These types of damage are related more to heart and root rots than to wind alone (4). Dense young stands often suffer top damage during winter storms.

In exceptional years, both firs can produce more than 570,000 seeds per acre (1.4 million/ha), but only 10 percent of that number is produced in good years. Good to heavy seed crops are borne every 1 to 4 years by red fir and every 3 to 9 years by white fir (5, 13). Seeds are wind-disseminated as the cones disintegrate between late September and mid-October. Most seeds fall within 1 to 1.5 times tree height (5, 10). Because fir seeds are borne only in the crown tops, any top damage reduces seed production. The most prolific and reliable seed bearers are healthy, mature dominants. Immature trees can produce heavy crops but are erratic. Proportions of sound seed are low, generally less than 50 percent (13). Seed germination in the field can be as low as 5 percent.

Bare mineral soil is the best seedbed, although seeds of both species will germinate and seedlings will grow in light litter providing they are under partial shade. Early mortality is lowest under shade, but growth is best in full sunlight (7).[1]

Red fir is slightly less tolerant of shade and less sensitive to frost than white fir. Both species are more tolerant of shade and less tolerant of drought than lodgepole pine, Jeffrey pine (*Pinus jeffreyi* Grev. & Balf.), sugar pine (*Pinus lambertiana* Dougl.), western white pine (*Pinus monticola* Dougl. ex D. Don), or incense-cedar (*Libocedrus decurrens* Torr.)—all minor associates in the fir types (1, 9, 11). Unlike lodgepole pine, the firs are sensitive to wet or poorly-drained soils (9).[1]

Although both fir species can survive 40 years or more of suppression, tree growth increases dramatically after

[1] Laacke, Robert J. California red fir (*Abies magnifica* A. Murr.), and white fir (*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.). 1981. Two unpublished drafts supplied to the authors by Robert J. Laacke.

release. Diameter and height growth can triple, depending on tree condition as evidenced by prerelease live-crown ratio, and height and diameter growth (8). Both species grow slowly for the first 3 to 4 years from seed and then accelerate to 8 to 20 inches (20 to 51 cm) each year, if not suppressed (1). Good quality seedlings, especially those of white fir, can grow rapidly soon after planting. Both species can support unusually heavy stand densities and impressive volumes. On the best sites (site index 90 at 50 years), unmanaged stands of white fir can carry 471 square feet of basal area per acre (108 m^2/ha) and a volume of 23,100 cubic feet per acre (1617.0 m^3/ha) at age 150. Mean annual increment of unmanaged stands culminates at 70 years (14). On sites of equivalent quality, red fir can carry 573 square feet of basal area per acre (131.6 m^2/ha) and a volume of 31,900 cubic feet per acre (2233.0 m^3/ha) at 150 years. Mean annual increment of unmanaged stands culminates at 140 years (15).

Management practices vary, but can be grouped generally into two categories on average quality sites: a short rotation of 70 years and a long rotation of 125 years (16). On the basis of data from normal yield tables for average sites (14, 15), annual growth averages 128 and 102 cubic feet per acre (9.0 and 7.1 m^3/ha) for white fir having 70 and 125 year rotations. On the same basis, red fir growth averages 81 and 129 cubic feet per acre (5.7 and 9.0 m^3/ha). In areas where the types overlap and the two species grow together, red fir will usually outgrow white fir in height and diameter.

Seed and cone insects that affect the two fir species are not unusual, and insects significantly damage regeneration only locally and periodically. White fir in the central and southern Sierra Nevada is subject to infection by true mistletoe (*Phoradendron bolleanum* (Seem.) Eich. subspecies *pauciflorum* (Torr.) Fosb.), which results in topkilling of old trees and reduced seed production.

Three major threats to new seedlings are cutworms (*Noctuidae*), drought, and heat, which account for 70 percent of early mortality (3). Brush, including various species of ceanothus (*Ceanothus* spp.), manzanita (*Arctostaphylos* spp.), chinkapin (*Castanopsis* spp.), and others, rapidly invade disturbed sites. In general, brush alone does not prevent reforestation because both firs can survive and, within 30 to 50 years, overtop the brush to dominate the site. In forests managed for timber production, however, neither this delay nor the frequently haphazard stocking are acceptable.

Pocket gophers are nearly ubiquitous in both fir types and can kill or cause substantial growth losses to seedlings and saplings over large acreages (7). Damage to poles and sawtimber has been observed. Enclosing seedlings in plastic tubing and direct control of gophers by baiting can offer effective protection, but are expensive. Chemical control of preferred food, such as lupine and other herbaceous vegetation, may be needed to help keep gopher populations to acceptable levels and reduce costs of direct control. Browsing of succulent growth by deer and elk can retard height growth for years. Normally, trees are not killed and grow rapidly when browsing pressure is removed. Once the sapling is about 4 feet (1.2 m) tall, browse damage is no longer a concern.

Annosus root disease fungus (*Heterobasidium annosum* (Fr.) Bref.) is present in most fir stands. Direct damage from the disease, although restricted primarily to heart rot of butt and major roots, leads to windthrow and breakage. Root damage also causes moisture stress and loss of vigor, which predispose trees to insect attack. New infection centers begin by aerial spread of spores and infection of basal wounds and freshly-cut stumps. Once established, the fungus spreads from tree to tree through root contacts. Two other heart rots cause major volume losses. Yellow cap fungus (*Pholiota adiposa* (Fr.) Kumm.) and Indian paint fungus (*Echinodontium tinctorium* (E. & E.) E. & E.) infect basal wounds, old dwarf mistletoe (*Arceuthobium abietinum* Engelm. ex Muntz f. sp. *concoloris* Hawks. and Weins and *A. abietinum* Engelm. ex Muntz. f. sp. *magnificae* Hawks. and Weins) bole cankers and other wounds, and cause major volume losses. With intensive management and multiple entries in young stands, mechanical damage to the thin-barked fir will become a serious consideration because these and other heart rots can reduce final volume by as much as 1 percent for each year until harvest.[1,2]

Dwarf mistletoes infect about 30 percent of white fir and 40 percent of red fir stands (12). Heavily infected trees suffer significant growth losses and are vulnerable to insect attack and branch kill caused by cytospora canker (*Cytospora chrysosperma* Pers. ex Fr.). Two varieties of dwarf mistletoe are involved. The parasite can be controlled silviculturally by even-aged management, because both varieties are host-specific, spread slowly, and grow slowly (12).

Conditions that reduce tree vigor, including overstocking, drought, fire, and disease, predispose trees and stands to insect attack. The fir engraver (*Scolytus ventralis* LeConte) is the major killer of true fir, although several other beetles contribute to the volume loss each year.

With strictly controlled prescriptions, fire is a potential management tool. Thin bark, long-lived crowns, retention of branches, and heavy litter accumulations, however, make use of fire hazardous in dense, immature stands.

Almost all land in the red and white fir types that is currently managed for timber is under, or is being converted to, even-aged management. The capacity of both species to produce large volumes in dense, even-aged stands and the opportunity to control dwarf mistletoe make even-aged management attractive. Artificial and natural regeneration are both possible.

For natural regeneration under even-aged management, shelterwood and seed-tree cuttings work well, but selection of seed trees is critical. The trees chosen must be windfirm and capable of reliably producing seed. Mature, healthy dominants with sound tops, full crowns, and rot-free stems and butts are the best choice (5). Down-wind dimensions of clearcut openings should not exceed 1 to 1.5 times tree height to ensure adequate seed coverage (4). The shelterwood or seed trees should be removed as soon as regeneration is achieved and before the young trees are 3 feet (0.9 m) tall, to reduce logging damage and chances of dwarf mistletoe infection from above (12).

Artificial regeneration is gaining in acceptance. Until recently, lack of information concerning necessary growing conditions and lifting schedules in the nursery and inadequate care of stock resulted in many failures. With current practices, survival rates vary from 40 to 80 percent (with red fir slightly higher than white fir) (7) and these rates can be improved if each step from seed collection to planting of seedlings in the field is followed carefully. Timely access to planting sites at high elevations can be a problem because of snow-blocked roads.

Both natural and artificial regeneration are most reliable after thorough site preparation. Site preparation methods vary

[2] Aho, P. E.; Fiddler, G.; Srago, M. Logging damage in thinned second growth true fir stands in California. 1981. Unpublished paper supplied to authors by Paul Aho.

depending on local conditions including slope, soil, prelogging stand condition, and expected vegetation response. Tractor piling and subsequent burning of slash and brush is commonly used on slopes of up to 35 percent. Where terrain and soil permit, double discing can be effective for controlling grasses, forbs, and some brush. Discing is not recommended for sprouting species. Broadcast burning is often used, especially on slopes too steep for tractors. Control of competing vegetation is essential. Growth losses from competition by lesser vegetation can be excessive even if survival is high. Herbicides, applied aerially, by tractor, or by hand sprayer, are usually the most cost-effective control. Machine cutting or chipping of nonsprouting brush can be effective on suitable slopes. Choice of equipment and operator skill are critical. Ability of the operator to locate seedlings to be released is vital to success. Hand weeding of brush seedlings less than 4 years old may also be cost effective, particularly on steep slopes in places where herbicides cannot be used.

True fir forests have come under intensive management only recently and published data regarding growth response to various stocking levels are lacking. Thinning prescriptions developed for other types are being applied and modified on the basis of experience. On National Forest lands, two general approaches are used for commercial thinning. Young stands (40 to 70 years old) are reduced to 55 or 60 percent of the basal area indicated in normal yield tables for natural, uncut stands. For less vigorous or older stands, the guideline suggests thinning from below to leave those trees that currently produce 80 percent of the cubic foot periodic annual increment. Young (12 to 15 years old) stands can sometimes be thinned profitably through sale of Christmas trees.

Uneven-aged management is possible. But with the dense stand conditions normally encountered on good sites, at least several trees must be removed in a group to allow regeneration to take place. Site preparation of small spots is expensive and seedling growth exceedingly slow. Infection of young trees by dwarf mistletoe in the overstory is impossible to prevent. In managed, all-aged stands, risk of loss to fire may become unacceptably high, since slash disposal in closed stands is difficult and may be undesirable because of injury and subsequent infection by rot organisms. The large amount of cull usually found in old trees would add to the problem, at least during conversion to all-aged management. For these reasons and others, single-tree selection is not a usable option for management.

Group selection is possible with openings as small as 0.4 acre (0.16 ha) (2). Many of the same disadvantages mentioned earlier, such as poor growth and dwarf mistletoe infection, apply, although their seriousness decreases as opening size increases. With either approach to uneven-aged management, maintenance of the required age-size class distributions is a formidable task.

High elevation true fir forests provide much of the water for California's more than 20 million people and habitat for more than 123 bird, 60 mammal, and 14 amphibian species. Seven bird and one mammal species are considered sensitive, rare, or endangered. Recreation use is high at upper elevations where stands are open and vistas common. As a result, visual and water resources management are a concern. Livestock grazing in and around meadows is a consideration primarily where true fir grades into open forests and ranges of the eastern Sierra Nevada and Cascades.

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Sierra Nevada Mixed Conifers

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Sierra Nevada Mixed Conifers, Society of American Foresters Forest cover type 243, occupy between 4.5 and 7.8 million acres (1.8 and 3.2 million ha) of commercial forest land in California and southern Oregon (2, 7, 15) and dominates mid-elevations of the Sierra Nevada's western slopes. The type covers extensive areas of the southern Cascades, Klamath Mountains, and interior Coast Ranges as far south as Lake County. Extensions of the type are found in various mountain ranges as far south as San Diego County and on eastern slopes of the Sierra Nevada in Plumas County (6).

The type grows at elevations from 2,500 feet (760 m) to 4,600 feet (1400 m) in the north, 3,000 feet (915 m) to 6,000 feet (1830 m) in the central Sierra Nevada, and 4,000 feet (1220 m) to 10,000 feet (3050 m) in the south. Below this range of elevations are Pacific Ponderosa Pine–Douglas-fir, Pacific Ponderosa Pine, or Interior Ponderosa Pine Types (types 244, 245, 237); above are the White Fir and Red Fir types (types 211 and 207) (6). Long, irregular parts of the mixed-conifer forest type extend into adjacent cover types, sometimes complicating stand delineation and management (6).

In the Sierra Nevada, air temperatures decrease fairly regularly as elevations increase. In summer, temperatures are seldom above 96° F (35.6° C) or below 40° F (4.4° C). Winter temperatures generally range from 60° to −10° F (15.6 to −23.3° C) (26). Temperatures occasionally drop below −25° F (−31.7° C) and rise above 100° F (37.8° C) (19). Potential growing seasons vary with elevation and, in the northern Sierra Nevada, are from 90 to 330 days, with 40 to 200 frost-free days. Potential growing seasons in the south are from 180 to 365 days, with about 180 frost-free days (15). Prevailing winds are westerly to southwesterly and may cause problems on exposed ridges and in some canyons. Precipitation is not as clearly related to elevation as is temperature because of the effects of rugged, mountainous terrain and major storm patterns (19). Total precipitation is from 30 to 90 inches (760 to 2290 mm) per year. In general, precipitation increases as elevation increases, as does the proportion that falls as snow. Snow comprises almost 80 percent of the total precipitation at the upper limits of the type (19), but as little as 20 percent at lower elevations. In California's Mediterranean-like climate almost all precipitation arrives from October to May (19). Summer storms are unusual and rarely deliver enough water to significantly affect available soil moisture (15, 19). The lack of effective summer precipitation emphasizes the importance of the balance between water demand and soil-water storage capacity in determining site quality. Available soil moisture is especially critical for regeneration. Access to water stored below the soil in fractured or decomposed rock can affect site quality significantly (1) and is dependent on local geologic conditions.

The age, size, structure, and species composition of many current stands were largely determined by timing and kind of logging as accessibility, technology, market condition, and landowners changed. When logging began 50 to 100 years ago, access was largely by railroad, and large, high-quality pine was removed. Later entries took more pine and large Douglas-fir. As trucks were developed, subsequent entries were for salvage, sanitation, and removal of the remaining high-value trees to pay for extending road access. Tax laws strongly favored heavy cutting on most private lands. Logging history, therefore, combined with biological characteristics of the tree species and local variables of slope, aspect, soils, elevation, geology, and fire history, produced the current mosaic of small stands or groups. These stands or groups, usually between 0.5 and 10 acres (0.2 and 4.0 ha) in extent, are recognized as the basis for silvicultural prescriptions. Differences in species composition and vertical mixing with up to five species in the overstory and one to three species in the understory are common (6).

Five conifer and one hardwood species define the type: California white fir (*Abies concolor* var. *lowiana* (Gord.) Lemm.), ponderosa pine (*Pinus ponderosa* Dougl. ex Laws. var. *ponderosa*), coast Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*), sugar pine (*Pinus lambertiana* Dougl.), incense-cedar (*Libocedrus decurrens* Torr.), and California black oak (*Quercus kelloggii* Newb.). Douglas-fir dominates the mix in the north, white fir at higher elevations and on north slopes, ponderosa pine at lower elevations and on south slopes. Douglas-fir is absent from the mixture south of the Merced River. White fir and incense-cedar are the most common species, although incense-cedar, unlike white fir, is seldom more than a minor component in the overstory (6). Any of the major conifer species, however, can dominate a specific stand.

Jeffrey pine (*Pinus jeffreyi* Grev. & Balf.) replaces ponderosa pine at high elevations, on cold sites, and on soils derived from serpentinaceous and ultramafic parent materials. Giant sequoia (*Sequoiadendron giganteum* (Lindl.) Buchholz) is found in groves scattered through the central and southern Sierra Nevada. Red fir (*Abies magnifica* A. Murr.) is a minor associate at the highest elevations (6).

Each of the species has a combination of silvical characteristics that suits it to particular environments and stages of succession.

White fir bears heavy seed crops on a 3- to 9-year cycle and adequate to good crops every 2 to 5 years. The most prolific seed producers are mature, healthy dominant trees 12 to 35 inches (30 to 89 cm) in diameter at breast height (d.b.h.) (10, 13). Relatively small proportions (20 to 50 percent) of seeds are sound, but as many as 600,000 can fall per acre (1.5 million/ha) where white fir is the dominant species, and as many as 220,000 per acre (544 000/ha) where white fir is a minor component (10, 14). Seeds are wind disseminated and will travel as far as 2.5 times tree height downwind into openings (14). Although seed germination and seedling establishment are best on bare mineral soil, white fir seedlings survive and grow better in light litter than seedlings of associated pines (21, 30). Early survival rates are highest in partial shade, but subsequent growth is best in full sunlight (8, 9). Seedling growth is inherently slow for the first 3 to 5 years but then, if free from overstory competition, accelerates rapidly (15).

Compared with its five associated species, white fir is the most shade tolerant and the least tolerant of hot, dry sites. It is least damaged by snow (23). All six species are easily destroyed by fire when they are young and small, but white fir remains vulnerable longer than the others (4) and is moderately susceptible to fire damage when mature (23). White fir can survive more than four decades of suppression beneath closed canopies and dramatically increase height and diameter growth when released (12).[1] In spite of its low relative drought tolerance (23), white fir can survive the presumably intense root competition of dense brush fields for 30 years or more until it grows above the brush canopy and begins to dominate the site (4, 15).

On medium-to-poor quality sites, white fir will grow faster than any of its associates in height and diameter (4). Gross volumes increase as the proportion of white fir increases in young, unmanaged, mixed-conifer stands (5).

Douglas-fir bears heavy seed crops irregularly with a cycle of 2 to 11 years (27). Seeds are wind disseminated, lighter, and travel farther than seeds of associated species (23). Seeds will germinate on a wide variety of seedbeds although bare mineral soil is best. Early survival of natural Douglas-fir seedlings is strongly related to microclimate. After the first summer, survival ranged from 3 percent in full sunlight and 6 percent in heavy shade to 22 percent in partial shade (32). Growth, however, is best in full sunlight (8).

Douglas-fir is moderate in relative shade tolerance. It is more tolerant than ponderosa pine, about equal to sugar pine, and less tolerant than white fir or incense-cedar. It does not respond well to release after long suppression. Douglas-fir is moderately susceptible to snow damage and is about average in drought tolerance (23). Two-year-old Douglas-fir seedlings do not have tap roots as deep or lateral roots as long as ponderosa pine, sugar pine, or incense-cedar (31). The volume of soil tapped and, therefore, the amount of water potentially available is less than that for the other three species. Early growth from seed is slow but accelerates rapidly.

Ponderosa pine bears large seed crops on a cycle of 2 to 5 years (27), but produces fewer seeds per acre than the associated conifers. The largest trees bear the most seed (10). Seeds are wind disseminated and are carried somewhat farther than white fir seeds but not as far as Douglas-fir seeds (29). Germination rate is about 70 percent (27). Bare mineral soil and full sunlight favor ponderosa pine regeneration.

In mixed-conifer forests, ponderosa pine is the least tolerant of suppression by an overstory and rapidly loses its ability to respond to release. It is the most drought resistant of the conifer seedlings because of its extensive root system with deep tap roots, wide-reaching laterals, and many deep sinker roots (8, 23, 31). It also is more tolerant of heat. Growth is relatively slow at high elevations and snow damage can be severe (23). Jeffrey pine replaces ponderosa pine as temperature decreases and snow increases with elevation. Initial growth rates in full sunlight are high and, on all but the poorest sites, sufficient to achieve dominance over brush if regeneration is established within 1 to 2 years after logging or fire (30).

Sugar pine bears heavy seed crops on a cycle of 3 to 5 years (27) and, of the conifers, generally has the highest proportion of sound seed. Cone production increases with tree size and crown vigor (10) and most seeds are produced by large, mature dominant trees (8). About 180,000 seeds per acre (445 000/ha) are produced (10). Sugar pine seeds are large and are carried no more than about 200 feet (61 m) even in gale winds (10). The seeds germinate best in light litter and full sunlight (30). Sugar pine is moderate in relative shade tolerance. It is more tolerant than ponderosa pine, about the same as Douglas-fir, and much less tolerant than white fir (23). It responds well if released from overstory competition within 30 to 40 years. Sugar pine seldom survives heavy brush competition, unless it is established before the brush can assert dominance (8).

Sugar pine grows slowly at first but then accelerates and sustains high growth rates longer than the other conifer species. It can exceed ponderosa pine by 20 percent in volume and basal area in as few as 40 years, even on a hot, dry site (24). Sugar pine ultimately will outgrow most other species but cannot survive under a dense overstory of white fir or Douglas-fir (4, 8). Sugar pine is a common associate of Jeffrey pine, Douglas-fir, and incense-cedar on serpentine or ultramafic soils that are relatively infertile and have low available soil moisture storage.

Incense-cedar seed production has no clear cycle and can vary dramatically from tree to tree in any year (8). The species can produce large numbers of seeds—up to 186,000 per acre (459 610/ha)—even though it rarely dominates the stand (10). Seeds are wind disseminated. Seeds germinate well on both bare soil and light litter and seedling survival is best under partial shade (30). Field germination rates are between 20 and 40 percent (9). Incense-cedar is rated as tolerant to shade in California (8). Response to release is good but growth is generally slower than that of the other conifers (8). Up to a diameter of 24 inches (61 cm) and under ideal conditions, however, young incense-cedar can outgrow all associated species except white fir (4). It is relatively drought tolerant and can grow on physically and chemically undesirable serpentine-derived soils.

California black oak, although widespread, is rarely more than a minor stand component and, in spite of its potential for quality hardwood lumber, has insufficient economic value to warrant specific management except in limited situations. Wildlife value of the tree, especially its acorn crop, however, is high.[2] Black oak produces heavy seed crops every 2 to 3 years (27). Trees and seedlings sprout vigorously. Most mature trees appear to have originated from sprouts.[2]

Various cone and seed insects attack all of the species and are periodically a serious local problem. Unless controlled, rodents can consume most seeds from either natural seedfall or sowing. Cutworms (*Noctuidae*) can destroy 30 percent or more of seedlings in natural regeneration areas and are most damaging to incense-cedar and white fir (11). Summer drought alone can kill more than 20 percent of all natural regeneration (11).

Annosus root disease (*Heterobasidium annosum* (Fr.) Bref.) is a threat to conifers, killing pines directly, and white fir and Douglas-fir indirectly, through heart rot of roots and butt (3). A common root rot (*Armillariella mellea* (Vahl. ex Fr.) Karst.) infects all trees in the mixed-conifer forest, including black oak (3). In much of the Klamath Mountains and certain areas of the northern Sierra Nevada, young sugar pine rarely survives beyond the pole stage because of white pine blister rust (*Cronartium ribicola* J. C. Fisch.) (3). Until a rust-resistant strain is either identified or bred, and resistant stock becomes available, sugar pine is not a realistic manage-

[1] Helms, John A.; Standiford, R. B. Release of advance growth mixed conifer species in California following overstory removal. Unpublished paper supplied to author by John A. Helms.

[2] McDonald, Philip M. *Quercus kelloggii* Newb. California black oak. 1981. Unpublished draft supplied to author by Philip M. McDonald.

ment option for some areas. All of the conifers except incense-cedar are infected by their own species-specific dwarf mistletoes (*Arceuthobium* spp.), which predispose their hosts to insect attack, cause varying degrees of damage from growth reduction to topkill and, indirectly through entry courts in open cankers, heart rots (26). True mistletoe species (*Phoradendron* spp.) infect white fir from Lake Tahoe south and incense-cedar throughout the mixed-conifer type. Damage to incense-cedar is minimal but can be important to severe on large, old firs (3). All conifers except incense-cedar are attacked by one or more species of bark beetles (*Scolytus*, *Dendroctonus*, or *Ips*). Damage is widespread but generally significant only locally and primarily in overstocked or diseased stands and occasionally near fresh slash accumulation. Salvage cutting of trees that die because of overmaturity and/or insect and disease attacks has been as high as 180 million cubic feet (5.09 million m^3) per year. After a recent 2-year drought, mortality was estimated as 1.3 billion cubic feet (36.8 million m^3) for 2.5 years (15). Pocket dry rot (*Tyromyces amarus* Hedgc. Lowe) enters through fire scars (8) and causes major volume loss in old incense-cedar but is not significant in trees less than 150 years old (3).

Fire is always a hazard during California's long, dry summers and each year many thousands of acres are burned. Massive efforts during the last half century have reduced greatly the frequency of wildfires within a stand and enhanced the importance of the tolerant and relatively fire-sensitive white fir. Reintroduction of fire under carefully controlled conditions may have potential as a silvicultural tool for species and stocking control. Fire is used widely for site preparation and slash treatment for fuels management.

The major threat to productivity, at least in the short term, is a variety of aggressive woody shrub species that are well adapted to take advantage of forest disturbance. Slightly more than 2 million viable shrub seeds per acre (4.9 million/ha) have been found in the duff and soil of mature, virgin forests (25). Under some conditions, various species of woody brush (*Ceanothus*, *Arctostaphylos*, *Chamaebatia*), and brush forms of tanoak (*Lithocarpus* spp.) and chinkapin (*Castanopsis* spp.) can prevent successful conifer regeneration for decades. Where maximum tree growth is desired, control of competing vegetation must be accomplished early and maintained until the trees fully dominate the site. Delayed or incomplete control can reduce growth from 2 to 14 percent, and total lack of control can reduce volume in plantations as much as 67 percent (33).

Damage from vertebrate pests in the mixed-conifer type is generally limited to regeneration and varies considerably from place to place. Usually, pocket gophers are the most damaging, followed by deer, porcupine, rabbits, and hares. Pocket gophers can destroy seedlings over extensive acreage and can prevent regeneration unless controlled.

Current management schemes vary depending on owners' objectives, site quality, stand structure, stand condition, and economic constraints. Uneven-aged management is theoretically possible, although group selection with relatively large openings—greater than 90 feet (27.4 m) in diameter—is necessary to prevent a species change because smaller openings and partial cutting tend to eliminate the shade-intolerant species (4, 11, 21). On the extensive acreage where uneven-aged management is practiced, the objective is not to regulate stand structure by controlling diameter class distribution. Instead, existing irregular stand structures are maintained or changed to a two- or three-aged stand through a modified diameter-limit cutting, as described by Marquis (20). On lands under group selection, regeneration cuttings are from 0.5 to 1 acre (0.2 to 0.4 ha) in extent with the intent to achieve complete regulation in 40 to 70 years. Single-tree selection is used rarely where timber production is a major objective. Limitations to single-tree selection are: slow growth of young trees, extreme difficulty of maintaining a mix of shade-tolerant and intolerant species, inability to control dwarf mistletoes, diseconomy of scale for cultural treatments (including site preparation), and the immense cost of inventorying and maintaining required age-class distribution.

Probably more than one-half of the mixed-conifer forest is currently under, or being converted to, even-aged management. Although individual management schemes differ, they can be described as generally falling into two categories on average quality sites—a short rotation (85 years) and a long rotation (130 years). Rotation lengths differ considerably within these general classes. Growth under the short rotation scheme averages 112 cubic feet per acre (7.8 m^3/ha) per year, and under the long rotation 90 cubic feet per acre (6.3 m^3/ha) per year (34). Intensively managed young stands on better-than-average sites can be expected to produce from 150 to 200 cubic feet per acre (10.5 to 14.0 m^3/ha) per year (15). In the absence of sound, published data to indicate stocking levels for maximum wood production in young, managed, mixed-conifer stands, stocking decisions are based mostly on experience and judgment. Commercial thinning is generally from below, although some owners cut both large and small trees to make thinning more profitable. Well-stocked, vigorous young stands (40 to 70 years old) are often reduced in merchantable volume by 30 to 40 percent. A common Forest Service practice is to reduce stocking to 55 to 66 percent of the basal area indicated in normal yield tables for uncut, natural stands every 10 years. On poor sites or in older stands, the residual basal area is increased. Another approach is to thin from below and leave the trees that are producing 80 percent of the periodic annual increment (cubic volume). Intermediate cuts of all kinds are used currently and provide an opportunity to adjust species composition as well as stocking.

Artificial regeneration of all conifer species is feasible now in most places if species and suitable seed sources are chosen, dormant seedlings are properly stored and correctly planted in spring, site preparation is adequate, and competing vegetation is controlled. Direct seeding is costly, uncertain, and rarely used, although it has been popular in the past (9, 28). Planting, after harvesting and site preparation, is the normal procedure. California's long summer drought places a premium on planting stock condition and treatment. Both a lack of information concerning species requirements in the nursery and often poor care and planting of nursery stock have resulted in many failures, even for ponderosa and Jeffrey pines. Nursery lifting and storage times that ensure high survival potentials in planting stock are now known for diverse seed sources of ponderosa pine, Jeffrey pine, white fir, and Douglas-fir (16, 17, 18). Threshold soil temperatures for root growth are known for the pines (16), Douglas-fir, and true firs (17), and can be used to select planting times.

Natural regeneration usually can be achieved under systems from single tree selection to clearcut, if site preparation and seed source are adequate. Control of competing vegetation is critical and control of various rodents, including pocket gophers, often is necessary. Regeneration cuts must be designed to suit stand conditions and the species desired. Openings of at least 0.2 acre (0.1 ha) are required for initial survival of the intolerant pines, however, long-term survival and growth are questionable. Single-tree selection provides adequate openings for the survival of the tolerant white fir although growth of all species increases as overstory density decreases (21, 22). Germination and growth of the generally intolerant brush also is favored by heavier cutting (11, 21, 22).

Stream protection and habitat requirements for nine wildlife species (seven birds, one reptile, and one mammal) listed as sensitive, rare, or endangered (35) are considerations in every timber sale on private or public lands. Protection of esthetic values in high travel zones and in areas receiving recreational use are additional management considerations on public land. Relatively little grazing is done within the type.

The range and heterogeneity of natural environments within the geographic area now occupied by the Sierra Nevada Mixed-Conifer type will maintain a mixed-conifer forest. Several variables, however, are changing species composition. Removal of frequent wildfires from the environment through massive fire suppression efforts, a history (not universal) of partial cutting, and limitations on brush control measures are favoring the more tolerant species—especially white fir.

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Pacific Ponderosa Pine

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The range of Pacific ponderosa pine (*Pinus ponderosa* Dougl. ex Laws. var. *ponderosa*), Society of American Foresters Cover type 245 (7), extends from latitude 43° N in the Klamath Mountains of Oregon, south through the southern Cascades, interior Coast Range, western Sierra Nevada, and Transverse Ranges, to its southern limit at latitude 33° N in the Peninsular Ranges of southern California near San Diego. Elevational limits of the Pacific ponderosa pine type range from 1,000 to 2,000 feet (305 to 610 m) in the Klamath Mountains, through 1,500 to 3,500 feet (455 to 1065 m) in the northern Sierra Nevada, to 5,300 to 7,300 feet (1615 to 2225 m) in the south (9). In all, this type covers about 1.5 million acres (607 000 ha) (39).

Pacific ponderosa pine develops best on western slopes of the southern Cascades and Sierra Nevada, forming a virtually continuous band of moderate to high productivity from Shasta County south through Eldorado County (40). Highly productive stands, however, also are found in southern Siskiyou County and as far south as Fresno County.

Spanning a broad range of site qualities, the type is found mainly on soils formed from extrusive and intrusive igneous rocks, their metamorphosed equivalents, and metamorphosed sedimentaries. Pacific ponderosa pine tolerates a broad span of soil pH with A-horizon reactions ranging at least between 4.9 and 7.5. The most productive stands have A-horizon pH's between 6.0 and 6.5, and B-horizon pH's between 5.5 and 6.0 (49). Perhaps the poorest stands grow on calcium-deficient soils formed from ultramafic rocks, where survival is possible because the calcium requirement for ponderosa pine is comparatively low and because the species has a strong potential for uptake of this and other nutrients (14, 35).

Growing seasons within the Pacific ponderosa pine type are warm, dry, and mostly cloudless. Annual temperatures average 42° to 50° F (5.5° to 10.0° C), with July and August temperatures averaging 62° to 70° F (16.6° to 21.1° C). Depending on elevation, consecutive frost-free days vary from 110 to 250 in the Klamath Mountains, 115 to 250 in the southern Cascades and northern Sierra Nevada, and 165 to 206 in the southern Sierra Nevada (27).

Most precipitation falls from November through April. Snowfall is light in the Pacific ponderosa pine type, averaging less than 6 percent of total precipitation, and varying between 0 and 15 percent (27). Snowfall increases rapidly with elevation, however, and may cause breakage where ponderosa pine is planted at higher elevations, or where stocking densities in stands of pole-sized trees are too great (37). December through February are the wettest months, and June through September the driest. July and August usually are rainless. Climatic records (27) show a narrow range in precipitation for the type in the southern Sierra Nevada, where annual averages vary from 30.0 to 37.5 inches (760 to 950 mm). In contrast, precipitation is greater and more varied in the northern Sierra Nevada, where productivity also is higher. There, precipitation varies from 39.8 inches (1010 mm) annually near Placerville, to 67.8 inches (1720 mm) at Challenge, where many of the most productive sites are found.

Because of the long, frost-free period and the summer-dry climate characterizing the Pacific ponderosa pine type, growing seasons typically are long and limited mainly by soil moisture availability. Radial growth periods last between 148 and 183 days in the 3,000 to 4,000 feet (915 to 1220 m) elevational zone of the central Sierra Nevada (8), and at least 167 days at 2,590 feet (790 m) elevation in the north-central Sierra Nevada (35). Although ponderosa pine is adapted to hot, dry summers, growth is greater and continues longer on deep, well-drained soils with moderate water-holding capacities. In a plantation on contrasting soils at 3,200 feet (975 m) elevation in the northern Sierra Nevada, height growth continued 42 days longer and was twice as great on a clay-loam soil formed from andesite as on a gravelly-loam soil formed from schist.[1]

The Pacific ponderosa pine type typically forms almost pure even-aged stands. Its characteristic structure and composition result largely from two natural conditions: low soil moisture availability during the summer and recurring wildfires (40). Ponderosa pine also has been planted extensively within other forest cover types (7), such as Douglas-fir–Tanoak–Pacific Madrone (type 234) and Sierra Nevada Mixed Conifer (type 243). Digger pine (*P. sabiniana* Dougl.) or knobcone pine (*P. attenuata* Lemm.) mix with the type on xeric soils at lower elevations and on lower- to mid-elevation ultramafic soils. Incense-cedar (*Libocedrus decurrens* Torr.), coast Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*), and sugar pine (*P. lambertiana* Dougl.) are common associates on zonal soils at upper elevations, and California white fir (*Abies concolor* var. *lowiana* (Gord.) Lemm.) grows at the edge of the mixed-conifer forest. Jeffrey pine (*P. jeffreyi* Grev. & Balf.) and incense-cedar displace the type on upper-elevation soils from ultramafic rocks. California black oak (*Quercus kelloggii* Newb.) is common throughout much of the Pacific ponderosa pine type, and tanoak (*Lithocarpus densiflorus* (Hook. & Arn.) Rehd.) and Pacific madrone (*Arbutus menziesii* Pursh) are associates in the northern Sierra Nevada and in parts of the Coast Range. Fire helps maintain the type by excluding relatively thinner barked species, such as Digger pine at lower elevations, and Douglas-fir and white fir at higher elevations.

Cones are produced fairly regularly on trees growing on the western slopes of the Cascades and Sierra Nevada, but heavy cone crops over broad areas are rare. Although no complete failures were noted in California for the period 1956–66, cone production was rated medium or better only once, and very light crops were recorded in 8 of 11 years (42). Good cone crops, however, are more frequent at specific locations. On the average, medium to better crops appear every 1 to 3 years (10, 45).

[1] Powers, Robert F. Unpublished data. 1980. U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station.

More than a dozen insects have been identified as causing seed losses (13). Insects can destroy as much as 95 percent of a cone crop, but losses ranging from 30 to 60 percent are more common. Usually the proportion of seed lost to insects is highest when crops are small. Seeds also are consumed by a great many birds and small mammals.

Even-aged silvicultural systems are well suited to the Pacific ponderosa pine type where wood production or maintaining the type are primary objectives. The species' intolerance of shade favors even-aged groups or stands. Regenerating stands by clearcutting with prompt site preparation and planting, or, in some instances seeding (28), is recommended. At the Challenge Experimental Forest, in the northern Sierra Nevada, California, seed-tree cuttings leaving 4 to 8 trees per acre (10 to 20/ha) and shelterwood cuttings leaving about 12 trees per acre (30/ha) are other systems that have regenerated ponderosa pine successfully (21), with the shelterwood method favoring shade-tolerant species as well (19).

Uneven-aged management systems are impractical for the type. Ponderosa pine regenerates and grows poorly in the presence of overstory competition (19). Other conifers and hardwoods, especially, become more numerous and the type may convert to the California black oak or the Sierra Nevada mixed-conifer type. When more shade-tolerant species are absent, group selection can maintain the Pacific ponderosa pine type more effectively than single-tree selection, but stocking and growth will be poor under both systems. In the short run, however, the selection system can result in a forest of visual variety, harmony, and beauty, and has been used in areas where these values are paramount (23).

Most managed stands of Pacific ponderosa pine are regenerated by planting (42), but natural seeding (19, 21) may be successful if an adequate seed source exists and the seedbed has been prepared properly. Natural seeding can be effective if mineral soil is exposed and if openings are not too large. At Challenge Experimental Forest (22) annual seedfall in 2-acre (0.8-ha) circular clearcuts averaged 10,420 sound seeds per acre (25 750/ha) for a 4-year period, compared with 4,045 per acre (9995/ha) in 10-acre (4 ha) clearcuts. Seedfall was twice as heavy within 100 feet (30.5 m) of the timber edge as in the center of the larger clearcuts. Of the sound seed cast into clearcuts, almost 90 percent falls within a distance from the forest edge equal to 1.5 times the height of dominant border trees (22). The stocking that results may be poorly distributed—too little in some areas and too much in others.

Seed-tree and shelterwood systems also provide adequate regeneration (19, 21) if harvests and site preparation are timed to match adequate cone crops, and seed trees are chosen with care. Selection criteria for trees left as seed producers are that they should be good phenotypes from the largest size classes (21, 45); show evidence of past cone production, such as fallen cones at the base of each tree (45); and be windfirm, as witnessed by full crowns and relatively large growing space before logging. Large trees compete strongly with seedlings for site resources, and will retard height growth of seedlings to distances of at least 40 feet (12.2 m) (20). For this reason, seed trees should be removed once regeneration stocking is satisfactory, allowing for an average stocking reduction of 8 percent attributable to felling and tractor skidding (18).

Natural seeding has an advantage of insuring that the regeneration is adapted to the site; it has a disadvantage in that harvest may not coincide with an adequate seed crop. As time passes, seedbeds rapidly become less favorable because of weed invasion and rodent buildup. Although expensive, direct seeding offers an alternative.

Controlling predatory rodents and birds, preparing seedbeds properly, and applying seed in appropriate amounts are the keys to effective direct seeding (28). Research at Challenge Experimental Forest shows that ponderosa pine seeded at the rate of 1.0 pound per acre (1.1 kg/ha) produces at least 400 seedlings per acre (990/ha) after the first year.[2] Because the best results have been obtained with predator repellents not currently registered for forestry use, direct seeding should not be attempted unless predator control is certain.

Planting is practiced more widely than seeding (42), and has several advantages. First, roots are placed deeply in the soil—an advantage in a summer-dry climate. Also, losses resulting from predators, pathogens, and high soil temperatures are reduced greatly or eliminated. Further, large seedlings compete more effectively with weeds, and are less susceptible to losses from frost-heaving and animal browsing. Finally, planting provides early stocking control, and offers a chance at improving genetic traits beyond those characterizing natural stands.

Keys to successful planting include adequate site preparation, appropriate stock, and proper lifting and planting procedures. Moisture is scarce in surface soil during the summer in the Pacific ponderosa pine type. Consequently, potentially competing vegetation must be removed before planting. On clearcut sites, logging slash often must be reduced to lower the risk of wildfire and insect buildup, and to improve access for subsequent silvicultural treatments. Because broadcast burning can stimulate germination of dormant seeds of manzanita (*Arctostaphylos* spp.) or ceanothus (*Ceanothus* spp.) species existing in the forest duff, logging slash and duff usually are piled and burned. In brushfields, many potential competitors sprout from root crowns even if tops are killed, and tractors equipped with brush rakes can uproot brush and push duff into windrows without excessive soil displacement (42). Windrows should be spaced at least 50 feet (15.2 m) apart and burned when dry to eliminate fuel hazards and to reduce competition from vegetation developing within them. When brush crowns are crushed or chipped, follow-up treatments to control sprouts usually are required.

Mountain misery (*Chamaebatia foliolosa* Benth.) is a particularly competitive shrub causing management problems throughout much of the western Sierra Nevada. Because the shrub forms a dense canopy and is a vigorous sprouter, single applications of topkilling herbicides are ineffective in preventing its regrowth, although they may improve survival of planted stock (1, 44). Usually, regrowth is swift and aggressive, and may depress stand yields by as much as 75 percent at 50 years (44). Better control is provided by a combination of treatments—late fall burning, herbicide spraying the next summer through fall, and additional spraying as needed (1). Contour terracing by tractor on slopes as steep as 45 percent also has proved excellent for controlling mountain misery, establishing ponderosa pine, and protecting watershed values where maintenance of esthetic values is not paramount. The effect of displacing fertile topsoil on terraces is unknown, but may not be detrimental if soils are deep and lateral displacement is small.

Seed collections for reforesting properly prepared sites should come from trees of medium or better phenotypes growing within 1,000 feet (305 m) elevation and 100 miles (160 km) north or south of the regeneration site. Seeds should be collected from the same seed zone or, if this is not

[2]Neal, Robert L., Jr. A successful test of the Challenge direct seeding prescription for ponderosa pine. 1981. Unpublished draft. U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station.

possible, from the nearest adjacent zone of the same physiographic and climatic region (5).

Root-growth capacity of ponderosa pine peaks in fall to winter, and seedlings should be lifted from nursery beds between December and February (15). Seedlings may be stored for up to 3 months without appreciable drop in root-growth capacity or outplant survival, provided that temperature is held near 33° F (0.6° C) and relative humidity is at least 90 percent (42).

Fall or winter planting sometimes results in satisfactory survival, but creates a heavy risk of losses from frost heaving and desiccation. Spring planting is favored, but should not begin until soil temperatures at the field site at 4 inches (10 cm) are warming above 41° F (5.0° C), and soon will exceed 50° F (10.0° C) (15). Seedlings planted too early in cold soils cannot grow new roots, may undergo severe moisture stress, and may exhaust stored energy reserves prematurely. Planting machines also may be used where slopes are not too steep, provided that the same sound practices used in hand planting are followed (42). Improper planting techniques produce stunted "J" and "L" rooted seedlings. Stunting effects may last for decades.

Compared with associated conifers, ponderosa pine requires more sunlight but less soil moisture for survival and satisfactory growth (26). Drought can be tolerated through strong stomatal control of water loss (17). Ponderosa pine also holds a competitive edge on infertile sites because of its low nutrient requirement and its ability to store considerable reserves in foliar biomass (35).

Because sites generally are productive within the Pacific ponderosa pine type, tree growth is rapid, exceeding rates found for ponderosa pine elsewhere within its native range. Young ponderosa pine grows faster than associated conifers. In a 6-year-old plantation at Challenge Experimental Forest, ponderosa pine averaged 2.6 times greater in biomass than the next largest species, sugar pine, and 41 percent taller than incense-cedar, the next tallest species (35). Planted trees reach breast height in 5 to 9 years depending upon site quality (32). On average and better sites, diameter growth increases linearly with height growth, and the ratio does not change until crowns nearly touch.[3] In managed plantations, periodic annual growth of pole-sized trees averages 0.2 to 0.4 inch (0.5 to 1.0 cm) in diameter, 1.5 to 2.5 feet (0.46 to 0.76 m) in height, 6 to 8 square feet per acre (1.38 to 1.84 m^2/ha) in basal area, and 150 to 250 cubic feet per acre (10.5 to 17.5 m^3/ha) in total volume (31, 33). Height growth is rapid for at least 80 years on medium to better sites, where heights reach 110 to 170 feet (34 to 52 m) (38). Growth rates slacken thereafter (2), but even 200-year-old dominant trees can grow 0.4 feet (0.12 m) in height annually on the best sites (24). Volume yields of well-stocked stands at 50 years range from 7,000 to 11,700 cubic feet per acre (490 to 819 m^3/ha) equivalent to 20,300 to 51,300 board feet (fbm)[4] (Scribner) per acre on the more productive sites (24, 33).

Rotation lengths vary depending upon criteria. Using culmination of mean annual increment, cubic measure, rotation ages of 50 to 80 years in unthinned stands or 100 to 120 years in thinned stands are anticipated. If financial considerations are paramount, shorter rotations of 40 to 60 years have been recommended for productive sites (46).

Growth losses commonly result from competition with woody shrubs and from high stand density. When numerous, shrubs can reduce growth of pines, including trees of sawtimber size.[5] When stand density is high, trees may grow little in diameter and, in extreme cases, little in height (29). To maintain acceptable rates of growth, young stands may require either release from competing brush (42), or a precommercial thinning, or both. Brush control usually is needed when manzanita or mountain misery are the competitors (1, 30, 36). Even a light cover of brush reduced the mean height of dominant and codominant trees by 20 percent in one 19-year-old plantation.[6] Tentative guidelines suggested by two separate studies (4, 16) that may be used for evaluating the need to control brush are 10,000 cubic feet per acre (700 m^3/ha) of total brush crown volume and 30 percent total brush crown cover. Densities that exceed these values will reduce growth of planted pine seedlings and saplings significantly. Firm recommendations, yet to be formulated, are expected to be site- and brush-species specific. Weeding and thinning in the sapling stage (as soon as potential crop trees can be identified) to 170 to 260 trees per acre (420 to 640/ha), depending on crop tree-size objectives, timing of yields, and site quality, should allow the stand to grow rapidly and to contain enough trees to support a thinning when the stand reaches sawtimber size.

Thinning stands of commercial size can promote stand health, transfer growth to the best crop trees, and provide an early return on investment (31). Recommended post-thinning stand densities depend upon the kinds of wood products desired, how frequently commercial thinnings are planned, and the density, vigor, and age of the stand before thinning. For vigorous 30- to 60-year-old stands managed for lumber production and thinned every 10 years, a post-thinning basal area of about 55 percent of normal yield (24) has been effective. For less vigorous or older stands with the same management objective and entry frequency, more basal area should be left after thinning. Another successful but conservative guideline for determining leave density for commercial thinning from below in unmanaged stands is to leave trees currently producing 80 percent of the periodic annual cubic increment. After thinning or release, stands usually respond rapidly even at advanced ages, provided that live crowns of leave trees have lengths at least equal to 40 percent of tree height (12).

Many ponderosa pine plantations are deficient in nitrogen—particularly on sites where site preparation was heavy.[5] There, nitrogen fertilization can increase height growth of saplings by 25 to 80 percent, and volume growth of poles by as much as 30 percent (34). Moisture supply on xeric sites, however, must be improved first by weeding or thinning before fertilization can be effective (36).

The most destructive insect pest threatening ponderosa pine is the western pine beetle (*Dendroctonus brevicomis* LeConte) which, when epidemic, kills vigorous trees 6 inches (15 cm) or more in diameter (11). Trees often are attacked jointly with the California fivespined ips (*Ips paraconfusus* Lanier) (11)—perhaps the second most destructive insect to ponderosa pine. Stands with basal areas that exceed normal stocking for that height and age (24) are especially susceptible. Thinning such stands usually will help them withstand insect attack. But because *Ips* populations build rapidly in slash, and can attack and kill standing trees as large as 6 inches in diameter and the tops of larger trees, thinning should be avoided in spring and early summer.

Western dwarf mistletoe (*Arceuthobium campylopodum* Engelm.) is responsible for significant losses in growth (41).

[3] Powers, Robert F., and Oliver, William W. Unpublished data. 1971.

[4] 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.

[5] Powers, Robert F. Unpublished data. 1971.

[6] McDonald, Philip M. Unpublished data. 1980. U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station.

Three important root diseases attacking ponderosa pine are Fomes root and butt rot (*Heterobasidium annosum* (Fr.) Bref.), shoestring root rot (*Armillariella mellea* (Vahl. ex Fr.) Karst.), and black stain root disease (*Verticicladiella wageneri* Kend.) (43). Fomes root and butt rot kills trees of all ages and usually results in groupwise mortality that is sometimes mistaken for the work of bark beetles, which are frequent secondary invaders. Borax sprinkled on freshly cut stumps seems to retard spread of the disease in logged areas. Shoestring root rot causes noticeable mortality in young plantations and thinned stands where the disease spreads from dead oak root systems.

Two needle diseases can, when injury is severe, result in growth loss and predisposition of the tree to attack by other agents. Pacific ponderosa pine is more susceptible to foliar injury from ozone than associated mixed conifers (25). Ozone injury presently is restricted to the southern California mountains and the west slope of the southern Sierra Nevada. A needle cast caused by *Elytroderma deformans* (Weir) Dark., however, is found throughout the Pacific ponderosa pine type (6).

Pocket gophers can kill many trees up to pole size, and rodent baiting or seedling protection with plastic mesh tubing may be needed (3, 42). Porcupines severely damage young pines when local populations are high. Shooting is the control method practiced widely.

Although fire helps perpetuate stands of ponderosa pine, destructive fires, logging, and smog may convert many lower elevation sites to the chaparral or California black oak types. Along the upper elevational margin, many areas would convert gradually to the Sierra Nevada mixed conifer type if fires were excluded (40). Potentially, low-intensity fires can reduce the hazard of destructive wildfires, but formulating prescriptions is difficult because understory shrubs and accumulated debris often are abundant (48).

The Pacific ponderosa pine type provides many benefits other than wood. Wildlife habitat can be enhanced if a maximum amount of edge is furnished with stands of all age classes, including those physiologically mature (47). Livestock find forage in young plantations and managed stands. But grazing should be avoided for a few years after planting because of damage from trampling and wrenching. Pacific ponderosa pine forests are found at low elevations offering year-round recreation, and they frequently border forest roads where esthetic values are high. Few, if any, rare and endangered plant species have been identified within this type. If present, most are found on enclaves of harsh sites caused by serpentinite rock that support a different forest type.

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Ponderosa Pine and Rocky Mountain Douglas-fir

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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 m^3/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 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.

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Western Larch

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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, insufficient 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 m^2/ha) on high-quality sites, and about 200 square feet per acre (45.9 m^2/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 m^3/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.

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Engelmann Spruce—Subalpine Fir

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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 coniferous 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).

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Lodgepole Pine

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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, 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 m^3/ha) to yields of about 2,400 to 3,200 cubic feet per acre (168.0 to 224.0 m^3/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 m^3/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 m^3/ha) on site index 50 lands (base age 100 years) to 105 cubic feet per acre (7.4 m^3/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 m^3/ha) on site index 50 lands to 80 cubic feet per acre (5.6 m^3/ha) on site index 85 to 90 lands.

[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.

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, 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).

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Mixed Conifers, Western White Pine, and Western Redcedar

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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 m^3/ha) per year with an average potential of 80 cubic feet per acre (5.6 m^3/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 m^3/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 m^3/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.

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Southwestern Ponderosa Pine

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Rocky Mountain ponderosa pine (*Pinus ponderosa* var. *scopulorum* Engelm.) occupies nearly 11 million acres (4.5 million ha) in New Mexico, Arizona, Utah, and Colorado (19). The variety, which is recognized as type 237 by the Society of American Foresters (5), grows in the Rocky Mountains and on canyons, plateaus, breaks, and discontinuous mountain ranges of the plains at elevations up to 10,000 feet (3050 m) in the southern Rocky Mountains (4, 19). Mostly, however, ponderosa pine in the Southwest lies between 6,000 and 8,500 feet (1830 and 2590 m) in elevation, reaching its best development between 7,000 and 7,800 feet (2135 and 2375 m) (19).

Soils on which ponderosa pine may be found are derived from igneous, metamorphic, and sedimentary materials, and range in texture from gravels to clay loams (4). About half of the soils in the Southwest are derived from basalt, while limestone, sandstone, and shale are common in many localities. In addition, sizable areas on the Colorado Plateau in Arizona are covered by cinders up to 5 feet (1.5 m) deep (19).

The climate of ponderosa pine forests in the Southwest is cool and mostly subhumid (4). Pinyon–juniper or oak woodlands generally are found in the warm-dry zone below ponderosa pine, while above, the more mesic mixed conifer, Douglas-fir, or lodgepole pine forests are situated (5, 19). Mean annual precipitation varies from about 15 to 25 inches (380 to 635 mm), depending on location; seasonal distribution also varies. In northeastern New Mexico and along the east slope of the Rocky Mountains, rainfall is well distributed throughout the growing season; elsewhere, scant precipitation is received in May and June. Early fall is also dry, but to a much lesser extent. Low rainfall coupled with low humidities, clear skies, increasing temperatures, and consistent winds create severe drought conditions during May and June. In contrast, July and August are wet. Precipitation at one northern Arizona station during these months, for example, was about 80 percent of the May through August total of 7.75 inches (195 mm). Average annual snowfall varies from a low of 12 inches (305 mm) in the southern portion of the species range to 94 inches (2390 mm) on the Colorado Plateau. Mean annual temperatures over the entire southwestern ponderosa pine type are relatively narrow, ranging from 44° to 52° F (6.7° to 11.1° C), and mean July temperatures are equally narrow, varying from 64° to 71° F (17.8° to 21.7° C). The frost-free period is about 135 days, but it varies widely within the type (19).

Ponderosa pine typically grows in pure stands at elevations where it is climax (5, 18). At higher and lower elevations, ponderosa pine may be replaced, respectively, by more mesic or xeric species that have a competitive advantage. Common associates of ponderosa pine at higher elevations throughout its southwestern range are Rocky Mountain Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco), blue spruce (*Picea pungens* Engelm.), and quaking aspen (*Populus tremuloides* Michx.). In Utah and Colorado, ponderosa pine grows with lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) and limber pine (*P. flexilis* James), while at higher elevations in New Mexico and Arizona, ponderosa pine is found with southwestern white pine (*P. strobiformis* Engelm.), white fir (*Abies concolor* var. *concolor* (Gord. & Glend.) Lindl. ex Hildebr.), corkbark fir (*A. lasiocarpa* var. *arizonica* (Merriam) Lemm.), and Engelmann spruce (*P. engelmannii* Parry ex Engelm.) (5, 10).

In the ecotone with lower woodland or grassland types, associates of ponderosa pine include Rocky Mountain juniper (*Juniperus scopulorum* Sarg.), alligator juniper (*J. deppeana* Steud.), Utah juniper (*J. osteosperma* (Torr.) Little), pinyon pine (*Pinus edulis* Engelm.), and Gambel oak (*Quercus gambelii* Nutt.) (5).

Cone crops are not produced regularly anyplace over the entire range of ponderosa pine but, in general, good crops can be expected every 3 to 4 years in the Southwest (4, 19). Seedfall varies somewhat, but in Arizona it begins about the middle of October and is 65 percent complete by the first week in December (13).

A number of cone and seed insects are harmful, but not all of them cause serious damage. Ponderosa pine seedworm (*Laspeyresia piperana* (Kearf.), ponderosa pine cone beetle (*Conophthorus ponderosae* Hopk.), and ponderosa pine coneworm (*Dioryctria auranticella* (Grote)) are among the most important (19).

In some years over 50 percent, and in localized areas nearly all, of the seed crop may be destroyed by insects (15, 17). The extent of depredation by rodents and birds is not known, but Abert's squirrels reduced the cone crop in one study about 21 percent over a 10-year period by clipping twigs bearing flowers or conelets (13). Seed viability may also be reduced a similar amount by the impact of southwestern dwarf mistletoe (*Arceuthobium vaginatum* (Willd.) Presl. subsp. *cryptopodum* (Engelm.) Hawks. and Wiens) (19).

Seeds are wind disseminated, but they are relatively heavy and are not borne far—about 75 percent falls within 120 feet (36.6 m) of the source (2). Spring germination may be the rule where rain falls in the spring, as on the east side of the Rocky Mountains in Colorado. Elsewhere, however, ponderosa pine seeds germinate during the summer rainy season, or even into August or early September if precipitation is delayed (19). Seedlings resulting from late seed germination are subject to greater mortality from frost heaving, fall drought, and an inability to harden-off before winter. The best seedbed is loose, mineral soil, which tends to cover seeds lightly as it settles, thus enhancing germination (15, 19).

Optimum seedbed conditions alone, however, will not insure natural ponderosa pine regeneration, which historically is sporadic in the Southwest. Site preparation to loosen and expose mineral soil and eliminate grass competition must coincide with a good supply of seed and adequate moisture for germination and initial seedling establishment. Protection from livestock and rodents is also necessary (19). On coarser textured sedimentary soils in the Southwest, large areas have been successfully regenerated by meeting all these conditions (9). Where fine-textured, basaltic soils with a high silt content exist, however, natural regeneration is more difficult to establish because of the greater probability of frost heaving.

Once established, ponderosa pine has the ability to withstand drought (4). It has a vigorous taproot, while lateral roots also elongate rapidly. Within a few months after seed germination, taproots can penetrate to 23 inches (58 cm) in loosened and watered soil, and about half that under natural conditions (11, 12). Lateral roots can more than double in length during the second growing season following seed germination. Furthermore, root growth of planted seedlings can be appreciable even in relatively dry soil if lifting at the nursery is timed to insure high root-regenerating potential of the seedlings (20). The deep-rooting habit of ponderosa pine imparts a relatively high degree of windfirmness, except where shallow soils or high water tables restrict root-system development (19).

Regardless of root growth capabilities, planted ponderosa pine seedlings cannot cope with competing vegetation, particularly grasses, during the spring and early summer drought following spring planting. Grasses that grow best in the cool season, such as Arizona fescue (*Festuca arizonica* Vasey), are especially competitive for moisture during spring and early summer (15, 19). Some grasses are also phytotoxic to ponderosa pine seeds and seedlings (16). Therefore, adequate site preparation by mechanical or chemical means is imperative if planting is to be successful.

Ponderosa pine is classed as shade-intolerant (4). As a consequence of its need for adequate light, it tends to grow and is usually managed under even-aged conditions. While ponderosa pine forests in the Southwest most commonly appear to be irregular, uneven-aged stands, they essentially consist of a mosaic of even-aged groups varying in size from a few trees to several acres (19). Other stands, however, are essentially even-aged following regeneration of past clearcuttings, burns, and other open areas (18). Although ponderosa pine seeds germinate best under partial shade, continued growth and survival are reduced when overhead sunlight is less than about 50 percent (15, 19). Stagnation is a serious problem in densely stocked stands and, although growth is slow, southwestern ponderosa pine remains physiologically young and will respond to release up to 200 years of age (15).

The four major causes of mortality in southwestern ponderosa pine are, in decreasing order of importance, diseases, insects, fire, and windthrow (19). Losses from lightning, however, may equal those of windthrow in some areas (15). Under some conditions, windthrow can cause major losses, as when strong winds, preceded by heavy rains in areas with shallow soils, blow from the opposite direction of prevailing winds. While a number of diseases—such as Atropellis canker (*Atropellis piniphila* (Weir) Lohm. and Cash), shoestring root rot (*Armillariella mellea* (Vahl. ex Fr.) Karst.), Annosus root rot (*Heterobasidium annosum* (Fr.) Bref.), and western root rot (*Dichomitus squalens* (Karst.) Reid)—damage or kill trees, the most prevalent and devastating is southwestern dwarf mistletoe. About one-third of all commercial forests in the Southwest are infected with dwarf mistletoe (17, 19).

Many insects also attack ponderosa pine, but the most destructive is the mountain pine beetle (*Dendroctonus ponderosae* Hopkins). At times, engraver beetles, especially Arizona fivespined ips (*Ips lecontei* Swaine), and pandora moth (*Coloradia pandora* Blake) also can be serious pests (17, 19). Many insect and disease problems can be lessened by applying intermediate cuttings, which improve growth and eliminate susceptible trees (14, 19). Common intermediate cuttings in the Southwest include improvement, sanitation, salvage, and thinning (19). Improvement and sanitation cuttings effectively maintain or increase net growth, but their repeated use could result in understocking or a reduction in potential snags of value to wildlife.

Older ponderosa pines are resistant to fire because of thick bark, but younger trees are easily killed (4, 19). Other damaging agents to seedlings and saplings include southwestern pine tip moth (*Rhyacionia neomexicana* (Dyar)), rabbits, hares, pocket gophers and other rodents, and browsing animals; among the abiotic factors are winter kill, frost heaving, and snow breakage or bending in dense stands, especially after thinning operations (19).

Site quality and stand density are major factors controlling growth. Studies have shown that diameter growth in young stands thinned to growing stock levels of 30 and 150 was 4.6 and 2.2 times greater, respectively, than the prethinning rate (19).[1] Average net annual increment on understocked experimental plots of old-growth timber in central Arizona ranged from 25 to 93 board feet (fbm) (Scribner Decimal C Log Rule) (5 to 19 cubic feet)[2] per acre (0.4 to 1.3 m^3/ha) (15). Under intensive even-aged management, in contrast, estimated annual net growth can be increased to 300 fbm (60 cubic feet) per acre (4.2 m^3/ha) or more (1).

Since ponderosa pine forests in the Southwest are composed of both even-aged and uneven-aged stands, a combination of even-aged and uneven-aged management is best suited to maintain present stand structures (18, 19). Furthermore, some uneven-aged stands can be converted to even-aged, depending on the age or size class distribution of individual groups. However, a long period may be needed to convert most stands—perhaps through the remainder of the present rotation. Conversion, if elected, should be affected with the least disturbance to growing stock levels (19).

Because of the need to protect seedlings from the harsh environmental conditions of the Southwest, the most effective means for regenerating even-aged stands is a two-cut shelterwood, consisting of a seed cut and an overstory removal cut (18, 19). Some fully stocked stands, however, may require one or more preparatory cuts to enhance seed production through crown development, and to develop windfirmness. Preparatory cuts should remove about 20 to 30 percent of the volume, whereas the seed cut should leave 20 to 40 square feet (4.6 to 9.2 m^2/ha) of basal area per acre, depending on the harshness of the site and the subsequent need for protection. Seed trees should be good producers, preferably 20 to 24 inches (51 to 61 cm) d.b.h. The overstory usually is removed in one cut when seedlings are 1 to 2 feet (0.3 to 0.6 m) tall to reduce seedling damage during harvest (19), and to minimize growth retardation (6, 15).

Historically, regeneration success in clearcuttings has been mixed (15, 19). While some clearcuttings logged during a good seed year have regenerated successfully, others generally were converted to grass or brush. Because of this uncertainty, and because better results have been obtained under the shelterwood system, clearcutting has been little used in recent years. Similarly, the seed-tree system—successful in 1913, but with no subsequent reported successes—is not particularly suitable for ponderosa pine forests (19). However, where management goals are to increase water yields or other multiple-use values, clearcutting and planting could be appropriate (3).

[1] Growing stock level, a numerical index, is defined as the residual square feet of basal area per acre when average stand diameter is 10 inches d.b.h. or more. Basal area retained in a stand with an average diameter of less than 10 inches is less than the designated level (1).

[2] 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.

Patch clearcutting is an effective means to control dwarf mistletoe (7) and such insects as the mountain pine beetle (14). Clearcuttings larger than a few acres should be planted immediately after harvesting following established planting techniques (8, 19). Regeneration by artificial seeding, whether by drilling, broadcasting, or seed spotting, is less reliable than planting. Although all have been successful in some instances, planting is still the preferred method of artificial regeneration in the Southwest (19).

The selection system can be applied to some stands in the Southwest to accomplish uneven-aged management objectives (18, 19). Since ponderosa pine is shade-intolerant, however, individual tree selection is not recommended. Stands harvested in such a manner most likely would not regenerate to pine, or would be converted to the more tolerant component species if any were present. Also, this method tends to accelerate the spread of dwarf mistletoe in infected stands (7).

Group selection, in contrast, is an appropriate way to regenerate stands having a suitable age-size class structure (18, 19). Under this system, the size of harvested groups should range from 0.5 to 2 acres (0.2 to 0.8 ha). Slash treatment in groups of this size, however, will be more difficult than under even-aged management. Furthermore, growth of regeneration along the edge of openings will tend to be reduced because of competition from adjacent groups (6).

Group selection, and even-aged cutting methods as well, will increase forage yields where livestock and big game management is desired (3). Herbage production increases with decreasing stand density from a maximum of 600 pounds per acre (672 kg/ha) in clearings to a minimum of 50 pounds per acre (56 kg/ha) or less under stands with basal areas between 60 and 100 square feet per acre (13.8 to 23.0 m^2/ha) (19).

Abert's squirrels, Kaibab squirrels, bald eagles, and Merriam's turkeys are important elements of forest wildlife, and their habitats must be considered when applying any silvicultural method. Large, mature trees or snags suitable for squirrel nests, eagle perches and nests, or turkey roosts must be left in sufficient numbers to provide for these, as well as other species of wildlife, such as cavity nesters. Similarly, cover and opening requirements for mule deer, white-tailed deer, and Rocky Mountain elk are also important considerations in the management of ponderosa pine. Special silvicultural provisions to meet these wildlife needs are probably not necessary, however, since suitable habitats can be created by modifying standard cutting methods.

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Southwestern Mixed Conifers

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The area covered by southwestern mixed conifer forests is about 2.0 million acres (0.8 million ha) of highlands and mountains in Arizona, New Mexico, and southwestern Colorado (11). Mixed conifer inclusions are also scattered within the Interior Ponderosa Pine, Society of American Foresters forest cover type (type 237) (7), where higher elevations or topography provide moister sites (12). Most mixed conifer stands are found between 8,000 feet (2440 m) and 10,000 feet (3050 m), but they may extend below 6,000 feet (1830 m) on north-facing slopes or in canyon bottoms and draws.

A mixed conifer forest in the Southwest may constitute one of the more complex plant associations known, exhibiting great variation in species composition. While some stands may consist of only two species, others can be comprised of as many as eight associates. Overstory species in these forests include Rocky Mountain Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco), Rocky Mountain ponderosa pine (*Pinus ponderosa* var. *scopulorum* Engelm.), white fir (*Abies concolor* var. *concolor* (Gord. & Glend.) Lindl. ex Hildebr.), Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), quaking aspen (*Populus tremuloides* Michx.), southwestern white pine (*Pinus strobiformis* Engelm.), blue spruce (*Picea pungens* Engelm.), and corkbark fir (*Abies lasiocarpa* var. *arizonica* (Merriam) Lemm.) (12). Subalpine fir (*A. lasiocarpa* (Hook.) Nutt. var. *lasiocarpa*) may replace corkbark fir in Colorado and northern parts of Arizona and New Mexico (2, 12).

Mixed conifer forests grow on nearly every kind of parent material. While soil types, textures, and species preferences are highly variable, best growth is on moderately deep to deep loamy soils where drainage is good (1, 6, 17, 22).

Mixed conifer forests are generally found in cool, subhumid to humid climatic zones, typically with short growing seasons, long winters, and moderate to heavy snowpacks (1, 17). Average annual temperatures vary from near freezing to more than 43° F (6.1° C), depending on location (1, 2, 18). The frost-free period usually ranges from about 30 to 120 days, but frost may occur during any month. Average annual precipitation varies from about 25 to more than 30 inches (635 to 760 mm), while snowfall may vary from about 70 to more than 200 inches (1780 to 5080 mm) (1, 5, 18). Spring, early summer, and fall are dry periods in the Southwest, but the resulting drought conditions are much less severe in the fall than earlier (12). In contrast, July and August are wet, with as much as 45 percent of the annual precipitation falling during this period (21).

Natural reproduction of species in mixed conifer stands is nearly entirely by seed except for aspen, which reproduces almost always by root sprouts (1, 2, 12). Blue spruce is the best seed producer, bearing moderate to heavy cone crops every 1 to 3 years (12, 20), whereas corkbark fir is considered the poorest, with infrequent crops of low yield. Good to large seed crops are produced by Engelmann spruce every 2 to 5 years and by white fir every 2 to 4 years, although the latter may be more sporadic (1, 12, 17, 20). Production of Douglas-fir seed is slightly less than that of Engelmann spruce (5, 12). Ponderosa pine seed crops are lighter and less frequent at higher than at lower elevations where good crops are produced every 3 to 4 years (12, 21). Large crops of southwestern white pine seed are produced every 3 to 4 years (15).

Seeds of all the conifers other than southwestern white pine are wind disseminated (15). Engelmann spruce seeds cover the greatest distances, as much as 600 feet (182.9 m), but most of the seed normally falls within 100 feet (30.5 m) to leeward of the seed source (3). The distance heavier true fir and Douglas-fir seeds are disseminated is probably even less, while that of ponderosa pine is the shortest (17). In one study of a ponderosa pine clearcut, only 22 percent as much seed was found 120 feet (36.6 m) into the opening as at the edge of the uncut stand (4). Southwestern white pine seeds, which are mostly wingless or sometimes vestigially winged, are disseminated primarily by rodents and birds (12, 15). Several species of jays and Clark's nutcracker are important dispersal agents for limber pine (*Pinus flexilis* James) and, presumably, for southwestern white pine as well (16).

Except for white fir, corkbark fir, and some southwestern white pine seed that germinates in the spring, germination of all other species is delayed until the summer rainy season because of the drought conditions that exist in late spring and early summer (12). Germination percentages under natural conditions in the Southwest are not available for mixed conifer species.

Seedlings of all species are exposed to many hazards that reduce survival, including voles, pocket gophers, rabbits, hares, big game, domestic livestock, snowmold (*Neopeckia coulteri* (Pk.) Sacc. and *Herpotrichia nigra* Hartig), and drought (3, 12). New growth of white fir, corkbark fir, and Engelmann spruce trees, regardless of age, is killed by growing-season frosts (3, 17, 19). Furthermore, seedlings of white fir, Douglas-fir, Engelmann spruce, and especially corkbark fir are killed or injured by solarization when grown in full sunlight, but ponderosa pine, southwestern white pine, blue spruce, and aspen are adapted to full sunlight (11, 12, 19).

The sensitivity of certain species to intense solar radiation is related to their shade tolerance, with the more tolerant trees being most susceptible to injury. For southwestern trees, tolerance ratings range from the very tolerant corkbark fir to the very intolerant aspen (2, 22). Engelmann spruce and white fir are tolerant, while southwestern white pine and ponderosa pine are intolerant; blue spruce and Douglas-fir are rated intermediate (1, 12). Reaction to competition is also a function of tolerance—suppressed Engelmann spruce, white fir, and presumably corkbark fir respond to release after being suppressed for long periods (1, 2, 17). Except for seedlings and saplings that have been severely suppressed, Douglas-fir also responds to release, especially in the older age classes (14). Ponderosa pine tends to stagnate easily in dense stands (6), but responds well to release. In fact, diameter growth in a 43-year-old stand of slow-growing trees in Arizona increased up to 4.6 times following thinning (21). In the Southwest, ponderosa pine remains physiologically young and will respond to release even up to 200 years of age (21). Similarly, southwestern white pine can maintain itself equally well in the presence of other conifers (8), since it appears to be somewhat more tolerant of shade than ponderosa pine (12).

Although growth and yield data are available for pure or nearly pure stands of the individual species comprising mixed conifer forests, little is known about stands with a mixture of species. In the Sacramento Mountains of New Mexico, an old-growth stand of Douglas-fir (61 percent) and associated species averaged 13,000 board feet (fbm) (Scribner Decimal C Log Rule) (2,600 cubic feet)[1] per acre (182.0 m^3/ha), with a range of 2,681 to 22,407 fbm (536 to 4,481 cubic feet) per acre (37.5 to 313.7 m^3/ha) (14). Another stand in eastern Arizona with a total basal area of 178 square feet per acre (40.9 m^2/ha), representing all eight mixed conifer species, yielded a gross annual basal area increment of 3.07 square feet per acre (0.7 m^2/ha) with a net annual volume growth of 356 fbm (71.2 cubic feet) per acre (5.0 m^3/ha) (8). In general, diameter growth of component species in mixed conifer stands may be relatively slow because of overstocking; for example, 12-inch (30-cm) diameter at breast height (d.b.h.) Douglas-fir trees in one stand averaged 130 years of age (14).

Because of the number of different species found in mixed conifer stands, the number of potentially destructive pests is formidable. Among the most damaging insects are bark beetles, such as the spruce beetle (*Dendroctonus rufipennis* (Kirby)), Douglas-fir beetle (*Dendroctonus pseudotsugae* Hopkins), fir engraver (*Scolytus ventralis* LeConte), Arizona fivespined engraver (*Ips lecontei* Swaine), and mountain pine beetle (*Dendroctonus ponderosae* Hopkins) (1, 6, 12, 21). Major defoliators are the western spruce budworm (*Choristoneura occidentalis* Freeman) on Douglas-fir, Engelmann spruce, corkbark fir, and white fir (1, 2, 5, 17); Douglas-fir tussock moth (*Orgyia pseudotsugata* McDunnough) on corkbark fir, white fir, and Douglas-fir (12, 17); and the western tent caterpillar (*Malacosoma californicum* (Packard)) on aspen (12, 22). Many other foliage, cone, and seed insects present in mixed conifer stands cause varying amounts of damage.

Dwarf mistletoes pose the most difficult disease problem in mixed conifer forests; especially serious are Douglas-fir dwarf mistletoe (*Arceuthobium douglasii* Engelm.) and southwestern dwarf mistletoe (*A. vaginatum* (Willd.) Presl. subsp. *cryptopodum* (Engelm.) Hawks. and Wiens) (9, 12). All coniferous species in mixed conifer stands are infected by dwarf mistletoes, but the amount of damage caused by the disease, while generally limited, may be locally severe. Other major diseases are fungal trunk and root rots, which affect all tree species.

Aside from direct damage, rots also contribute substantially to windthrow by weakening roots and stems. Most wind losses, however, are primarily a function of rooting habits and soil and topographical features; certain soil conditions decrease root-system depths, while topography influences wind behavior (12). Trees with deep tap roots, such as ponderosa pine, Douglas-fir, and southwestern white pine, are generally windfirm (6), whereas white fir, corkbark fir, and Engelmann spruce are susceptible to windthrow because of their shallow, lateral root systems (1, 2, 17). Blue spruce and aspen appear to be intermediate in tolerance to wind.

Fire appears to have had a major role in establishing most mixed conifer stands, and in maintaining the composition and structure of others, primarily because the different species vary in their susceptibility to fire (11, 12). Seedlings of all species are readily damaged or killed by fire, while mature trees show greater variation. For example, ponderosa pine and Douglas-fir are tolerant to fire (6); in contrast, Engelmann spruce, blue spruce, corkbark fir, and aspen are sensitive (1, 2, 12, 22). Southwestern white pine and white fir are intermediate (12). Differences in young trees are not as apparent, but spruces and true firs with thin bark and typically persistent lower branches are damaged easily.

Uneven- and even-aged forms of management are applicable for mixed conifer stands because of the different silvical characteristics exhibited by the component species (11, 12). The form selected depends on stand structure and composition and on management objectives, including species preference. Regardless of the form of management selected, consideration must be given to all resources, within the constraints imposed by the silvical characteristics of the species and the physical nature of the site. A critical ecological consideration for all mixed conifer stands is susceptibility to windthrow as related to specific tree and stand characteristics, with dense single-storied stands being the most subject to wind damage and multi-storied stands the least. These stands, in turn, are further classified by wind risk according to the topographical position they occupy. Consequently, basal area volumes removed in harvest cuts may vary from light to heavy (10 percent to 30 percent or more) in order to control wind loss. Under some circumstances, the only alternatives may be clearcutting or leaving the stand intact.

Individual tree and group selection systems are particularly suited to regenerating the shade-tolerant species found in mixed conifer stands (3, 17). These systems are especially applicable to well-stocked, uneven-aged stands where the objective is to maintain a balanced age-class distribution by harvesting at frequent, regular intervals. However, it may be difficult to achieve fully regulated conditions in practice because of logging, administrative, and recordkeeping problems. Maintenance of age diversity, which is characteristic of climax or near-climax forests, is possible only because some species comprising these successional stages exhibit the ability to grow in shade. In stands characterized by uniform spacing, individual tree selection is preferred, while clumpy stands are appropriately harvested by group selection which utilizes and maintains a mosaic age-class structure. In the latter instance, individual groups may be treated by a variety of silvicultural systems, ranging from shelterwood and its modifications to clearcutting. Since selection systems leave a continuous forest cover, they are suitable for harvesting in areas where the immediate foreground is visible to travelers and in other high-use recreational zones. They can also be applied in riparian zones where multi-storied stands are required by various mammals and where shading is necessary to maintain favorable stream temperatures for fish (23). In the Southwest, such habitats may be especially important to the threatened Arizona trout and the endangered Gila trout.

Harvesting in mixed conifer forests under either selection system is directed towards removing excess trees in all diameter-age classes. Initial cutting, however, may be aimed at removing the most defective and overmature trees, which can be abundant in some decadent old-growth stands (12). Regardless of the silvicultural system selected, windfall risk must be considered (12). For example, in stands consisting of nonwindfirm species where the windfall risk from soil and topographic features is below average, up to 30 percent of the overstory basal area can be removed in the first entry either as

[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.

individual trees or groups of trees, depending on tree distribution. However, a few defective trees may have to be retained in some instances to prevent excessive openness in the canopy, which may lead to unfavorable wind movement and subsequent blowdown. Where the residual stand consists of windfirm species, more basal area can be harvested and, conversely, less basal area where the windfall risk is greater.

Even-aged management provides the means to regenerate intermediate and intolerant mixed conifer species to meet timber and other resource needs (4, 5). Clearcutting in patches, blocks, or strips may be desirable to improve water yields from these forests, which produce relatively large quantities of high-quality water (18). Forage for domestic livestock or wildlife also can be increased. Furthermore, wildlife can benefit through habitat improvement resulting from the spatial arrangement, size, shape, and timing of silvicultural treatments (10, 11). Large clearcuts are not recommended in mixed conifer forests because they are difficult to regenerate with coniferous species (11). However, if aspen is an important component of the stand and continued maintenance is desired for esthetics or wildlife, regeneration by root sprouts will be greatest following clearcutting and light burning (22).

The shelterwood system and its modifications also are applicable in mixed conifer forests. Many stands in the Southwest are two- or three-storied, with well-stocked understories ranging from seedlings and saplings to pole-sized trees. Removal of the overstory is equivalent to the final removal cut of the shelterwood system, but is accomplished over 10 to 20 years by two or more cuts, depending on the existing wind risk or the need to protect advanced regeneration (12). Generally, understory trees 4 inches (10 cm) or larger in diameter in these stands appear especially susceptible to windthrow. The shelterwood method has been practiced in Douglas-fir and ponderosa pine stands in the Southwest and elsewhere (4, 5, 21) and in stands of more tolerant species in other regions (3). However, when it is applied to regenerate stands with overstories consisting of species with different degrees of tolerance, subsequent regeneration of the more tolerant species will tend to be increasingly favored by additional increments in residual stand densities resulting from regeneration cuts (1, 2, 17). Many resource benefits other than timber may be derived from the application of shelterwood systems, but to varying degrees depending on the intensity and timing of cutting.

Regeneration under any silvicultural system can be obtained by natural seeding, planting, or by protecting advanced regeneration. Artificial seeding has not been successful in the Southwest. Site scarification to expose mineral soil, generally the best seedbed (3, 4, 14), should be timed to coincide with a good seed crop. However, if natural regeneration has not become established, clearcuts should be planted within 2 years to avoid competition from invading grass (11). Planted seedlings of those species injured by intense sunlight or frost must be protected by artificial or natural shade, which often can be provided most easily by intentionally leaving some cull logs during slash-disposal operations (12, 19). Observation suggests that even the more resistant seedlings also will benefit from shade, presumably because of better moisture regimes. The species selected for planting should be adapted to the particular site (12, 13). In general, intolerant species should be planted on exposed sites at elevations below 9,000 feet (2745 m) on northerly slopes, and 9,500 feet (2895 m) on southerly slopes. Tolerant species should be planted under artificial or natural shade at elevations above 9,000 feet (2745 m) on southerly exposures, and 8,500 feet (2590 m) on northerly exposures. Species of intermediate tolerance appear suited to moderate shade at elevations between 8,000 and 10,000 feet (2440 and 3050 m) on southerly aspects, and somewhat lower on northerly aspects.

Intermediate cutting in mixed conifers is not yet a common practice. Although information on growth is not yet available, thinning operations were recently begun to favor individuals with the best potential of becoming crop trees (12). Annual mortality in mixed conifers is high—estimated at 50 million fbm (Scribner Decimal C Log Rule) (10 million cubic feet or 283 000 m^3) in Arizona alone—but merchantable volumes are salvaged wherever economic conditions permit. Some sanitation cutting, combined with intensive slash disposal, is conducted in areas infested with spruce beetles. Salvage and sanitation are also considered in marking regeneration cuts.

Although dwarf mistletoes are a problem in many stands, their host specificity and the large number of conifer species provide control options that do not necessarily result in large openings or excessive windthrow (9). Infected overstory trees can be harvested over a short period, and the understory can be treated with sanitation cuts as needed. If the overstory cannot be removed in a short time, understory trees of nonhost species can be encouraged naturally or established by planting.

Similarly, excessive damage by the western spruce budworm might be alleviated in mixed conifer stands through appropriate silvicultural practices utilizing tolerance traits of different species (24). For example, cuttings that discriminate against the more vulnerable true firs, yet favor establishment of nonhost species or the less susceptible Douglas-fir and spruces, would tend to reduce high population levels of budworms. Cultural treatments that maintain a thrifty, rapidly growing stand also would diminish the impact of insect attacks.

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Rocky Mountain Aspen

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Intermountain Region

The Rocky Mountain aspen forest cover type occupies about 4 million acres (1.6 million ha) of commercial forest land in eight Rocky Mountain States (7). Colorado and Utah, which contain 2.3 and 1.1 million acres (0.9 and 0.4 million ha), respectively, account for the majority of this acreage. These lands comprise 25 percent of the total commercial forest land in Colorado and 31 percent in Utah.

Aspen (*Populus tremuloides* Michx.) is a very important multiple-use species in the Rocky Mountains, providing wood, water, forage, wildlife, and recreation. Although the Rocky Mountain States have more aspen sawlog volume than the Lake States (25), the species is currently not being utilized to a great extent as a wood source. Most management of aspen in the Rocky Mountains is keyed towards recreation, forage production, wildlife, and esthetics.

Typical Rocky Mountain aspen stands yield from 10 to 12 inches (25 to 30 cm) of water, up to 2,500 pounds per acre (2800 kg/ha) of forage, and about 50 cubic feet net growth per acre (3.5 m^3/ha) per year averaged over a rotation (4).

Aspen typically grows on all aspects and slope positions in the Rocky Mountains and is associated with montane and subalpine vegetation along an elevational gradient from 7,000 to 11,500 feet (2135 to 3505 m) (25).

Productivity and development of aspen in the Rockies is largely dependent upon available water, which in turn is related to weather patterns, elevation, physiographic position, and edaphic characteristics. For example, stands on the west slope of the Continental Divide occupy large areas on all physiographic positions, whereas stands on the drier east slope are restricted to bottoms, draws, and other areas where sufficient soil water is available (21).

Soil characteristics further delineate the development of Rocky Mountain aspen. While aspen can be found on all soil types from loamy sands to heavy clays, rockiness greatly limits stand development. Most productive stands are found on deep, well-developed soils with abundant soil water (1). Aspen soils have higher organic matter content, water-holding capacity, and pH than soils under adjacent vegetation (11, 24). The nutrient content of leaf litter under aspen stands is higher than coniferous litter (3); and it decomposes rapidly (2), thus recycling these nutrients to the soil.

Climatic conditions under which Rocky Mountain aspen grows vary widely. In addition to the microclimatic differences caused by topography, differences in precipitation patterns also occur. Aspen grows in the Rocky Mountains on sites that receive from 16 to 40 inches (405 to 1015 mm) of precipitation per year, but most stands receive from 20 to 30 inches (510 to 760 mm) (4, 12, 25) per year, mostly from snow. These conditions, along with low dew points, high evaporative rates during the growing season, and cool spring temperatures (26), may account for the greater longevity and generally slower growth of Rocky Mountain aspen compared with aspen in other regions.

Aspen is an associate of many western tree species. It is recognized as a major component of Society of American Foresters forest cover types 217 and 251 and a minor component of sixteen others (5). It is a seral species and an aggressive invader following fire or other major disturbance to coniferous stands, even those containing only a few aspen stems (4). If a coniferous seed source is lacking, aspen can occupy a site for hundreds or perhaps even thousands of years (15).

Rocky Mountain aspen reproduces almost exclusively by suckering, whereby a number of stems are produced asexually by adventitious sprouting from a single parent root system to form a clone. Although stems within a clone are indistinguishable, clones can often be recognized from their neighbors by leaf shape and size, bark character, branching habit, stem form, suckering ability, time of flushing, and autumn leaf color (17). Such characteristics have important management implications. For instance, cutting a clone with an inherently poor stem form will only produce another stand with the same characteristics. Natural seedlings do occasionally occur in the West, and they may be responsible for genetic diversity and the colonization of new clones (16). A mature aspen tree can produce up to 1.6 million seeds in a single year (16, 22). Aspen begins bearing seed between 10 and 20 years of age and produces a large crop every 4 to 5 years (22). The small, light seeds are wind disseminated and usually mature in late June or early July in the Rocky Mountains (17). Seed can be stored under refrigeration for well over a year (17, 22), but loses viability under natural conditions 8 weeks or less after seedfall (16). Seed is not dormant and usually germinates well under a wide temperature range, but requires bare mineral soil, a continuous supply of abundant moisture, and relatively cool temperatures for survival (16). Such requirements preclude practical regeneration of aspen by seed under natural conditions, but make possible nursery or greenhouse production of landscape planting stock.

Aspen is more intolerant of shade than many other tree species. It demonstrates dominance well and restricts development of understory stems, which in turn contributes to its ability to naturally thin itself (4, 12). However, understory stems are capable of recovering from suppression where the competitive overstory has been removed.

Early growth of Rocky Mountain aspen suckers can be as rapid as those in the Lake States, with heights of 40 feet (12.1 m) reached in 20 years (12). Young stands can produce well over 150 cubic feet per acre (10.5 m^3/ha) per year (11), but most good quality mature stands produce about 50 cubic feet per acre (3.5 m^3/ha) per year (1, 21). Depending upon their location, most Rocky Mountain aspen stands will achieve an average height of 50 to 85 feet (15.2 to 25.9 m) at maturity. Individual stems 110 feet (33.5 m) tall at age 80 have been measured on extremely good sites (21).

Mature sawlog stands average about 95 years of age in Colorado and southern Wyoming (21). Sound stands over 110 years are not uncommon, and some as old as 200 years exist (4, 21). Stands younger than 50 years are rare in many areas of the Rocky Mountains because of long-term fire protection and the relative lack of utilization. The somewhat slower growth rates of Rocky Mountain aspen may allow longer rotations, as long as 120 years in some areas (1, 4).

Potential yield of managed aspen in the Rocky Mountains is not currently known. Young natural stands in Arizona have produced nearly 200 cubic feet per acre annually (14.0 m^3/ha) (12). Little precommercial thinning is currently practiced in the West.

Rocky Mountain aspen is host to numerous insects and diseases; however, only a few result in substantial damage. The western tent caterpillar (*Malacosoma californicum* (Packard)) is the most catastrophic insect pest, defoliating large acreages of aspen for several consecutive years, with considerable mortality occurring in heavily infested areas. Biologic control of outbreaks is possible by use of a water-suspension, bacteria spray. Several species of boring insects cause direct damage to the wood product value of aspen and serve as infectious agents for cankers and other diseases (4).

Although black leaf spot (*Marssonia populi* (Lib.) Magn.) is the most common disease of Rocky Mountain aspen, trunk cankers are the most serious. Sooty-bark (*Cenangium singulare* (Rehm.) Davids. & Cash), Hypoxylon (*Hypoxylon mammatum* (Wahl.) Mill.), Cryptosphaeria (*Cryptosphaeria populina* (Pers.) Sacc.), Cytospora (*Cytospora chrysosperma* Pers. ex Fr.), and black cankers (*Ceratocystis fimbriata* Ell. and Halst.) commonly infect wounds and can cause considerable mortality and trunk deformity (4, 9).

Decay is the most serious cause of volume loss in Rocky Mountain aspen. Although over 250 species of decay fungi occur on aspen, *Phellinus tremulae* (Bond.) Bond. & Boris., is most destructive (4, 10). Some rot is present in most stands. The infection rate appears to be related to age, and it usually becomes serious in stems older than 100 years. However, Rocky Mountain aspen does not appear to be as rot-prone as its eastern counterpart (4, 10).

Fire plays an important role in the ecology of Rocky Mountain aspen and is probably responsible for most even-age stands that exist in the West (4). In the absence of fire, many aspen stands are being replaced by other vegetation, or are evolving to an uneven-age mode. Protection of Rocky Mountain aspen from fire is largely unnecessary. Even a few aspen in a coniferous stand maintain root systems sufficient to restock the area after a serious fire (4), and pure aspen stands will not readily burn (6). However, basal wounds caused by light groundfires can serve as entry points for canker and decay infections (4). Light fuel loadings and normally high moisture content of succulent understory vegetation make prescribed burning of pure aspen stands difficult. Such burning can normally be successful only under extremely dry conditions (4), which occasionally exist after leaf fall during a warm dry autumn when understory vegetation has cured.

The intolerance of shade, ability to reproduce by suckering, and natural thinning tendencies of Rocky Mountain aspen ideally suit it to even-aged management by clearcutting, especially where the intent is to produce wood fiber. It is important that all stems, including nonmerchantable trees and understory saplings, be cut—not only to promote the best suckering (19), but to prevent poor-quality residual stems from being released and dominating subsequent regeneration. Past partial cuts and ''logger's choice'' clearcuts in Rocky Mountain aspen have resulted in either uneven-aged, inadequately stocked, or pathologically unsound stands that are not growing at optimum rates.

The occurrence of natural uneven-aged aspen stands in the Rocky Mountains (4, 21) indicates that some form of uneven-aged management may be possible where management objectives require vertical canopy diversity or the continual retention of a high forest, and where maximum fiber production is of little importance. In such cases, either individual tree or group selection cutting methods might be used to perpetuate or create uneven-aged stands. Individual tree selection should only be applied in stands that have an existing sucker understory and have demonstrated an ability to sucker under an existing overstory. Extreme care must be taken to avoid damage to residual stems when stands are selectively logged. Even so, wounding and stem breakage from falling and skidding operations could result in substantial insect and disease losses.

Deteriorating clones are of particular concern to western land managers. In healthy clones, the abundant production of suckers following clearcutting, fire, or other major disturbance that quickly kills most of the stems is apparently caused by a hormonal imbalance in the root system that promotes suckering (20). In deteriorating clones, the overstory has died slowly, and concurrent root system deterioration has maintained the hormonal balance and thus inhibited suckering (20). Cutting such clones is likely to result in sparse suckering, which may require additional protective or cultural measures to regenerate the stand adequately.

Other methods attempted to regenerate noncommercial aspen in the Rocky Mountains include bulldozing, herbicide application, and girdling. Most, except girdling, have met with varying success and, although evaluations of these techniques are underway, no recommendations can be made concerning their applicability as regeneration methods.

Many aspen stands grow in watersheds that supply municipal and agricultural water throughout the West. Compared to conifers, aspen stands intercept less precipitation, accumulate greater snowpacks (which melt faster and earlier), use less soil moisture, and yield more water of better quality with less erosion (4). As a broadleaf deciduous species, the leaf water vapor conductance of aspen is generally higher than corresponding subalpine coniferous species (13). However, any increased water use by aspen may be offset by its having a lower leaf area per unit area of sapwood water conducting tissue (14) and a shorter transpiration season than associated conifers.

Aspen stands typically yield more understory herbaceous biomass than adjoining coniferous types (25) and provide habitat for numerous wildlife species. Browsing of new sprouts by domestic and wild animals can prevent successful regeneration, and protective measures may be required for some stands to regenerate (18, 23). Clearcutting in large scattered units may be a silvicultural means of dealing with this problem where animals cannot be rigidly controlled (18). In some cases, fencing or manipulation of slash to discourage animal use may be necessary.

Human use can also be detrimental to aspen stands. Although highly desirable as a place for concentrated recreation activities, Rocky Mountain aspen stands are not suitable for such sites because of the high disease mortality of trees wounded by people using such areas (9). Relocation of the facilities is the only effective means of dealing with this problem.

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Interior Ponderosa Pine in the Black Hills

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The gross area of the Black Hills of South Dakota and associated Bear Lodge Mountains of eastern Wyoming is about 3.5 million acres (1.4 million ha). Roughly half the area supports forest or woodland cover. Essentially pure stands of climax Rocky Mountain ponderosa pine (*Pinus ponderosa* var. *scopulorum* Engelm.) predominate on about 1.5 million acres (0.6 million ha). Scattered, smaller aggregations of similar ponderosa pine stands occupy about 250,000 acres (101 170 ha) of butte-top and scarp sites to the north and south of the Black Hills in Nebraska, Wyoming, and Montana (3, 8, 19).

In addition to being isolated from the rest of the interior ponderosa pine forest cover type (Society of American Foresters forest cover type 237) by wide expanses of nonforested land, the ponderosa pine forests of the Black Hills are sufficiently distinctive in their silvical characteristics to warrant separate description and specialized silvicultural treatment (2, 4, 5).

The Black Hills are the weathered remains of a domal uplift of late Cretaceous/early Tertiary origin. A deep mantle of diverse sedimentary deposits, which overlaid the dome as originally uplifted, has been eroded almost entirely from its central portions. Rock types exposed in the core area are a complex of ancient and recent igneous intrusives and associated metasediments (10). Encircling this core of crystalline rock types are irregular, concentric bands of residual sedimentary rock strata. Several of the most recent of these sedimentary layers, steeply uptilted, form a hogback ridge that surrounds the hills like a rampart and boldly marks the prairie/ forest ecotone.

Truncated by erosion, the uplift now rises to only a fraction of its original height. The tallest peak, Harney, of durable Precambrian granite, reaches only 7,240 feet (2205 m) above mean sea level and a modest 4,000 feet (1220 m) above the surrounding plains. Although the topography is locally steep and rugged, the overall relief is gentle for mountainous terrain. It is easily roaded, and the bulk of the productive sites are accessible.

Soils show considerable variability attributable to parent materials and elevation/climate zones; yet, the influences of those factors on soil genesis and morphology evidently have been modified by coniferous forest cover. Most soils show morphological characteristics approximating those of the Eutroboralfs Group (Gray-Wooded Soils). Even within major grassland inclusions, where mixed prairie vegetation has prevailed for long periods, soils usually show some physical and chemical indications of previous occupancy by conifers. Thus, most sites, irrespective of parent material or existing vegetation, probably have the capability of supporting ponderosa pine stands (16, 22).

Soils may be characterized as medium- to fine-textured, moderately deep, and rocky. The upper horizon textural range generally runs from sandy loam through clay loam. A profile with an overall depth of 60 inches (152 cm) would be considered deep; a 24-inch (61-cm) profile is about average. Most residual soil profiles contain moderate volumes of weathered, fragmented parent material. Except where parent materials are of recent igneous origin, soils are usually underlain by deep zones of fractured bedrock. Joints and fissures in this rock admit and store gravitational soil water, and they are often penetrated deeply by roots—particularly those of ponderosa pine (2, 16, 22).

The climate of the Black Hills is similar, qualitatively, to that of the associated High Plains; i.e., typically continental and rigorous, with virtually all climatic elements showing unusual variability, both short- and long-term. Quantitatively, the climate of the Black Hills is sufficiently different from that of the surrounding steppe to favor forest cover over grass. The critical differences—increased precipitation and decreased temperature—are orographic effects (2, 14).

Compared to climates elsewhere in the type, the distinctive feature of the Black Hills climate is the relative abundance of precipitation early in the growing season (15). May and June are normally the wettest months; April and July are only slightly less so. Precipitation for these 4 months amounts to about one-half of the expected annual total of 30 inches (760 mm) (14). This prolonged moist period in late spring and early summer in most years is ideal for germination and establishment of ponderosa pine seedlings. The wet snows and cool rains of April and early May provide ample moisture for imbibition by pine seeds deposited the previous autumn. When germination occurs late in May, an additional 2 months of periodic rains can be expected to keep the duff moist while seedling roots grow toward the more dependable moisture supplies of the mineral soil. First-season growth of vertical roots of Black Hills pine seedlings averaged 6 inches (15 cm) in limestone soils and 7 inches (18 cm) in metamorphic soils by the first of July (20).

Recurrent, severe droughts also exert a potent influence on the vegetation of the High Plains and Black Hills. A tree ring study of drought in nearby western Nebraska indicated occurrence of 21 major droughts (5 years or longer in duration) during the 748 years between 1220 and 1952 A.D. Average duration was nearly 13 years; the most prolonged lasted an estimated 38 years. The average interval between droughts was about 24 years. The most recent severe drought in the plains—which produced the infamous dust bowl conditions of the 1930's—was, by comparison, well below average in duration (21).

These droughts not only kill vegetation outright but also increase its flammability. Drought and wildfires are the principal reasons why extensive stands of very old ponderosa pine were scarce even in the presettlement, virgin forests (7). Grassland fires, especially frequent during droughts, also tended to inhibit encroachment of ponderosa pine into the interior and surrounding prairies (6). Recently, pine invasion into pastures has become a range management problem, presumably a consequence of human interference with the natural wildfire regime, enhanced by recent absence of drought.

The Black Hills are a veritable melting pot, with tree species representing origins as diverse as the northern boreal, the eastern deciduous, the western subalpine and montane forests, and the pygmy conifer woodlands (2). Of the many indigenous tree species other than ponderosa pine, only three occur extensively enough to influence ponderosa pine silviculture.

White spruce (*Picea glauca* (Moench) Voss) forms pure, mostly even-aged stands on cool, moist sites where it is considered the climax forest type. Ponderosa pine is seral on these sites. Only about 2 percent of the commercial forest land is currently dominated by white spruce, but it is gradually replacing seral pine stands as a result of fire control, pine-killing insects and diseases, and silvicultural practices. On more xeric sites, spruce may mix with but is eventually replaced by pine.

Stands of quaking aspen (*Populus tremuloides* Michx.) occupy about twice as many acres as white spruce but, for the most part, less permanently. Most stands are seral, replacing pine or spruce only temporarily following disturbance. Stands of bur oak (*Quercus macrocarpa* Michx.) of tree form are mostly confined to low elevation bottoms on the eastern and northern margins of the Black Hills. However, a scrub form of oak also mixes with pine on some upland sites in the northern Black Hills and Bear Lodge Mountains. On these sites, loss of the dominant pine cover, through cutting or fire, can lead to capture of the site by oak brush. Natural recapture by pine is a very slow process; artificial restoration is difficult and expensive.

For managers of multi-purpose lands, the main problem with the associated forest types is their restricted occurrence. The predominance of ponderosa pine seriously limits diversity of forest vegetation and complicates management efforts to maintain or increase it (18).

Ponderosa pine is a dependable seed producer in the Black Hills. Seed crops are normally good to excellent every 2 to 5 years; the longtime average interval between good crops is 3 years. This characteristic, coupled with the favorable spring and summer moisture regime, makes natural reproduction readily and abundantly available. Ordinarily, deforested sites within 120 feet (37 m) of an adequate pine seed source restock promptly. Adverse seed bed conditions seldom prevent pine regeneration, but rank stands of grass or brush or heavy slash may delay it (2).

Extremely high stand densities are common in pine regrowth. Established seedling stands often contain more than one tree per square foot (11 trees/m^2). Natural thinning proceeds very slowly; initially overstocked stands are apt to remain crowded from youth to biological maturity. The usual result is early and persistent stagnation of growth. However, many trees in overstocked, even stagnant stands, retain a capacity to respond favorably to release. Satisfactory improvements of growth (especially in stem diameter) are usually attainable by thinning stands less than 100 years old (2).

Ponderosa pine site index is the only means available for rating the productivity of Black Hills sites, whether they support pine, other vegetation, or none at all. Various plant community and habitat types have been identified and described, but type-productivity relationships have not been quantified. Conventional site index curves, developed during the 1930's and based on dominant/codominant tree heights at age 100, are still in use (9). These have been augmented by a vegetation-independent system that derives estimates of index values from soil and topographic parameters (2). The range of site index values is narrow, from 20 feet (6.1 m) to 100 feet (30.5 m). Sites with indexes at or near the maximum are rare, and account for only a small fraction of the forest land area. The modal site index class, 50 to 60 feet (15.2 to 18.3 m), lies between Meyer's classes V and VI (2, 9, 11).

Research on growth and yield of ponderosa pine has a long history in the Black Hills but, from the start, the effort has focused mainly on cutover and regrowth stands; only limited information is available on biological growth potentials of natural stands (2, 9, 12). Unpublished data from old plots indicates that gross mean annual increments will consistently range from 25 to 35 cubic feet per acre (1.8 to 2.5 m^3/ha) at age of culmination (130 to 150 years) in fully stocked, unmanaged stands on average sites. If harvested at age 150 years, such stands could be expected to yield about 3,000 merchantable cubic feet per acre (210.0 m^3/ha) or 14,000 board feet (fbm)[1] per acre, in trees 9 to 11 inches (23 to 28 cm) d.b.h. For comparison, forest survey estimates 32 cubic feet per acre (2.2 m^3/ha) average annual net growth on commercial forest lands of all ownerships and condition classes. Similarly, Black Hills National Forest growth and mortality plots indicate an average net growth of 33 cubic feet per acre (2.3 m^3/ha) in existing stands, including volumes harvested between remeasurements (8, 18).

While no Black Hills pine stands have been under management long enough to demonstrate the gains in growth and yields attainable through continuous, reasonably intensive management, conservative estimates, based on research and experience, indicate that: trees, 14 to 18 inches (36 to 46 cm) in diameter at breast height (d.b.h.), can be grown on rotations as short as 100 years; and gross mean annual increments can be increased by roughly 50 percent above current levels to 50 cubic feet per acre (3.5 m^3/ha) on average sites or across large forest tracts (18). Best case estimates, derived by using the Rocky Mountain Yield Simulation program (RMYLD) indicate that, with prompt restocking followed by periodic thinnings to maintain proper stocking levels, gross mean annual increment in stands managed at growing stock levels considered optimum for timber production on a 120-year rotation can vary from about 40 cubic feet per acre (2.8 m^3/ha) on site index 50 lands to about 90 cubic feet per acre (6.3 m^3/ha) on site index 80 lands (1). However, these simulations may not fully account for all the diverse social, economic, biological, and physical constraints that limit productivity.

A distinctive pathological characteristic of Black Hills ponderosa pine forests is the absence of dwarf mistletoe (*Arceuthobium* spp.). This permits silviculturists to consider a wide range of harvest/regeneration options, free of the threat of mistletoe transmission from old to new stands. There is some incidence of most other disease problems common to the type (4); shoestring rot (*Armillariella mellea* (Wahl. ex Fr.) Karst.), western gall rust (*Peridermium harknessii* J. P. Moore), and red rot (*Dichomitus squalens* (Karst.) Reid) are prominent and chronically troublesome (2). However, none of these is serious enough to require major modifications of silvicultural practices forestwide.

The most damaging insect pest is the mountain pine beetle (*Dendroctonus ponderosae* Hopkins). Periodic epidemics kill millions of trees, typically in patchwise fashion in uniform, heavily stocked, large pole and small sawtimber stands. The most widely applied control practice is timely harvest and utilization, or burning, of infested trees. Subjective evidence suggests that the beetle problem will be mitigated as intensified intermediate cutting programs reduce the prevalence of overstocked stands and increase diversity of size and age classes (1, 2, 17). Pine engravers (*Ips* spp.) occasionally produce tree-killing populations in heavy thinning slash; the red turpentine beetle (*Dendroctonus valens*

[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.

LeConte) sometimes makes a primary attack on healthy trees; and pine terminal borers often impede height growth of juvenile trees (2).

Because it has posed so few problems, little research has been done on natural regeneration of Black Hills ponderosa pine. Most of what is known about silvicultural systems and harvesting methods has been learned by experience. Fortunately, the experience has been abundant, varied, and instructive. During the more than a century of timber harvesting in the Black Hills, the silvicultural systems applied on Federal lands have covered the spectrum from clearcutting (1876 to 1896), to seed-tree cutting (1897 to 1907), to shelterwood cutting (1908 to 1925), to individual tree selection (1926 to 1955), and then returned to shelterwood cutting (since 1956). Virtually every operable acre has been cutover at least once; the majority have received repeated partial cuts of one kind or another (2, 13).

Several important lessons have been gained from these diverse harvesting experiences: even-aged silviculture is eminently suited to Black Hills ponderosa pine; within the even-aged system, any one of the three standard regeneration methods may be a valid option under appropriate circumstances; the shelterwood method offers more advantages and entails fewer disadvantages than either the seed-tree or clearcut methods; and uneven-aged silviculture is not a desirable option for timber production in Black Hills ponderosa pine, but the selection method is a valid option in special situations.

The shelterwood method capitalizes on the species' natural tendency to form even-aged stands. Furthermore, it combines the advantages of continuous vegetative protection of the site; absence of obvious openings; assurance of an adequate, well-dispersed seed supply; fair control over development of competitive ground cover; good control over accumulations of hazardous and unsightly logging residue; and an esthetically acceptable appearance, provided the harvest job is skillfully planned and executed (2). An important disadvantage is that the parent overwood will hamper development of the replacement stand if it is too dense or left in place too long. Another disadvantage is that even a light shelterwood is likely to supply more seed than is needed, thus aggravating the problem of excess reproduction. The grass-forb seral stage which is desirable for wildlife and livestock forage does not develop fully nor persist for long under a shelterwood (2).

A uniform, two-cut shelterwood appears to be the most efficient and silviculturally acceptable variant of the method. The seed cut should be heavy enough to interrupt the competitive continuity of the mature stand and leave only 12 to 18 good parent trees per acre (30 to 44/ha); the removal cut should be completed soon after regeneration is established. A three-cut variant is an acceptable option in situations where two cuts pose unusual problems of visual impact, residue buildup, risk of windthrow, or logging damage to reproduction (2).

The other even-aged methods—seed-tree or clearcutting—are acceptable alternatives to the shelterwood under some conditions. Each, however, lacks one or more of the advantages of the shelterwood method. The seed-tree cutting method entails the highest risk of loss of seed source, especially from blowdown. Also, the widely spaced seed trees offer little competition to invading ground cover in the unlikely event of delayed pine regeneration. If it is surrounded by well-stocked stands, a seed-tree area has nearly the same visual impact as a cleared opening. In well-stocked stands, a seed-tree cut results in heavy accumulations of logging residue on the first entry. These disadvantages may be partially offset by reduced seed supply, less damage to reproduction during seed stand removal, and higher production of herbage (2).

The clearcutting method creates conspicuous stand openings. The size of opening should normally be restricted to about twice the 250 feet (76.2 m) dispersal distance of ponderosa pine seed if there is a seed-producing stand all around the perimeter. In well-stocked stands, clearcuts generate maximum amounts of logging residues which may require costly abatement. After the slash dissipates, pine regeneration is likely to develop vigorously, free of overhead competition. Lack of timely pine regeneration may lead to site capture by other vegetation for relatively long periods of time. The clearcut method is most likely to produce significant increases in forage and water yields (2).

For regeneration, the uneven-aged system is out of place in the naturally even-aged pine forests of the Black Hills. Light selection cuts, which remove only a few individual trees or small groups, ordinarily do not lead to satisfactory establishment and development of replacement growing stock. Stands of uneven- or all-aged structure can only be produced and maintained at spacings wide enough to make all stand components essentially free growing. For purposes other than regeneration, individual tree selection can be a very useful harvest practice. It is particularly applicable in the management of remnant old-growth stands being perpetuated for esthetic reasons; for manipulation of stands on or adjacent to riparian zones or other sensitive sites; and for management of unusually large trees for high-quality wood, specialized habitats, or visual appeal. The selection method is difficult to prescribe and costly to apply, however (2).

Thinning is an appropriate and generally necessary intermediate cutting method. In typically crowded regeneration stands, precommercial thinning should begin early, before stagnation occurs, while trees are large seedling or small sapling size. One moderately heavy, precommercial thinning is more cost-effective than no precommercial thinning. Commercial thinnings should be made at regular intervals (usually 20 years) throughout the rotation to upgrade the quality and productivity of the growing stock, to reduce susceptibility to mountain pine beetle attack, and to promote development of understory vegetation. Thinning to stocking levels below the optimum for wood production results in significant increases in forage for livestock and wildlife. Low levels of growing stock also favor water yields; fully stocked pine stands are capable of utilizing most of the moisture which infiltrates the soil mantle in years of normal or deficient precipitation (1).

Prescribed burning is an effective, efficient way to eliminate unwanted pine reproduction invading grasslands adjacent to forest; it may be an equally good way to control advance reproduction in lightly stocked, immature pine stands (6). Burning, either in piles or broadcast, is useful for fuel and hazard reduction following harvest cuttings or commercial thinnings; burning may or may not benefit ground cover vegetation. Prescribed burning of precommercial thinning slash is risky in that it is likely to kill small, thin-barked trees.

Intensive management should provide for improving the genetic quality of the forest growing stock. Selection for desirable traits should be routine in the choice of leave trees in intermediate and harvest cuts. Seed used for artificial regeneration should be from recognized, local collection zones or seed production areas. When bona fide improved strains of adapted ponderosa pine become available, their use should be considered for reforestation of at least the most productive sites.

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Pinyon – Juniper

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Pinyon–juniper woodlands (Society of American Foresters forest cover type 239) occupy about 48 million acres (19.4 million ha) in the western United States (2), primarily in Nevada, Utah, Arizona, New Mexico, and Colorado. Extensive stands also occur in California and Texas, and a few stands are in southern Idaho, southern Wyoming, and the western tip of Oklahoma. The woodlands are on piedmont slopes, foothills, mountain slopes, mesas, and plateaus at elevations generally ranging from 4,500 to 8,000 feet (1370 to 2440 m). The lower elevational limit is above valley floors of the high desert in the Great Basin and above low plains in other parts of its range. Soils are derived from a wide variety of parent materials and are typically well drained. Soil orders include Mollisols, Alfisols, Entisols, Inceptisols, and Aridisols.

The pinyon–juniper type is one of the most xeric forest cover types in the United States, and consequently, one of the least productive. In the western portion particularly, cloudy days are rare and relative humidity is extremely low during the growing season, resulting in very high potential evapotranspiration. Since the type covers a wide geographical area and has broad elevational limits, it apparently tolerates a wide range of temperature extremes. The mean minimum temperature in January, the coldest month, can be as low as 14° F (−10.0° C); and the mean maximum temperature in July, the hottest month, can be as high as 95° F (35.0° C). Mean annual temperature varies from 40° to 60° F (4.4° to 15.5° C). Average annual precipitation varies from 10 to 20 inches (255 to 510 mm), but can be as low as 8 inches (205 mm) on some alluvial fans and piedmont slopes where surface and subsurface flow contributes to the soil moisture supply. In the western portion of the type, most precipitation occurs during the winter months (December through April), usually as snow. In the eastern portion, most of the precipitation occurs in summer (July through September). In the central portion, precipitation is more evenly divided between summer and winter, but spring and fall are usually dry.

The pinyon–juniper type is composed of several different associations of pinyon and juniper species and includes pure stands of pinyon or juniper. The most important species in this type are pinyon (*Pinus edulis* Engelm.), singleleaf pinyon (*P. monophylla* Torr. and Frém.), Utah juniper (*Juniperus osteosperma* (Torr.) Little), oneseed juniper (*J. monosperma* (Engelm.) Sarg.), and alligator juniper (*J. deppeana* Steud.). Other species of local importance are Rocky Mountain juniper (*J. scopulorum* Sarg.), Mexican pinyon (*Pinus cembroides* Zucc.), Parry pinyon (*P. quadrifolia* Parl. ex Sudw.), and California juniper (*Juniperus californica* Carr.). The singleleaf pinyon–Utah juniper association occurs throughout the type in Nevada and in parts of California, Utah, and Arizona. The pinyon–Utah juniper association is also widespread, occupying most of the type in Utah, western Colorado, and northern Arizona. The pinyon–oneseed juniper association occurs in New Mexico, eastern Arizona, and south-central Colorado. Alligator juniper is also a common component at higher elevations of the type in Arizona and New Mexico. Rocky Mountain juniper is a component at higher elevations in Colorado, New Mexico, Arizona, Utah, and eastern Nevada. Mexican pinyon occurs in a few localities in southeast Arizona, southwest New Mexico, and southwest Texas. California juniper is a component in parts of southern California and western Arizona. Parry pinyon is a minor species in southern California.

Juniper species produce abundant berry crops nearly every year. Birds and mammals eat juniper berries and excrete viable scarified juniper seeds over extensive areas. Pinyon species produce good cone crops at irregular intervals, usually varying between 3 and 7 years. But good crops in any particular year vary from locality to locality. The heavy wingless seeds are disseminated by birds and rodents. Rodents usually do not carry pinyon seeds far, but birds may transport seeds considerable distances. Clark's nutcracker has been reported to carry pinyon seeds nearly 14 miles (22 km) (13). Both birds and rodents cache pinyon seeds in the ground, often at depths favorable for germination. They consume most of these caches during the winter, but some caches and individual seeds are overlooked and left to germinate. Fresh pinyon seeds have high viability and germinate readily with little or no stratification. Pinyon seeds lose viability rapidly after one year, but juniper seeds probably remain viable for several years. Seeds usually germinate in early spring if the soil is moist. In the eastern portion of the type, germination may be delayed until the summer rainy season.

Few seedlings survive without some degree of shade until they reach a height of about 12 inches (30 cm). Surviving seedlings are generally found under shrubs or tree crowns. Those growing under shrubs have the best chance for survival because the tree seedlings can often overtop the shrubs. Those beneath tree crowns usually die eventually, unless the overstory is removed. When a tree is cut, seedlings under it may die because of the sudden exposure to solar radiation, unless they are shaded by the tree stump or by slash. When a pinyon–juniper stand is cut, reestablishment of the stand can be hastened by avoiding damage to the residual stand of small trees and seedlings and by providing a shading cover of slash over small seedlings exposed to full sunlight.

Although pinyon and juniper are not shade tolerant, water rather than light is the limiting factor in survival and growth. Because of low precipitation and high potential evapotranspiration, overstory foliage is rarely dense enough to reduce light intensities below tolerance levels. Complete crown closure is rare, but soils under well-developed pinyon–juniper stands are completely occupied by tree roots, resulting in suppression of understory vegetation. The intense competition for moisture often results in suppression of smaller trees. Young trees can be killed by severe moisture stress. Older trees usually survive, though at greatly reduced growth rates. Limited studies indicate that suppressed pinyon and juniper trees gradually resume normal growth when released from severe competition (9).

Growth rates of pinyon and juniper are highly variable but generally quite low. Height growth of dominant pinyon and juniper trees is usually 2 to 4 inches (5 to 10 cm) per year. Average annual diameter growth of dominant trees generally varies from 0.04 to 0.2 inches (1 to 5 mm). Diameter growth rates are governed primarily by moisture availability and do not necessarily decrease with tree age (9). A typical dominant tree takes about 150 years to reach a height of 28 feet (8.5 m) and a diameter of 12 inches (30 cm) at stump height, which is 6 inches (15 cm). Since pinyon and juniper grow so slowly, rotations for wood production are quite long. Even on the best sites, rotations should be at least 100 years. Rotations should be about 200 years on average sites and as much as 300 years on poor sites. Rotations for Christmas trees vary from 20 to 50 years.

Volume increments and yields vary greatly depending on stand density, age, and site quality. Gross annual increment averaged 9.5 cubic feet per acre (0.7 m^3/ha) on sample plots in northern Arizona and New Mexico (6). Annual increment of cordwood on fully stocked plots in the Great Basin ranged from 6 to 30 cubic feet per acre (0.4 to 2.1 m^3/ha) and averaged 17 cubic feet per acre (1.2 m^3/ha) (10). Cordwood volumes up to 1,440 cubic feet per acre (100.8 m^3/ha) and cordwood increments up to 45.6 cubic feet per acre (3.2 m^3/ha) per year have been reported for overmature stands of dense pinyon in western Nevada (11).

Mistletoe is the most important pathogen in the pinyon–juniper type. Juniper mistletoe (*Phoradendron juniperinum* Engelm. Subsp. *juniperinum* Wiens) is specific to juniper species, and pinyon dwarf mistletoe (*Arceuthobium divaricatum* Engelm.) is specific to pinyon species (5). Both cause reduced vigor and occasional dieback but rarely cause mortality. The most important insect pest is pinyon ips (*Ips confusus* (LeConte)), which breeds primarily in pinyon and is endemic throughout the range of pinyon (4). Minor epidemics can occur in areas where uprooted trees or slash accumulation permit the population to build up and successfully attack healthy trees. Removal or burning of all pinyon slash larger than 3 inches (8 cm) diameter during harvest will usually prevent pinyon ips populations from reaching epidemic proportions.

Pinyon and juniper species are rarely used for sawn products because of their small size and poor growth form (1), but pinyon–juniper woodlands provide a variety of other products. Pinyon nuts were a major source of food for Indians for many centuries and are still a major product (7). The woodlands supplied most of the charcoal and fuelwood to the booming mining industry in the Great Basin during the latter half of the 19th century (14). Throughout the Southwest, pinyon–juniper woodlands have been major sources of fuelwood, fenceposts, and Christmas trees. As demands increase and technology improves, the woodlands may become important sources of other products (1).

Pinyon–juniper woodlands provide food and shelter for deer, elk, antelope, wild horses, turkeys, and many other species of mammals and birds (3, 12). Mule deer depend on pinyon–juniper woodlands for cover and travel corridors in many parts of the West, and also for food and shelter during severe winters (3).

The woodlands have been extensively grazed by livestock for more than a century and some parts have been grazed for as long as four centuries. All too often, grazing was continuous and excessive, resulting in deteriorated range conditions. Grazing on most of the pinyon–juniper ranges has been brought under management in the past 70 years, but recovery of the range has been slow. In the past 35 years, extensive areas of pinyon–juniper have been clearcut, cabled, chained, crushed, or burned and then seeded to grass to increase forage production for livestock. Some of these conversion projects were successful, resulting in greatly increased carrying capacity for livestock, but many others failed to increase carrying capacity for more than a few years, and the treated areas have been reoccupied by juniper and pinyon.

With few exceptions, the woodlands have been used with little regard for good forestry practices. Vast areas around mining towns and other settlements were clearcut during the 19th century for firewood, charcoal, and other wood products. Throughout the rest of the woodlands, most stands have been high-graded, leaving residual stands of poorly formed trees and inferior species. The few remaining virgin stands are confined to remote areas and to poor sites.

No silvicultural methods have been tested in pinyon–juniper woodlands. The following recommendations are based on limited knowledge of the silvical characteristics of pinyon and juniper. No single silvicultural method is best for all situations. The appropriate method depends on management objectives and stand characteristics. Management considerations include wildlife and esthetics as well as production of fuelwood, juniper posts, Christmas trees, pine nuts, and forage.

Where wood production is the primary objective, individual tree selection appears to be the best method because it provides the best conditions for regeneration and continuously maintains adequate growing stock. Cutting cycles should be long, usually 50 to 100 years, to avoid excessive administration and harvesting costs. Each harvest cut should reduce stand basal area (measured at stump height) to about 40 square feet per acre (9.2 m^2/ha) to provide adequate growing space until the next harvest without reducing current annual increment excessively. Studies in Nevada indicate that pinyon–juniper stands achieve full site dominance at about 40 square feet per acre (9.2 m^2/ha) basal area (10). To meet immediate demands for wood, basal area could be reduced to as low as 20 square feet per acre (4.6 m^2/ha), particularly if there is a good stand of advanced reproduction. However, annual increment and future yield would be reduced accordingly.

The harvest cut should remove all merchantable trees that have poor growth form, that are infested by mistletoe, or that would not be expected to survive until the next harvest. Where pinyon and juniper occur together, pinyon should be favored by selective removal of juniper except in localities where juniper is at least as desirable as pinyon for firewood or where there is existing or potential demand for other juniper products. If the best nut producing pinyons are left uncut, the immediate adverse impacts of tree cutting on nut production would usually be small, and the long-term yields of nuts would be increased in many cases (8).

Harvesting operations should be carefully managed to minimize damage to residual vegetation, including advanced reproduction and shrubs. Slash burning should be limited to that needed to reduce fire hazard to acceptable levels. Slash burning damages residual vegetation and results in loss of nitrogen and other nutrients. Lopped and scattered slash provides partial shade for seedlings, reduces soil erosion, and gradually returns nutrients to the soil.

While Christmas trees can be harvested in woodlands that are managed by the selection method, such harvesting should be closely supervised to avoid cutting trees that should be left to produce wood. As much as possible, Christmas tree cutting should be confined to younger stands that have reoccupied old burns and other cleared areas. The seed tree method should be applied to those areas where Christmas tree production is the primary management objective. About 10 seed trees per acre (25 per ha) are needed for an adequate seed source to maintain a continuous supply of Christmas trees, and a good shrub understory is necessary for survival of new seedlings.

Forage production would usually increase in stands harvested by the individual tree selection method, but the increases would be small and of short duration because roots of the residual stand reoccupy the soil mass previously utilized by the harvested trees. In those localities where substantial increases in forage production are required, patch cutting should be used. The patches should be no larger than 5 acres (2 ha) and should be irregularly shaped to reduce visual impact and to increase edge effect. Clearcutting of larger areas is not appropriate in pinyon–juniper woodlands unless the management objective is type conversion to livestock range.

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Eastern Forest Cover Types

Red Pine

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Red pine (*Pinus resinosa* Ait.) is native in the Lake States, New England, New York, and Pennsylvania but planted stands now comprise a major portion of the type over its entire range. Red pine plantations have also been established somewhat south of the species' natural range. The area of the Society of American Foresters red pine forest cover type 15, totals more than 1.5 million acres (0.6 million ha) with about two-thirds of it in the Lake States (3).

Red pine is most common on level to gently rolling sand plains with soils classified as Entisols, Spodosols, or Alfisols. In the East it grows on mountain slopes and hilltops in addition to outwash plains. Although red pine stands are found from sea level to more than 2,000 feet (610 m) elevation, it is most common between 700 and 1,400 feet (215 to 425 m).

Climatic conditions within the red pine range are generally from cool to warm summers, cold winters, and from low to moderate rainfall. Average annual maximum temperatures reach 95° F (35.0° C) and average annual minimum temperatures −40° F (−40.0° C) in some areas of the type in the United States. Frost-free periods average from 80 to 160 days and July temperatures from 60° to 70° F (15.5° to 21.1° C). Summer droughts are common, particularly in the western part of the range. Average growing season precipitation is 15 to 25 inches (380 to 635 mm) and average annual precipitation reaches more than 50 inches (1270 mm) in the eastern part of the range (5).

Red pine occurs in pure stands or comprises a majority of the stocking in mixture with eastern white pine (*Pinus strobus* L.), jack pine (*Pinus banksiana* Lamb.), or both. In addition to white pine, associates on fine sands to loamy sands include red maple (*Acer rubrum* L.), northern red oak (*Quercus rubra* L.), white spruce (*Picea glauca* (Moench) Voss), and balsam fir (*Abies balsamea* (L.) Mill.). Associates on coarser, drier soils are jack pine, quaking aspen (*Populus tremuloides* Michx.), bigtooth aspen (*P. grandidentata* Michx.), paper birch (*Betula papyrifera* Marsh.), and northern pin oak (*Quercus ellipsoidalis* E. J. Hill). Composition in planted stands is similar to that in natural stands because common associates invade or because red pine is planted in mixture with white pine or jack pine (3).

Red pine may be a coordinate species in mixture with white pine, especially on dry, sandy loam soils. On the better sites the rate of succession to white pine is much more rapid than on the poorer sites. On the most fertile sites the pines may be replaced by northern hardwood or spruce−fir types, but on some sandy sites the succession may stop with red pine as a persistent subclimax type. In the Lake States, red pine may be established as a subordinate species with jack pine or aspen in a mixed type. As these shorter-lived species drop out, red pine predominates. The most common undergrowth in red pine stands includes American and beaked hazel (*Corylus americana* Walt. and *C. cornuta* Marsh.), blueberry (*Vaccinium* spp.), raspberry (*Rubus idaeus* L.), sweetfern (*Comptonia peregrina* (L.) Coult.), prairie willow (*Salix humilus* Marsh.), dwarf bush-honeysuckle (*Diervilla lonicera* Mill.), trailing arbutus (*Epigaea repens* L.), and spiraea (*Spiraea* spp.) (3).

Most old-growth stands became established following fire when a few scattered surviving trees had good seed crops that coincided with favorable weather (1). Although red pine seeds can germinate on the organic forest floor, few seedlings survive because of the shade and rapid drying of the litter. Exposed mineral soils or disturbed seedbeds increase the chances for seedling success. Shrub competition may limit seedling establishment especially on the better sites. Natural regeneration requires a combination of good seed production, seedbed preparation, and favorable precipitation during germination and seedling establishment. Because all these requirements are difficult to meet, more reliance is currently placed on artificial regeneration, especially planting (1).

Seed production normally begins at about 25 years in open-grown trees and at 50 years in closed stands. The average number of seeds in a medium to good seed year ranges from 75,000 to 110,000 per acre (185 330 to 271 810/ha) and in an excellent seed year exceeds 1 million (2 471 00/ha). Excellent red pine seed crops occur at irregular and infrequent intervals of from 10 to 12 years or more. Medium to good seed crops are produced every 3 to 7 years (5). Several pests reduce red pine seed crops including the red pine cone beetle (*Conophthorus resinosae* Hopk.) and several other insects that prevent normal cone development. Red squirrels often cut cones and cone-bearing branch tips. They may completely destroy the current and succeeding year's cone crop but damage is usually less in closed stands than in open-grown trees. White-footed mice, redbacked voles, chipmunks, and birds also eat large quantities of seed (5).

Seeds are wind-disseminated up to 900 feet (274 m) but the effective range, as measured by established seedlings, averages about 40 feet (12 m). Germination and survival are best on mineral soils, averaging five times as many seedlings as on undisturbed surfaces (5). Successful seedling establishment has been noted in years with more than 4 inches (100 mm) of rainfall in May, June, and July. But if rainfall is deficient, some germination may be delayed up to 3 years. Little germination occurs at temperatures below 60° F (15.5° C) and is best at 70° F (21.1° C) or higher (5).

Direct seeding has only had limited success and is not widely used at present. The best success has been on mineral soil with the seed planted at a depth of 0.25 inch (6 mm) but most seed is broadcast on the surface following site preparation. Seed should be coated with bird and rodent repellents and sown in the spring at the rate of 15,000 viable seeds per acre (37 070/ha) (1). Red pine seed is normally not dormant and germinates promptly after spring sowing.

The most common method used to establish red pine stands is planting 400 to 1,200 trees per acre (990 to 2970/ha). Planting 800 trees per acre (1980/ha) will allow them to reach merchantable size for posts or pulpwood by the time the first thinning is needed, at about 25 years of age on the most productive sites and 35 years on the less productive ones, and will provide enough trees for periodic thinnings throughout the rotation. Planting bare-root stock should be done in the spring before growth begins, setting the trees the same depth or slightly deeper than they grew in the nursery (1). Container-grown seedlings can be planted any time during the growing season although fall planting is not recommended, especially on fine-textured soils where frost heaving may kill the seedlings. Sites with competing vegetation that may overtop the planted seedlings should be planted with large, vigorous seedlings. It is important to use seedlings with a well-developed root system and a favorable top-root ratio. Site preparation to reduce the competing vegetation will greatly improve survival.

Natural stands with less than 2,000 seedlings or saplings per acre (4940/ha) will thin themselves through mortality, but denser stands may stagnate. Dense stands respond well to thinning and red pines overtopped by oak and red maple for as long as 40 years have responded to release (5). Red pine is relatively resistant to damage from herbicides commonly used to release it from competing vegetation.

Red pine is less tolerant of shade than its common associates except the aspens, paper birch, and jack pine. It grows slowly at first but after 4 or 5 years height growth increases and seedlings usually reach breast height by 8 years of age. Some shade increases seedling survival on dry sites but it may seriously inhibit growth. A light overstory of only 30 square feet of basal area per acre (6.9 m^2/ha) will reduce volume growth by 70 percent (1).

Red pine is a long-lived tree and can grow in stands up to age 200 or more but commercial rotation age may be as low as 60 years in some managed stands. In stands managed at 100 square feet or more of basal area per acre (23.0 m^2/ha), mean annual board foot growth culminates around age 120 (1). The total net yield of 100-year-old, well-stocked, managed stands on site index 50 feet (15.2 m) averages about 40,000 board feet (fbm) (8000 cubic feet)[1] of sawtimber and approximately 2,000 cubic feet of pulpwood per acre (700 m^3/ha) and on site index 60 feet (18.3 m) about 55,000 fbm (11,000 cubic feet) of sawtimber and approximately 3,000 cubic feet of pulpwood per acre (980 m^3/ha) (2). More than half of the total yield is removed in periodic thinnings, beginning when the stand is approximately 30 years old. The initial planting density, timing of thinnings, and stand density left after thinning greatly affect tree diameter growth (6). Generally, recommendations based on obtaining maximum timber yields favor a higher initial stand density than those based on economic considerations.

Red pine is generally believed to have fewer natural enemies than most other trees commonly associated with it. However, trees may be injured or killed by disease, insects, animals, fire, or weather.

Diseases that have caused problems in red pine plantations include Scleroderris canker (*Gremmeniella abietina* (Lagerb.) Morelet) especially the European strain in the Northeast, Sirococcus tip blight (*Sirococcus strobilinus* Preuss.), and root rots (*Heterobasidium annosum* (Fr.) Bref. and *Armillariella mellea* (Vahl. ex Fr.) Karst.). Insects that sometimes damage red pine include the redheaded pine sawfly (*Neodiprion lecontei* (Fitch)), European pine shoot moth (*Rhyacionia buoliana* (Schiffermuller)), Sarotoga spittlebug (*Aphrophora saratogensis* (Fitch)), pine root collar weevil (*Hylobius radicis* Buchanan), pales weevil (*Hylobius pales* (Herbst)), and white grubs (*Phyllophaga* spp.) (5).

The leaders and shoots of red pine seedlings are sometimes nipped by white-tailed deer or snowshoe hare. During periods of peak populations, the snowshoe or varying hare may be very destructive. Mice occasionally damage planted trees in local areas by girdling them under the snow, and porcupines may girdle some larger trees by feeding on the bark.

Young red pine stands are susceptible to fire injury, but prescribed fires can be used in pole-size and larger timber to control understory development and help reduce the risk of wildfires. Mature trees are resistant to fire injury because of their thick bark but sometimes hot fires cause fire scars that can weaken trees and increase the risk of wind breakage. Red pine has a wide, spreading root system and is relatively wind firm, but occasionally suffers losses from wind, especially in old even-aged stands on exposed sites, such as along lakeshores (5).

Summer droughts and high surface temperatures frequently kill or injure young seedlings. Drought resistance varies with the condition of the trees but red pine is one of the most drought resistant conifers. Frost damage is more severe on dry than wet soils but red pine is generally frost hardy and only rarely is the succulent growth killed by frost. However, ice storms may cause breakage in dense sapling stands (5).

Even-age silvicultural systems are best for growing red pine because it is intolerant. The clearcutting, seed-tree, and shelterwood regeneration methods have occasionally been used successfully to naturally regenerate stands following a good seed crop or when advance regeneration was already established. Natural regeneration, however, is not very dependable so the most reliable silvicultural system to regenerate red pine is clearcutting the mature trees and planting a new stand (1). Planted stands range from only a few acres to more than 100 (40 ha) but a large proportion of them are about 40 acres (16 ha).

The seed-tree system, leaving about 6 trees per acre (15 trees/ha), received extensive trials in Minnesota as one of the first large-scale efforts to regenerate red pine (4). It had very limited success. New stands were established only where seeding, seedbed, and weather conditions were favorable so this system is not currently recommended for regenerating red pine (1).

The shelterwood system is recommended where esthetic or other multiple-use needs require the mature stand to overlap establishment of the seedling stand. Managed stands are periodically thinned beginning soon after the trees reach merchantable size. As stands near rotation age, advance regeneration can be encouraged by a heavier thinning or shelterwood cutting (4). If established seedlings are not adequate for a fully stocked stand at rotation age, planting or direct seeding will be needed. A shelterwood strip harvesting system that leaves about 16-foot (4.9 m) wide strips of mature trees between 50-foot (15.2 m) wide cleared strips can be used to keep large trees on the area until the seedling stand is well enough established to dominate the landscape. Removing the narrow shelterwood strips will provide access to the seedling stand for protection and cultural operations such as cleaning, releasing, thinning, and pruning (1). The shelterwood system should not be used in stands infected with Sirococcus tip blight because the disease may spread from the overstory trees to the seedlings.

Although red pine is not well suited to uneven-age silvicultural systems, it is sometimes desirable to keep continuous forest cover on special areas. Uneven-aged red pine stands require careful cutting of mature trees and frequent release of seedlings, saplings, and pole-size trees to maintain several age classes in small groups (1). The group selection system may also be appropriate for a more even

[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.

flow of products and uses from small areas where it is not possible to have enough age classes for even-age management. Growing trees to 100 years would require 50 acres (20 ha) to sustain cutting a one-half acre (0.2 ha) group every year or 10 acres (4.0 ha) to cut one group every 5 years.

The red pine type is dependent on planting not only to maintain its present area but to restore it on some of the several million acres where it once grew. Site preparation to remove excessive slash, to control shrubs and unmerchantable trees, and to prepare the soil for planting should be prescribed for each specific site. Planting stock, especially bare-root, requires careful handling to ensure successful establishment of high quality, vigorous seedlings.

Seedling stands need to be kept free from overtopping shrubs and trees to maintain favorable growth. One or more release cuttings or the use of selective herbicides will be needed on many areas. Commercial thinnings are recommended for merchantable stands with more than 140 square feet of basal area per acre (32.1 m^2/ha). Periodic thinnings should remove the smaller, slower-growing intermediate trees to favor the larger crop trees. High risk, poor quality, and damaged red pines should also be removed along with undesirable species at the periodic thinnings. Rotation ages in stands managed for recreation or visual quality may be extended beyond those recommended for timber production. On the other hand, stands managed for wildlife habitat may have much shorter rotations so that a larger proportion of the area is regenerated more frequently.

Red pine stands in general are not considered prime habitat for game birds and mammals, such as ruffed grouse and white-tailed deer. However, even-aged seedling stands provide a relatively open area for about a decade with a large variety of pioneer plant species favorable for edge wildlife. And dense sapling stands provide cover for many species of wildlife. Old-growth stands provide favorable habitats for some wildlife species such as the red squirrel, pine martin, and pileated woodpecker (5). As already noted, mice, voles, and chipmunks use red pine seed for food. The American bald eagle builds nests in large old-growth trees and several songbirds are associated with pine forests including the red-breasted nuthatch, blackburnian warbler, pine warbler, and chipping sparrow. Red pine stands managed near the minimum recommended stocking level for timber production will favor a greater variety of understory plants and increase the supply of wildlife food. Carefully planned landings for the periodic thinnings can also serve as wildlife openings and provide some of the desirable food plants for wildlife (1).

Although grazing domestic livestock in red pine stands is not a generally accepted practice, there is growing interest in utilizing this potential range resource. In trials underway in Minnesota, cattle are used to control growth of vegetation and prepare planting sites. Grazing has also been utilized in young red pine plantations as a means of reducing fire fuels.

The snow pack water content and the spring snowmelt runoff is higher in young red pine stands than in unplanted areas or those with deciduous trees (5). But watersheds with closed pine stands have more interception and less streamflow than those with aspen stands. Net precipitation under a mature red pine stand with 100 square feet of basal area per acre (23.0 m^2/ha) averaged 75 percent of gross precipitation compared to 84 percent under a comparable aspen stand (7). Red pine stands managed near the minimum recommended stocking level for timber production will yield more water than denser stands.

Stream temperature and water quality are influenced by tree species, stocking, and harvesting methods. Stands near lakes and warm water streams are desirable for shade and esthetics. In areas sensitive to erosion, harvesting operations need to be carefully planned to prevent soil and logging debris from getting into the water. Location of landings and skid trails may be critical and on some areas the erosion hazard may be severe enough to warrant harvesting only when the soil is frozen.

Stands of majestic red pine trees have a natural appeal to hikers, campers, and other forest visitors. In mature red pine stands used for camping or picnicking, undergrowth may be desirable for screening, but along traveled routes such as forest highways or trails, an open, parklike appearance is preferred. Heavy shade and a needle ground cover enhance the scenic effects. Red pine stands in and adjoining recreation areas should be managed to create or maintain a higher proportion of the forest in large trees with a general appearance of an old-growth stand.

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Jack Pine

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Jack pine (*Pinus banksiana* Lamb.) occurs in the northern forests of the United States and Canada. The range of the species extends latitudinally from 41°41′ N to 64°40′ N and longitudinally from 60° W to 127° W (15, 27, 28). The major portion of the species range is in Canada. In the United States it is found in Maine, northern New York, and the northern Lake States. Isolated stands occur in southeastern Minnesota, northern Illinois, northern Indiana, and New Hampshire. The range has been artificially extended by planting on strip-mined areas in the central and northeastern States and on the sand hills of Nebraska (8, 25, 29).

Although jack pine grows best on well-drained loamy sands, it is usually found on dry sandy or gravelly soils and it also occurs on loamy soils, thin soils over granites, and peats (12, 25, 29). The most extensive stands are found on level to gently rolling sand plains, usually of glacial outwash, fluvial, or lacustrine origin. It occurs less commonly on eskers, sand dunes, rock outcrops, and bald rock ridges (25).

In the Lake States jack pine is found chiefly at elevations between 1,000 and 1,500 feet (305 to 455 m). In the northeastern United States it grows on a variety of sandy sites from near sea level to about 2,000 feet (610 m) and an outlier in New Hampshire occurs at 2,500 feet (760 m)(25).

Except in the eastern part of its range where it grows in a maritime climate, jack pine is found primarily in diverse continental climates with short, warm to cool summers, cold winters, and low rainfall. The average January temperatures range from −20° to 25° F (−28.8° to −3.9° C) and the average July temperatures range from 55° to 72° F (12.7° to 22.2° C). Mean annual temperatures are between 23° and 49° F (−5.0° to 9.4° C) (28).

The frost-free period over much of the range is between 80 and 120 days. Generally, temperatures, frost-free period, and rainfall increase from the northwestern toward the southeastern part of the range so the averages from these factors may be higher in many areas in the Lake States and the northeast than the averages for the entire range (25).

Average annual precipitation ranges from 10 to 55 inches (255 to 1400 mm) but 15 to 30 inches (380 to 760 mm) are most common. The average warm season precipitation—April through September—ranges from 6 to 25 inches (150 to 635 mm). Summer droughts commonly occur in the Lake States (25).

Jack pine, a small- to medium-sized tree, is short-lived, intolerant, and a pioneer in succession. When a source of seed is available, jack pine establishes itself on areas where mineral soil has been exposed by disturbances such as fires. As a result, it is most often found in extensive pure even-aged stands of Society of American Foresters forest cover type 1 (17, 25). However, it also occurs in mixed stands and is a component of other forest types: black spruce (type 12); paper birch (type 18); aspen (type 16); red pine (type 15); and northern pin oak (type 14).

Associated tree species ranked from dry to mesic sites include northern pin oak (*Quercus ellipsoidalis* E. J. Hill), bur oak (*Quercus macrocarpa* Michx.), red pine (*Pinus resinosa* Ait.), quaking aspen (*Populus tremuloides* Michx.), bigtooth aspen (*Populus grandidentata* Michx.), paper birch (*Betula papyrifera* Marsh. var. *papyrifera*), northern red oak (*Quercus rubra* L.), eastern white pine (*Pinus strobus* L.), red maple (*Acer rubrum* L.), balsam fir (*Abies balsamea* (L.) Mill.), white spruce (*Picea glauca* (Moench) Voss), black spruce (*Picea mariana* (Mill.) B.S.P.), tamarack (*Larix laricina* (Du Roi) K. Koch), and balsam poplar (*Populus balsamifera* L.) (17, 25).

Jack pine is less shade tolerant than any of its principal associates except the aspens and paper birch. Thus, unless natural succession is interrupted by a major disturbance such as fire, jack pine is a temporary type that, at least on the better sites, is replaced by the more tolerant species (6, 7). On dry, sandy, low fertility sites, where associated species can scarcely survive, jack pine may form an epaphic climax (7).

After regeneration cuts, establishment and survival of jack pine from natural seeding is best on sites where mineral soil has been exposed, competition from other vegetation is not severe, some early but temporary partial shade is available, and the water table is within 5 to 6 feet (1.5 to 1.8 m) of the soil surface (12, 25). If conditions for germination and early seedling survival are not favorable, direct seeding following site preparation or planting will be required to establish a new stand. Seed for direct seeding should be coated with a bird and rodent repellent and sown at a rate of 20,000 viable seeds per acre (49 420/ha) (less if seeding is on prepared scalped spots only) early in the spring, or on snow in the winter to take advantage of snowmelt waters for germination (7).

If precipitation is lacking during germination and early seedling establishment, direct seeding will likely fail. If the first direct seeding fails, the site can be reseeded the following spring but some additional treatments to control competing vegetation and potential leaf smother may be necessary. When competing vegetation is to be controlled by phenoxy herbicides, timing and dosage must be carefully controlled to avoid injury to the jack pine seedlings. On sites where direct seeding cannot be successfully accomplished and on deep, dry, sandy soils planting will be necessary. Planting should be done in the spring when nursery-grown bare root stock is used, but container-grown stock can be planted throughout the growing season. Spacing should be about 6 to 8 feet (1.8 to 2.4 m) (7).

Under good early growing conditions in the greenhouse and/or nursery, female flowering may be initiated on a small percentage of seedlings before they are planted in the field (26). Jack pine begins to produce significant amounts of seed at 5 to 10 years in open stands but not until later in dense, closed stands (25, 27). The cones are serotinous and persistent so viable seeds can be retained on the trees for many years (25). These seeds are not released until the cones are opened by heat. Therefore, when stands are destroyed by fire, a new stand can be regenerated from the stored seed on the trees. Once cone production in jack pine begins, some seed is usually produced every year and total crop failures are rare (18, 25).

In southern parts of the jack pine range, cones on some trees are nonserotinous and begin releasing seed soon after they mature, so seed may be disseminated during any season. The effective range of seed dissemination is about two tree heights, but is low beyond one tree height (25).

Germination is best on exposed, moist mineral soil seedbeds and poorest on undisturbed litter and humus where the surface is apt to dry out rapidly (12, 25). Thus, fires that consume most of the litter and humus result in suitable seed beds. Mechanical equipment may also be used to bare the mineral soil (7, 31).

Jack pine seed occasionally exhibits some dormancy but under favorable conditions usually germinates to capacity within 15 to 60 days (25). However, some seeds have delayed germination (27) so substantial increases in stocking may be noted up to 3 years after direct seeding (24). Most germination occurs the first or second growing season following fire but mortality is also highest between the first and second growing seasons. Heat and drought are important factors causing seedling mortality. The partial shading and reduced evapotranspiration provided by slash and snags on cut-over or burned-over areas can contribute substantially to good germination and early survival (12, 22, 25). Once established, seedlings grow best in full sunlight (21). In natural stands, jack pine seedlings are usually not found under crown cover greater than 60 percent (25).

In well-stocked stands, jack pine develops into a short to medium tall, slender tree, with a narrow crown. In dense stands, it develops spindly stems that are susceptible to breakage by wind, ice, and snow. During the first 20 years, jack pine in its native range is the fastest growing conifer other than tamarack. In the Lake States, a 20-year-old stand on a site index 70 site will average 32 feet (9.8 m) tall and 4 inches (10 cm) in d.b.h. (7). Height growth slows in later years and by age 80 may be less than 6 inches (15 cm) per year. Mature trees are usually about 55 to 65 feet (16.8 to 19.8 m) tall and 8 to 10 inches (20 to 25 cm) in d.b.h. although trees 100 feet (30.5 m) tall and 25 inches (64 cm) in d.b.h. have been noted (7, 27).

Jack pine rotation ages of from 40 to 50 years are recommended for pulpwood production and from 60 to 70 years are recommended for poles and sawtimber (7). Total volume yields from well-stocked stands at 40 years will range from 950 cubic feet per acre (66.5 m^3/ha) on site index 40 sites to 2,500 cubic feet per acre (175.0 m^3/ha) on site index 60 sites. At age 60 yields on the same sites will be 1,630 cubic feet per acre (114.1 m^3/ha) and 3,800 cubic feet per acre (266.0 m^3/ha) respectively (7). Much shorter rotations may be used when growing jack pine biomass for fiber and/or energy on good sites, particularly when genetically improved stock is grown (27, 32).

Jack pine is subject to numerous agents that can cause damage or mortality at various stages of reproduction and growth. Cone and seed crops may be reduced by rainy weather at time of pollination and by red squirrels and other rodents that destroy cones and eat seeds (14, 25, 27). Cone and seed insects causing serious losses include the jack pine budworm (*Choristoneura pinus* Freeman), a mirid (*Platylygus luridus* Reuter), a cone borer (*Eucosma monitorana* Heinrich), the webbing coneworm (*Dioryctria disclusa* Heinrich), the red pine cone beetle (*Conophthorus resinosae* Hopk.), and various cone midges (*Lestodiplosis grassator* Fyles, *Resseliella silvana* (Felt), and *Asynapta hopkinsi* Felt) (23). Many other insects usually cause lesser direct damage to conelets, cones and seed or damage to potential cone-bearing shoots (19, 23). Ovulate and cone abortion, due to unknown causes, can also reduce seed crops (13).

Survival and growth of jack pine seedlings can be affected by many insects including root borers (*Hylobius* spp.); shoot and stem borers (*Pissodes* spp.); leaf feeders such as sawflies (*Neodiprion* spp.) and the introduced pine sawfly (*Diprion similis* (Hartig)), the jack pine budworm, the pine chafer (*Anomala oblivia* Horn), the pine webworm (*Tetralopha robustella* Zell.), and a tip moth (*Tortrix pallorana* (Rob.)); lodgepole needletier (*Argyrotaenia tabulana* Freeman), pine needleminer (*Exoteleia pinifoliella* (Chamb.)), pine needle sheathminer (*Zelleria haimbachi* Busck); root feeders including primarily white grubs (*Phyllophaga* spp.); and numerous sucking insects (30).

Many of the same insects that attack young trees are also active in sapling- and pole-sized stands but at least two destructive species, the pine root tip weevil (*Hylobius rhizophagus* M.B. & W.) and a pine tussock moth (*Parorgyia plagiata* Walker), prefer sapling- and pole-sized jack pine (25, 30).

Numerous diseases attack young jack pines reducing survival and growth[1] (25). Most serious are a needle rust fungus (*Coleosporium asterum* (Diet.) Syd.), Diplodia blight (*Diplodia pinea* (Desm.) Kickx.), Sirococcus shoot blight (*Sirococcus strobilinus* Preuss.), scleroderris canker (*Gremmeniella abietina* (Lagerb.) Morelet), sweetfern blister rust (*Cronartium comptoniae* Arth.), pine-oak (eastern) gall rust (*Cronartium quercuum* (Berk.) Miy. ex Shirai), pine to pine (western) gall rust (*Endocronartium harknessii* (J.P. Moore) Y. Hirat.), stalactiform rust (*Cronartium coleosporioides* (Diet. & Holw.) Arth.), mistletoe broom (*Arceuthobium americanum* Nutt. ex Engelm.), and root rot caused by *Armillariella mellea* (Vahl. ex Fr.) Karst.

Sapling- and pole-size jack pine suffer from Diplodia blight, the European strain of scleroderris canker, rust fungi, root rot fungi including annosum root rot caused by *Heterobasidium annosum* (Fr.) Bref., and major decay organisms including *Phellinus pini* (Thore ex Fr.) A. Ames, *Phaeolus schweinitzii* (Fr.) Pat., and *Fomitopsis pinicola* (Swartz ex Fr.) Karst. Sapling- and pole-size trees frequently show growth loss but rarely are killed by needlecast disease (*Davisomycella ampla* (Davids.) Dark.)[1] (25).

Severe droughts may kill established jack pine seedlings, particularly on coarse textured soils; saplings are more drought tolerant. Several mammals, including the white-tailed deer, snowshoe hare, and meadow vole can severely damage or kill young trees by feeding on them (25).

Fire is an important factor in the jack pine type. Most older stands were established following wildfires (25). Surface wildfires kill seedlings and saplings and hot fires can kill pole-size stands (7). But fire can also be used to obtain natural regeneration following cutting or to prepare sites for direct seeding or planting (1, 4, 5, 11). It can be used to reduce slash following cutting to reduce the hindrance to regeneration, to control shrubs and other vegetative competition, to reduce humus and litter and expose mineral soil seedbeds, and to open cones on remaining trees and on slash so seeds can be released. However, the use of fire in jack pine requires intensive, experienced supervision and even then the outcome is frequently unpredictable (5, 22).

Because of jack pine's intolerance, especially to shade, even-age management using the clearcutting, shelterwood, or seed-tree silvicultural system is the only practical method to maintain the forest type (6, 7).

The clearcutting method is recommended for harvesting most jack pine stands (6, 7). Regeneration can be obtained by direct seeding, by planting genetically improved seedlings of

[1] Skilling, D. D. Personal communication. October 15, 1981. U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station, St. Paul, Minn.

an adapted seed source, or by scattering serotinous cones from high quality trees (6, 7). Whichever regeneration method is used, some additional site preparation will usually be necessary to reduce slash, expose mineral soil seedbeds, and control competing vegetation.

Some existing stands may have originated by seeding from cull trees left in the previous harvest and some plantations established during the 1930's and 1940's and now being harvested were planted with nonadapted provenances or with stock from seed of poor quality open-grown trees (27). Catastrophic wood yield losses result from planting nonadapted provenances (20). Such stands are not a suitable source of seed for regeneration, so prescribed burning under conditions that will consume the slash and kill the seeds it contains should be considered, followed by planting or direct seeding with an adapted, desirable seed source.

If tree quality in a stand to be harvested is good and the cones are serotinous, a new stand can be established by scattering cone-bearing slash within 12 inches (30 cm) above prepared bare mineral soil seedbeds. The heat near the ground surface will open the serotinous cones and release the seed. The scattered slash will provide partial shade that is beneficial during germination and early seedling establishment, but care is needed to avoid accumulations of slash that might interfere with subsequent seedling development, provide habitat for high rodent populations, or present a fire hazard during the most vulnerable seedling stage. These problems are minimized if the slash is brought down close to the ground where the seed will be released quickly and the slash deteriorates rapidly.

The seed-tree system is an alternative silvicultural system for high quality stands with serotinous cones (6, 7). During the harvest, at least 10 well distributed, high quality seed trees should be left per acre (25 trees/ha). Prescribed burning is recommended to consume the slash, kill the vegetative competition, expose mineral soil, and open the cones on the seed trees. This method has the advantage of maintaining stand quality and of producing some genetic gain from generation to generation because the best can be selected as seed trees. For such potential gain to be realized, the prescribed burn must kill the seed in the slash to assure that regeneration is only from the selected trees. The slash should be burned as soon after harvest as it is dry enough, to minimize the time for windthrow-loss of seed trees before cones are opened by the fire and seeds dispersed. Early spring fires result in seeding at the most favorable time but late fall fires with the released seed overwintering for early spring germination may also be effective if rodent populations are low. If weather conditions following seed dispersal are unfavorable for seedling establishment, direct seeding or planting will be required because the seed trees will have been killed by the hot prescribed burn (7).

The shelterwood silvicultural regeneration system can be successful in vigorous, well-stocked jack pine stands in which trees with nonserotinous cones form at least 8 square feet of basal area per acre (1.8 m^2/ha) (7, 10).[2] The initial or regeneration cut should leave 30 to 40 square feet of basal area per acre (6.9 to 9.2 m^2/ha), favoring trees with open cones (10).

The removal cut should be made when milacre (4.0 m^2) stocking reaches 60 percent, usually from 7 to 10 years after the regeneration cut. Removal of the shelterwood overstory as soon as possible after adequate regeneration is established will reduce volume losses due to mortality in the shelterwood trees, seedling losses due to suppression and logging damage, and the risk of jack pine budworm buildup in the overstory and subsequent defoliation of the newly established seedlings (10).

There are several disadvantages of the shelterwood system for jack pine: first, regeneration of a fully stocked new stand may take longer than in the clearcut or seed-tree systems; second, control over stocking and density is lacking; and, third, stands containing a mixture of associated species may convert to other, more tolerant species so it may not be possible to maintain the jack pine type (10).

Intermediate cutting methods will depend on the initial stand density, economic feasibility, and whether the final crop is to be pulpwood, or poles and sawtimber. Precommercial and intermediate cuts in overly dense stands may not increase total volume yields but the growth will be concentrated on the better trees. Stands containing more than 2,000 sapling-size trees per acre (4940 trees/ha) should be precommercially thinned to about 1,000 trees per acre (2470 trees/ha) to improve growth and development of the potential crop trees (7). In denser young stands, mechanical methods that clear strips about 8 feet (2.4 m) wide and leave strips of trees about 2 feet (0.6 m) wide, for example, may be more efficient than leaving uniformly spaced trees. The mechanical equipment, however, frequently damages the crop trees and growth responses to precommercial thinning are not always favorable and may not justify the cost (2, 3, 9, 16).

For production of poles and small sawlogs, jack pine stands on site index 60- or-better sites respond well to commercial thinnings that can begin in stands at about age 30 (7). Stands can be thinned to 80 square feet of basal area per acre (18.4 m^2/ha) but no more than 30 percent of the basal area should be removed per thinning to minimize postlogging mortality. Row thinnings in plantations or other systematic methods are recommended only when economics or high stand densities prevent marking individual trees for removal. Thinning should remove the smaller, slower growing, and damaged or poor quality trees to improve overall stand quality (7).

Harvesting, site preparation, and regeneration practices in the jack pine type should be based on multiple-use objectives. Harvesting and site preparation on slopes and near lakes and streams must be carefully managed to protect the watershed and to prevent soil erosion and debris from entering the water. Harvesting when soils are frozen will reduce erosion hazards on some areas (7).

Many wildlife species find food or shelter in jack pine forests including major game species such as the snowshoe hare and the white-tailed deer (7). Clumpy stands of jack pine in the Lower Peninsula of Michigan between 5 and 20 feet (1.5 to 6.1 m) tall, provide nesting sites for the endangered Kirtland's Warbler. Management for this bird requires application of silvicultural systems that will periodically regenerate stands covering large areas of 80 acres (32 ha) or more to keep enough area in young stands where branches reach the ground to provide nesting sites (7).

Before applying silvicultural systems that make major changes in the appearance of an area, managers must also consider recreation and esthetic values of the jack pine type. Where it can be practically applied, the shelterwood system may be esthetically more pleasing than the clearcut or seed-tree system because a new stand is already established before the mature one is completely removed (10).

Jack pine has been planted on strip-mine areas, mine tailings, and pond levees; as windbreaks; and as protection for dunes and sand-blows (8, 25, 29).

[2] Schantz-Hansen, R. Personal communication. January 21, 1982. Potlatch Corporation, Cloquet, Minn.

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Black Spruce

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Black spruce (*Picea mariana* (Mill.) B.S.P.) occurs mainly in pure stands and makes up a majority of the stocking in the black spruce forest cover type, Society of American Foresters type 12 (1). Although primarily a Canadian type, it occupies 1.7 million acres (0.7 million ha) of commercial forest land in the northern Lake States (more than 1 million acres (0.4 million ha) in Minnesota), and approximately 300,000 acres (121 400 ha) in the Northeastern States (chiefly in northern Maine and New York).

In the Lake States the black spruce type grows mainly on glacial lake beds and lake-swamp-moraine plains at elevations averaging about 1,000 feet (305 m). In the Northeast most of the type is found in the Adirondack-New England highlands from elevations of about 1,000 feet (305 m) to more than 2,000 feet (610 m).

The black spruce type in the United States is found mainly on peatland sites where the organic soil or peat is more than 12 inches (30 cm) thick. The type also commonly occurs on transitional sites between peatlands and uplands, as well as on upland sites.

Most peatland sites are extensive areas on gently sloping lake beds or smaller filled lakes. In both cases site quality and associated vegetation differ greatly depending on water sources and movement (1). The most productive peatland sites occur where the soil water is continuous with the regional ground water system and thus contains nutrients from mineral soil areas. These sites have moderately well decomposed peat that includes much partially decayed wood and is dark brown to blackish. The poorest sites have thick deposits of poorly decomposed, yellowish brown sphagnum peat (7).

Transitional sites with shallow organic to wet mineral soils are among the most productive black spruce sites. In the Lake States the black spruce type is common on upland or mineral soil sites mainly on the Laurentian Shield in northeastern Minnesota and in a few isolated areas of Michigan's Upper Peninsula. On the Shield, black spruce grows on gravelly and bouldery loam and on shallow soil over bedrock, usually mixed with other species and occasionally as a pure type. Growth is best where the slope is gentle and moisture is plentiful, either from a shallow water table or seepage. South of the Shield, black spruce is sometimes found on sandy soil with a high water table (7).

The climate in which the black spruce type grows in the Lake States and Northeast is generally humid, with short, cool summers and long, somewhat severe winters. Average annual precipitation ranges from about 20 inches (510 mm) in northwestern Minnesota to 48 inches (1220 mm) or more in the Adirondack-New England highlands; most of the precipitation comes in the summer. Average annual snowfall ranges from about 40 inches (1015 mm) to more than 150 inches (3810 mm). Average July temperatures range from about 65° to 70° F (18.3° to 21.1° C); January temperatures range from 0° to 20° F (−17.8° to −6.7° C). The average frost-free period ranges from about 90 to 150 days.

Because of its exceedingly broad distribution (especially in Canada) and various ecological attributes, the black spruce type has been divided into six subtypes (1). Most of the type's commercial forest area in the Lake States and Northeast, however, is occupied by the following four subtypes: black spruce−feather moss, black spruce−sphagnum, black spruce−speckled alder, and black spruce−dwarf shrub. These subtypes occur mainly on peatland sites. Tamarack (*Larix laricina* (Du Roi) K. Koch) is the most common tree associate. Other common associates, especially on the better sites where the black spruce−speckled alder subtype is characteristic, include northern white-cedar (*Thuja occidentalis* L.), balsam fir (*Abies balsamea* (L.) Mill.), white spruce (*Picea glauca* (Moench) Voss), quaking aspen (*Populus tremuloides* Michx.), paper birch (*Betula papyrifera* Marsh.), black ash (*Fraxinus nigra* Marsh.), and red maple (*Acer rubrum* L.). Jack pine (*Pinus banksiana* Lamb.) is the most common associate on the drier sandy and rocky sites. Red spruce (*Picea rubens* Sarg.) is sometimes associated with black spruce and hybridizes with it in northern New England and New York (1).

Natural seeding is still the most important mode of reproduction in the black spruce type, although artificial (direct) seeding is being used extensively on large, peatland harvest areas in Minnesota. Vegetative reproduction by layering—where branches become buried in moss and develop adventitious roots—is common on poor sites, particularly in the black spruce−sphagnum subtype (1). Planting is often used on upland and transitional sites where associated trees are very competitive because it results in faster establishment and thus better control of composition. However, planting black spruce to reforest productive, brushy peatlands has met with little success despite many past attempts.

Black spruce stands 40 or more years old have a nearly continuous seed supply because the persistent cones shed seed for at least 4 years after ripening (7). Some new seed is produced almost every year; heavy crops occur at intervals of 2 to 6 years. Natural seeding is effective up to about 260 feet (79.2 m) from the windward edge of a mature stand and up to half that distance from the leeward edge (7).

Seedling establishment is generally successful on peatland sites if the surface organic layer is removed by fire or machine, compacted (as in a skid road), or composed of living sphagnum moss (*Sphagnum* spp.). Most types of sphagnum moss make good seedbeds, although some types outgrow black spruce seedlings and smother them. Other mosses—particularly the feather mosses *Pleurozium schreberi* (Brid.) Mitt., *Hylocomium splendens* (Hedw.) BSG, and *Ptilium crista-castrensis* (Hedw.) De Not.—dry up and die when a stand is opened and make extremely poor seedbeds. Thus seedbed conditions are usually much improved by removing or compacting such mosses (7), especially in the black spruce−feather moss subtype where they dominate the moss carpet.

On both peatland and upland sites fires that completely remove the surface organic layer usually prepare good seedbeds for black spruce. On upland sites, however, scarification that incorporates this layer into the mineral soil is probably a safer and more effective and economical way to prepare seedbeds. Moist mineral soils usually provide good seedbeds for black spruce (6), but exposed mineral soil may be too waterlogged or subject to frost heaving in some low-lying areas (12).

Except in poorly stocked stands, harvesting can produce a heavy cover of slash that buries good seedbeds (such as sphagnum moss) or suitable advance growth. Thus slash disposal by broadcast burning, full-tree skidding, or piling and burning usually favors black spruce reproduction.

Black spruce is shade-tolerant, but survival and growth of seedlings (and apparently layers) are much better in the open (3). Trees in older stands are generally susceptible to breakage or uprooting by wind because rot becomes common and black spruce has a shallow root system. Both breakage and uprooting occur mainly along stand edges exposed to the prevailing wind and in stands opened by partial cutting. However, wind damage is not heavy on poor sites where trees are short. Black spruce growing on peatlands is especially susceptible to mortality or reduced growth from impeded drainage, such as that caused by roads and beaver damming (7). Although black spruce is apparently tolerant of frost, new growth has been damaged by frost on young trees planted on transitional and upland sites.

Black spruce encounters substantial competition where associated trees and shrubs are abundant, especially on peatland and transitional sites occupied by the black spruce–speckled alder subtype. Although black spruce will eventually grow above such vegetation on most of these sites, slow growth and understocking result when it is severely suppressed for several years. Fortunately, quaking aspen and paper birch, which often reproduce well on peatland harvest areas, should not severely suppress black spruce except on the best sites. Aerial spraying of selective herbicides will usually release black spruce in brushy stands (7, 12).

Under normal conditions, mature black spruce averages from 40 to 65 feet (12.2 to 19.8 m) tall and about 9 inches (23 cm) in d.b.h. on good sites (12). However, height of dominant trees at 50 years ranges from about 45 feet (13.7 m) on the best sites to less than 15 feet (4.6 m) on the poorest (7). A site index of 25 feet (7.6 m) is about the minimum for commercial forest land. The growth rate of black spruce could undoubtedly be increased on peatlands by draining and fertilizing, but specific practices have not been developed (7).

Cordwood rotations based on variable-density yield tables for black spruce range from 60 to 150 years or more, depending on stand age and basal area. Most rotations have a range because the mean annual increment is near the maximum for a number of years. And young, well-stocked stands usually have shorter rotations than older, poorly stocked stands. However, except for excluding trees smaller than 3.6 inches (9 cm) in d.b.h., these rotations do not consider tree size (7). Therefore, excessively dense stands or those on poor sites may require longer rotations to produce merchantable yields.

Mature, even-aged stands of black spruce on good sites commonly yield 3,000 total cubic feet per acre (210.0 m^3/ha) or 30 cords per acre (189.0 m^3/ha) for trees 3.6 inches (9 cm) and larger in d.b.h. In contrast, many stands on poor sites never produce merchantable quantities of pulpwood (7). However, such stands have possible future use for producing energy (biomass), especially in northern Minnesota where they occupy large areas. Little is known about the growth and yield of uneven-aged stands, but they apparently grow more slowly and have lower volumes than even-aged stands (4).

Eastern dwarf mistletoe (*Arceuthobium pusillum* Peck) is the most serious disease of black spruce in the Lake States. Besides causing witches' brooms, it significantly reduces volume growth and eventually kills infected trees. Thus mistletoe should be controlled, especially on the better sites. Butt and heart rot caused by such fungi as *Phaeolus schweinitzii* (Fr.) Pat., *Haematostereum sanguinolentum* (Alb. & Schw. ex Fr.) Pouz., *Armillariella mellea* (Vahl. ex Fr.) Karst., and *Phellinus pini* (Thore ex Fr.) A. Ames can lead to windbreakage. Rot becomes common after about 70 years in upland stands and 100 years in peatland stands (3). It is serious enough in upland stands to usually limit their rotation to 70 years (7).

The spruce budworm (*Choristoneura fumiferana* (Clemens)) is generally the most important insect pest of black spruce, particularly when black spruce is mixed with balsam fir. Budworm defoliation for several years in succession may result in moderate to severe mortality. The yellowheaded spruce sawfly (*Pikonema alaskensis* (Rohwer)) sometimes severely defoliates young, open-grown black spruce whereas most dense stands (natural or planted) are practically immune to attack.

Snowshoe hares may extensively damage black spruce seedlings and saplings when hare populations are high. Red squirrels gather cones in large quantities, and thus may consume much of the seed supply in some areas during poor seed years.

Black spruce is easily killed by both ground and crown fires. However, the risk of wildfire is low on most black spruce areas in the United States and good fire protection now results in little loss (7).

Many of the present black spruce stands originated after wildfire because mature trees (even if killed) bear persistent cones that disseminate viable seed (3). These stands are generally even-aged, although closed stands that escape fire for more than 100 years usually become uneven-aged because new trees begin to fill in as overstory trees die. Also, the less tolerant black spruce is eventually succeeded by balsam fir and, to a lesser extent, northern white-cedar if undisturbed by fire, especially on the better upland and peatland sites (4, 5).

Broadcast burning of slash is a common practice for favoring black spruce reproduction on peatland harvest areas in the Lake States, especially Minnesota. Under prescribed conditions, it is a safe and efficient way not only to dispose of slash but also to simultaneously kill residual conifers, eradicate dwarf mistletoe, improve nonsphagnum seedbeds, and kill the stems of brush species. Although the last two items apparently require more severe burns than the others, burning should not be done during abnormally dry periods when fires can burn deeply in peat and become extremely difficult to extinguish (7).

The black spruce type is usually managed to produce a high sustained yield of pulpwood as efficiently as possible without adversely affecting other forest resources. For this objective, the type can probably be managed best in fairly large, even-aged stands similar to those in virgin forests. Such stands should be well suited for efficient cultural operations and mechanized harvesting (7). Uneven- or all-aged management is best applied on poor sites where stands are windfirm and have abundant layering, and where only the largest trees produce pulpwood anyway. The poorest sites should be managed mainly for Christmas trees if a market exists (7).

Black spruce is well adapted to even-aged management. Clearcutting in strips or patches is generally considered the best silvicultural system for managing the type (7, 12). This is because clearcut areas provide the full light needed for optimum survival and growth, and they have no wind damage. However, adjacent strips or stands of mature timber should not be exposed to the prevailing wind or serious damage may occur along their edges. Clearcutting is definitely better than the shelterwood and seed-tree systems for controlling dwarf mistletoe because all infected trees (including advance reproduction) should be killed by cutting or broadcast burning (7).

In contrast, areas with a shelterwood have slower growing reproduction, and in both the seed-tree and shelterwood systems many of the reserved trees are broken or uprooted by wind. However, the shelterwood system is a satisfactory alternative in small, fairly windfirm stands in which clearcutting is undesirable for esthetic or other reasons. An advantage of the shelterwood system in mixed stands is that the proportion of black spruce reproduction can probably be increased by removing associated trees during the first or seed cutting.

So, except under special conditions or perhaps on poor sites, black spruce stands should be clearcut at maturity, either in strips to be seeded naturally or in large patches followed by direct seeding. Strips (preferably progressive rather than alternate) can be applied best in large, windfirm stands that do not require broadcast burning. They should generally be perpendicular to and progress toward the prevailing wind direction, and can be 260 feet (79.2 m) wide with natural seeding from the windward side. An advantage of burning large patches of 40 acres (16 ha) or more is that it substantially reduces site preparation costs per unit area. A disadvantage is that it is sometimes difficult to obtain enough seed of acceptable provenance at reasonable cost to regenerate the area (7).

Broadcast burning of the slash will foster establishment and growth of new stands when any of the following conditions exist on the harvest area before or after a clearcut: witches' brooms (from dwarf mistletoe) are readily noticeable; undesirable residual stems are abundant; brush is readily noticeable; sphagnum seedbeds are poorly distributed; or slash cover is heavy (7). However, if slash cover is the only problem expected, full-tree skidding can be used as a satisfactory alternative to broadcast burning (8).

In the uneven-aged management of black spruce on poor sites, individual tree selection is the best silvicultural system to use, whether for producing pulpwood or Christmas trees. Stands managed for Christmas trees should be partially cut about every 10 years or some trees may become unmarketable (7). On better sites selection cutting will generally increase the proportion of balsam fir and northern white-cedar in the succeeding stand.

Heavy thinning in dense, middle-aged black spruce stands increases diameter increment but often decreases volume increment, probably because the site is not fully utilized (10, 11). Thinning of overstocked stands in the sapling and pole stage is not recommended due to the low economic return and risk of increasing wind damage (7).

The spruce grouse depends mainly on the black spruce type for food and cover (7); the snowshoe hare and red squirrel also use it to a large degree. Birds common in black spruce stands during the summer include the ruby-crowned kinglet, magnolia warbler, and Cape May warbler. Others such as the pine grosbeak, pine siskin, and crossbills sometimes feed on black spruce seed (2). And the American osprey, a sensitive species, often nests in lowland types such as black spruce.

Small stands of black spruce add diversity to the landscape, and ones that border other vegetation types—especially tamarack, which turns yellow in the fall—are esthetically appealing (9). Mature, nonbrushy stands with a carpet of moss have special appeal, as do the crops of blueberries (mainly *Vaccinium angustifolium* Ait.) that often grow on harvest areas during the establishment period. The impact of harvesting black spruce on esthetics can be minimized by having harvest boundaries follow natural type lines and disposing of slash or other debris to leave harvest areas neat (7).

Clearcutting black spruce on peatland sites has little effect on annual water yields or water tables. And nutrient concentrations in streamflow should not increase significantly unless harvesting (with or without broadcast burning) is on a massive scale (9). However, harvesting should be done only in winter after the ground is frozen and snow-covered to minimize peat disturbance and its possible effect on water quality. Also, the normal movement of water must be maintained to prevent damage from impeded drainage (7).

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Tamarack

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Tamarack (*Larix laricina* (Du Roi) K. Koch) is pure or comprises a majority of the stocking in the tamarack forest cover type, Society of American Foresters type 38 (7). Besides being a widespread type in Canada, it occupies 850,000 acres (344 000 ha) of commercial forest land in the northern Lake States (55 percent of which occurs in Minnesota) and 110,000 acres (45 000 ha) in the Northeastern States (almost all in Maine).

In the Lake States the tamarack type grows mainly on glacial lake beds and lake-swamp-moraine plains at elevations averaging about 1,000 feet (305 m). In Maine most of the type is found between the Atlantic coast and New England highlands from elevations of less than 500 feet (150 m) to more than 1,000 feet (305 m).

The tamarack type in the United States occurs mainly on poorly drained sites and occupies extensive areas on such sites in northern Minnesota. It commonly grows on wetter sites than black spruce (*Picea mariana* (Mill.) B.S.P.) (7). However, the type grows best on more favorable sites such as moist but well-drained, loamy soils along streams, lakes, and swamps; seep areas; and mineral soils with a shallow, surface layer of organic matter (3).

The tamarack type is found especially on peatland sites where the organic soil or peat is more than 12 inches (30 cm) thick. It occurs on the full range of peatlands from rich swamp (forested rich fen) to raised bog but is most characteristic of poor swamps where the soil water is weakly enriched with mineral nutrients (4). Along the southern limits of the type's range tamarack is found in small scattered stands on poor peatland (bog) sites (7).

The climate in which the tamarack type grows in the Lake States and Maine is generally humid, with short, cool summers and long, somewhat severe winters. Average annual precipitation ranges from about 20 inches (510 mm) in northwestern Minnesota to 48 inches (1220 mm) near the Atlantic coast in Maine; most of the precipitation comes in the summer. Average annual snowfall ranges from about 40 inches (1015 mm) to more than 150 inches (3810 mm). Average July temperatures range from about 65° to 70° F (18.3° to 21.1° C); January from 0° to 20° F (−17.8° to −6.7° C). The average frost-free period ranges from about 90 to 150 days.

In mixed stands, black spruce is usually tamarack's main tree associate on all sites. Other common associates in the United States, especially on the better peatland (swamp) sites, include northern white-cedar (*Thuja occidentalis* L.), balsam fir (*Abies balsamea* (L.) Mill.), black ash (*Fraxinus nigra* Marsh.), and red maple (*Acer rubrum* L.) (7). Paper birch (*Betula papyrifera* Marsh.) and eastern white pine (*Pinus strobus* L.) are common associates on transitional sites between peatlands and uplands.

The tamarack type commonly supports an understory of black spruce, and because of the light shade cast, it usually has a dense undergrowth of shrubs and herbs. Dominant tall shrubs include low birch (*Betula pumila* var. *glandulifera* Regel), willows (*Salix* spp.), speckled alder (*Alnus rugosa* (Du Roi) Spreng.), and red-osier dogwood (*Cornus stolonifera* Michx.) (7).

Presently, natural seeding is the only important mode of reproduction in the tamarack type. Although little tamarack has been planted, tests indicate good growth on mineral soil sites but not on peatland sites. Vegetative reproduction is uncommon in tamarack. However, layering may occur when branches are covered by fast-growing sphagnum moss (*Sphagnum* spp.) and roots are known to produce shoots (3). Practically no tamarack has been artificially (direct) seeded, even experimentally.

Seed production in large quantities begins when tamarack trees are about 40 years old, with the optimum age being about 75 years. Vigorous, open-grown trees produce the best cone crops; seed production in stands is generally confined to dominant and codominant trees. Tamarack bears good seed crops at intervals of 3 to 6 years, with some seed produced in intervening years. Seed dispersal occurs from September to spring, but apparently most of the seed is released by the end of October. Although little seed falls at a distance greater than twice the tree height (3), tamarack can reproduce well as far as 200 feet (61.0 m) from seed-bearing trees if favorable seedbeds are present (6).

The best seedbed is warm (65° to 70° F (18.3° to 21.1° C)), moist mineral or organic soil with no brush but a light cover of grass or other herbaceous vegetation. Hummocks of slow-growing sphagnum moss often make a good seedbed, but some sphagnum mosses may offer too much competition (3). Findings from peatland harvest areas in Minnesota show that slash-burned seedbeds favor tamarack reproduction, whereas slash hinders it (6). On uplands, tamarack apparently reproduces well on rock-raked areas after natural seeding.

Up to half the tamarack seed that falls may be destroyed by rodents. As a result of this loss plus that by fungi or bacteria, only a small percent of the seed may germinate (3). In addition, tamarack seed apparently germinates poorly, even under greenhouse conditions.

For best growth tamarack seedlings need abundant light and a constant water level. Seedlings established under fully stocked stands do not survive beyond the sixth year; those under little or no cover may be as tall as 18 to 25 inches (46 to 64 cm) by the third year. Early seedling losses are primarily caused by damping-off; drought, flooding, and inadequate light sometimes cause appreciable loss in the second and third years, and snowshoe hares kill many seedlings in some areas (3).

Tamarack is very intolerant of shade. Although it can tolerate a little shade during the first 3 or 4 years, it must become dominant to survive. Abnormally high water levels often kill tamarack stands, and those that survive under very wet conditions usually grow very slowly (3). Wetland road crossings and beaver damming are the primary causes of such flooding damage. Strong winds can uproot large tamarack trees growing in swamps or other wet sites where rooting is shallow (3). However, compared with black spruce, tamarack seems to be fairly windfirm, probably because of its wide root system (1, 3).

Various tests, especially those on brushy peatlands in Minnesota, indicate that competing vegetation hinders the establishment of tamarack. Also, because tamarack is very intolerant, it cannot compete with its associates (7). Thus tamarack is practically never found in the understory when mixed with other species, and it does not become established in its own shade. Consequently, the more tolerant black spruce eventually succeeds tamarack on poor (bog) sites; northern white-cedar, balsam fir, and swamp hardwoods succeed tamarack on good (swamp) sites (3).

With abundant light, tamarack is one of the fastest growing conifers on uplands in the northern forest region (3). And on peatlands it outgrows any other native conifer (1, 3). However, growth apparently drops sharply when the crowns close (3) or after the age of 40 to 50 years.

Average height of mature, peatland tamaracks is 50 to 75 feet (15.2 to 22.9 m) and d.b.h.'s are usually 14 to 20 inches (36 to 51 cm) (3). However, the growth rate of tamarack differs greatly, with the potential being much greater on uplands than on peatlands. Height of dominant trees at 50 years ranges from more than 60 feet (18.3 m) on the best swamp sites to less than 15 feet (4.6 m) on the poorest bog sites. A site index of 35 feet (10.7 m) is about the minimum for commercial forest land.

No yield tables have been published for tamarack, so rotations based on age at culmination of mean annual increment cannot be recommended. Generalized rotations derived from State and National Forest silvicultural handbooks or guides for Minnesota and Wisconsin are as follows: 90 years for a site index of 50 feet (15.2 m), 100 years for 40 feet (12.2 m), and 120 years for 30 feet (9.1 m). However, some agencies use a rotation of 90 or 100 years for all site indexes. These rotations apply mainly to peatland sites. The State of Wisconsin recommends a rotation of 70 years for all mineral soil sites.

Little is known about the growth and yield of tamarack stands. Limited data indicate that the annual growth of poletimber stands in northern Minnesota is from 0.3 to 0.4 cord per acre (27.0 to 36.0 ft^3/acre or 1.9 to 2.5 m^3/ha). In 70- to 100-year-old stands, annual periodic growth averaged 0.6 cord per acre (54.0 ft^3/acre or 3.8 m^3/ha) on well-stocked plots with a basal area of 93 square feet per acre (21.4 m^2/ha) and 0.3 cord per acre (1.9 m^3/ha) on poorly stocked plots with 35 square feet per acre (8.0 m^2/ha) (3). Basal area ranged from 55 to 102 square feet per acre (12.6 to 23.4 m^2/ha) among six pure stands that were sampled when 72 to 119 years old (at breast height) on medium to poor peatland sites in northern Minnesota (9).

The larch sawfly, *Pristiphora erichsonii* (Hartig), is the most destructive insect enemy of the tamarack type. Epidemics occur periodically across the northern United States and Canada (8), causing defoliation of tamarack stands over large areas for several successive years. Growth is greatly reduced and many trees are killed (3). Recurring outbreaks have reduced the type's area and speeded the succession to black spruce or other associates (7).

The larch casebearer, *Coleophora laricella* (Hübner), is also a serious defoliator of tamarack. A native of Europe, it is now widely distributed in eastern North America, including the Lake States (3, 8). The larch casebearer attacks tamarack of all ages, and several severe outbreaks have caused extensive mortality in some areas (10). However, outbreak severity has lessened in recent years, probably because imported parasites of the casebearer have also become widely established (8).

Rusts, such as the leaf rust caused by the fungus *Melampsora medusae* Thüm., are the only common foliage diseases of tamarack and they do little damage (5). Root- and butt-rot fungi include *Armillariella mellea* (Vahl. ex Fr.) Karst. and *Inonotus tomentosus* (Fr.) S. C. Teng. The principal heart-rot fungi are *Fomitopsis officinalis* (Vill. ex Fr.) Bond. & Sing. and *Phellinus pini* (Thore ex Fr.) A. Ames. Rot fungi, however, are not aggressive killers of tamarack (5).

Porcupines commonly feed on the inner bark of tamarack and deform the stem or kill the tree. Many stands of tamarack have been damaged by this pest in the Lake States. The animal is also an enemy of tamarack in Maine (3).

Tamarack is highly susceptible to fire damage except perhaps in older, upland stands. On peatlands it is usually killed by all but very light burns (3). The habitat of tamarack in the United States, however, is normally wet enough to protect the type from fire.

Tamarack is fairly well adapted to reproduce successfully on burns. Thus it is a pioneer type, especially on burned peatlands; and stands on peatlands have been reproduced in the past mainly in areas cleared by wildfire (7). Although slash-burned seedbeds favor tamarack reproduction, the use of fire on harvest areas depends at least partly on stand composition. Fire is not considered useful for pure tamarack stands because pure tamarack slash is difficult to broadcast burn (6). However, broadcast burning the slash from mixed (or other) peatland conifer stands will probably increase the tamarack component if the new stands receive ample tamarack seed.

The tamarack type is usually managed to produce a high sustained yield of pulpwood, but other products such as poles and sawtimber may also be grown. The intolerance of tamarack dictates the use of even-aged management to maintain the type or it will be succeeded by more tolerant associates such as black spruce.

Some adaptation of clearcutting or seed-tree cutting is generally considered the best silvicultural system for managing the type. This is because tamarack seeds apparently germinate better in the open and the seedlings require practically full light to survive and grow well. Also, tamarack is usually windfirm enough for the seed-tree system to succeed. An advantage of this system in mixed stands is that the proportion of tamarack reproduction can probably be increased by leaving only tamarack seed trees during harvesting.

Research and experience on specific cutting practices for reproducing tamarack are limited, but recommendations are available from State and National Forest silvicultural handbooks or guides for Minnesota and Wisconsin. Except in small stands (less than 10 acres or 4.0 ha), a combination of clearcut and seed-tree strips is recommended. Strips in sets of three are suggested—the first two would be clearcut progressively, with natural seeding from the adjacent uncut strip(s), and the last strip would leave seed trees. If favorable seedbeds are present, clearcut strips perpendicular to the prevailing wind direction can be 200 feet (61.0 m) wide with seeding from the windward side. Seed trees should be well-spaced dominant tamaracks numbering about 10 per acre (25/ha).

Though usually less efficient to administer than strips, clearcutting in small patches is a satisfactory alternative for reproducing tamarack by natural seeding. And in small stands where harvesting in strips or patches is impractical, the entire stand can be removed at one time, leaving seed trees if necessary. Because tamarack is very intolerant, the shelterwood system will favor more tolerant associates such as black spruce. Thus it is an appropriate system only where removal of all (or nearly all) trees is undesirable for esthetic or other reasons. The first or seed cutting should be from below and leave a residual basal area of about 30 to 40 square feet per acre (6.9 to 9.2 m^2/ha), with the objective of obtaining a crown closure of 30 to 50 percent.

In addition to cutting practices, satisfactory reestablishment of tamarack will often require site preparation. Broadcast burning of slash is the preferred method because it not only improves seedbeds by removing slash and the surface organic layer but also controls competing vegetation by killing residual conifers and the stems of brush species. However, burning should not be done during abnormally dry periods when fires can burn deeply in peat and become extremely difficult to extinguish.

If broadcast burning is not feasible (for example, because of pure tamarack slash), the slash can be removed by full-tree skidding and the area herbicide-sprayed to keep brush from overtopping tamarack seedlings (6). Other alternatives include piling and burning the slash and shearing or chopping the brush. Sedges and grasses can also hinder the reestablishment of tamarack, but satisfactory control methods have not been developed.

Little information is available on intermediate cutting methods for tamarack except recommendations from State and National Forest silvicultural handbooks or guides for Minnesota and Wisconsin. Thinning is probably economically feasible only on good sites when the objective is to grow high quality products such as poles and sawtimber. If a market exists for smaller products such as posts and pulpwood, a commercial thinning can be made as soon as the stand will produce these products. Additional, periodic thinnings are recommended up to 20 years prior to the end of the rotation. Each thinning should leave a basal area of 80 to 90 square feet per acre (18.4 to 20.7 m^2/ha) in the faster growing, better formed trees.

The tamarack type is utilized to some extent by such mammals as the red squirrel, snowshoe hare, and porcupine. Because tamarack stands are deciduous and usually have a dense undergrowth of shrubs, their avian community includes bird species common in shrubby areas as well as species generally associated with hardwood forests. Birds common in tamarack stands during the summer include the white-throated sparrow, song sparrow, veery, common yellowthroat, and Nashville warbler (2). The American osprey, a sensitive species, often nests in lowland types such as tamarack. And the great gray owl, a rare winter visitor in the northern Lake States, apparently nests there only in the tamarack peatlands of northern Minnesota.

The tamarack type is esthetically appealing, especially in early autumn when the trees turn yellow. Also, a tamarack component frequently grows at the fringe around black spruce peatlands, providing a pleasing contrast of colors in the fall. The impact of harvesting tamarack on esthetics can be minimized by having harvest boundaries follow natural type lines and leaving tamarack seed trees.

Management of the tamarack type probably has little or no effect on water yield or quality because harvesting is generally on a small scale. However, harvesting should be done only in winter after the ground is frozen and snow-covered to minimize peat disturbance and its possible effect on water quality. Also, the normal movement of water must be maintained to prevent flooding damage.

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Balsam Fir

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The balsam fir forest cover type is common in the northern portions of New England, New York, Michigan, Wisconsin, and Minnesota. It is type 5 of the Society of American Foresters forest cover types and one of 12 that is combined into the spruce–fir type group by the USDA Forest Service (2). The balsam fir type totals more than 7 million acres (2.8 million ha) of commercial forest land or about 60 percent of the spruce–fir type group. Recent forest inventories show 5 million acres (2.0 million ha) in the Northeastern States and 2 million acres (0.8 million ha) in the Lake States. The balsam fir type often grades into one of the other forest cover types included in the spruce–fir type group and it may be more appropriately managed as spruce–fir, particularly if the objective is to favor spruce.

Balsam fir (*Abies balsamea* (L.) Mill.) stands grow on a wide range of sites from gravelly sands to peat swamps but they develop best on moist, well drained, sandy loam soil classified as Alfisols. They occur at elevations from sea level along the New England coast to over 3,000 feet (915 m) in the New England-Adirondack and Appalachian highlands and between 700 and 1,400 feet (215 and 425 m) in the Lake States. The climate is cool and moist with average temperatures 70° F (21.1° C) or less and average monthly precipitation 3 inches (76 mm) or more during the growing season. The frost free period is from 80 to 180 days. Average annual minimum temperature ranges from 0° to −40° F (−17.7° to −40.0° C) and average annual maximum temperature is around 90° F (32.2° C) (3). Average annual precipitation ranges from 20 to 50 inches (510 to 1270 mm).

Balsam fir stands have several associated tree species that are common in both the Northeastern States and the Lake States. They include paper birch (*Betula papyrifera* Marsh.), quaking aspen (*Populus tremuloides* Michx.), bigtooth aspen (*Populus grandidentata* Michx.), red maple (*Acer rubrum* L.), sugar maple (*Acer saccharum* Marsh.), yellow birch (*Betula alleghaniensis* Britton), eastern hemlock (*Tsuga canadensis* (L.) Carr.), and eastern white pine (*Pinus strobus* L.) on the moist uplands. On the wetter sites, associates are white spruce (*Picea glauca* (Moench) Voss), black spruce (*Picea mariana* (Mill.) B.S.P.), northern white-cedar (*Thuja occidentalis* L.), tamarack (*Larix laricina* (Du Roi) K. Koch), black ash (*Fraxinus nigra* Marsh.), and balsam poplar (*Populus balsamifera* L.). Other common associates in the Northeast are red spruce (*Picea rubens* Sarg.) and American beech (*Fagus grandifolia* Ehrh.). Undergrowth associated with the balsam fir type include speckled alder (*Alnus rugosa* (Du Roi) Spreng.), beaked hazel (*Corylus cornuta* Marsh.), mountain maple (*Acer spicatum* Lam.), pin cherry (*Prunus pensylvanica* L.f.), red-osier dogwood (*Cornus stolonifera* Michx.), red raspberry (*Rubus idaeus* L.), and blueberries (*Vaccinium* spp.). Some of the common herbaceous plants are bracken (*Pteridium aquilinum* (L.) Kuhn), twinflower (*Linnaea borealis* L.), bunchberry (*Cornus canadensis* L.), starflower (*Trientalis borealis* Raf.), sedges, and several mosses (2).

Seed production begins early in balsam fir and good seed crops occur every 2 to 4 years after age 30. Cones mature toward the latter part of August or early September and most of the seed is disseminated within a few weeks. The cones shed their seeds and scales, which are often coated with pitch, leaving the characteristic candle standing erect near the tips of the upper branches. Many of the seeds stick tothe cone scales and fall near the base of the tree. Although not all balsam fir seed show dormancy, best germination has been obtained by stratifying seeds in a wet medium at 41° F (5.0° C) for 3 months or longer. Natural seeding in the fall allows the seed to stratify over winter on the forest floor (7).

Balsam fir seed averages about 60,000 per pound (132 280/kg) and 5 or more pounds per acre (6 or more kg/ha) are produced in a good seed year (3). The effective seeding distance from a mature tree is probably less than 200 feet (61.0 m).

The frequent seed crops and the ability of seedlings to become established and survive for several years in dense shade assures a continuous supply of small seedlings in most mature balsam fir stands (7). Most seed germinates from late May to early July with an average germinative capacity of about 26 percent (3). Almost any moist seedbed is considered satisfactory but exposed mineral soil with some shade is best. Humus layers deeper than 3 inches (8 cm) are less favorable seedbeds especially if they are in the open. Seedling losses the first year are often heavy due to late germinants, surface temperatures exceeding 115° F (46.1° C), drought, frost heaving, or smothering by leaves and other litter. Best seedling establishment is under a light to moderate forest cover.

Balsam fir is very tolerant of overstory competition. Of all the commonly associated tree species only eastern hemlock, American beech, and possibly red spruce and sugar maple, are as tolerant. Seedlings can become established in fairly dense shade with only 10 percent of full sunlight (1). Early growth is determined by the amount of overhead shade. Balsam fir can grow in dense shade for the first 6 or 8 years and will survive for many years. After the first few years, however, best growth is in 45 percent or more of full sunlight where seedlings reach breast height in about 10 years.

Balsam fir is a small- to medium-sized tree reaching average diameters of from 12 to 18 inches (30 to 46 cm) and average heights of from 30 to 80 feet (9.1 to 24.4 m) depending on site quality. Although individual trees have been reported to live up to 200 years, balsam fir stands break up at much younger ages. Pathological rotation age, especially on upland soils, is between 70 and 80 years, and economic rotation is usually from 45 to 55 years.

Well-stocked even-aged balsam fir stands will yield from 2,500 cubic feet per acre (175.0 m^3/ha) on low quality sites to more than 4,000 cubic feet per acre (280.0 m^3/ha) on high quality sites at 50 years of age (5). Uneven-aged stands will yield about 400 to 800 cubic feet per acre (28.0 to 56.0

m^3/ha) at 10-year cutting cycles on low-to-high quality sites, respectively (1).

Site quality, as measured by 50 year site index, ranges from 30 to 70 feet (9.1 to 21.3 m). Tree ages are determined at breast height because the tolerant balsam fir seedlings may be suppressed many years before trees are released and free to grow. The use of some site index curves requires adding an assumed average number of years to reach breast height which may range from about 10 years for open-grown seedlings to 15 years or more for suppressed seedlings. Despite the problems associated with using site index in balsam fir stands, it is the method most commonly used to estimate productivity.

Insects and diseases are usually not serious limiting factors in the production of seed because balsam fir is a prolific seed producer and has frequent good seed crops. However, little seed is produced during spruce budworm (*Choristoneura fumiferana* (Clemens)) epidemics, and the fir coneworm (*Dioryctria abietivorella* (Grote)) commonly attacks cones and may cause seed losses. The seeds are often coated with pitch which may make them less attractive than other food for insects as well as for birds and rodents. Balsam fir seedling mortality due to insects and diseases is unknown but total losses of seedlings in the open are few after the first or second year.

Insects and diseases seldom threaten immature balsam fir stands except during severe outbreaks. Mature trees, however, are the prime hosts for the spruce budworm—one of the tree's most damaging enemies. Overmature stands are likely to have the heaviest damage. Extensive outbreaks have occurred periodically both in the Lake States and in the Northeastern States. Dense stands that are pure or have a high proportion of balsam fir are the most susceptible but managing for better age class distribution of future stands may reduce the risk of outbreaks. Other insects that feed on foliage and damage balsam fir include the balsam woolly adelgid (*Adelges piceae* (Ratzeburg)), hemlock looper (*Lambdina fiscellaria fiscellaria* (Guenee)), eastern black-headed budworm (*Acleris variana* (Fernald)), and the balsam fir sawfly (*Neodiprion abietis* (Harris)).

Heart rot begins early in balsam fir and by age 50 about 20 percent of the trees are infected. It spreads rapidly, doubling in the next decade, and by age 70 more than half the trees are infected (1). Red heart trunk rot is caused by *Haematostereum sanquinolentum* (Alb. & Schw. ex Fr.) Pouz. Although trunk rot and top rot cause most of the cull in standing trees, butt rots weaken trees and make them susceptible to wind breakage. White stringy butt rot is caused by a number of fungi (*Scytinostroma galactinum* (Fr.) Donk., *Resinicium bicolor* (Alb. & Schw. ex Fr.) Parm., *Poria subacida* (Pk.) Sacc., and *Armillariella mellea* (Vahl. ex Fr.) Karst.). Brown cubicle butt rot is caused by several different fungi (*Coniophora puteana* (Schum. ex. Fr.) Karst., *Tyromyces balsameus* (Pk.) Murr., and *Serpula himantioides* (Fr. ex Fr.) Karst.).

Balsam fir is subject to losses from wind breakage and because of its shallow roots it is also subject to losses from uprooting, especially on wet and thin soils. The shallow root system, thin resinous bark, long crown, and flammable needles make it difficult for balsam fir to survive fires. Although trees are easily killed by fire, the moist wet sites help reduce the chances of fires in the balsam fir type. Because of thin bark, care also is required to reduce damage during logging.

Both even-aged and uneven-aged silvicultural systems are applicable to the balsam fir type. Even-aged systems are preferred, but uneven-aged management is possible because the tree is tolerant of shade and seedlings can and do become established in the understory. Uneven-aged management should be limited to sites where balsam fir can maintain itself as a climax type without the need for excessive silvicultural practices. On all other sites, even-aged management is generally recommended.

Mature even-aged stands well stocked with advance regeneration can be harvested by the clearcut method. Advance regeneration should be 3 feet (1 m) or taller on sites with average brush competition and 6 inches (15 cm) or taller on sites without competition or where it is only minor. In mature stands that do not have adequate advance regeneration, the shelterwood method applied in narrow strips, uniformly, or in groups can be used to stimulate seedling establishment (4). The shelterwood can be removed as soon as the seedling stand is established. Artificial regeneration of balsam fir by direct seeding or planting has only had limited success and is generally not recommended, but sometimes the spruces (red, white, or black) are planted to increase their proportion in the next stand. The seed-tree method is not recommended because of the high windfall risk before the area is successfully regenerated. Both the shelterwood and clearcut silvicultural systems produce large amounts of slash that may hinder seedling establishment on some areas. Full-tree skidding or forwarding will remove the tops and branches from the area but some slash may be beneficial to seedlings especially on hot, dry sites. In addition, scarification may be needed to prepare seedbeds under the shelterwood system. Scarification should be done by skilled operators with small, maneuverable equipment so the residual shelterwood and advance reproduction will not be damaged.

Uneven-aged silvicultural systems include both single tree selection and group selection regeneration cuttings. Small openings can be used to favor regeneration of the more tolerant species and large openings can be used to favor the less tolerant species. The selection system is suitable for stands with several age classes and size classes where repeated light cuttings every 10 to 20 years can remove trees of various size and age classes to make room for the establishment of new seedlings and growth of the residual stand (4). Although some uneven-aged stands have been perpetuated by diameter limit cuttings, maximum benefits require tree marking to leave about 80 square feet of basal area per acre (18.4 m^2/ha) and to control the distribution and quality of the growing stock. On sites where balsam fir is not the climax type, light selection cuttings will tend to advance succession to less desirable hardwoods more rapidly and will require additional weedings to maintain balsam fir.

Immature stands are not normally thinned because the major product is fiber and little premium is placed on tree size. Some thinning, however, may reduce the time for balsam fir to reach minimum merchantable tree size and thus allow harvest on shorter rotations before the trees become prime targets for a spruce budworm outbreak or before the net growth is severely reduced by heart rot. It is also possible to increase the production of small saw logs with one or two thinnings and a longer rotation.

Many of the associated species in balsam fir stands are undesirable and should be removed in an improvement cutting if they need to be controlled before the regeneration harvest. Defective trees can be removed in a sanitation cut, but this is seldom done as a separate operation. In the selection system, immature trees are thinned, undesirable trees are controlled, and defective trees are removed at each cutting cycle. Selective herbicides can be used to eliminate undesirable trees.

The balsam fir type is climax or near climax on many sites and can be maintained by assuring the establishment of advance regeneration before removing the mature overstory.

The type may be increased by allowing earlier successional stages to advance, such as aspen or paper birch stands with a balsam fir understory, or by controlling the more tolerant species in later successional stages, such as American beech or sugar maple stands with a balsam fir understory.

Balsam fir, probably the most symmetrical tree in the north woods, adds beauty to the landscape through its contribution of form, patterns of light, shade, and color. The associated species, such as aspen, paper birch, and red maple, provide variety for additional visual quality of the forest type. Balsam fir stands have a distinct fragrance and play an important role in the recreational use of the forest land both in the Northeast and Lake States areas. They also protect many watersheds and provide habitat for a number of wildlife species including primary and secondary carnivores, herbivores, and several songbirds of the boreal forests.

A multiple-use evaluation of the spruce–fir forest type (predominantly balsam fir) in the Lake States rated the impacts of even-age management with clearcutting 20 to 50 acres (8.1 to 20.2 ha) more favorable for timber, water yields, and interior wildlife species than smaller clearcut areas or uneven-age management. Selection cuttings were considered the most favorable for edge wildlife species and visual quality. Water yield was not affected by uneven-age management and water quality was not affected by any of the harvest options rated (6).

Wildlife inhabitants of balsam fir stands are typical of those in the coniferous forests of the northern Lake States and the Northeast. They characteristically have abundant populations of small mammals, many of which become browsers in winter; a large variety of nesting birds, many of which migrate for the winter; and a complete food chain from herbivores to carnivores.

The bay-breasted warbler and Arctic three-toed woodpecker are unique associates in spruce budworm infested balsam fir stands. The spruce grouse and ruffed grouse are common inhabitants as are a variety of songbirds. Small mammals that are common include the red-backed vole, meadow vole, deer mouse, chipmunk, red squirrel, and snowshoe hare. Larger herbivores associated with the balsam fir type include beaver, white-tailed deer, and moose. Carnivores that frequent balsam fir stands include fisher, martin, Canada lynx, and timber wolf (1).

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Northern White-Cedar

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Northern white-cedar (*Thuja occidentalis* L.) is pure or comprises a majority of the stocking in the northern white-cedar forest cover type, Society of American Foresters type 37. Although much of the type occurs in Canada, especially in Ontario and Quebec (13), it totals about 2.0 million acres (0.8 million ha) of commercial forest land in the Northern Lake States and 1.4 million acres (0.6 million ha) in the Northeastern States. Within the United States it is most abundant in Michigan and Maine (13)—each has more than 1 million acres (0.4 million ha).

In the Lake States the northern white-cedar type grows mainly on glacial lake beds and lake-swamp-moraine plains at elevations averaging about 1,000 feet (305 m). In Maine it is found from near sea level along the Atlantic coast to more than 1,000 feet (305 m) in the New England highlands. Most of the remaining type area in the Northeast is in the Adirondack-New England highlands of northern New York and Vermont from elevations of about 1,000 feet (305 m) to more than 2,000 feet (610 m).

The northern white-cedar type occurs mainly in swamps, where white-cedar can compete well with its associates (13) and is normally protected from fire (8). The tree is usually dominant in rich swamps (forested rich fens) that have a strong flow of moderately mineral-rich soil water (9). The best swamp sites have well-decomposed organic soil or peat that is derived from woody plants and is neutral or slightly alkaline. They also have actively moving soil water and are usually near streams or other drainageways (12).

The type also occurs on seepage areas, limestone uplands, and old fields. In fact, it generally grows best on limestone-derived soils that are neutral or slightly alkaline and moist but well drained. Northern white-cedar often forms pure stands on old-field (upland) sites in Maine and southeastern Canada (13). Although old-field soils differ greatly, the tree's form and volume growth are much better on old fields than in poorly drained swamps (3).

The climate in which the northern white-cedar type grows in the Lake States and Northeast is generally humid, with short, cool summers and long, somewhat severe winters. Average annual precipitation ranges from about 20 inches (510 mm) in northwestern Minnesota to 48 inches (1220 mm) along the Atlantic coast in Maine and in the Adirondack-New England highlands; most of the precipitation comes in the summer. Average annual snowfall ranges from about 40 inches (1015 mm) to more than 150 inches (3810 mm). Average July temperatures range from about 65° to 70° F (18.3° to 21.1° C); January temperatures range from 0° to 20° F (−17.8° to −6.7° C). The average frost-free period ranges from about 90 to 150 days.

Although northern white-cedar grows in pure stands, the white-cedar type more commonly occurs as mixed stands. In the United States common tree associates on the wetter sites (especially swamps) include balsam fir (*Abies balsamea* (L.) Mill.), black spruce (*Picea mariana* (Mill.) B.S.P.), white spruce (*P. glauca* (Moench) Voss), red spruce (*P. rubens* Sarg.), tamarack (*Larix laricina* (Du Roi) K. Koch), black ash (*Fraxinus nigra* Marsh.), and red maple (*Acer rubrum* L.). Common associates on the better drained sites (especially uplands) include yellow birch (*Betula alleghaniensis* Britton), paper birch (*B. papyrifera* Marsh.), quaking aspen (*Populus tremuloides* Michx.), bigtooth aspen (*P. grandidentata* Michx.), balsam poplar (*P. balsamifera* L.), eastern hemlock (*Tsuga canadensis* (L.) Carr.), and eastern white pine (*Pinus strobus* L.) (13).

Vegetative reproduction and natural seeding are the two main modes of reproduction in the northern white-cedar type. Layering—where branches become buried in moss and develop adventitious roots—is the most important type of vegetative reproduction. It probably accounts for more than half the stems of white-cedar reproduction in northern Michigan and Maine swamps (6), especially on poor sites with abundant sphagnum moss (*Sphagnum* spp.) (3). Natural seeding is the main mode of reproduction in swamp openings created by wildfire or by harvesting, especially if slash is broadcast burned. It is also the main mode on abandoned upland fields.

Effective and economical ways to artifically reproduce the northern white-cedar type are still largely undeveloped. Direct seeding has been attempted both experimentally and operationally but with limited success. Some planting has been done on upland sites, but success apparently will often require protection from animal damage such as deer and hare browsing.

Seed production in large quantities begins when northern white-cedar trees are about 30 years old but is best after 75 years. White-cedar generally bears good or better seed crops at intervals of 3 to 5 years (6), but in Wisconsin a 25-year record indicates that such crops are produced every 1 to 3 years with medium crops to failures in the intervening years (7). Seed dispersal usually begins in September and most of the seed is released by November; however, some seed continues to fall throughout the winter. Because the tree is usually of medium height, the effective seeding range is estimated to be from 150 to 200 feet (45.7 to 61.0 m) under normal conditions (6).

Apparently the main requirements for initial establishment of northern white-cedar seedlings are a constant moisture supply (4) and warm temperatures. Seedlings do best on neutral or slightly acid soil but will grow on slightly alkaline soil (6). Decaying (rotten) wood—mainly logs in the middle stage of decay and dominated by mat-forming bryophytes (11)—is the most important seedbed type on undisturbed areas, where it often accounts for more than 70 percent of the seedlings (4, 11). On disturbed areas, white-cedar seedlings are commonly aggressive on both upland and swamp burns (4, 6). However, broadcast burning (or wildfire) apparently must be fairly severe to expose favorable, mineral soil seedbeds on uplands or to improve moss seedbeds in swamps (12). White-cedar seedlings also reproduce well on skid roads where the moss has been compacted and stays moist throughout the summer (6).

Except in poorly stocked stands, harvesting can produce a heavy cover of slash that buries suitable advance growth or seedbeds. Thus slash disposal by broadcast burning or full-tree skidding usually favors northern white-cedar reproduction (12).

Although moisture is often the most important factor during the first few years, ample light is needed for continued development of northern white-cedar seedlings. Growth is greatest from about half to full light and larger seedlings occur mainly in pronounced openings or on old fields. Mortality of white-cedar seedlings during their early years is evidently extremely high. Drought is probably the most important cause, but other causes that are sometimes important include smothering by fast-growing spaghnum moss and cutting or girdling by small rodents (3, 6).

Northern white-cedar is generally classed as shade tolerant, but vegetative reproduction is considered more tolerant than seedlings (3). On wet sites such as swamps, an abnormally high water level or slow-moving to stagnant ground water usually reduces the growth rate of white-cedar and in some cases kills entire stands (6). Wetland road crossings and beaver damming are the primary causes of such flooding damage. Uprooting and breakage by wind sometimes occur in older white-cedar stands on both upland and swamp sites, especially along stand edges exposed to the prevailing wind and in stands opened by partial cutting. However, northern white-cedar is less susceptible to wind damage than balsam fir and black spruce because it is usually shorter and apparently has butt rot less commonly than balsam fir (12).

Both even-aged and uneven-aged stands are common in the northern white-cedar type. Even-aged stands usually originate in large swamp openings created by wildfire or harvesting and on abandoned upland fields (13). White-cedar often invades thickets of speckled alder (*Alnus rugosa* (Du Roi) Spreng.) that form in swamps following wildfire or changes in water level. It can also reproduce directly on burned peat (4).

Uneven-aged white-cedar stands develop when new trees begin to fill small openings created by partial cutting or wind damage (13). If growing in pure stands, white-cedar will apparently perpetuate itself under such conditions (6), especially on poor sites where reproduction is mainly of vegetative origin (13). In mixed stands on better sites, however, associates such as balsam fir or swamp hardwoods (especially black ash) often reproduce in these openings (12) and may eventually overtop the surrounding, older white-cedar.

Stands of northern white-cedar can also develop where it gradually succeeds associates—such as balsam poplar, tamarack, and black spruce—that are not as shade tolerant or long lived (13). These stands may be even- or uneven-aged depending on when the white-cedar became established.

Although northern white-cedar is commonly in the understory, it is often not much younger (and may be older) than the overstory species. Thus much of what appears to have developed through succession may really be due to suppression (8) or to white-cedar's inherently slow growth. The tree can withstand severe suppression for several years without appreciable ill effects, and it responds well to release at nearly all ages (6). However, white-cedar apparently forms stands on old fields only where competition from other species is not severe (3).

In general, northern white-cedar grows more slowly and so is shorter than associated trees, especially on swamp sites (6). Mature white-cedars are commonly 40 to 50 feet (12.2 to 15.2 m) tall and 12 to 24 inches (30 to 61 cm) in d.b.h. However, the tree's growth rate differs greatly depending on site productivity. In the Lake States height of dominant trees at 50 years ranges from about 40 feet (12.2 m) on the best sites to 15 feet (4.6 m) on the poorest. A site index of 25 feet (7.6 m) is about the minimum for commercial forest land (12).

Timber rotations for northern white-cedar differ greatly with site productivity and the size of the main product. They also have a range because the mean annual increment is near the maximum for a number of years. Recommended rotations for merchantable cubic volume—for trees 5 inches (13 cm) and larger in d.b.h.—range from 70 to 90 years for a site index of 40 feet (12.2 m) and from 80 to 100 years for an index of 30 feet (9.1 m). Rotations for sawtimber volume—for trees 9 inches (23 cm) and larger in d.b.h.—range from 110 to 140 years for a site index of 40 feet (12.2 m) and from 130 to 160 years for an index of 30 feet (9.1 m). In areas where the white-cedar type provides important shelter for white-tailed deer, rotations should generally be at least the minimum ones for sawtimber (12).

Information on yield of northern white-cedar is limited mainly to normal yield tables for pure, fully-stocked, even-aged stands in the Lake States. At rotation age on good sites, such stands yield about 4,000 merchantable cubic feet per acre (280.0 m^3/ha) for trees 5 inches (13 cm) and larger in d.b.h. Much of this volume is in logs and poles, whereas many stands on poor sites produce only small posts (12). Unfortunately, in terms of timber value, the tree commonly has a curved butt and poor form, especially in swamps (3).

The northern white-cedar type is relatively free from serious insect injury (3). Carpenter ants and leafminers are probably its most important insect pests. The black carpenter ant, *Camponotus pennsylvanicus* (De Geer), commonly reduces the timber value of larger trees and often makes them subject to windbreakage. Outbreaks of the arborvitae leafminer, *Argyresthia thuiella* (Packard), have severely damaged white-cedar stands in Maine (1).

Immature white-cedar stands are relatively free of disease (6). Although several root- and butt-rot fungi attack white-cedar, they mainly attack old or damaged trees and have not yet proved to be economically important (10). *Poria subacida* (Pk.) Sacc., causing a white stringy butt rot, and *Tyromyces balsameus* (Pk.) Murr. and *Phaeolus schweinitzii* (Fr.) Pat., both causing a brown cubical rot, are apparently common in trees on knolls or other drier parts of swamps (6).

Browsing by white-tailed deer often severely damages northern white-cedar in the Lake States (6) and can prevent the satisfactory reestablishment of the type after harvesting (12), especially in deeryards. Snowshoe hare browsing does damage equal to or greater than deer browsing in some areas of the Lake States (6), but hares are apparently not greatly destructive to white-cedar in Maine (3). Porcupines sometimes kill white-cedar trees or lower their growth and timber quality by feeding heavily on foliage (3) and by partially or completely girdling the stem and branches (6).

Northern white-cedar is highly susceptible to fire damage (8, 10), even by light ground fires. However, the risk of wildfire is low on most white-cedar areas in the United States and good fire protection now results in little loss (12).

Many of the present even-aged stands of northern white-cedar originated after wildfire, probably because seedbed conditions on burns (including increased temperature and light) seem to favor white-cedar seedlings. However, the type usually occurs where it is protected from fire. Without major disturbance such as fire, the type is exceedingly stable because white-cedar is long lived and balsam fir is the only important associate sufficiently shade tolerant to grow in dense white-cedar stands (4). In fact, white-cedar may have the highest potential for replacing other species in the absence of fire (8).

Because northern white-cedar commonly reproduces well on burns, broadcast burning is the preferred method of slash disposal on peatland harvest areas unless residual trees or advance growth are to be saved. Under prescribed conditions, it is considered a safe and effective way not only to eliminate most slash but also to simultaneously kill residual conifers, improve seedbeds, and kill the stems of hardwoods and brush species. Although improving seedbeds and killing hardwood and brush stems apparently require more severe burns than the other items, burning should not be done during abnormally dry periods when fires can burn deeply in peat and become extremely difficult to extinguish (12).

Timber management and deeryard management are usually inseparable in the northern white-cedar type, especially in the northern Lake States where the type is particularly valuable for deeryards in severe winters. White-cedar is highly preferred by deer for both shelter and browse; sapling stands produce a great amount of deer food and much browse is made available by cutting in mature stands (15). Thus the type is most commonly managed to produce a moderate sustained yield of merchantable timber, while maintaining or increasing the quality and quantity of deeryards.

Wherever possible, the northern white-cedar type should be managed in fairly large, even-aged stands because these are apparently best for both timber production and deeryards. However, an adequate sustained amount of deer shelter and browse (in addition to timber) is possible only if the type is managed so that stands at different stages of development are properly distributed throughout the forest (12, 15).

Northern white-cedar is fairly well adapted to even-aged management. Clearcutting in narrow strips (or small patches) is probably the best silvicultural system for managing the type. This is because white-cedar seedlings, which are preferable to vegetative reproduction for producing timber and deer shelter, require ample light for greatest growth. Also, hardwood competition (2) and wind damage are generally less with clearcutting than with partial cutting.

However, shelterwood cutting is preferred for the last set of strips (or patches) in large stands to ensure adequate natural seeding of white-cedar (12). Also, the shelterwood system is a satisfactory alternative in small stands in which clearcutting is undesirable for esthetic or other reasons. An advantage of the shelterwood system in mixed stands is that the proportion of white-cedar reproduction can probably be increased by removing associated trees during the first or seed cutting.

So, in general, a combination of alternate or progressive clearcut and shelterwood strips is recommended for reproducing the northern white-cedar type. The first or intermediate set of strips should be clearcut and the last set cut in a two-stage shelterwood, leaving a basal area of 60 square feet per acre (13.8 m^2/ha) in the first stage or seed cutting. Clearcut strips should not exceed 150 to 200 feet (45.7 to 61.0 m) wide, while shelterwood strips should be narrower to minimize their area (12).

Slash disposal is recommended for the clearcut strips because unless a stand is poorly stocked, clearcutting produces a heavy cover of slash that hinders satisfactory reproduction of northern white-cedar. Broadcast burning should be limited to the widest strips, whereas full-tree skidding is recommended on narrower strips or where advance growth is to be saved. To minimize overbrowsing of white-cedar reproduction in deeryards, large patches of 40 acres (16 ha) or more must be completely cleared in 10 years or less. And if the yard is large, cutting in several different areas every winter is desirable to distribute the deer more and to attract them away from patches of young white-cedar (12).

Although uneven-aged stands of northern white-cedar are common, they generally are not as productive for timber and deeryards as even-aged stands. Also, uneven- or all-aged management would probably increase the proportion of balsam fir in the succeeding stand. Thus such management should be considered mainly for poor sites where white-cedar does not grow tall enough to provide optimum deer shelter and where only the largest trees are merchantable anyway. Individual tree selection is the best silvicultural system to use for uneven-aged management.

Thinning and preparatory treatment should be limited to white-cedar stands where intensive management for timber or deeryards can be justified. Middle-aged stands can be thinned to a residual basal area of 150 square feet per acre (34.4 m^2/ha) and still provide adequate deer shelter and inhibit undesirable undergrowth. Preparatory treatment—by felling, girdling, or applying herbicide—should be done at least 5, and preferably 10, years before reproduction cutting to control undesirable trees, especially hardwoods. To minimize regrowth after treatment, it is important to have a residual basal area of about 150 square feet per acre (34.4 m^2/ha) (12).

Besides providing winter habitat for white-tailed deer, the northern white-cedar type is also utilized to some extent by other mammals such as the snowshoe hare, porcupine, and red squirrel. Birds common in white-cedar stands during the summer include several warblers (northern parula, black-throated green, blackburnian, black-and-white, and magnolia), white-throated sparrows, and kinglets (5). The pileated woodpecker commonly bores into mature white-cedars for carpenter ants (3).

Small stands of northern white-cedar add diversity to the landscape and provide an attractive fringe around lakes and peatlands. Stands with high basal area, large trees, and little undergrowth are especially attractive (14). Also, the tree's unusual bark and foliage patterns are esthetically appealing to many forest users. The impact of harvesting white-cedar on esthetics can be minimized by having harvest boundaries follow natural type lines and disposing of slash or other debris to leave harvest areas neat (12).

Clearcutting northern white-cedar on peatland sites has little effect on annual water yields or water tables (14). Nutrient concentrations in streamflow (14) or temperatures in trout streams (12) should not increase significantly unless harvesting (with or without broadcast burning) is on a massive scale. However, harvesting should be done only in winter after the ground is frozen and snow covered to minimize peat disturbance and its possible effect on water quality. Also, the normal movement of water must be maintained to prevent flooding damage (12).

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Eastern Redcedar

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Eastern redcedar (*Juniperus virginiana* L.) is the most widely distributed conifer of tree size in the eastern United States, occurring in every State east of the 100th meridian. The species range extends northward into southern Ontario and the southern tip of Quebec (18). Eastern redcedar is the dominant commercial species on nearly 2.5 million acres (1.0 million ha), primarily in Arkansas, Missouri, Kentucky, and Tennessee.

Eastern redcedar grows on a wide variety of soils, ranging from dry rock outcroppings to wet, swampy land. It is most frequently associated with thin soils derived from limestone and dolomite where rock outcroppings are common. Like most tree species, however, eastern redcedar grows best on deep, moist, well-drained alluvial sites where it may reach a height of 55 to 60 feet (16.8 to 18.3 m) in 50 years (12). The species also grows well on deep upland soils, particularly abandoned farmlands. On the better sites, however, hardwood competition is often so severe that the species rarely becomes dominant. Because of competition from more tolerant species and perhaps its relatively slow growth rates, eastern redcedar is generally confined to poorer sites having thin, rocky soil and intermittent rock outcroppings. These areas are called glades in the Ozarks and Tennessee. Soils on glade sites are usually less than 12 inches (30.5 cm) deep, medium sites have soil less than 24 inches (61.0 cm) deep with large crevices, and good sites have soil deeper than 24 inches (61.0 cm) (5). Eastern redcedar grows on soils having pH values ranging from 4.7 to 7.8 (4), and is not particularly tolerant of high pH levels. Establishment of eastern redcedar tends to increase the pH and improve the physical properties of soil (8, 12, 21).

The wide natural distribution of eastern redcedar indicates its ability to grow under diverse and extreme climatic conditions. Average annual precipitation over the species range varies from about 15 inches (380 mm) in the Northwest to 60 inches (1525 mm) in the southern parts of its range (13). Over its habitat, annual snowfall averages extend from 0 to 100 or more inches (2540 mm). Average annual temperatures vary from about 39° F (3.9° C) in the North to 68° F (20.0° C) in the southern part of the species range. Temperature extremes, however, extend from −40° F (−40.0° C) in the Central Plains and Minnesota to 115° F (46.1° C) in the central and southern Great Plains (26). The average growing season varies from about 120 days in the Dakotas to 250 days in the southern sections of its territory. Elevations at which the species grows range from zero in the South to over 5,000 feet (1525 m) in western Nebraska and Kansas (26). In the western portion of its range, the species is more commonly found on north-facing slopes and along streambanks where it is sheltered from heat and drought (2).

Relatively pure stands of eastern redcedar are scattered throughout the species' habitat, but they are most common on abandoned farmlands and drier upland sites (13). Because of its wide occurrence, the eastern redcedar forest cover type (Society of American Foresters forest cover type 46) has many associates (25). Variants of the eastern redcedar type are eastern redcedar−pine, eastern redcedar−hardwood, and eastern redcedar−pine−hardwood. In the eastern redcedar−pine variant, shortleaf pine (*Pinus echinata* Mill.) and Virginia pine (*P. virginiana* Mill.) are common associates in the southern half of the species range. The eastern redcedar−hardwood variant occurs throughout the central part of its range and includes a mixture of northern red oak (*Quercus rubra* L.), white oak (*Q. alba* L.), hickories (*Carya* spp.), black walnut (*Juglans nigra* L.), and other hardwoods. The eastern redcedar pine-hardwood variant includes all of the above associations (13).

Eastern redcedar is among the first species to invade old abandoned fields and areas cleared for pasture (11). On deeper soils, common persimmon (*Diospyros virginiana* L.) and sassafras (*Sassafras albidum* (Nutt.) Nees) are associated invasion species and may crowd it out. On cedar glades, eastern redcedar is commonly associated with blackjack oak (*Quercus marilandica* Muenchh.), post oak (*Q. stellata* Wangenh.), Ozark chinkapin (*Castanea ozarkensis* Ashe), winged elm (*Ulmus alata* Michx.), fragrant sumac (*Rhus aromatica* Ait.), Carolina buckthorn (*Rhamnus caroliniana* Walt.), rusty blackhaw (*Viburnum rufidulum* Raf.), and Alabama supplejack (*Berchemia scandans* (Hill) K. Koch) (25). Many herbaceous plants are associates of the eastern redcedar type and the species occurs as a minor component of several other forest types.

Most eastern redcedar natural reproduction occurs on relatively poor hardwood or pine sites, along fence rows, or in pastures that are not burned or mowed. Good seed crops occur every 2 or 3 years, with lighter crops occurring in the intervening years (12). Seeds are disseminated when birds and other animals eat the fruit (15).

Eastern redcedar stands may also be established by planting wildlings or 2−0, 3−0, 1−2, 2−1, or 2−2 nursery grown seedlings. Climatic conditions at the time of and immediately following planting are also important (1). Eastern redcedar may be successfully established by hand-direct-seeding or machine sowing using about 0.5 to 0.75 pounds of stratified seeds per acre (0.6 to 0.8 kg/ha) on sites where both the hardwood overstory and the litter have been removed. The rate of sowing must be adjusted to allow for variations in germinative capacity of the seeds and degree of competition control.

Seedling development on very dry sites is slow and survival rates may be very low if competition is severe (19). During the first year seedlings do not normally produce much height growth, but they develop long, fibrous root systems. However, under favorable environmental conditions, 2−0 and older nursery stock may have good height growth the first year after planting. Once established, eastern redcedar seedlings will survive for extended periods under heavy competition, although growth is severely retarded. Eastern redcedar also competes very well in shelterbelts, where it is the species most frequently found in natural regeneration.[1]

Growth rates of eastern redcedar depend largely on site quality, competition from other species, and stand density. Trees 20 to 30 years old are generally 18 to 24 feet (5.5 to 7.3 m) tall and 2 to 3 inches (5 to 8 cm) diameter at breast height (d.b.h.) (13). In the Arkansas Ozarks, annual d.b.h. growth of well-stocked stands on medium to good sites averaged 0.2 to 0.3 inches (4 to 8 mm) (5). Trees on these sites averaged 26 to 32 feet (7.9 to 9.8 m) in height at age 30 (12).

Growth and yield of eastern redcedar are affected by stand density and hardwood competition. In 45-year-old stands, the highest volume growth was obtained in unthinned stands from which hardwoods had been removed. These stands averaged 28 cubic feet per acre (2.0 m^3/ha) per year during a 14-year period. This was double the growth where the competing hardwoods were left. A stocking of 175 crop trees per acre (430/ha), 3 inches (8 cm) d.b.h. and larger, with 80 percent of the competing vegetation removed, had nearly the same 14-year growth as unthinned stands having 440 trees per acre (1085/ha) (12).

Over a 10-year period in northern Arkansas, completely released stands averaged higher d.b.h., basal area, and volume growth than stands where only crown competition was removed. The greatest mean diameter growth, 2.5 inches (6 cm), occurred with the lightest stocking of 50 crop trees per acre (125/ha). Mean d.b.h. growth decreased as stocking increased. Basal area growth was greatest in stands having 400 crop trees per acre (990/ha). As stocking levels were reduced, basal area and volume growth decreased. The stands with 400 trees per acre (990/ha) produced more than 2,000 fbm (400 ft^3)[2] per acre (28.0 m^3/ha) in 10 years. A stocking of 175, 4-inch (10 cm) redcedar trees per acre (430/ha) produced slightly more volume during the same period on similar sites (12). In Missouri, recommended stocking rates are based on crown closure and diameter, using the numerical value for diameter in inches plus 6, $D + 6$, giving the recommended spacing in feet. Thus, a stand of 4-inch (10 cm) trees would have a spacing of 10 feet (3.0 m) or about 436 trees per acre (1080/ha). As the trees develop, they are thinned to the $D + 6$ spacing.[3]

Aspect influences stand characteristics but not total growth and yield. North and east aspects generally have fewer eastern redcedar trees because of hardwood competition, but individual trees tend to be taller than those on south and west aspects. Topographic position is often related to depth of soil, with lower slopes tending to produce taller trees because of greater soil depth (5).

On many sites, growth rates of eastern redcedar are relatively slow, and long rotations may be required to produce conventional saw logs. However, the small sizes of the speciality products manufactured from eastern redcedar and the wide range in acceptable defects allows shortening of rotations and periods between intermediate harvests. A period of 20 to 30 years is required for post material and 40 to 60 years for saw timber (12).

Insects usually do not seriously damage eastern redcedar. Several boring insects sometimes feed on living and dead trees, and bagworms (*Thyridopteryx ephemeraeformis* (Haworth)) occasionally completely defoliate trees. Roots of seedlings are very susceptible to attack by nematodes and grubs. Several weevils, bark beetles, and sawflies may also attack various parts of redcedar (6).

Eastern redcedar, especially when weakened by stress or insects, is very susceptible to damage by the root rot fungus, *Heterobasidium annosum* (Fr.) Bref. This disease is considered to be the species' most serious pathogen over much of its range. Two cubical rot fungi (*Fomitopsis cajanderi* (Karst.) Kotl. & Pouz. and *Daedalea juniperina* Murr.) and juniper pocket rot fungus (*Pyrofomes demidoffii* (Lev.) Kotl. & Pouz.) may enter through dead branch stubs and attack the heartwood (16). Because of this potential problem, pruning of eastern redcedar is usually not recommended. If pruning is done, branch stubs should be 8 to 10 inches (20 to 25 cm) long to minimize fungal attack (12). Cedar-apple rust (*Gymnosporangium juniperi-virginianae* Schw.) attacks eastern redcedar trees in all stages of development, but it rarely is a serious disease. Phomopsis blight (*Phomopsis juniperovora* Hahn) and Cercospora blight (*Cercospora sequoiae* E. & E.) are important foliage diseases. Phomopsis blight can be controlled in nurseries by application of a suitable fungicide and use of several management procedures (3). Control of Cercospora blight is feasible through careful timing of fungicide applications (20).

Fire is probably the worst enemy of eastern redcedar. The thin bark and fibrous roots near the ground surface are easily injured by fire. Fortunately, the foliage does not burn readily, and litter accumulation beneath the trees is often limited, especially on shallow soils (12). Protection from fire has been the primary reason that eastern redcedar has increased in many States (7), but it has also increased through invasion of abandoned agricultural fields and discontinued grazing in pastures.

Newly established seedlings are subject to frost heaving and occasionally foliage may be damaged by severe winter weather (17). Mice and rabbits may also damage young eastern redcedar seedlings. Livestock generally avoid browsing seedlings and trees but may trample the plants and their roots or rub trees while grazing. During times of food stress, deer will heavily browse eastern redcedar (15) and destroy much of the reproduction (12). Redcedar withstands the weight of snow fairly well, but it has only moderate resistance to ice damage (9).

Studies in north Arkansas indicate that even-aged management is suitable for eastern redcedar (12). Many of the better natural stands tend to be even aged, particularly on old fields and pastures where fire or other catastrophes have reduced competition from other tree species. On the cedar glades, eastern redcedar stands tend to be uneven aged. This occurs because these sites are not capable of supporting a closed forest canopy.

Silvicultural practices used to manage eastern redcedar in even-aged stands depend on site sensitivity, stand density, tree quality, existing reproduction, and management objectives. Shelterwood, seed-tree, and clearcut silvicultural systems are all suitable for regenerating eastern redcedar. Control of competing vegetation and protection of seedlings from livestock are essential under all systems. The shelterwood system is effective in cedar and cedar-hardwood stands if the understory competition is sparse. A light shelterwood cut, leaving the best stems, maximizes diameter growth of residual trees. Fire and mechanical site preparation methods should not be used with the shelterwood system.

[1] Van Haverbeke, David F. Personal communication to Edwin R. Lawson. Affiliated with the U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Forestry Sciences Laboratory, Lincoln, Nebr.

[2] 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.

[3] Robinson, James L. Personal communication to Jay R. Law. 1981 October. Affiliated with U.S. Department of Agriculture, Soil Conservation Service, Columbia, Mo.

The seed-tree cutting method requires leaving 10 or more well-dispersed trees of seed-bearing age per acre (25/ha). The residual trees should constitute a harvestable volume and must represent both sexes, since the species is essentially dioecious. Burning and mechanical site preparation methods may be used, but the shallow root systems and above ground tree parts must be protected from injury.

The clearcut system is appropriate where the stand is mature or where establishment of new redcedar stands is the management objective. Under this system, all merchantable materials are removed, undesirable trees deadened, and the seedbed prepared by burning or mechanical site preparation. The new stand may be established by planting or by direct seeding. If vegetation control is adequate, sites to be planted should not be burned.

Use of patch or strip clearcuts may be desirable for managing stands of eastern redcedar on small ownerships, since they form a mosaic of even-aged stands. However, these cutting methods require a more extensive access road network, make site preparation more difficult, increase the potential for fire damage to residual trees from fuel build-up, and in general are more costly to implement. The more extensive road network would, however, provide firebreaks and added protection against extensive fire losses.

Under an even-aged management system, intermediate cuttings should be from below, leaving the best trees in the residual stand. A cutting cycle of 10 years and a saw timber rotation age of 60 years are recommended for eastern redcedar. When the stands are young, stocking levels should be between 175 and 400 trees per acre (430 and 990 trees/ha) on the medium and better sites where the site index is at least 35 feet (10.7 m), or a sufficient number to keep the stand canopies closed. As the stands develop, thinnings should reduce the number of trees to about 175 per acre (430/ha). The stands should be maintained at a dense stocking level or where only the upper half of the canopy is open to full sunlight. Closed and dense stocking levels are important in maintaining tree height growth and development of a desirable heartwood-sapwood ratio in the tree bole.

Uneven-aged management of eastern redcedar on medium to good sites is probably not practical, since the species requires closed canopies to maintain good height growth. Opening up such stands through individual tree selection would stimulate growth of undesirable species, reduce height growth of redcedar, and allow excessive branching to develop on individual trees. On glade sites, individual tree selection may be a suitable alternative, since these sites are only capable of supporting sparse stands of redcedar intermixed with grasses. Natural regeneration on these sites can be obtained by providing brush control and fire protection. On many such areas, grazing by livestock is often considered to be the primary management objective, even though it may undermine fragile soils and eastern redcedar growth and yield.

In most of the areas where eastern redcedar grows, the number of trees and volume have increased (7). It is likely that the area of the eastern redcedar type is expanding also, but data are not available. Opportunities remain to expand the type by converting poor hardwood stands to redcedar, since the species has the ability to grow on sites that are too poor either for hardwood saw log production or to justify the expense of pine conversion. Conversion of such sites to redcedar may increase the forest value and be of benefit to other resources as well.

Much of the eastern redcedar type is on shallow soils and glades with sparse stocking of redcedar. Grasses occupy the spaces between trees and provide forage for livestock. Range is the dominant use on most private ownerships and some public ownerships are leased for this purpose. Grazing must be carefully controlled on these areas in order to protect the often fragile soils. These sites are among the few in forested areas where overland flow occurs rather frequently; therefore sheet erosion is a potential hazard if the soils are disturbed through over-grazing or other activities. Watersheds containing a high proportion of shallow soils rank among the highest for water yield, with storm flows of 50 to 75 percent of precipitation being common.

Eastern redcedar is one of the best tree species for protecting soils from wind erosion and reducing the desiccating effects of wind. It ranked high in the Great Plains shelterbelt plantings because of its ability to withstand extremes of drought, heat, and cold (13). It is the most suitable species for single-row field windbreaks (24). The fibrous root system also helps to hold soil in place, especially on shallow soils.

Eastern redcedar, with its wide distribution, is important to wildlife. As an evergreen, it provides good nesting and roosting cover for many birds. When in dense thickets it provides good escape cover for deer. Glade sites provide habitat for several rare and endangered plant species (22) and birds (10). The abundant foliage, although low in nutritional values, provides emergency food for deer during times of stress. Fruits are high in crude fat and fiber, moderate in calcium, and very high in total carbohydrates (15). Eastern redcedar fruits are eaten by many wildlife species, including waxwings, bobwhite quail, ruffed grouse, pheasants, wild turkeys, rabbits, red foxes, gray foxes, raccoons, opossums, skunks, and coyotes (15).

Eastern redcedar trees and stands add variety to a forest and are esthetically very appealing. Many varieties of eastern redcedar are used as ornamental plantings (14, 23). The species is ranked among the five most desired species of trees chosen for Christmas trees (11).

Eastern redcedar, with its bright to dull red heartwood and white sapwood, has many special uses. The heartwood is very resistant to decay, and has outstanding qualities of rich color, aromatic odor, fine and uniform texture and workability. The greatest quantity of eastern redcedar is used for fenceposts, but its lumber is being increasingly used in the manufacture of chests, wardrobes, closet linings, furniture, flooring, novelties, woodenware, pencils, scientific instruments, and small boats. Aromatic oils, medicine, perfumes, and alcohol are also manufactured from eastern redcedar (11).

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Aspen

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The major portion of the Society of American Foresters eastern aspen forest cover type 16 (6) spans the northern tier of States from Minnesota to Maine. More than 80 percent of this type occurs in the Lake States Region where it covers 13 million acres (5.3 million ha) of commercial forest land. The bulk of the remainder is in Maine and New York (20), but the type is found as far south as New Jersey and Pennsylvania, westward to Iowa, and north to the Canadian border (9). For information about aspen in the West and in Alaska (types 217 and 251), see discussions of Rocky Mountain Aspen, Southwestern Mixed Conifers, and Interior Alaska White Spruce–Hardwoods in this publication.

This wide-ranging type grows on a diversity of soils. Fifty-year height growth ranges from less than 40 feet (12.1 m) on dry sands, rock outcrops, and poorly drained mineral soils and peats, to more than 90 feet (27.4 m) on deep, well drained, high calcium fertile loams (5, 7, 14).

Climates within the range of aspen are humid warm-summer continental (2). Daily minimum temperatures average as low as −5° F (−20.6° C) in January and July maximums average as high as 86° F (30.0° C). Frost free periods range from about 90 to 150 days. Mean total annual precipitation ranges from about 20 inches (510 mm) to 50 inches (1270 mm), about one-sixth to one-third falling as snow (10, 12). Precipitation is more or less evenly distributed throughout the year and droughts are not common, except at the western extent of the type. Occasional intense thunderstorms, tornadoes, or—in the northeast—hurricanes produce damaging winds. Summer sunshine ranges from 8 to 10.5 hours daily, grading with decreasing cloudiness from east to west (18).

Principal components of this type are quaking aspen (*Populus tremuloides* Michx.) and, especially in the Lake States, bigtooth aspen (*Populus grandidentata* Michx.). Common associated tree species include paper birch (*Betula papyrifera* Marsh.), pin cherry (*Prunus pensylvanica* L.f.), sugar maple (*Acer saccharum* Marsh.), yellow birch (*Betula alleghaniensis* Britton), American basswood (*Tilia americana* L.), eastern hophornbeam (*Ostrya virginiana* (Mill.) K. Koch), balsam poplar (*Populus balsamifera* L.), balsam fir (*Abies balsamea* (L.) Mill), red spruce (*Picea rubens* Sarg.), white spruce (*P. glauca* (Moench) Voss), jack pine (*Pinus banksiana* Lamb.), red pine (*P. resinosa* Ait.), and white pine (*P. strobus* L.) (5, 6).

Despite abundant seed production, aspens reproduce most commonly from adventitious root sprouts (suckers). Suckering creates naturally occurring clones—the typical genetic entity of aspens rather than the individual stem (3). Aspen suckering is suppressed by auxin transported from growing shoots (16), so the parent stand must be killed by cutting, fire, or herbicides to relieve this apical dominance and allow suckering to occur. Exposing the forest floor to sunlight warms the soil, further enhancing sucker development (11). Initial sucker growth depends on stored root carbohydrates (16). Except for some trials with genetically improved stock (11, 19), aspen is seldom planted.

Aspens produce good spring seed crops every 4 or 5 years after age 10 to 20. The seeds are light, averaging 3 million per pound (6.6 million/kg). They are buoyed by long silky hairs and may be carried for several miles by the wind. A single tree may produce a million or more seeds, and germinative capacity at seedfall usually exceeds 95 percent (17). However, seedbed and microenvironment requirements for seedling establishment are stringent. Mineral soil seedbeds are best but they must be continually moist during the short period of seed viability (less than 4 weeks) and during early root growth. Because these requirements are seldom met in nature, pure seedling stands are uncommon (5, 11, 19).

Both seedlings and suckers are intolerant of shade and can endure little suppression. Natural thinning in dense young stands is rapid and trees that fall below the canopy stop growing and die within a few years. Young sucker stands are especially tolerant of drought because of their extensive root systems and reduced evapotranspiration (13). Seedlings may be killed by drought during their first year or two until roots are well established but older stands are seldom killed by drought. However, their growth and vigor may be reduced by drought to the point of increased susceptibility to disease and insects (5).

Depending on site quality and clonal ability (5, 21), young trees grow rapidly and by age 20 may be from 20 to 75 feet (6.1 to 22.9 m) tall (14). During the first several years, however, seedlings do not grow as fast as suckers, which draw on the extensive parent root system to sustain their rapid growth. Dominant suckers grow 4 to 6 feet (1.2 to 1.8 m) or more in height during the first year—easily enough to outgrow any competition of the same age. In contrast, seedlings may grow only from 6 to 24 inches (15 to 61 cm) the first growing season (5). Mature stands (50 years of age) typically average 66 to 82 feet (20.1 to 25.0 m) tall. Under the best conditions a few aspens may eventually exceed 100 feet (30.5 m) (5). On equivalent sites, bigtooth aspen will usually outproduce quaking aspen, especially on sandy soils (7).

According to site quality (site index 40 to 80 ft (12.2 to 24.4 m) at 50 years) and species, fully stocked aspen stands on rotations of 30 to 40 years will produce about 0.7 to 4.4 tons per acre (1.6 to 9.9 t/ha) per year of biomass (fresh weight). On rotations of 30 to 50 years, these same stands can produce about 20 to 130 cubic feet per acre (1.4 to 9.1 m^3/ha) per year of bolewood (14). Only the best sites (70+ ft (21.3+ m) at age 50) will produce much sawtimber and they will require close utilization and rotations of 50 years or longer. The pathological rotation seldom exceeds 60 years so few opportunities exist to grow aspen sawtimber except on the very best sites (5, 14).

The aspens are vulnerable to a multitude of damaging agents. They are injured by the feeding of birds and mammals and by leaf and shoot blights, rusts, and mildews. Although few trees are killed by these agents, they do slow the growth of aspen—particularly in young stands (19).

Viruses slow the growth of some quaking aspen clones and regeneration by suckering maintains the infection (4). Stain and wetwood reduce wood quality. Trunk rots, especially that caused by the fungus *Phellinus tremulae* (Bond.) Bond. and Boris, are the major deterrent to growing aspen on long rotations. Several stem cankers either reduce timber quality or kill the tree. *Hypoxylon mammatum* (Wahl.) Mill. is the most serious of these and kills up to 2 percent of the aspen annually. Bigtooth aspen is more resistant to this disease than is quaking aspen (19).

The aspens host at least 300 species of insects but only a few are known to cause much damage. The most serious defoliators are the forest tent caterpillar (*Malacosoma disstria* Hubner) and the large aspen tortrix (*Choristoneura conflictana* (Walker)). Outbreaks usually persist for 2 or 3 years, greatly slowing growth but causing little direct mortality. The gypsy moth (*Lymantria dispar* (L.)) is also an important defoliator in the Northeast. Leaf tiers, leaf rollers, and leaf miners are less important defoliators, but in aggregate they significantly slow the growth of juvenile stands (19).

Wood-boring beetles of the genus *Saperda*, *Oberia*, and *Agrilus* infest most juvenile sucker stands. Their activities provide infection courts for stem cankers and wood rots. In some cases they girdle and kill suckers outright by tunneling under the phloem. The poplar borer (*Saperda calcarata* Say) is the most important of the stem borers and is most serious in pole stands. Other damaging but less important insects include aphids, leafhoppers, scale insects, cutworms, and carpenter ants (19).

Fire can be used to regenerate aspen if woody fuel accumulations are sufficient to provide the heat required to kill the stand. Light fuel accumulations will support only relatively cool fires. These may reduce growth and quality by scarring the lower bole to provide avenues for wood-rotting fungi and by destroying surface feeding roots. Excessive fuel accumulations will support intense fires that will diminish sucker growth. Overall, the aspen type is low in flammability unless there is slash on the ground. Consequently, the type forms a fuel break and fires in the type can be extinguished easily (14).

Aspen can also be injured by frost, wind, hail, ice storms, and sunscald (5, 7, 19). The only feasible way to minimize losses by any of these damaging agents is to maintain fully stocked stands (5, 7, 14).

The intolerance of aspens to shade and the physiological requirements for suckering dictate even-aged management systems using clearcutting to maintain the type at full productivity (5, 7, 14). Single tree or group selection will discriminate against the aspens. Shelterwood or seed-tree systems are not needed and indeed shading by residual stems is detrimental to sucker growth. However, selection systems to leave associated species will hasten natural succession and conversion to other forest types when they are desired. Aspen stands often have a conifer understory that can be released with a single careful cutting of the aspen (14). Openings of about 1 acre (0.4 ha) in size provide minimally acceptable conditions for regenerating aspen. Clearcuts of at least 40 to 50 acres (16 to 20 ha) are needed for efficient harvesting. Maximum clearcut size has no silvicultural limit but size is often constrained to 10 or 20 acres (4.0 or 8.1 ha) for other multiple resource considerations (13).

Typically from 10,000 to 30,000 suckers per acre (24 710 to 74 130/ha) are regenerated by complete clearcutting (5, 7). As many residual trees (except those for special purposes) and tall shrubs should be destroyed during or soon after harvest as is economically practical. The seasonal timing of harvest influences sucker vigor and survival. It is desirable to harvest aspen during the dormant season when root carbohydrate reserves are highest (16), especially where brush or bracken fern compete (5, 14, 19). Dense sucker stands provide the best protection from insects and disease and assure a healthy new forest (14). On well drained sites, clearcutting stands containing as little as 50 well distributed quaking aspens per acre (124/ha) will normally create a fully stocked stand of suckers (14).

The vast majority of aspen stands are suitable for growing only pulpwood on rotations from 35 to 45 years (depending on utilization standards) (13). However, some of the best sites (site index 70 (21.3 m) or better) will produce sawtimber if thinned at age 30 (5, 14). An additional thinning at age 10, and optionally again at age 20, on exceptional sites (site index 80 (24.4 m) or better) can dramatically improve yields of large products. Sawtimber rotations of only 50 years are needed but can be extended to 60 years in disease-resistant stands for even greater yields. Fifty-year-old stands that have been thinned three times can produce about 35 percent more sawtimber volume than 60-year-old unthinned stands (15).

As far as is known, the aspen type can be maintained indefinitely by clearcutting. However, the presence of viruses in some clones may gradually deteriorate some stands (4). Also, because quaking aspen contains high amounts of nutrients, nutrient drain in harvested products, especially with whole tree systems, might lower the productivity of some soils (1). Without cutting or other disturbance the type will be succeeded by its more tolerant or longer-lived associates. On dry sites, these are chiefly red pine, red maple (*Acer rubrum* L.), and the oaks (*Quercus* spp.). On moist fertile soils these are northern hardwoods, balsam fir, white spruce, and eastern white pine, and on wet sites balsam fir, black spruce (*Picea mariana* (Mill.) B.S.P.), and northern white-cedar (*Thuja occidentalis* L.) (5). Pure aspen stands lacking a tolerant species seed source will deteriorate to a shrubwood containing only a few scattered aspen suckers (19).

Despite the lush herbaceous component, especially in regenerated stands, the aspen type is little used for pasture in the East in contrast to its importance for range in the West. However, the type is particularly good habitat for wildlife associated with forest margins and openings, such as white-tailed deer, ruffed grouse, woodcock, snowshoe hare, and a large number of songbirds (13). A diversity of aspen age classes along with intermixed conifer stands provide the best wildlife habitat. Aspens are predominately dioecious, and the male flower buds are important winter food for grouse. For increased grouse production, clearcuts should be no larger than 10 acres (4.0 ha). When clearcuts are greater than 10 acres (4.0 ha) in size, some of the negative impacts to grouse can be reduced by leaving the male clones of from 30 to 50 trees (8). Deer and moose habitat can be improved by limiting aspen clearcuts to 40 acres (16 ha), or up to 100 acres (40 ha) for moose, and by short rotation management (14). Although aspen snags deteriorate rapidly, they are important for cavity-nesting ducks and other hole-nesting species. No rare or endangered species are exclusively associated with the aspen type. However, the type is critical for white-tailed deer and beaver which are key prey species for the gray wolf. Remnant old-growth red and eastern white pines are especially important for bald eagle nesting and may be reserved from cutting where they occur in the aspen type (13, 14).

Compared to conifer forests, aspen allows greater ground water recharge and streamflow due to lower seasonal use and smaller interception loss. Clearcutting entire small watersheds may temporarily increase streamflow up to 60 percent but with rapid sucker regrowth, preharvest water yields are restored in about 10 years. The impact of harvesting on large watersheds is minor because only a small percentage of the area is cut within any year. Clearcutting of aspen need not alter water quality (13).

Aspen stands display bright yellow foliage in the fall and strong color contrast between bark and leaves in the spring and summer. When aspen is associated with other species of hardwood or conifers, landscape variety is heightened because of the contrast of color and texture. Travel corridors dominated by aspen are most pleasing when a variety of age-classes are present. Good landscape planning can mitigate the esthetic impact of clearcutting in the type, and in some cases, clearcuts can even improve landscapes by providing interesting vistas (14).

The aspen type usually has a brushy understory and so, except for hunters and mushroomers, is not heavily used by recreationists. Aspen stands make poor campgrounds because they provide favorable habitat for mosquitoes and black flies, are short lived, and cannot long endure injury caused by trampling or vandalism (5).

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Oak – Hickory

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The upland oak–hickory forest type occupies nearly 114 million acres (46.1 million ha) of commercial forest land in the eastern United States—more than any other single forest type in the country, excluding types in Alaska (38). It is found along the prairie borders from Texas north to the Dakotas, eastward throughout the Central States and Appalachian region into southern New England, and from the northern hardwood transition zone southward into the Piedmont Plateau and Coastal Plain. The type is well developed in the Cumberland Plateau and portions of the Appalachian Mountains and most continuous in the Ozark and Ouachita Highlands (3).

Within this vast area oak–hickory occurs on soils ranging from cool-moist Boralf and Orthod Spodosols to warm-dry Mollisols and Alfisols. These soils are derived from glacial material, residual sandstone, shales, and limestones and from gneisses, schists, and granites and range from clay to loamy. The type is found on all topographic positions from dry rocky ridges to deep coves to well-drained valley floors (8).

The climate over the range of the oak–hickory type is humid except in the southwestern fringe where it is moist subhumid to dry subhumid. Average annual precipitation is 22 inches (560 mm) in central Texas, from 30 inches (760 mm) to 40 inches (1015 mm) in the Central States, and about 80 inches (2030 mm) in the southern Appalachians. Generally, about one-half or more of the annual precipitation falls in the dormant season, and from 2 to 8 week periods with little or no rainfall are common late in the growing season, particularly in the western part of the range. Average annual snowfall is 100 inches (2540 mm) or more in the North, from 15 to 20 inches (380 to 510 mm) in the Central States, and a trace in the South. Mean annual temperature averages 40° F (4.4° C) in the North, 55° F (12.8° C) in the Central States, and 65° F (18.3° C) in the South. The frost-free period averages 100 days in the North, 180 days in the Central States, and 290 days in the South (8).

Within the broad oak–hickory type, the Society of American Foresters has defined nine forest cover types as oak types. Oaks and hickories are also listed as components of 31 other forest cover types (7). The great range of climate, soil, and topography results in widely different stand compositions. White oak (*Quercus alba* L.), northern red oak (*Q. rubra* L.), and black oak (*Q. velutina* Lam.) are found throughout the type. Other common oaks on drier sites are scarlet oak (*Q. coccinea* Muenchh.) and chestnut oak (*Q. prinus* L.) in the Appalachians and adjoining areas; northern pin oak (*Q. ellipsoidalis* E. J. Hill) and bur oak (*Q. macrocarpa* Michx.) in the northern and western parts of the range; and post oak (*Q. stellata* Wangenh.), blackjack oak (*Q. marilandica* Muenchh.), bluejack oak (*Q. incana* Dartr.), and southern red oak (*Q. falcata* Michx.) in the West and South. Pignut hickory (*Carya glabra* (Mill.) Sweet), mockernut hickory (*C. tomentosa* (Poir.) Nutt.), shagbark hickory (*C. ovata* (Mill.) K. Koch), and bitternut hickory (*C. cordiformis* (Wangenh.) K. Koch) are consistent but minor components of the type.

The mixture may also contain yellow-poplar (*Liriodendron tulipifera* L.), ashes (*Fraxinus* L. spp.), elms (*Ulmus* L. spp.), sugar maple (*Acer saccharum* L.), red maple (*A. rubrum* L.), blackgum (*Nyssa sylvatica* Marsh.), black locust (*Robinia pseudoacacia* L.), black cherry (*Prunus serotina* Ehrh.), black walnut (*Juglans nigra* L.), and many other hardwood species. On suitable sites, shortleaf pine (*Pinus echinata* Mill.), loblolly pine (*P. taeda* L.), pitch pine (*P. rigida* Mill.), Virginia pine (*P. virginiana* Mill.), eastern white pine (*P. strobus* L.), eastern hemlock (*Tsuga canadensis* (L.) Carr.), and eastern redcedar (*Juniperus virginiana* L.) may also be present. The oak–hickory type often grades into the oak–pine type in the Piedmont Plateau (3).

Many species of understory trees and shrubs occur in oak–hickory stands. Some of the most common ones are flowering dogwood (*Cornus florida* L.), gray dogwood (*C. racemosa* Lam.), sassafras (*Sassafras albidum* (Nutt.) Nees), sourwood (*Oxydendrum arboreum* (L.) DC.), eastern redbud (*Cercis canadensis* L.), downy serviceberry (*Amelanchier arborea* (Michx. f.) Fern.), blueberry (*Vaccinium* L. spp.), mountain laurel (*Kalmia latifolia* L.), witch-hazel (*Hamamelis virginiana* L.), beaked hazel (*Corylus cornuta* Marsh. var. *cornuta*), and bramble (*Rubus* L. spp.) (3, 8).

Oaks and hickories produce large seed crops at 2- to 10-year intervals with great variation among species (32). Acorn production differs greatly from year to year, species to species, and tree to tree within the same species and forest stand (2, 8). In some years the seed crop of some species fails completely and in most years animals, birds, and insects eat a large proportion of the acorns and nuts.

Acorns and nuts are dispersed primarily by gravity, but squirrels and mice or voles may be important dispersal agents through their burial and caching activities. Buried acorns are not always retrieved and those that are not may be in an excellent position to germinate. Germination and first-year seedling survival are best when acorns are buried about 1 inch (3 cm) deep in the soil. Germination is not inhibited by a light litter covering but seedlings may not be able to emerge through a heavy litter cover. In natural seedbeds most 1-year-old oak seedlings came from acorns that were in the soil or in the lower humus layer and covered with litter (27).

Few oak or hickory seedlings will survive more than a few years under crown cover (overstory and/or understory) that allows little light to reach the forest floor (16, 27). Under moderately dense canopies oak and hickory seedlings can survive for several years, however, their tops usually die and new sprouts originate from dormant buds near their root collars (1, 29). Top dieback and resprouting may occur a number of times with each successive shoot attaining a larger size and a stronger root system than its predecessor. By this process oak and hickory advance reproduction slowly develops to a size that allows it to be competitive with sprouts of other woody species and other vegetation that develops after complete overstory removal (28).

The oak and hickory reproduction following overstory removal will consist of stump sprouts, new sprouts from advance reproduction, and advance reproduction. The proportion of stumps that will sprout is related to species, stump size, and tree age. Chestnut, scarlet, and northern red oak stumps sprout more frequently than black and white oak stumps, and small stumps of all species sprout more frequently than large ones (17, 30, 39). Stump sprouts grow faster than any other kind of oak reproduction; low origin sprouts from small stumps have a low likelihood of developing decay and can grow into good quality trees (29).

New sprouts from advance reproduction occur when the old stem is cut off, broken, or damaged in the logging operation (29); however, new sprouts sometimes occur even if the old stem is not damaged. The growth of these sprouts is related to the size of the stem from which they originate—the larger the stem, the faster they grow (25). They are generally of good form and the most desirable type of oak reproduction. Oak and hickory seedlings that become established after a harvest cutting grow very slowly and seldom live more than a few years.

The oaks, hickories, and other more valuable species, such as yellow-poplar, white ash (*Fraxinus americana* L.), black walnut, and black cherry, in oak–hickory forests range from intolerant to moderately tolerant of shade (8). However, many associated trees, such as the maples, blackgum, beech, dogwood, and sourwood, and most shrubs are tolerant to very tolerant of shade. Consequently, if undisturbed, the successional trend of the oak–hickory type is toward the shade-tolerant species, particularly on the higher quality sites. When a seed source is present, yellow-poplar will be a component in new stands following overstory removal on the higher quality sites (16, 29). Oaks and hickories are able to become established and persist on the drier sites where stands are usually more open and development of many of the more tolerant species is restricted (4).

Many insects and diseases attack oaks and hickories. A high proportion of acorns and nuts are destroyed by nut weevils (*Curculio* spp.), gall forming cynipids (*Callirhytis* spp.), and the acorn moth (*Valentinia glandulella* (Riley)). Oaks are the preferred food of the imported gypsy moth (*Lymantria dispar* (L.)) and defoliation for 2 or 3 years can cause widespread mortality. In areas where gypsy moth populations are heavy, it may be difficult to maintain oak stands. Oak wilt (*Ceratocystis fagacearum* (Bretz) Hunt) usually kills only scattered individuals or small groups of trees. Stem borers are an important cause of lumber quality degrade, but seldom successfully attack vigorously growing trees. Decay by wood-rotting fungi often renders the entire stem unusable for timber. The primary entry points for decay fungi are wounds caused by fire or mechanical injury and dead branch stubs (8). The most practical measure to control insect and disease attacks in oak-hickory stands is to maintain healthy, vigorous stands. Rapidly growing, vigorous trees are often able to reject attacks or if attacked, have a good chance to recover.

The oak–hickory type provides habitat for numerous wildlife species. Creating and maintaining diverse vegetation is the key to providing habitat for the greatest number of wildlife species (21, 34). Regeneration cuttings in even-aged systems create openings that provide the edge habitat needed by some species. Even small openings used in group selection provide this edge. When regeneration cuts are made to provide a range of well-dispersed age classes, several vegetation stages and diverse habitats will be present. Regeneration areas provide browse; sapling stands are ideal for some species of birds; and pole, immature sawtimber, and mature sawtimber stands provide mast and cover. Mature oak-hickory stands also contain dens for many species of birds and animals. Trees left specifically for den trees should be carefully selected because many defective trees do not make good den trees. Some cull trees are also excellent mast producers. Snags are valuable as nest sites or perches and can be left standing. Killing instead of cutting cull and unmerchantable trees in regeneration cuts will provide snags.

Fire probably had an important role in the development of existing oak–hickory stands over much of the range (18). The frequent fires that followed cutting the original stands probably reduced the numbers of the less fire-resistant species. The oaks and hickories survived because of their ability to sprout repeatedly and the ability of these sprouts to grow rapidly. Little research has been conducted on the use of fire as a silvicultural tool. A single burn in 4- and 5-year-old stands containing oak, yellow-poplar, and cherry failed to have much influence on stand composition. Three years after the fire, oaks were still plentiful but red maple had increased in numbers and yellow-poplar maintained a dominant position. The ultimate composition of the stands is still uncertain (18). Research may ultimately show prescribed fire to be beneficial to oak seedling establishment and growth but its general use is not recommended at the present time. Wildfires can do much damage and should be excluded from oak–hickory stands.

Any silvicultural system applied to the oak–hickory type will maintain a forest stand. However, species composition following cutting will differ by geographic location, site conditions, other species present, and the intensity of the cutting. The choice of silvicultural systems and regeneration methods will depend greatly on the objectives of management and the requirements of the species desired. If the management objective is to perpetuate the oaks, even-aged systems will best satisfy the reproduction and growth requirements (5, 26, 28).

Of the three even-aged reproduction methods—seed-tree, shelterwood, and clearcutting—the seed-tree method is least useful for reproducing oaks and hickories. The heavy seed is poorly distributed and the slow growing seedlings are not able to compete with the other vegetation that will be present.

Rapidly growing new stands containing oaks, hickories, other shade-intolerant species, and some tolerant species will follow clearcutting of any size and shape (13, 16, 19, 23, 26, 28). When the new stand is 10 years old on sites below oak site index 70, oaks and hickories will usually be dominant; blackgum, red maple, and other hardwood species may also be present. In the southern and southwestern parts of the range, loblolly, shortleaf, Virginia, or pitch pine may also be present if a seed source is adjacent to the cut area and logging resulted in the scarification needed for the pine seed to germinate. On higher quality sites, except in the Ozark-Ouachita Highlands, the species mixture will be diverse. The new stands will contain a component of oaks but along the northern hardwood transition zone stands will also contain sugar maple, elms, American basswood (*Tilia americana* L.), white ash, black cherry, and other northern hardwoods. In the Central States, the Appalachians, and southern areas yellow-poplar will become a dominant component of the new stands along with the oaks. Other mesic species including white ash, American beech, (*fagus grandifolia* Ehrh.), basswood, cucumber tree (*magnolia acuminata* L.), and black locust may also be present (29).

If the regeneration objective is to reproduce oaks, whether to use clearcutting or the shelterwood method depends on the potential of existing advance reproduction and stump sprouting to replace the stand. Clearcutting will be successful if combinations of oak advance reproduction over 4.5 feet (1.4 m) tall and potential stump sprouts are equivalent to 435 well distributed, advance-reproduction stems per acre (1075/ha). However, stump sprouts should not be relied upon as the only source of reproduction (29).

After harvest, cutting or killing unmerchantable trees larger than about 2 inches (5 cm) d.b.h. is an important step in clearcutting. If left, these stems will suppress the reproduction (19, 23, 26). Preharvest herbicide control of species not wanted in the new stand is effective (14). Unmerchantable stems of oaks and other desired species can be forced to sprout if cut close to the ground.

The size of clearcuts is an important consideration but no size is optimum. The maximum size should be determined by stand and site uniformity, esthetic impacts, and wildlife needs. The minimum size is determined by silvical requirements, wildlife impacts, logging economy, and mapping and record-keeping limits. Although 0.5 acre (0.2 ha) openings will satisfy most silvical requirements (35), a large proportion of the opening will be affected by the surrounding stand. Openings must be about 2 acres (0.8 ha) before a substantial area of the opening is not affected by the surrounding stand (29). And if deer populations are high, even larger openings may be needed to provide more browse than the deer can eat.

The shelterwood method should be used when oaks and hickories are wanted in the next stand but advance regeneration is absent or too small. A series of cuts will be necessary to establish new oak seedlings and provide conditions that will allow them or existing small advance reproduction to develop into large sturdy stems (27, 28). The first cut should reduce the stand to from 60 to 70 percent stocking according to the stocking criteria for upland central hardwoods (9) and the crown coverage should be as uniform as possible. At the time of the first cut the density of the understory may also need to be reduced to allow the establishment and development of the oaks because any existing understory will respond to the increased light provided by reducing the overstory density. If the first cut can coincide with a good acorn crop, the likelihood of increasing the number of oak seedlings is enhanced. From 20 to 30 years or more may be required to develop adequate oak regeneration. Additional cuts and/or understory control should be made as needed to keep the oaks growing. When 435 oaks per acre (1075/ha) more than 4.5 feet (1.4 m) tall are present, any remaining overstory should be removed (27). With intensive silviculture, thinnings made at about age 50 or 60 may actually be the beginning of the shelterwood method.

Using the single tree selection system in the oak–hickory type will not perpetuate the oaks or other intolerant species. Harvesting single trees as they mature and cutting to maintain the specified size (age) class distribution results in an essentially complete crown cover at all times. Although oak seedlings will become established, they will be unable to survive and grow into the sapling and larger size classes. Furthermore, as the existing pole and small sawtimber size oaks pass through succeedingly larger size classes and are harvested, the sapling and small tree component will become dominated by whatever shade-tolerant species are present. Eventually the entire stand will be composed of these shade-tolerant species (32, 36, 37). However, if maintaining an almost continuous canopy is more important than species composition, the single tree selection system can be used.

Group selection is a successful regeneration method when used in the oak–hickory type. Initial reproduction establishment and species composition will be the same as in clearcutting in openings of 0.1 to 0.25 acres (0.04 to 0.1 ha). Oaks will be present only to the extent they were present as large, advance reproduction or as stump sprouts (16, 29). Reproduction growth, however, will be retarded near the opening edges; maximum growth will occur only in the central part of the opening not influenced by the surrounding stand (29, 31, 35). If deer populations are high, browsing may extensively damage the reproduction throughout the opening. Although group selection is an effective regeneration method, the individual openings must be considered as integral parts of the entire stand being managed. This makes it difficult to regulate a size class distribution and a sustained flow of products, particularly when the group size is 1 to 2 acres (22). If regulation and sustained yield are not important, small openings can be used for regeneration.

Regeneration of the oak–hickory type by planting or direct seeding has limited application at present. Upland oaks can be planted and survival will generally be acceptable. However, planted oaks usually grow very slowly and vegetation control is needed for several years before they will grow well enough to become part of a new stand (12, 24). However, planting may be the best way to establish oak seedlings quickly in situations such as rehabilitating low quality stands with too little acceptable growing stock and inadequate potential for reproducing the stand with the desired oak species. Direct seeded acorns must be protected from squirrels and other rodents to prevent pilferage. Many repellents have been tried but none have been successful. The high cost of mechanical protection for seeded acorns make direct seeding a marginal operation (24).

Thinnings should be an integral part of managing even-aged, reasonably well-stocked, oak–hickory stands. For maximum growth and yield, the first thinning should be at about age 20 and thinnings should be continued at about 10-year intervals through about three-fourths of the rotation (6, 10).

If a thinning at age 20 will not yield commercial products, crop trees with an average spacing of about 15 feet (4.6 m) should be selected and released. Generally, competing trees smaller or of a lower crown class than the crop tree can be ignored, but trees directly competing with the crown of the crop tree should be removed. Stands should generally be thinned from below to leave 60 percent stocking. However, the first thinning in stands 30 years old or older should reduce stocking to only 70 percent to reduce the tendency of the residual trees to develop epicormic branches. Subsequent thinnings should reduce stocking to about 60 percent (10, 26).

A single thinning will benefit an oak–hickory stand. However, if the stand is more than 30 years old one thinning will not put it in the best condition for growth. Some of the residual trees will be defective or of unwanted species; uniform spacing will be difficult to attain. If only one thinning is planned because a stand is inaccessible or for other reasons, it should be recognized that the stand will develop much like an unthinned stand, the yield will not be much affected.

As a result of past cutting, wildfire, insects, and disease, many oak–hickory stands contain many culls and low quality trees. The recommended treatment of these stands depends on the potential stocking of acceptable trees in the stand and management goals (20). Some low quality stands can be rehabilitated by improvement cuts that remove culls and undesirable stems. However, if a stand does not contain enough acceptable growing stock trees to fully occupy the site 10 years after treatment, cutting may further deteriorate the stand and it should be regenerated immediately (19, 26). Low quality stands on sites below about site index 55 for black oak will produce higher timber yields if converted to pine. Conversion should be considered primarily within the parts of the oak–hickory range where pine occurs naturally and where it is compatible with overall management objectives (19, 26).

The single tree selection system limits wildlife habitat diversity. Edge habitat does not exist, browse production is low, and although mast production is high initially, it will decline as the oaks and hickories are harvested and replaced by other species. The vertical structure of uneven-aged stands provides good habitat for some birds but the number of species is limited and the same structure can be provided when even-aged stands are left well beyond normal rotation age and become overmature.

Thinnings temporarily increase browse and if a few defective trees are left, cavities or potential cavities are provided for hole-nesting species. Leaving defective trees may lower the yield of quality timber but to what extent is unknown.

Special measures may be required to provide habitat for rare or endangered animal or plant species (11). Wherever rare or endangered species are found within the oak–hickory type, silvicultural prescriptions must provide for their continued existence.

Carefully executed silvicultural operations will have little effect on water quality from oak–hickory forests. Water yield will increase in proportion to the amount of the stand removed, with the highest yield coming after complete overstory removal. However, after a few years water yield will be the same as from an undisturbed stand. Most of the increase occurs in late summer and although peak flows are higher from areas where the overstory has been removed, the increase does not usually contribute to flooding (15).

Erosion and sedimentation can occur regardless of which silvicultural system is used but can be minimized by taking proper precautions. Water will not flow over land even in clearcut areas unless the forest floor is destroyed. Practically all erosion and sedimentation resulting from silvicultural operations occurs because of poorly located, constructed, and maintained roads and skid trails. Planning and executing silvicultural operations carefully should make it possible to protect water quality (15).

If the water resource is of primary importance, such as areas that contribute to municipal water supplies, the principles of good watershed management must be followed. Although a silvicultural operation may temporarily degrade water quality, regulating the timber resource and maintaining a healthy vigorous forest should maintain a high quality water resource over the long run.

Any type of logging will change the appearance of a stand. To minimize adverse visual impacts, cut-over areas particularly clearcut and shelterwood areas, should be planned and located so they blend into the topographic and landscape features as much as possible. If they are large, they should be irregular in shape so that only portions are visible from one observation point. Cutting areas should be clean and orderly and roads and skid trails should be designed to minimize landscape disruption.

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Northern Hardwoods

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The northern hardwood association comprises a group of forest types that vary considerably in species composition and whose species vary in silvical characteristics by geographic area. Consequently, responses to silvicultural practices vary by region. Separate bodies of silvicultural information have developed within each broad region. Some techniques are widely applicable while others are applicable only to specific areas. As a result, the silvics and silviculture of the northern hardwoods are reported separately to take regional differences into account.

North Central Northern Hardwoods

The northern hardwood forest of the North Central area covers about 10 million acres (4 million ha). The terrain generally is level to rolling, with elevations from 600 to 2,000 ft (185 to 610 m). Northern hardwoods are locally important in all of the North Central States, but the largest concentrations are in Wisconsin, Michigan, Ohio, Indiana, and Minnesota.

Characteristic species are sugar maple (*Acer saccharum* Marsh.), yellow birch (*Betula alleghaniensis* Britton), American beech (*Fagus grandifolia* Ehrh.), American basswood (*Tilia americana* L.), and eastern hemlock (*Tsuga canadensis* (L.) Carr.). Sugar maple, beech, and hemlock have a high tolerance to shade and are principal components of the northern hardwood climax forest (7), though hemlock is more prominent as a member of a subclimax in the north. The common associates, yellow birch and basswood, are intermediate in light requirements. Other associated species that are locally important include the shade-tolerant balsam fir (*Abies balsamea* (L.) Mill.), the moderately tolerant American elm (*Ulmus americana* L.), black ash (*Fraxinus nigra* Marsh.), red maple (*Acer rubrum* L.), northern red oak (*Quercus rubra* L.), eastern white pine (Pinus strobus L.) and white ash (*Fraxinus americana* L.), and the very intolerant paper birch (*Betula papyrifera* Marsh.).

Society of American Foresters forest cover types included are: sugar maple (type 27), hemlock−yellow birch (type 24), sugar maple−beech−yellow birch (type 25), sugar maple−basswood (type 26), beech−sugar maple (type 60), red maple (type 108), black ash−American elm−red maple (type 39), variants of the northern red oak (type 55), and, rarely, eastern white pine (type 21) (7).

American beech is not found west of eastern Wisconsin; eastern hemlock is most abundant in northern Michigan, Wisconsin, and northeastern Ohio; yellow and paper birch are rare or absent south of the northern parts of the Lake States; American basswood can be locally abundant anywhere, but is most common in the west; sweet birch (*Betula lenta* L.) is found only in southern Michigan and Ohio (18). Red maple is rare in the western part of the region but increases in importance toward the east, where it may be very abundant. Black ash is most abundant in the north. Black maple (*Acer nigrum* Michx. f.) is most abundant in the Central States.

The northern area was glaciated repeatedly but extensive unglaciated areas are found in Ohio, Indiana, and Wisconsin. Northern hardwoods occupy a wide range of soils. In the North, characteristic soils are the Haplorthods (Podzols and Brown Podzolics) and Boralfs (gray wooded soils). Udalfs (gray-brown podzolics) are northern hardwood soils characteristic in southern regions (40). Beech−maple, maple−basswood, and the mesophytic types are most common on gray-brown podzolics. Other northern hardwood types grow on Podzols (59). The elms, black ash, yellow birch, red maple, eastern hemlock, and balsam fir survive best on high-moisture sites, while sugar maple, white ash, basswood, and beech generally are confined to better drained soils. The latter species are especially intolerant of flooding while red maple is very tolerant of flooding (3). Paper birch is especially prominent on coarse-textured soils. Red maple and eastern hemlock often are abundant on excessively well-drained soils. Species normally confined to very wet or very dry soils grow well on well-drained soils when competition is absent (54).

Average annual precipitation ranges from 25 inches (635 mm) in the west to more than 40 inches (1015 mm) in the most southerly areas. Average annual days with snow cover range from about 140 in the northern region to about 20 in the southern region. Temperatures may drop as low as −50° F (−45.6° C) and exceed 100° F (37.8° C) in the northern area (56). Daily minimum temperatures in January are about 0.0° F (−17.8° C) in the northwest and 25° F (−3.9° C) in the south. July daily maximum temperatures range from about 90° F (32.2° C) in the south to 75° F (23.9° C) in the north. Frost-free days range from 40 to 190; in the northern areas, freezing temperatures can occur in any growing season month.

Regeneration is most commonly from seed (56), but most species produce stump sprouts. Sugar maple and yellow birch produce good seed crops about every 3 years, but as many as 4 years have elapsed without good crops (13). Among associated hardwoods, quaking aspen and bigtooth aspen (*Populus tremuloides* Michx. and *P. grandidentata* Michx.) are the most reliable seed producers and black ash the least; associated conifers, northern white-cedar (*Thuja occidentalis* L.) and hemlock, are most reliable and white pine the least. Red and sugar maple, elm, and basswood sprout vigorously (56); basswood reproduction is almost entirely vegetative in many areas. Sprout-origin stands of sugar and red maple cover large areas (8). Younger paper birch stems sprout well. Yellow birch sprouts poorly. Seedling sprouts of any species grow desirable trees and basswood stump sprouts are considered desirable; red maple stump sprouts are least desirable, though sprout clumps can be improved by thinning at an early age. It has been observed that sprouting of some northern hardwood declines toward the south (2). In the United States, planting is occasional because of the relative ease in obtaining natural regeneration.

Lighter seeded species such as yellow birch and eastern hemlock generally require seedbed disturbances to reduce the physical impediments to rooting, provide the seed and young seedlings with proper moisture and germination temperatures, and reduce competition from advanced growth. Sugar maple and beech all establish themselves on undisturbed litter. Requirements for establishing basswood and white ash seedlings are unknown. Drought, extreme temperatures, and competition from other plants are common factors that affect seedling mortality. Heavy shade adversely affects the less tolerant species.

The long-lived, tolerant sugar maple, American beech, and eastern hemlock can respond to release after long periods of suppression. The short-lived, tolerant balsam fir, red maple, and yellow birch respond well to release only after relatively short periods of suppression. Average annual diameter growth of sugar maple and yellow birch more than 6 inches (15 cm) d.b.h. in managed all-aged stands ranges from about 0.21 inch (0.5 cm) in stands of low residual basal area densities to 0.14 inch (0.4 cm) in stands of high density (4). Maximum rates range between 0.35 to 0.40 inch (0.9 to 1.0 cm) per year over 20 years. In even-aged stands, the diameter growth of heavily thinned yellow birch saplings can average 0.36 inch (0.9 cm) per year; poles grow 0.26 inch (0.7 cm) per year, and sawlogs equal 0.16 inch (0.4 cm) per year (5). American elm, white ash, and basswood have the highest potential diameter growth rates. Gross basal area production of managed selection stands is usually between 2.0 and 2.5 square feet per acre (0.5 and 0.6 m^2/ha) per year, but it is possible to sustain 3 square feet per acre (0.7 m^2/ha) per year. Gross cubic-foot volume growth ranges from 65 to 75 cubic feet per acre (4.6 to 5.3 m^3/ha) per year in mature stands, and from 102 to 123 cubic feet per acre (7.1 to 8.6 m^3/ha) per year in young stands (6). Maximum growth is about 300 board feet (fbm) (International ¼-inch) or 60 cubic feet per acre[1] (4.2 m^3/ha) in all-age stands. Cutting cycles typically range from 5 to 15 years. Longer cycles typically are used in conjunction with low residual stocking in lowlands or areas of difficult accessibility.

Financial maturity objectives in managed stands are about 19 inches (48.3 cm) d.b.h. but vary with grade, growth, and interest rate (14). Larger diameter trees are commonly grown to fulfill multiple-use management objectives, to maintain recommended stand density levels in stands undergoing rehabilitation, or to fulfill industrial requirements.

Long-term yields from managed all-aged stands have averaged 250 fbm (50 cubic feet) per acre (3.5 m^3/ha) per year plus about 45 cubic feet (0.5 cord or 3.2 m^3) of chemical wood (6, 14). Published normal yields are variable perhaps because of variations in species composition, and difficulty in aging stands of tolerant trees and determining site index accurately. Total volume from normal stands at 80 years on medium sites range from 2,970 to 3,600 cubic feet (33 to 40 cords) per acre (208 to 252 m^3/ha). Yields from managed even-aged stands are not available.

Quality yield is as important as volume yields and is the top priority silvicultural goal in managing stands for timber production. For example, grade 1 trees were 20 times more valuable than grade 3 trees (41). Initial partial cuts of previously unmanaged stands, whether old growth or cutover, typically produce only 20 to 30 percent of the harvested volume in high-quality sawlogs (23, 55). Improvement cuts, skillfully done, improve the value of yields dramatically; after several partial cuts, it is possible to both increase the yield of grade 2 and better logs to 85 percent and maintain a residual stand of equally high quality (55). The investment yields of well-managed stands have compared favorably with leading standards of investment (45).

Pruning is a biologically acceptable way of increasing quality yields, but this practice should be preceded by careful cost-return analysis.

Few insects and diseases cause catastrophic mortality in the northern hardwood type. The exceptions include the widely spread Dutch elm disease (*Ceratocystis ulmi* (Buism.) C. Mor.) and the locally important crown diebacks and declines. Many kinds of defoliating insects attack northern hardwood species, though defoliation alone seldom causes mortality. Suggested strategies for reducing the incidence of diebacks and declines include encouraging species diversity, maintaining vigorous trees through stand improvement measures, and cutting trees before they are overmature (21). A number of insects and diseases, as well as logging injuries, cause degrade, discoloration, and decay; affected trees should be removed in improvement and harvest cuts. Trees with Nectria canker (*Nectria galligena* Bres.) and maple canker (*Eutypella parasitica* Davids. & Lorenz) in particular should be removed before shelterwood seeding cuts (11). Bud-mining insects cause serious forking of sugar maple in even-aged stands not maintained at high-density levels during the sapling and pole growth stages (11).

The northern hardwood types can support relatively high populations of deer without serious injury; damage will be minimal if management practices favor dense reproduction and vigorous shoot growth (22). Damage from feeding by the yellow-bellied sapsucker can be serious, especially to yellow birch, in open stands, but such damage is minimal in mixed stands maintained at recommended density levels (11).

Sugar maple forest types usually are found on well-drained, upland loamy soils. The major type associations include sugar maple, sugar maple–beech–yellow birch, beech–sugar maple, and sugar maple–basswood. Sugar maple is the characteristic tree throughout.

Advanced regeneration on moist sites is composed of shade-tolerant, long-lived species, most commonly sugar maple. Good seed crops occur frequently enough to reseed selection forests, though poor crops are common (13) and contribute to variations in regeneration success under even-age practices (42).

In the upland sugar maple types, forest owners can choose from among several silvicultural systems depending on their management objectives.

All-aged management by individual-tree selection is well suited for continuous production of high-quality veneer and sawlogs. Although shade-tolerant species predominate, other species are produced; their abundance depends primarily on variations in soil characteristics. Advance reproduction of desirable shade-tolerant species is almost always present. Periodic cuttings develop a distribution of size classes and concentrate growth on the more desirable trees with long clear boles (4, 6). Residual density ranges from 50 to 90 square feet per acre (11.5 to 20.7 m^2/ha) depending on average tree diameter and owner objectives.

Even-aged silviculture is necessary to maximize the number of light-demanding species such as yellow birch (60) or less aggressive tolerant species such as eastern hemlock. Shelterwood cuttings provide the greatest flexibility and consistency in establishing even-aged stands. The amount and composition of residual overstory can be varied to meet species requirements for establishment and early growth while reducing the danger of losing the site to herbaceous vegetation. Control of advance regeneration and scarification before logging encourages the establishment of light-seeded

[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.

species; without such understory treatment, tolerant species will continue to dominate the new stands. Normally, only one cutting is required in upland stands of seed-bearing age to assure adequate establishment. The remaining overstory can be removed in stages to develop regeneration slowly, or in a single cut after suitable regeneration is fully established (15). Size of seedlings is the most important criterion for gauging establishment. Suitable size varies by species and locality (58).

Alternate clear-strip cutting has shown potential, but results have been unpredictable. Better results with this method have been obtained when plentiful, vigorous advance reproduction was present, or during good seed years when competition was eliminated (42). Large-area (0.5 acre or 0.2 ha and larger) clearcutting without advance reproduction should be avoided. These cuttings, as well as the unsuccessful alternate clear-strip cuttings, have resulted in patchy communities of trees, grassy openings, and shrub-dominated areas that persist for several decades (43).

Guidelines for even-aged management include: precommercial thinnings to ensure the survival and growth of yellow birch, elimination of defective overstory trees, and periodic thinning whose residual stocking varies substantially by species composition (57).

Conversion of northern hardwoods to pine on upland sites by clearcutting and planting results in substantial increase in volume. Economic returns are likely to be greatest on sites with a low site index for sugar maple that are occupied by stands of low actual or potential quality (52). Planting must be followed by repeated weeding and cleaning to ensure the survival of pine.

The major northern hardwood associations on poorly drained sites are hemlock, hemlock–yellow birch, or black ash–American elm–red maple and variants of the red maple type. These are mostly long-lived subclimax types (2). The ash–elm–red maple type is an edaphic climax on the wettest areas. The types commonly grade into each other and into variations of the maple and conifer types. Sugar maple usually is present on all but the wettest sites. Logging and fire on these sites have resulted in a variety of secondary successions in which almost any species common to the region may be dominant.

On the most poorly drained sites, it is difficult to regenerate species other than black ash, American elm, or red maple. To regenerate yellow birch and hemlock, the desired species on the somewhat poorly drained sites, scarification or burning is needed to create suitable seedbeds, undesirable advance reproduction must be eliminated, and adequate seed must be available.

Regeneration methods suitable on these sites include individual-tree and group selection, shelterwood cutting, and alternate clear-strip cuttings. Selection will favor tolerant hardwoods but all species present in the overstory usually will be represented in the reproduction (56). With uneven-aged methods, because of the danger of windthrow and postlogging decadence, the first cutting in previously unmanaged stands should leave relatively high stocking levels (57). After 5 years, a second cut should be made to reduce the stands—trees 10 inches (25.4 cm) or more in d.b.h.—to 70 feet^2 of basal area per acre (16.1 m^2/ha); succeeding cuts also should be to this stocking level. When heavy cuts are necessary, cutting should not be less than 50 feet^2 (11.5 m^2) of basal area since lower residual stands result in reduced sawtimber volume growth and poor quality development of the remaining stems (10).

Group selection is possible in the hemlock types and can be used with site preparation to favor regeneration of yellow birch (8). However, the method creates management problems. It is unwieldy for large tracts; it does not stimulate growth of trees in the areas between groups; and the quality of border trees may be reduced around larger openings. Some of these disadvantages can be overcome when group cuttings are combined with thinning in the adjacent areas (57).

The proportion of yellow birch and hemlock can be increased by shelterwood treatments that include removing advance reproduction or scarification before the seed cut (60). Without site preparation, shelterwood cuttings generally favor those more tolerant species which establish themselves easily on forest duff. Choice of overstory density and number of preparatory cuts depends on the abundance of the regeneration, stand age and vigor, soil depth, and on other factors related to wind firmness and postlogging mortality. Generally, the first cut should leave around 80 percent crown cover.

Large-area (0.5 acre or 0.2 ha and larger) clearcutting to produce regeneration should be avoided. Regeneration is unpredictable on such sites in the Lake States. Because successful alternate clear-strip cutting requires both the elimination of competition and the presence of plentiful established, advanced regeneration (42), this method is essentially a shelterwood strip. When these requirements are not met, grass-shrub-herbaceous communities can develop and persist for several decades before they are replaced by desirable tree species (43). Clearcutting without advance regeneration when appreciable numbers of red maple and American elm are present usually results in undesirable fast-growing sprouts which suppress seedling stems (12). When swamp conifers are prevalent, regeneration can be accomplished by alternate clear-strip cuttings of one or two tree heights in width (57). Swamp conifers are mixtures of white spruce (*Picea glauca* (Moench) Voss), black spruce (*Picea mariana* (Mill.) B.S.P.), white cedar, balsam fir, and eastern hemlock.

In abused stands of any species, timber stand improvement practices generally should remove undesirable trees in several cuttings to develop residual stands with stocking levels similar to those recommended for mature stands (57). Where the major portion of the stand is defective or undesirable, shelterwood treatments can be used for regeneration as soon as desirable species reach seed-producing age.

Each of the stages of forest growth is associated with a different group of animals and birds. Even-aged and all-aged management tend to create habitats for separate groups of animal species or different visual characteristics, but methods can be modified to meet a variety of nontimber objectives. Where demands for recreation and esthetic considerations require a continuous cover of sizeable trees, the selection system is preferred. All of the even-aged systems can be used to enhance the habitat for forest-edge game and nongame species. The shelterwood method is especially good for browse production and offers the best opportunity for establishing hemlock, an important cover species for deer and other wildlife in the northern Lake States. The clearcutting system produces a greater variety of plant species. The long-lived, brush-grass-herbaceous communities that result from clearcutting without established tree regeneration provide excellent summer wildlife habitat (61). Unless precautions are taken, reproduction cuts by even-aged methods may have negative impacts on visual quality, particularly during the 3 to 5 years that logging slash is visible.

Northeastern Northern Hardwoods

The northern hardwood forest in the northeastern United States, covering nearly 15 million acres (6 million ha), is characterized by sugar maple, American beech, and yellow birch. These species are found in various combinations in the following Society of American Foresters cover types: sugar maple (type 27), sugar maple–beech–yellow birch (type 25), beech–sugar maple (type 60), and red spruce–sugar maple–beech (type 31). On well-drained soils of moderate texture, successional types such as red maple (type 108), gray birch–red maple (type 19), and eastern white pine (type 21) include varying amounts of key northern hardwood species depending on the stage of development (7). Other common associations are beech–red maple and hemlock–beech. Concentrations of northern hardwoods are found in northeastern and central Maine, Vermont and central New Hampshire, New York, northern Pennsylvania, and western Massachusetts. In scattered areas in southern New England and New York, northern hardwood species blend with oak and mesophytic types. Types similar to those mentioned are found from Wisconsin to northern Virginia but do not necessarily react similarly to silvicultural treatment (59).

In the Northeast, beech, yellow birch, and sugar maple dominate older stands, while younger, even-aged stands commonly contain paper birch, white ash, red maple, and other hardwoods such as aspen, red oak, and sweet birch. Conifers such as eastern hemlock, white pine, balsam fir, and red spruce (*Picea rubens* Sarg.) grow with the hardwoods, especially on excessively dry, wet, or shallow soils (26) on cool steep slopes, and on poorly drained soils at lower elevations. Repeated cuttings, wildfire, and past land use have created numerous combinations of stand conditions, age classes, and species. Yellow birch, sugar maple, paper birch, and white ash are the most desirable hardwoods for timber production; all species contribute to pleasant fall color.

Total average annual precipitation ranges from 40 to 50 inches (1015 to 1270 mm) in northern hardwood areas; as much as 25 percent of this precipitation occurs as snow. Average annual days with snow cover range from 60 to 140. Average maximum temperatures range from 74° F (23.3° C) to 84° F (28.9° C). January maximums range from 24° F (−4.4° C) to 36° F (2.2° C). Frost-free days range from 120 to 150 and mean annual water surplus is 10 to 34 inches (255 to 865 mm) where northern hardwoods are prevalent (35). Hurricane force winds occur sporadically; glaze or wet snow damage is common over wide areas, especially at high elevations.

Species composition of stands depends on stand age, site characteristics, geographical region, and past land use. Northern hardwood sites are found at elevations up to 2,500 feet (760 m) (31) on land that is rolling to mountainous. The hardwoods generally occupy a zone between white pine and spruce types in the river valleys and the spruce–fir type. Hardwoods grow in a wide range of soils, the most productive of which are fine- to medium-textured tills or organically enriched areas (25).

All important commercial species characteristically reproduce from seed, and some also reproduce by vegetative means. Yellow and paper birches seed prolifically, producing reasonably good crops every other fall. White ash, sugar maple, and beech produce good crops at intervals as long as 5 years. Red maple produces abundant seed nearly every spring. Red maple sprouts prolifically from stumps of poletimber and small sawtimber. Sugar maple, beech, and birches sprout reasonably well from stumps of small (sapling or small pole-size) trees. Beech sprouts on larger stumps generally are short lived. Beech root suckers prolifically, especially following cutting. Striped maple also sprouts prolifically. Brambles (*Rubus* spp.) and pin cherry (*Prunus pensylvanica* L. f.) reproduce from seed buried in the upper soil horizon for as long as 100 years, though numbers decline sharply after 40 years (17).

Planting has been confined largely to paper birch and conifers such as white spruce, red pine, and white pine. Experience in other regions suggests that white ash and basswood may be plantable on a large scale. Current trials with sugar maple have been successful where seedlings have been protected from animal damage.

Species in the type differ in shade tolerance, longevity, and growth rate. Yellow birch is intermediate in tolerance and growth rate. White ash and red maple also are intermediate in shade tolerance and have moderately fast growth rates. Paper birch is one of the fastest growing commercial species, but the typical variety is short lived and very intolerant. Sugar maple, beech, hemlock, and red spruce are shade tolerant, long-lived species. Sugar maple, beech, and red spruce have moderately slow growth rates while hemlock grows rapidly in diameter, though not in height (36, 49, 59). Tolerant small trees and shrubs such as striped maple (*Acer pensylvanicum* L.), eastern hophornbeam (*Ostrya virginiana* (Mill.) K. Koch), and hobblebush (*Viburnum alnifolium* Marsh.) affect silvicultural procedures. Pin cherry, a very shade-intolerant small tree, can be a serious competitor in clearcuts.

The highly shade-tolerant beech and sugar maple are the most common tree species in the understories of northern hardwood stands on well-drained sites. Red spruce and hemlock are more commonly found on wet or excessively well-drained sites. These species and the other long-lived tolerant species, when established, can respond to release after long periods of suppression. Tolerant shrubs and small trees also respond well to release. Yellow birch and paper birches need overhead light and seedbeds of moist humus or mineral soil for optimum early establishment and development (38). Paper and yellow birch must become dominant early in life to survive to maturity. The capacity of the birches and other less than tolerant species to respond to release after suppression is moderate to poor.

On average northern hardwood sites, mean annual growth in cubic and board feet culminates at about age 50 and 160, respectively, in even-aged stands (32). In managed stands, culmination of total board-foot production is expected at age 100 to 120. At maturity, fully stocked northern hardwoods commonly support gross volumes of 2,500 to 3,500 feet^3 per acre (175 to 245 m^3/ha) and 8,000 to 17,000 fbm per acre (112 to 238 m^3/ha) depending on site and species mix (27). Intermediate yields from managed stands vary greatly depending on the intensity of management and markets, but there is some evidence that as an upper limit, long-term total yields from managed stands can be twice that from no management (28). In managed, uneven-aged stands, quality yields have declined due to beech bark disease (*Cryptococcus fagisuga* (Lindinger) and *Nectria coccinea* Pers. ex Fr. var. *faginata* Loh., Wats, & Ay.) (9).

Appropriate residual stocking in even-aged stands ranges from about 55 to 95 square feet of basal area per acre (12.6 to 21.8 m^2/ha) as mean stand diameter increases from 5 to 18 inches (13 to 46 cm). In uneven-aged stands managed by either group or individual-tree selection, residual basal areas in trees 5 inches (13 cm) or more in d.b.h. should be a minimum of 60 to 70 square feet per acre (13.8 to 16.1 m^2/ha) with a minimum of 30 square feet (6.9 m^2) in acceptable sawtimber (30). Cutting cycles typically are 15 to 20 years.

Northern hardwoods in this region have several natural enemies that influence the application of silvicultural treatments. Beech bark disease is a lethal disease of beech (46). Harvesting beech before it attains a diameter of 18 inches (46 cm) will reduce losses from beech bark disease (9). Group selection or clearcutting of mature beech promotes other desirable species and is an effective way to reduce losses. Birch dieback has caused heavy mortality in both birch species; and even when the disease has subsided, a recurrence is possible. Postlogging decadence often develops in birches and eastern hemlock exposed by heavy partial cutting. Cankers caused by sugar maple borer (*Glycobius speciosus* (Say.)) (48) increase the susceptibility of maple to wind breakage. Lumber grades of all hardwoods are lowered by discoloration and decay organisms which enter through branch stubs and logging wounds (47). Birch is killed by severe defoliation by the saddled prominent (*Heterocampa guttivitta* (Walker)) (50).

Choice of silvicultural systems and intensity of management in the northern hardwood types of the Northeast is influenced by species composition, habitat, site productivity, animal damage, local markets, and management objectives.

Individual tree selection favors sugar maple on enriched habitats in New England (26) and better maple–ash sites throughout the Northeast. In New England, individual tree selection favors beech on coarser, less fertile soils, and tolerant conifers on moist or excessively well-drained sites. Group selection favors the less tolerant species whose proportions depend on the size of the opening. This technique can be used in conjunction with single-tree selection to increase the diversity of tree species (29), to reduce undesirable species such as beech and striped maple, or to salvage overmature and defective stems. Low residual basal areas favor sugar maple reproduction over beech or red maple on some sites (1, 26). Low stocking may result in reduced quality in residual maple stems due to increased branchiness (10).

Shelterwoods have been used to produce even-aged stands of hardwoods. The final removal of shelterwood overstories simply releases established natural regeneration, so it is necessary to consider treatment of preexisting understories to ensure that desirable species are represented in the next stand, and to control stand density or crown cover during the earlier cuts. In the Adirondacks, a two-cut system is used to favor yellow birch and sugar maple. The removal of beech understories and control of deer populations are necessary (24). Farther east, paper birch becomes a more important component of the new stand if shelterwood overstories are adjusted to provide good growing conditions for this intolerant species. Although both yellow and paper birch regeneration are encouraged by scarification or logging disturbance (37, 38), scarification or summer logging may not be necessary on moist sites, or if competition from understory vegetation is minimal (60). Mortality of released regeneration is reduced when the final removal is done in the winter. In New York and southern New England, shelterwoods produce rich mixtures of hardwoods, including black cherry (*Prunus serotina* Ehrh. var. *serotina*), oaks, white ash, yellow-poplar (*Liriodendron tulipifera* L.), and butternut (*Juglans cinerea* L.) (34). Three-cut shelterwoods have been reported (60) and can be used to develop advanced regeneration of tolerant species where they are absent, to control browse production, or to provide for certain elements of scenic vistas.

Clearcutting by patch, strip, or block enhances chances for intolerant and moderately tolerant species in the next stand and suppresses undesirable tolerant trees and shrubs. The size of the clearcut often influences the relative proportion of tolerant and intolerant species. Greater exposure in larger areas favors intolerants; the reverse is true for tolerant species (33). Summer logging and clearcutting areas larger than two tree heights reduce striped maple; this species endures suppression for about 30 years (19, 20) and responds quickly to release when openings are small. Clearcutting can be followed by scarification to ensure suitable seedbeds and to reduce competition on sites which are dry or occupied by unwanted species. Clearcutting of stands before seed-bearing age results in sprouts, shrubs, and herbaceous growth (44).

Large block clearcuttings (more than 5 acres (2.0 ha)) result in conditions suitable for the establishment of roughly equal numbers of intolerant and tolerant tree species, though individual areas may vary considerably. Patch cutting up to 0.75 acre (0.3 ha) encourages the more intolerant species but may be unwieldly to manage. Cutting strips 50 to 100 feet (15.2 to 30.5 m) wide usually increases the number of species intermediate in tolerance, such as yellow birch and white ash, while reducing the number of intolerant species (32). Other things being equal, the proportion of species resulting from each of the silvicultural systems varies by soil-site (26) and geographic area. For example, in New England, white ash may be the predominant intermediate after alternate clear-strip cutting on enriched habitats while yellow birch replaces ash after clear-strip cutting on other habitats. The aggressiveness of paper birch in clearcuts diminishes from east to west so that the clearcutting of large blocks toward the west may result in few, if any, paper birch.

Precommercial stand tending may be necessary to preserve an acceptable species composition in young even-aged stands. Most desirable species compete poorly with fast-growing weed species such as pin cherry, red maple sprouts, or advanced growth of any species. Early tending is essential for the survival of birch. Thinnings and timber stand improvement in intermediate size classes maintain individual tree growth rates, reduce cull, harvest mortality, and upgrade the quality of even-aged stands (62). Commercial thinnings are especially important in stands of both long- and short-lived species. Partial cutting in uneven-aged stands have the same objectives but the focus usually is on the larger size classes of the more tolerant species.

Northern hardwoods are found on steep slopes and on the finer textured or compacted soils which are erodable; they also border streams and lakes, and harbor various animal life. On steep slopes, partial cutting along streams has minimal adverse impact upon water quality. Clearcutting may temporarily change streamwater and nutrient cycling patterns. When clearcutting is indicated, progressive strip clearcutting with a buffer strip produces the least change (39). Logging roads are planned to prevent erosion during and after logging, and the use of water bars is effective in reducing erosion (32, 53).

Recreation-area silviculture may include long rotations, higher residual stand basal areas, and stand structures which favor large trees. Frequent salvage, or short cutting cycles, or both, are needed to reduce losses from mortality and defect, which increase with length of the cutting cycle, rotation, maximum tree size, and stocking level. Rotations of several hundred years are possible with the tolerant long-lived species if growth loss from decay and mortality are acceptable or if frequent salvage is possible.

Generally, clearcutting creates abundant and varied browse for short periods (51). Shelterwoods provide as much browse as clearcutting, but species variety declines. Individual tree selection produces the least browse per acre. Group selection and patch cutting concentrate browse on small areas. On lower slopes, partial cutting at intervals shorter than 15 years promotes hobblebush, a food source for wintering deer (16).

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Eastern Spruce – Fir

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The eastern spruce–fir forest cover type is one in which red spruce (*Picea rubens* Sarg.), white spruce (*Picea glauca* (Moench) Voss), and balsam fir (*Abies balsamea* (L.) Mill.) individually or collectively make up a plurality of the stocking. It includes a number of forest cover types recognized by the Society of American Foresters (3). These include paper birch–red spruce–balsam fir (type 35), red spruce–balsam fir (type 33), red spruce (type 32), red spruce–yellow birch (type 30), and red spruce–sugar maple–beech (type 31). Also included are white spruce (type 107), and sometimes balsam fir (type 5) when the objective is to favor spruce. A common managerial objective is to favor spruce and increase its proportion in the mixtures. If the objective is to favor balsam fir, then the appropriate guides are found in the discussion of the balsam fir type.

Throughout most of the spruce–fir type, forest site characteristics are a result of past glacial action. Unsorted drift and till are the better forest sites; they are composed of heterogeneous material deposited on the midslopes of hills and higher mountains. The coarser, water-transported, sorted, and often stratified drifts found in kames, eskers, outwash plains, and glacial lake shores and bottoms are usually the poorer sites (1). Spruce–fir forests occupy the shallow soils of these poorer sites on the steeper mountain slopes and also on the flats. On the better sites and deeper soils on the lower slopes, hardwoods grow in various mixtures with the conifers (1, 9, 11).

The eastern spruce–fir type occurs primarily in the northern portions of Maine, New Hampshire, Vermont, New York, Michigan, Wisconsin, and Minnesota. There are about 12.3 million acres (5.0 million ha.) of commercial spruce–fir forests in these States, including 7.2 million acres (2.9 million ha) of balsam fir. The red spruce type occurs primarily in New England and New York but is also found at higher elevations in the mountains as far south as Tennessee and North Carolina. The white spruce type occurs in New England, New York, and the Lake States but does not extend southward. In the Lake States it is found mostly in plantations. Balsam fir is the most widespread type and grows at higher elevations in Virginia and West Virginia, but to the south it is replaced by Fraser fir (*Abies fraseri* (Pursh) Poir.).

The soils where red spruce, white spruce, and balsam fir grow are mostly acid Spodosols, Inceptisols, Alfisols, and sometimes Histosols with a thick mor humus and a well-defined A_2 horizon—characteristics commonly associated with abundant rainfall and conifer forests (1, 5, 9). Commonly, these soils range in pH from 4.0 to 5.5. Spruce–fir is often found on shallow till soils with an average depth to a compact layer of 18 inches (45.7 cm).

The climate is cool and moist, with long, cold winters. Annual precipitation is well distributed, amounting to 24 to 52 inches (610 to 1320 mm); annual snowfall is 48 to 160 inches (1220 to 4065 mm); days with snow cover are 100 to 140; daily maximum January temperatures average 15° to 30° F (−9.4° to −1.1° C); daily minimum January temperatures average −5° to 20° F (−20.5° to −6.6° C); and frost free days are between 90 and 150.

Associated species include northern white-cedar (*Thuja occidentalis* L.), eastern hemlock (*Tsuga canadensis* (L.) Carr.), eastern white pine (*Pinus strobus* L.), black spruce (*Picea mariana* (Mill.) B.S.P.), tamarack (*Larix laricinia* (Du Roi) K. Koch), red maple (*Acer rubrum* L.), paper birch (*Betula papyrifera* Marsh.), aspen (*Populus* spp.), ash (*Fraxinus* spp.), American Beech (*Fagus grandifolia* Ehrh.), sugar maple (*Acer saccharum* Marsh.), yellow birch (*Betula alleghaniensis* Britton), and basswood (*Tilia americana* L.). Depending on successional stage and site conditions, various combinations of the associated hardwoods and softwoods may be found within the spruce–fir type (3).

Spruce–fir stands in New England are regenerated primarily by natural seeding (5). In recent years, however, container-grown seedlings have been planted to increase the proportion of spruce in new stands. Many acres of abandoned farm land were also planted with bareroot spruce seedlings in past years. In the Lake States the white spruce type is dependent on planting.

Good seed crops occur about every 4 to 8 years for red spruce, 2 to 6 years for white spruce, and 2 to 4 years for balsam fir (4). Seed is disseminated primarily by wind and gravity, over relatively short distances. Seed production begins at about age 30 for the spruces and balsam fir although instances of earlier production have been noted (4, 9).

Cones of all three species ripen early in the fall of the same year that flowering occurs. Most seed is dispersed in the fall and germinates in late May to early July the next spring (4). Little viable seed remains in the forest floor beyond 1 year (5).

Germination will take place on almost any seedbed except sod and duff more than 3 inches (7.6 cm) thick, but mineral soil is probably the best, followed by rotten wood and shallow duff (4, 9).

Initial establishment of the spruces and balsam fir is best under a high canopy that admits up to 15 percent of full sunlight. However, as the seedling develops, it needs at least 50 percent of full sunlight for optimum growth. The faster growing, somewhat deeper root system of balsam fir seedlings gives them a competitive advantage over the spruces (9).

Temperatures of 68° to 86° F (20.0 to 30.0° C) are favorable for the germination of red spruce and probably also for white spruce and balsam fir. Soil surface temperatures higher than 115° F (46.1° C) will cause heavy mortality if seedlings are exposed for even a short period. Drought, frost heaving, and crushing by hardwood litter and snow cause heavy losses, especially during the first year (4, 5, 9).

Balsam fir, red spruce, and white spruce are all tolerant or very tolerant to low light conditions (4). Advance spruce–fir reproduction will persist under an overstory and responds readily to increasing light intensities as the overstory is removed (9). Where advance growth is well established and of sufficient size, satisfactory new stands will usually develop when the mature overstory is removed, unless fire occurs.

Management practices that salvage trees that die naturally and increase the percentage of red and white spruce in the stand will greatly influence net growth (5). The mean annual growth in spruce–fir stands (66 percent or more softwood species) receiving a minimal silvicultural input is about 50 cubic feet per acre (3.5 m^3/ha.) (10). Well-managed stands on productive sites can produce nearly twice as much merchantable wood as unmanaged stands over the course of a rotation, primarily because trees that die are salvaged (5).

Site index is difficult to measure in spruce–fir stands because tolerant species often survive for years in a suppressed state. However, it has been shown to be as good a measure of productivity as any of several growth functions. Site index curves are available for even-aged spruce–fir stands in northern Maine and the Lake States. Recently, polymorphic site index curves have been developed for spruce–fir stands in northern Maine (8).

In New England, spruce–fir sites may be grouped into primary softwood sites and secondary softwood sites, classifications that are meaningful in terms of potential growth, stand composition, and ease of regenerating softwoods. Primary sites include spruce swamp, upper spruce slope, old field spruce, spruce flat and balsam fir flat, and lower spruce slopes. Usually drainage is impeded in these sites, and they are occupied mostly by softwoods. Secondary softwood sites occur on the better drained parts of intermediate topographic positions. Hardwoods can successfully compete with the softwoods on these sites (5).

Red and white spruce and balsam fir are subject to damage from a number of insects and diseases. The greatest impact on the type is from the spruce budworm (*Choristoneura fumiferana* (Clemens)) which defoliates and eventually kills great amounts of timber in periodic outbreaks. In spite of its name, its preferred host is balsam fir, which bears the brunt of each epidemic in growth loss and mortality. Another insect that causes serious mortality of balsam fir is the balsam woolly adelgid (*Adelges piceae* (Ratzeburg)) (5, 9). In parts of the Lake States, severe damage from the yellowheaded spruce sawfly (*Pikonema alaskensis* (Rohwer)) can occur in white spruce plantations.

Two important diseases of spruce are red ring rot (*Phellinus pini* (Thore ex Fr.) A. Ames) and red brown butt rot (*Phaeolus schweinitzii* (Fr.) Pat.), both usually confined to overmature or damaged trees. Red heart (*Haematostereum sanguinolentum* (Alb. & Schw. ex Fr.) Pouz.) causes 90 percent of all trunk rot in living balsam fir trees (5). Several fungi are important causes of decay in living balsam fir trees; they include a top rot and a number of butt rots (9). They occur so frequently in balsam fir that it is usually managed on a pathological rotation of about 50 years on poorer sites and about 70 years on better sites.

Wind damage is extensive in the spruce–fir forest because of the shallow root systems, generally thin soils, and prevalence of butt rots in balsam fir. Wind, in combination with snow and ice, can cause top breakage. Shallow root systems, thin bark, and flammable needles make spruce–fir forests very susceptible to killing by fire (5).

Animals may cause damage to spruce–fir forests. Rodents and birds consume and store large quantities of seed. Damage to the terminal buds of young spruce and fir, presumably by birds, has also been noted. Some injury and mortality are occasionally caused by porcupine, bear, deer, moose, and yellow-bellied sapsuckers (5). Red squirrels clip twigs and terminals and eat reproductive and vegetative buds.

Spruce–fir stands are amenable to either even-aged or uneven-aged management and most of the associated silvicultural systems except seed tree cutting—the seed trees are likely to be windthrown before the stand is regenerated (5, 7, 11).

Individual tree selection is applicable to stands that are uneven-aged, like many older stands that have been lightly disturbed by man or nature. The shade-tolerant spruce and fir are well adapted to the selection system, and the repeated light harvests create favorable conditions for the establishment of abundant regeneration. A continuous high forest cover is maintained, which is desirable for esthetics and for maximum site protection, especially along streams and rivers. Some control over regeneration is possible by manipulating the overstory seed source. The frequent harvests at 5- to 20-year intervals allow salvage of wood that might otherwise be lost to mortality. Under the selection system, growing space is more fully utilized in the vertical plane. Also, the shorter-lived fir component of the stand may be effectively reduced, rendering the stand less vulnerable to spruce budworm damage (1, 5, 6, 9, 11).

The selection system is more complicated than even-aged systems because of the mixture of age and size classes; harvesting occurs over a larger area to get the allowable cut; and logging damage to growing stock is difficult to prevent. Wind damage is a constant threat if too much volume is removed in one harvest. Present mechanical harvesting machines are probably not practical (1, 5, 9, 11).

Group selection, a variant of individual tree selection, creates larger openings but has many of the same advantages and disadvantages. It has no silvicultural advantage for tolerant species such as spruce and fir; the somewhat larger opening, however, may have advantages from an operational standpoint and may aid in rapidly developing desirable regeneration.

The shelterwood system is applicable in spruce–fir stands that lack adequate advance regeneration and where soils are deep enough, sites protected enough to prevent windthrow, and there are no insect or disease problems of concern. One-third to one-half of the stand basal area may be removed in two or more harvests (on sites known to have a windthrow problem removing less than one-third of the basal area may be prudent), opening up the stand uniformly to permit establishment of reproduction under the shelter of the remaining trees. The system allows some control over species composition of the regeneration and provides good growing conditions for the residual overstory, but it may require 10 to 15 years before regeneration has developed enough that the remaining overstory can be removed, and some damage to new seedlings may result from the final harvest. It is more pleasing esthetically than clearcutting, especially in the years immediately following cutting (1, 2, 5, 11).

Clearcutting is probably the most common even-aged silvicultural system used in spruce–fir today. It is recommended for mature, overmature, or insect- and disease-ridden stands where partial removal could result in considerable mortality or damage to residual trees (1, 5, 11). It is the system best adapted to mechanical harvesting (2).

Although most definitions of clearcut harvesting allow for the presence of advance regeneration, there is usually no deliberate effort to control initial species composition or quality. If excessive seedling losses due to drastic exposure or mechanical damage are anticipated, harvesting should be done in narrow strips (progressive or alternate clear-strip cuttings) as wide as half the height of the border trees or small patches of about 1 acre (0.4 ha) or less in size. Thus, adjacent uncut areas can provide partial shade to protect the seedlings and provide new seed if regeneration is not adequate. In a sense these are variants of the shelterwood system.

Extensive clearcut areas lacking in established advance seedlings may require planting. Such areas may have high surface temperatures and excessive drying that is detrimental to natural regeneration. Large accumulations of slash and the development of heavy herbaceous cover, such as raspberries (*Rubus* spp. L.), may inhibit natural regeneration in any size clearcut (1, 2, 5, 11).

The initial operations in uneven-aged stands to be managed by the selection system are usually salvage cutting, improvement cutting, and/or thinnings. The object is to rid the stand of overmature trees of poor vigor, rough or rotten trees, and trees of undesirable species. Deadening of completely unmerchantable trees is also silviculturally desirable. Thereafter, harvesting, improvement cutting, thinning, weeding, and cleaning are part of the same operation (2, 5).

Even-aged stands of spruce–fir usually regenerate very densely and need early thinning for trees to reach mechantable size in a relatively short time. The initial thinning in even-aged stands is recommended at about 25 years of age, and periodic thinnings at 10- to 20-year intervals thereafter. A precommercial thinning can be a combined cleaning and thinning to establish a species priority and may be needed when trees are from 6 to 15 feet (1.8 to 4.6 m) tall depending upon density. Timber removals from intermediate cuttings should not exceed 10 to 40 percent of total basal area, depending on the site, or windthrow may result (2, 5, 11).

The pulp and paper industry has been the dominant user of the spruce–fir resource, but solid wood products have always been important and in recent years demand for structural softwood lumber has increased. Spruce is also used for poles, piling, boatbuilding stock, cooperage, and specialty products such as piano sounding boards.

The runoff water from the spruce–fir forest type is stored in the many lakes and ponds which, along with the streams and rivers, provide habitat for fish and other aquatic life. The spruce–fir type supports a diverse wildlife population including both game and nongame species of birds and animals. Spruce–fir stands are especially valuable as winter cover for deer, and timber harvesting has generally improved browse conditions for deer and moose. Of particular importance is the juxtaposition of an adequate winter cover of older forest with younger openings where browse production is high.

The low human population, many lakes and streams, and reasonably good fish and wildlife populations throughout most of the range of the spruce–fir type provide excellent opportunities for outdoor recreation. Because of the remoteness of most of the region it is generally associated with activities such as canoeing, wilderness trips, hunting, fishing, snowmobiling, and skiing. And of course, the natural spruce–fir forest scene is esthetically pleasing to many people (2).

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Eastern White Pine Including Eastern Hemlock

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Eastern white pine (*Pinus strobus* L.) is an important forest type in northeastern United States, southern Ontario and west to southeastern Manitoba, the Lake States, and throughout the Appalachian Mountains to north Georgia, eastern Kentucky, and eastern Tennessee. Eastern hemlock (*Tsuga canadensis* (L.) Carr.) is a common associate of white pine. Its range coincides closely with that of white pine except that it stops south of Duluth, Minn., and does not extend as far west and north as white pine (23).[1] Together, eastern white pine and hemlock constitute type 22 of the Society of American Foresters forest cover types (8).

White pine is a major component in 3 other forest types and an associate in 23 others including conifers and hardwoods. Eastern hemlock occurs in pure stands or is a major component in 4 types and is listed as an associate in 25 other conifer and hardwood types. White pine commonly occurs in mixture with many other eastern species. Pure stands seldom occur in nature though some developed along with short-lived pioneer hardwoods after hot fires or on abandoned old fields.[2] Hemlock on the other hand is most commonly a species that occupies the lower strata of mixed forests. Hemlock seedlings and saplings can endure decades of suppression yet they retain the capacity to respond to release.[2]

White pine grows on many sites: from wet swamps to dry sand plains or rocky ridges and from moist stream bottoms and coves to upper slopes and ridgetops (24). In New England and the Lake States, white pine is usually found on more or less freely drained, sandy, or stratified sand and gravel derived from glacio-fluvial deposits. The most common soils supporting white pine in the central Appalachians are derived from acid sandstones and shales. In general, white pine has grown on most soils within its range.

The soil requirements of eastern hemlock are not exacting but are usually characterized as moist to very moist but with good drainage.[3] Typical Lake States soils are loamy sands, sandy loams, and silt loams of glacial or fluvial origin.

In the Northeastern States and Canada, hemlock grows on rocky acid soils and on loams and silt loams that are nearly neutral in soil reaction. Hemlock does best on moist, well-drained soils but it will grow well on sandy loam to clay loam soils with high humus contents; on limestone soils, if not too dry; and on almost swampy, loamy clay soils (11). In the Quebec lowlands, hemlock colonizes sand, marine, or fluvial banks with generally acid, well- to imperfectly-drained lithic Regosols, lithic and gleyed Podzols, or orthic Gleysols (8).

White pine occurs at elevations ranging from sea level in the north to about 3,500 ft (1065 m) and occasionally 4,000 ft (1220 m) in the southern Appalachians. Hemlock grows at similar elevations but in the southern Appalachians is found mostly from 2,000 to 5,000 ft (610 to 1525 m) in elevation.[3]

The climatic requirements for white pine and hemlock are similar. Generally, distribution coincides reasonably well with that part of eastern North America where July temperatures average between 65° and 74° F (18.3° and 23.3° C). Precipitation ranges from 20 to 80 inches (510 to 2030 mm) over most of the range with about half falling during the growing season. The growing season ranges from 90 to 180 days (22). Hemlock and white pine are regenerated more easily in New England than in the Lake States because the New England area has somewhat warmer temperatures and higher and better distribution of precipitation during critical periods.

White pine trees begin to bear cones before age 20, but the optimum seed-bearing period is between the ages of 50 and 150 years (20). Good white pine seed crops occur at intervals of 3 to 10 years (19). Cones mature in two seasons and seeds may be dispersed 200 feet (61 m) within a white pine stand and more than 700 feet (213 m) in the open. During good seed years and depending on stand density, 2 to 4 million seeds per acre (4.9 to 9.9 million/ha) may be produced (16). Hemlock trees begin to produce seeds at 20 to 30 years of age (30). Cones mature in one season, and though some seed is produced each year, large crops occur at 2- to 3-year intervals. Germination capacity of hemlock seed is commonly less than 25 percent, but it is better than 90 percent for white pine (19, 30).

Seedbed condition is important in regenerating white pine. In full sunlight, favorable seedbeds are moist mineral soils, polytrichum moss, or a short grass cover of light-to-medium density. Unfavorable seedbeds include dry soil, conifer litter, lichen, and very thin or very dense grass covers (24). Partial shade, mechanical scarification, and burning improves the seedbed. However, frequent and severe fires can eliminate white pine from natural stands. White pine is often a pioneer, and it grows in either relatively pure stands or mixtures with other pioneer species on abandoned fields and pastures (25).

Favorable seedbeds for hemlock include moist, well-decomposed litter, rotten wood, mineral soil, and moss mats on soil, rocks, and fallen trees (9). The best seedbeds are mixed mineral soils and humus (32). Hemlock seedlings cannot tolerate direct sunlight and shading is usually necessary in the first 1 or 2 years after germination.[2] Even though hemlocks can endure more shade than white pine, under extremely dense shade, survival of both species is reduced. On shaded, moist sites in New England, white pine seedlings in mixture with hemlock seedlings need release or they will be crowded out by the hemlocks.[4] Hemlock roots are shallow and sensititve to low soil moisture and may dry out when stands are opened up (11). In this circumstance, white pine when mixed with hemlock will dominate. In the Lake States, some overhead shade usually is retained to maintain better soil moisture regimes and increase the hemlock survival.[3]

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Hemlock germinates best at 59° F (15.0° C), but between 44° and 64° F (6.7° to 17.8° C), high germination percentages can be achieved.[3] Germination peak for hemlock is between 45 and 60 days. Dormancy in hemlock seed can be broken by stratification for 10 weeks at or slightly above freezing. Unstratified seed must be exposed to light to break dormancy. Under natural conditons, germination is seldom delayed because of seed dormancy.[3]

Embryo dormancy is common in white pine. For nursery sowing, stratification of seeds for 60 days at 33° to 41° F (0.6° to 5.0° C) is recommended (19). Under field conditions, white pine embryo dormancy is usually broken over winter, and most seeds germinate in 10 to 15 days in spring when temperature is favorable for germination. Optimum white pine germination in the Lake States and Canada occurs at temperatures between 64° and 74° F (17.8° to 23.3° C) (10). On sandy and relatively dry sites in New England, white pine, white oak, and scarlet oak may form a physiographic climax. On fertile and relatively moist soils, white pine eventually is displaced by more shade tolerant species such as beech (*Fagus grandifolia* Ehrh.), sugar maple (*Acer saccharum* Marsh.), and red oak (*Quercus rubra* L.).[4] Throughout most of its range, however, white pine is a minor component of the climatic climax forest. Although white pine may play an ecological role similar to that of the most light demanding species, it is intermediate in shade tolerance. In the seedling stage, it can survive and grow, if slowly, with as little as 20 percent full sunlight. Light intensity less than full sunlight will prevent seedling losses due to high surface soil temperatures (20). White pine grows slowly during the first 5 years of establishment and competes well with the hardwoods on poorer sites. On better sites, hardwood control is essential. Once established, optimum growth occurs under full sunlight (24). Establishment of eastern hemlock is much better under shade than full sunlight, which may cause direct heat injury to young stems.[3] Shade provides more stable moisture conditions for developing seedlings, but under hardwood cover, small seedlings may be smothered by leaves.

Hemlock responds well to release. Often seedlings with a history of suppression and release may make better late growth than those that were free to grow from the start (9). Hemlock can survive a suppression period that ranges from 25 to about 200 years.

White pine can be regenerated naturally or artificially. Planting is generally used in situations where there is no natural seed source or whenever genetically improved planting stock is to be used. This is true in northern Minnesota where limited amounts of blister rust resistant white pine are being planted. Clearcutting of hardwood stands, followed by planting without site preparation and herbicide release of the white pine 3 years later, has worked well in the southern Appalachian white pine belt (27). Areas that have dense stands of laurel and rhododendron are sprayed with an herbicide, burned if necessary, and planted the following winter sometime after February 1 to reduce seedling winter kill. Mortality of white pine is increased in the southern Appalachians and height growth may be reduced by 50 percent in the first 4 years if the organic layer is removed (27). On fair-to-medium hardwood sites in the Central Appalachians, Maine, Canada, and South Carolina, underplanted white pines respond to overstory removal (3, 12, 14). Normally 3 to 5 years are required for white pine to become established. If the underplanted pines are released sometime after establishment, a large proportion will successfully compete with the hardwood sprouts. Release is generally more successful on medium and fair sites. On better sites, two or more releases may be required. Site quality and spacing strongly influence volume production in white pine plantations, but thinnings can reduce the overall number of sawlog-size trees (2, 5, 20).

Reports on hemlock planting are scarce. In northwestern Pennsylvania, planting of 3–0 hemlock stock for grouse cover in north aspect, understocked hardwood, orchard-type stands was highly successful (18). Direct seeding hemlock in open areas, even with site preparation, usually failed. In Maine, removal of humus layers or mixtures of humus and mineral soil under shade provided receptive seedbeds for seeding hemlock for at least 3 years (4). Direct seeding of stratified seed in the spring or unstratified seed in the fall at a rate of 0.5 pound per acre (0.56 kg/ha) on well-scarified sites is recommended for artificially regenerating hemlock in the Lake States (32). Planting of large seedling stock soon after cutting may be used to supplement seeding if necessary.

Growth characteristics of white pine indicate that it can be managed best under even-aged stand conditions, though considerable leeway is allowed in choosing regeneration methods. White pine has been naturally regenerated by clearcutting in blocks and strips, and by seed-tree, shelterwood, and group selection methods. Single tree selection cutting has usually not proven satisfactory and the seed-tree method has little to recommend it (24).

Abundant, established, advance white pine regeneration can be released by cutting the remaining pines or hardwoods. Clearcutting during, or just after, a heavy seed crop often results in well-stocked stands on light soils (20, 24, 27). Release from competing hardwoods is often necessary at some time after overstory removal. Clearcutting in small patches or strips with seed dispersed from adjacent stands is also possible, but the constraints imposed by periodicity of seed crops and future release requirements should be considered. In lower Michigan and the upper Piedmont of South Carolina, the competing ability of released pine was directly related to height of the pine before release (7, 14). White pine has been successfully regenerated by group selection (25). However, other methods are more economical, especially where mechanical means are used to improve seedbed conditions or eliminate competition. Where esthetics are important, group selection may have merit (24).

The most versatile system for regenerating white pine is the shelterwood. Control of overstory density through a series of shelterwood cuts is used to improve seedbed conditions; to allow accumulation of seedlings over a period of years; to protect seedlings on hot, dry aspects; and to help suppress competition from herbaceous vegetation and hardwood sprouts. Three or more cuts spread over a number of years may be used, but white pine can be successfully regenerated with only a two-cut shelterwood system. The seed cutting should be timed to take advantage of a good seed crop, but considerable leeway exists in timing the removal cut (24). The two-cut shelterwood method is recommended for regenerating white pine in New England (20). The first cut removes 40 to 60 percent of the overstory and 5 to 10 years later, after the pines are established, the shelter trees are removed. In the Lake States, the shelterwood method is also recommended for regenerating white pine (13). White pine regeneration methods work well in areas with a low incidence of blister rust. In the cool, moist northwestern part of the range, white pine is no longer managed commercially because of extremely high seedling and sapling mortality from blister rust.[1]

Growth rates of white pine vary with site and stocking density. Over a rotation, white pine will produce more volume than hardwoods on poor and good sites in New England (20). On the better sites in the region, white pine does not compete well with hardwoods. On the medium-textured and lighter, sandy and gravelly soils, white pine competes well with the hardwoods and usually dominates. In the southern Appalachians, white pine has the highest site index of its 10 most common associates. It is surpassed only by yellow-poplar (*Liriodendron tulipifera* L.) on the best sites (2). Over the range of sites in which it grows in the Appalachians, white pine volume production is substantially greater in a given length of time than that of associated hardwoods.

In the southern Appalachian white pine belt, with a rotation of 40 years, thinnings made at age 21 and 30 remove about 10,000 board feet (fbm) (2,000 cubic feet)[5] per acre (140 m^3/ha), and the final harvest yields about 16,000 fbm (3,200 cubic feet per acre (224 m^3/ha)) (27). For stands in the Northeast, white pine stocking guides can be followed to maintain rapid growth rates and maximize production (20, 28). However, Leak (21) has pointed out some shortcomings in the guides, and these should be considered when using them.

Because of its tolerance to shade, hemlock can regenerate under low-light conditions. To increase the proportion of hemlock and hasten growth of the understory hemlock in mixed stands, single tree selection can be used (11). This requires removal of mature trees or groups of trees periodically to increase hemlock growth, but it should not open up the stand excessively or windfall may occur. To regenerate hemlock in the Lake States on poorly to moderately well-drained sandy loam or heavier soils, the two-cut shelterwood system may be used (32). Leave at least 50 percent—110 square feet per acre residual basal area (25.3 m^2/ha)—of the canopy in evenly spaced trees, reduce hardwood competition, and scarify soil before cutting. The overstory is removed when reproduction is 3 to 5 feet (0.9 to 1.5 m) tall. On drier sites, in overmature stands, or where grass-brush invasion may occur, the three-cut shelterwood system should be used. Leave 70 to 80 percent of the crown cover after the first cut; reduce this to 50 percent 8 to 12 years later, and make the final cut when reproduction is 4 to 5 feet (1.2 to 1.5 m) tall. Scarify the site before the first cut and control unwanted hardwoods during the first and second cut.

Hemlock stands are usually thinned from below leaving about 70 to 80 percent crown cover, which corresponds to 100 to 125 square feet per acre (23.0 to 28.7 m^2/ha) of basal area in pole stands and 120 to 150 square feet per acre (27.6 to 34.4 m^2/ha) in sawlog stands. Thinning should be repeated when crowns begin to touch (32). To encourage hemlock development in well-stocked northern hardwood pole stands with 50 percent or more hemlock, improvement cuttings should be made to remove poor quality sugar maple and other hardwoods (31). Fully stocked stands of eastern hemlock often have in excess of 300 square feet per acre (68.9 m^2/ha) of basal area, and no more than one-third of the basal area should be removed in a single cut to prevent overcutting and mortality from shock.[3]

The white pine weevil (*Pissodes strobi* (Peck)) and white pine blister rust (*Cronartium ribicola* J. C. Fisch.) are the most damaging pests of white pine. The white pine weevil is the most troublesome in New England and the central part of its range. Blister rust tends to increase with increasing latitude, in fog and dew pockets and in belts along the shores of the Great Lakes. Root rot caused by *Heterobasidium annosum* (Fr.) Bref. is found on white pines growing on poorly aerated soils; damage increases when stands are thinned (17). The white pine cone beetle (*Conophthorus coniperda* (Schwarz)) occurs throughout the range of white pine and in certain instances may destroy the entire cone crop as it did in Maine in 1962 (15). The gypsy moth (*Lymantria dispar* (Linnaeus)) will also attack white pine when it grows in mixtures with a preferred hardwood host (1). In nursery beds, damping-off and root-collar rots are common. Other damaging agents of white pine are white-tailed deer; glaze and/or snow, which often cause limb and stem breakage; sulfur dioxide emissions from large-scale burning of coal and from oil refining; flourine gas from brick kilns; atmospheric ozone; and ocean spray (17).

With increasing age and size, hemlock is subject to wind shake, radial stress cracks, and often, sudden exposure may cause bark sunscald on young trees (17). Hemlock is also sensitive to sulfurous smelter fumes. Although there are many fungi that attack hemlock at various stages of its development, few cause widespread damage. The strawberry root weevil (*Otiorhynchus ovatus* (L.)) is very destructive to hemlock and other conifer seedlings in nurseries. Two species of hemlock looper (*Lambdina fiscellaria fiscellaria* (Guenee) and *L. athasaria athasaria* (Walker)) and one species of the hemlock borer (*Melanophila fulvoguttata* (Harris)) cause sporadic or local tree mortality and are the only insect species of economic importance (9). When hemlock occurs in mixtures with oaks, it sustains high mortality following the first defoliation by gypsy moth. Drought is probably the most damaging agent to eastern hemlock during its seedling stage.[3] Hemlock along highways is highly sensitive to road salt during winter months (29).

The white pine type is not extensively grazed in the East. However, in the past, light to moderate grazing by livestock has resulted in the removal of grasses, weeds, and hardwoods. In fact, grazing accounts for many of the pure stands of pine we have today (29). White pine and eastern hemlock seeds can be an important local source of food to upland game birds, songbirds, and small mammals (26). When browse is scarce, white pine foliage is often heavily browsed. However, in the presence of a variety of browse species, browsing of white pine is light (6). However, no rare or endangered species is exclusively associated with the white pine or hemlock types. Large, old-growth white pines are used for nesting trees by osprey and bald eagles in the Lake States. When these large horizontally branched trees are present in existing or potential eagle territories, preservation for nest trees should be considered. The dense, low foliage of young hemlocks makes excellent winter cover for ruffed grouse, deer, and other wildlife (26).

White pine and hemlock stands are popular for recreational activities. This is particularly true for remnant old-growth stands near lakes and streams. Understory vegetation can be controlled or modified to enhance the opportunity for recreation by providing a park-like appearance. In travel corridors, mixed stands of white pine, hemlock, and hardwoods enhance variety. The esthetic impact of shelterwood or clearcutting can be minimized by good landscape planning.

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Pitch Pine

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Pitch pine (*Pinus rigida* Mill.) occupies a wide geographic range from central Maine to northern Georgia. It occurs in pure stands as Society of American Foresters forest cover type 45 and is also a major component of at least eight other recognized forest types (3). Pitch pine as a pure type covers more than 1.5 million acres (607 000 ha), and an additional 1.0 million acres (405 000 ha) are classified as pitch pine—Virginia pine—hardwood type.

Pitch pine occurs in fairly humid climates with annual precipitation between 37 and 56 inches (940 to 1420 mm). The length of the frost-free season ranges from 112 to 190 days, and temperature extremes range from −40° F (−40.0° C) in the north to more than 100° F (37.8° C) in most sections of the range.

Competition often restricts pitch pine to soils low in natural fertility. In New England and along the Atlantic Coast it occurs on sandy soils of alluvial or marine origin, and in the Mid-Atlantic and Southern States it generally occurs on ridges, steep slopes with a southwest aspect, and plateaus where soils tend to be shallow (5).

Pitch pine is a prolific seeding species with good cone crops at intervals of approximately 3 years (4). Dissemination of seed varies between areas and between trees on the same area. Cones on trees growing in areas with a history of frequent severe fires tend to be serotinous such as areas in the central portion of the New Jersey Pine Barrens. Heat from severe fires is required to open the serotinous cones, whereas the more common nonserotinous cones open at maturity (1, 5). Seeds have the large wings associated with pines but do not travel far—usually not in excess of 300 feet (91 m) from the source tree. Germination averages better than 75 percent under ideal conditions (8).

Deep litter is a serious deterrent to establishment, and few seedlings are found on undisturbed sites. Where fires or mechanical scarification have occurred before seed dispersal, as many as 23,000 seedlings per acre (56 830/ha) have been found.

Planting of improved pitch pine seedlings would be the preferred regeneration option on most sites. Adequate genetic variation within the species economically justifies such a program. The use of hybrids that combine the hardiness to cold and the resistance to disease of pitch pine with the excellent form and growth rate of loblolly pine (*Pinus taeda* L.) could improve yield even more on most sites occupied by pitch pine. Selected hybrids have outgrown seed orchard pitch pine seedlings by 50 percent in some plantings (6, 7).

Pitch pine is intolerant of shade and can be maintained best in stands by forms of even-aged management, such as clearcutting where advance reproduction is present, or the retention of seed-trees where nonserotinous cones are present. Fires have been primarily responsible for the present distribution of this type, but fire is also responsible for the slow growth and characteristic poor form of the species on some sites. Pitch pine is outstanding among eastern conifers in its ability to survive all but the most severe fires. Trees will produce new needles even if all foliage is killed, and new sprouts will develop from dormant buds on trees with pronounced basal crook if the main stem is killed by fire. Although this ability is an asset in survival of the species, it can be a liability. Stems deformed by fire and forced to develop new crowns are poorly formed and slow growing. Also, the ability to survive and recover from such damage may be greater in slow-growing strains that in fast-growing ones.

Pitch pine can be killed by intense heat and resulting stands, if from sprout origin on older trees, may be inferior to either seeded or planted stands. On the Pine Barrens of New Jersey, it is common practice to burn periodically to eliminate fuel buildup and thereby reduce the danger of uncontrolled wild fires. Prescribed burning is also used to prepare seedbeds before final harvest cuts.

If natural regeneration from seed is expected following harvest operations, it is essential that proper seedbeds be prepared and that openings be no smaller than 1 acre. Either controlled burning or some form of scarification before harvesting has been effective in exposing the necessary mineral soil. Direct seeding on prepared sites will also produce fully stocked stands if moisture conditions are adequate for several years following seeding. Small rodents, birds, and insects consume some seed on exposed sites, but the supply of seed is usually more than adequate for regeneration purposes.

The primary market for pitch pine throughout its range has been fiber production with lesser amounts being used for solid products. Pure, fully stocked stands of pitch pine have growth rates averaging 50 percent faster than oak (*Quercus* spp.) and other associated species on the same sites. Maximum total volume occurs at about 90 years when fully stocked stands may yield as much as 25,000 board feet (fbm) (5,000 cubic ft) per acre (350 m^3/ha).[1] Mean annual growth on most sites is at a maximum between 30 and 40 years with up to 83 $feet^3$ per acre (5.8 m^3/ha) on site quality I sites (57 ft (17.4 m) at age 50) and 42 $feet^3$ per acre (2.9 m^3/ha) on site quality III sites (38 ft (11.6) at 50 years)(2, 4).

Rotation age for fiber production should be between 30 and 45 years depending on site quality, and larger solid products can be harvested between 50 and 70 years. Older stands of pitch pine are subject to many insect and disease problems, and net volume decreases rapidly after age 90 as stands begin to break up.

Seedlings and trees in young stands are attacked by a number of fungi that cause minor damage. Eastern gall rust (*Cronartium quercuum* (Berk.) Miy. ex Shirai), Fusiform rust (*C. quercuum* (Berk.) Miy. ex Shirai f. sp. *Fusiforme* Burds. & Snow), comandra blister rust (*C. commandrae* Pk.), sweetfern rust (*C. comptoniae* Arth.), needle casts (*Meloderma desmazierii* (Duby) Dark., *Ploioderma lethale*

[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.

(Dear.) Dark., *P. hedgcockii* (Dearn.) Sigg., and *Scirrhia acicola* (Dearn.) Sigg.), and needle rust (*Coleosporium* spp.) all occur on pitch pine. Heart rot occurs in older trees and is not uncommon in trees over 75 years old. A number of insects attack the foliage and stem of this species throughout its life. Tip moth, sawfly, southern pine beetle (*Dendroctonus frontalis* Zimmermann), web worms, and needle miners are among the most serious. Cone insects, including the webbing coneworm (*Dioryctria disclusa* Heinrich), cause significant reductions in seed production, but in a normal year enough seed should still be available for regeneration purposes.

Pitch pine and associated types provide important cover and food supplies for many forms of wildlife including white-tail deer and rabbits. Clearcutting or seed-tree cutting, which is essential for regeneration of this species, provides openings and edges favored by wildlife. Because the pitch pine types are usually found on lighter, drier soils, management options seldom influence either water quality or fish habitat.

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Cherry – Maple

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The cherry–maple or Allegheny hardwood forest type (type 28 of the Society of American Foresters (2)) covers about 12 million acres (4.9 million ha) in the Allegheny Plateau and Allegheny Mountain sections of New York, Pennsylvania, Maryland, and West Virginia. It occurs at elevations from 1,000 to 2,600 ft (305 to 790 m) on both glaciated and unglaciated areas. Soils are mostly derived from sedimentary parent materials and have textures that range from sandy loam to silty clay loam.

The climate in cherry–maple forest areas is generally cool, moist, and temperate, with average annual precipitation of 38 to 44 inches (965 to 1120 mm) well distributed throughout the year. Droughts are not common. The frost-free season is 120 to 155 days (11).

The cherry–maple type is composed primarily of black cherry (*Prunus serotina* Ehrh.), red maple (*Acer rubrum* L.), sugar maple (*Acer saccharum* Marsh.), and white ash (*Fraxinus americana* L.), with American beech (*Fagus grandifolia* Ehrh.), eastern hemlock (*Tsuga canadensis* (L.) Carr.), yellow birch (*Betula alleghaniensis* Britton), sweet birch (*Betula lenta* L.), yellow-poplar (*Liriodendron tulipifera* L.), and cucumbertree (*Magnolia acuminata* L.) as common associates. Cherry and the maples usually dominate stands in Pennsylvania and southward; white ash and sugar maple tend to be more important, and red maple less important, in the New York portions of the range (2).

Allegheny hardwoods are second- and third-growth forests that followed extensive commercial clearcutting during the railroad logging era of 1890 to 1930 (12). Although generally considered even-aged, many stands contain residuals from the previous stand, and some stands that were cut less heavily are mixtures of two to four age classes. Allegheny hardwoods represent an early- to mid-successional stage that would ultimately lead to a climax forest dominated by beech, hemlock, and sugar maple if left undisturbed for a long period (9).

Allegheny hardwood forests yield many products and services. They are the source of nearly all the world's supply of cherry lumber for furniture and veneer, and provide substantial proportions of fine ash and maple sawtimber. Pulpwood and bulk products are also important. Allegheny hardwood forests represent one of the few major blocks of contiguous forest land in the Eastern United States, yet they are within a day's drive of nearly one-third of the U.S. population. Thus, they are heavily used for many types of outdoor recreation and serve as watersheds for many eastern cities.

Natural regeneration is relied on for the reestablishment of nearly all cherry–maple stands after cutting and natural disturbance. Artificial seeding and planting are rarely used, except in those unusual cases where natural regeneration is impossible for some reason. Natural regeneration originates from advance seedlings present beneath the canopy before cutting, from seed stored in the forest floor, from seed dispersed into the areas after cutting, and from sprouts and suckers.

Black cherry and red maple are frequent seed producers, with good crops every 2 or 3 years. White ash and sugar maple have good seed crops somewhat less frequently, while beech is least frequent with good crops only one in 6 or more years (1, 3). In addition, black cherry, white ash, and yellow-poplar seeds remain dormant but viable in the forest floor for 3 to 5 years, insuring a relatively constant seed supply. Red maple and birch seeds sometimes remain dormant in the forest floor for a year or two, whereas sugar maple and beech seeds commonly germinate the year following dispersal. Pin cherry (*Prunus pensylvanica* L. f.)—a noncommercial tree—brambles, grasses, and other herbaceous plants also have seeds that may remain viable in the forest floor for decades, providing reproduction of these plants in cutover areas where they were not previously apparent (13, 28).

Cherry seeds and beech nuts fall to the ground near the seed tree, and the abundance of advance seedlings of these species is closely related to the number and distribution of seed trees in the overstory. However, small mammals also provide wider distribution of seeds, and songbirds and omnivorous mammals sometimes account for a surprising abundance of cherry advance seedlings in stands that lack cherry seed producers. Seeds of most of the other Allegheny hardwood species are wind disseminated, and dispersal is somewhat wider than for beech and cherry. Birch seeds are especially small and light and they are sometimes dispersed over considerable distances, especially late-falling seeds that blow over crusted snows. Seeds of the Allegheny hardwood species mentioned here except red maple are dispersed in the fall; red maple is dispersed in the late spring or early summer.

The birches are the only Allegheny hardwood species for which scarified seedbeds are required for seedling establishment, although red maple, white ash, and hemlock also germinate somewhat better on seedbeds where the surface organic layers have been disturbed or mixed with mineral soil. Sugar maple, beech, and black cherry germinate as well on undisturbed humus or litter as on disturbed seedbeds. For all species, maintenance of high surface moisture is required for good germination, and the shade of a moderately heavy overstory is beneficial in providing such a stable moisture supply. Germination of even the shade-intolerant species is consistently higher in partial shade than in areas exposed to direct solar radiation (15).

Fire generally destroys the advance seedlings that are a primary source of regeneration in Allegheny hardwood stands. Since disturbed seedbeds are not necessary or even desirable for many of the favored species, controlled burning is not useful for the establishment of regeneration in this type. However, fire may have some potential as a means of removing understory competition of beech or other unwanted species (26).

Advance reproduction is of major importance in the regeneration of black cherry, white ash, red maple, sugar maple, beech, and hemlock. The latter three species are quite tolerant of shade, and seedlings of these species are capable of surviving and growing beneath uncut or lightly cut stands for extended periods. Cherry, ash, and red maple are less tolerant of shade, but seedlings of these species will become established and survive for 3 to 5 years under a moderately heavy canopy. Although considerable canopy opening is necessary for these seedlings to survive for longer periods or make appreciable growth, those that die are constantly being replaced by new seedlings. Thus, advance seedlings of all the important species are often present beneath seed-bearing trees to form a new stand when the overstory is removed.

All species in the Allegheny hardwood type except hemlock reproduce from sprouts or root suckers. Red maple is a prolific sprouter, and black cherry, white ash, sugar maple, and the birches sprout readily from dormant buds around the base of cut stumps. Sprouts are most numerous from stumps of small trees less than 40 to 50 years old. Beech often sprouts from the cambium region on the surface of cut stumps, and suckers from roots of both living and cut beech trees are common. The beech underbrush common in many Allegheny hardwood stands is composed primarily of root suckers.

Although seedlings and seedling-sprouts are generally preferred for timber production, most stump sprout clumps contain one or two stems that are capable of growing into quality sawtimber. The incidence of butt rot from the parent stump is not great from stumps that are 10 inches (25 cm) or less in diameter or that have been healed over by 35 years of age (10, 29). Beech root-suckers seldom develop into high-quality sawtimber.

Because Allegheny hardwoods contain species that span the full range of shade tolerance and growth rate, stands usually have a complex structure. Black cherry and yellow-poplar usually outgrow and eventually overtop all other species. Sugar maple, beech, and hemlock generally grow slower than their associates, but being shade tolerant, they survive when overtopped, and often form a distinct lower canopy and diameter strata in mixed species, even-aged stands (19).

Economic timber rotation ages differ widely among species because of the large differences in growth rates. In unmanaged stands, black cherry reaches large sawtimber size and is considered financially mature at 80 to 90 years of age. Red maple and white ash require 90 to 100 years, while sugar maple and beech may require 120 to 160 years or more (4, 24).

Stocking and yield vary considerably in Allegheny hardwoods, depending upon species composition. For example, stands that have a 10 inch (25 cm) average stand diameter will be at average maximum stocking with 138 feet^2 per acre (31.7 m^2/ha) of basal area if 20 percent cherry, ash, or yellow-poplar is present, but would require 184 feet^2 per acre (42.2 m^2/ha) to be at maximum stocking if those intolerant species represent 80 percent of the basal area (25). At age 80, cubic and sawlog volumes in stands containing 20 percent cherry, ash, and yellow-poplar average 4,690 feet^3 per acre (328.3 m^3/ha) and 9,321 board feet (fbm) (International ¼-inch) per acre (130.5 m^3/ha)[1]. Comparable values in stands with 80 percent cherry, ash, and poplar are: 5,578 feet^3 per acre (390.5 m^3/ha) and 13,787 fbm per acre (193.0 m^3/ha).

There are a variety of insect and disease pests in cherry–maple stands, but none that limit effective management or require major alterations in silvicultural procedures. Mice and voles cause considerable mortality of seedlings by girdling the stems near the ground. These small mammals are especially important in grass or other herbaceous cover which provides suitable habitat, and their damage is probably one of the major causes of planting failure in old fields or clearcuts where natural regeneration has not become established.

White-tailed deer cause extensive damage by feeding on Allegheny hardwood seedlings. In parts of Pennsylvania where deer populations are especially high, deer browsing is a major obstacle to new stand establishment. In such areas, reproduction is sometimes completely eliminated by browsing, and most regeneration cuts are affected by reduced stocking, delays in establishment, and shifts in species composition toward less palatable beech and striped maple (18, 22). Damage is dramatic after clearcutting, but damage to advance reproduction is also important. Thinnings and shelterwood cuts that would normally encourage establishment of advance seedlings often result in development of understory plants such as ferns, grasses, beech root-suckers, and striped maple that interfere with desired reproduction (5, 6). Preferential browsing on the desired tree species prevents their establishment, permitting the understory to be taken over by the interfering plants.

The choice of silvicultural systems in Allegheny hardwood forests would be wide were it not for the unusual deer damage to regeneration in some parts of the range. All-age silviculture, as exemplified by selection cutting, requires that new seedlings be established at each partial cut, and that they gradually grow into the main crown canopy to fill small openings created by cutting. But such seedlings are exposed to deer browsing over a long time, and repeated selection cutting in areas of high deer population eventually results in the complete removal of present trees without replacement by new seedlings and saplings. Only the less palatable beech and noncommercial striped maple are likely to survive, creating a forest of very low value, perhaps lacking in tree cover of any type in many spots (22).

Therefore, all-age silviculture cannot safely be practiced in areas of high deer population. Only even-age methods that provide abundant sunlight for seedlings to grow quickly out of reach of deer are practical in such areas. However, all-age silviculture can be used successfully in those portions of the Allegheny hardwood range where deer populations are in better balance with their habitat.

Detailed guidelines have been developed to help foresters analyze stand conditions and prescribe appropriate silvicultural treatments in Allegheny hardwood forests (23, 25). Where management objectives call for maximizing high-quality timber production, or maximizing habitat for such wildlife as deer, grouse, rabbits, or hares, even-aged silviculture is the proper choice. All-age silviculture is usually better where timber production and management of these game species are secondary to maintenance of a high forest canopy for visual or recreational objectives (assuming that deer populations will permit regeneration establishment) (27). Modifications of both major silvicultural systems are also possible to help reconcile conflicting resource uses where this is necessary.

Regeneration under even-age silviculture is obtained in Allegheny hardwood stands using either clearcutting or shelterwood cutting methods. If advance seedlings of desired species are abundant and well distributed before final harvest, the overstory can be removed in a single cut. Overstory removal or clearcutting will release the advance seedlings. Along with new seedlings and sprouts that start after cutting, they will provide the basis for a new stand.

Where advance seedlings are scarce before final harvest, they must be established by a sequence of shelterwood cuts. The first, or seed, cut of the shelterwood sequence should

[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.

reduce the overstory to 60 percent of average maximum stocking in areas of high deer population (50 percent elsewhere) to make additional sunlight, moisture, and nutrients available for the establishment of new seedlings (16, 17).

However, these conditions also provide for rapid expansion of ferns, grasses, beech root-suckers, and striped maple, which can interfere with desired seedlings. Areas where these plants are prevalent before cutting, or where soil conditions are conducive to their spread, must be treated with an herbicide before the seed cut (7, 8).

Once an adequate number of seedlings has become established, the remaining overstory may be removed in one additional cut. Usually, 5 to 10 years will be required after the seed cut. The overstory removal cut in this two-cut shelterwood sequence is essentially identical to the overstory removal or clearcutting recommended where advance seedlings are naturally abundant.

The final removal cut in Allegheny hardwoods should remove all trees larger than about 2 inches (5 cm) diameter at breast height (d.b.h.) to insure that unmerchantable trees left on the site do not interfere with regeneration. However, a few good quality, vigorous saplings and poles of tolerant sugar maple, beech, and hemlock may be retained to insure perpetuation of these species and help them achieve a position in the main crown canopy of the next stand. These residuals survive and grow well after release. Faster growing intolerants will catch up with these residuals in 40 to 60 years, creating a mixed stand in which all species are more uniform in size than if all started at the same time. The immediate value of the residuals as pulpwood is very low, so little income is lost by reserving them. But they will grow into sawtimber sooner than new reproduction and help make early commercial thinnings possible in the next stand (20, 21).

Once a new even-aged stand has been established, it can usually be left to develop naturally without silvicultural intervention until it is at least 25 years old. Thereafter, the stands can be opened up to encourage rapid diameter growth in the clean-boled trees present. Commercial thinnings become feasible when the basal area in saplings (trees less than 5.5 inches (14 cm) in diameter at breast height (d.b.h.)) drops below about 20 feet^2 per acre (4.6 m^2/ha). Before this time, saplings are such a large proportion of the stand stocking that attempts to cut only merchantable-size trees and ignore saplings result in high-grading that removes the cherry and ash and seriously reduces future stand value.

Intermediate cuttings in even-aged Allegheny hardwoods must be planned carefully because of the complex mixture of species with widely different growth rates and stand structures. Two major species groups are recognized: intolerant, fast-growing cherry, ash, and yellow-poplar; and tolerant, slower growing maples, beech, and other species. Within each group, trees removed in early thinnings should come predominantly from the smaller diameters in an attempt to favor the bigger, better quality trees. This increases the average diameter of the group and reduces the time it will take for the residuals to reach financial maturity. The general goal is to concentrate diameters in a narrow range within the crop tree portion of each species group.

In all intermediate cuts, stand density should be reduced to 60 percent of average maximum stocking, as measured by stocking charts (25). This density provides excellent individual tree growth and near maximum net stand growth without loss of tree quality from epicormic branching that is sometimes experienced at lower densities. The major exception to the 60 percent residual density rule is for stands that are at or near maximum stocking. Trees in such stands tend to have small crowns, and opening the stand to 60 percent in one cut often leaves growing space unused for many years until the crowns can expand to fill the space. Degrade from excessive exposure also may occur. No thinning should remove more than one-third of the existing stocking in a single cut.

Under all-aged silviculture, regeneration must be obtained in each stand after every cut. Since considerable overstory is always present, regeneration is dominated by tolerant species such as sugar maple, beech, and hemlock. But some small proportion of intolerants can be maintained if residual densities are kept low, and if small openings are created at scattered places in the stand. Therefore, single-tree selection cutting supplemented with small openings up to about 0.25 acres (0.10 ha) is the recommended all-aged practice in Allegheny hardwoods.

Where deer populations are very high, as in northern Pennsylvania, excessive browsing often results in failure of regeneration to become established. All-age silviculture should not be used in these localities. Each cutting under all-age silviculture should create and maintain a residual stand that contains all sizes and ages of trees at the same time. To achieve this, a residual stand goal must be established, and each cut must remove only trees of a size that are excess to that goal. In this way, regular sustained yields are assured (14). Recommendations are available on the combinations of residual stand density, maximum tree size, and diameter distribution (or stand structure) that produce best results in Allegheny hardwood stands.

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Appalachian Mixed Hardwoods

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Appalachian mixed hardwoods, commonly called cove hardwoods, are found on moist slopes of the Appalachian Mountains and adjacent portions of the Allegheny and Cumberland Plateaus (37). However, these hardwoods are not specifically identified as forest cover types (15). Appalachian mixed hardwoods are found within the oak–hickory ecological forest classification (6) and are associated with the oaks, yellow-poplar (*Liriodendron tulipifera* L.), and northern hardwood forest cover types. Cove hardwoods are found from southeastern New York and east-central Pennsylvania south to northern Georgia and Alabama. These hardwoods predominate on an estimated 26 million acres (10.5 million ha). Ownership consists of small holdings except on Federal, state, and industrial lands.

Certain Appalachian mixed hardwood species can produce high-quality sawlogs, veneer logs, pulpwood, fiber, and fuelwood on relatively short rotations. These stands are characteristic of rich, moist sites and typically are found in coves, on lower slopes with a northern or eastern aspect, and on gentle terrain (41). Cove hardwoods occupy good to excellent sites, 65 to 90 feet at age 50 years (19.8 to 27.4 m) on the oak site-index scale (26), 70 to 120 feet (21.3 to 36.6 m) on the yellow-poplar site-index scale (2, 14). Soils are fairly deep, medium textured, and well drained. Annual precipitation ranges from 40 to 60 inches or more (1015 to 1525 mm) and is well distributed throughout the year, mostly as rainfall. Temperatures range from an annual minimum-maximum of −20° to 100° F (−28.8° to 37.7° C) in the north to an annual minimum-maximum of 15° to 100° F (−9.4° to 37.7° C) in the south. Frost-free days range from 120 in the north to 240 in the south.

Stands are characterized by a large number and variety of plant species. Overstory composition may range from nearly pure stands of northern red oak (*Quercus rubra* L.) or yellow-poplar to typical mixtures of 20 or more commercial species. Other more important species include black cherry (*Prunus serotina* Ehrh.), sugar maple (*Acer saccharum* Marsh.), white ash (*Fraxinus americana* L.), southern red oak (*Quercus falcata* Michx.), red maple (*Acer rubrum* L.), American beech (*Fagus grandifolia* Ehrh.), hickories (*Carya* spp.), white oak (*Quercus alba* L.), black locust (*Robinia pseudoacacia* L.), American basswood (*Tilia americana* L.), and white basswood (*Tilia heterophylla* Vent.). Conifer species include eastern white pine (*Pinus strobus* L.), red spruce (*Picea rubens* Sarg.), and eastern hemlock (*Tsuga canadensis* (L.) Carr.). On good sites at higher elevations, Appalachian mixed hardwoods merge with types dominated by sugar maple, yellow birch (*Betula alleghaniensis* Britton), American beech, and eastern hemlock and/or mixtures of black cherry, red maple, white ash, and sweet birch. On drier sites with shallow soils, the Appalachian mixed hardwoods merge with oak and hickory types.

Sources of reproduction in these hardwood stands include buried seed, stump sprouts, root suckers, and advance regeneration. Seed of several species such as yellow-poplar, basswood, white ash, black locust, and black cherry remain viable in the forest floor for at least three winters (38). Acorns and seed from maples, birches, and American beech commonly remain viable over one winter. Nearly all hardwood species sprout vigorously especially when young, but as stems mature, sprouting decreases (16). Advance regeneration of tolerant species such as maples and American beech occurs under dense canopies. Advance oak regeneration composed of seedlings an inch or more in base diameter, with a well-developed root system, is generally necessary for satisfactory growth after release. Logging usually does not kill advance regeneration because damaged stems sprout vigorously (21). During their early years, sprouts grow rapidly, often dominating other forms of reproduction. Stump sprouts can produce high-quality trees for a number of species (3, 17, 42). Prolific sprouters include oaks, yellow-poplar, American and white basswood, black cherry, red maple, black locust, and American beech.

Reproduction of intermediate tolerant species usually follows a moderate opening of the canopy on Appalachian mixed hardwood sites. This reproduction can persist for several years. Seeds of white ash, yellow-poplar, black cherry, and the basswoods germinate when favorable conditions of light, temperature, and moisture are created by canopy removal (37).

Because of the abundance of different species in the Appalachian mixed hardwood stands, it is rare that seed crops do not occur for several of these species (16). Consistent seed producers are the basswoods, yellow-poplar, black cherry, sugar maple, and, to a lesser degree, hickories; acorn production is extremely variable. Wind is the primary agent in disseminating light-weight seeds such as basswoods, yellow-poplar, sugar maple, and birches. Heavier seed such as acorns, hickory nuts, and seeds of beech and black cherry are distributed largely by gravity, animals, and birds.

Since there are so many available species and management objectives in these mixed hardwood stands, a variety of seedbed conditions are acceptable. Logging disturbance usually is sufficient to create adequate exposure of mineral soil. Exposed mineral soil provides good germination for seeds of American beech, birches, yellow-poplar, and basswood. Acorns and hickory nuts germinate under leaf cover; black cherry seed does not have rigid germination requirements, though compacted soil is undesirable (16). Conditions usually exist for some species to become established regardless of the climatic regime or stand disturbance. However, regenerating specific species can present problems.

Among major Appalachian mixed hardwood species, shade tolerance ranges from very tolerant American beech, eastern hemlock, and sugar maple to the intermediately tolerant oaks, hickories, birches, and white ash to intolerant black cherry, black locust, basswoods, and yellow-poplar (37). Most intolerants and some intermediates will not survive long under a dense canopy. Sugar maple, American beech, and, to a lesser degree, oak saplings and pole-size trees can persist for a long time under a dense canopy and then respond to release (33). Many intermediate and intolerant species in these mixed hardwood stands developed in large openings due to windthrow, fire, snow, ice, logging, etc. Intolerant species exposed to light are faster growing than tolerant species, especially in sapling- and pole-size stands. Also, stump sprouts generally grow faster than seedlings in sapling- and pole-size stands. As stands mature, differences in growth between seedling- and sprout-origin stems narrow considerably, but when this occurs is unknown (28). Some species such as oaks can respond with good diameter growth when released. Often, the response is comparable to or even surpasses that of the more intolerant species (36, 37), but the duration is unknown.

Mature cove hardwood stands commonly range in volume from 10,000 to 20,000 board feet (fbm) (International ¼-inch) (2,000 to 4,000 cubic feet)[1] per acre (140 to 280 m^3/ha), though it is not uncommon for volumes to exceed 20,000 fbm (4,000 cubic feet) per acre (280 m^3/ha). On some sites, trees 20 to 24 inches (51 to 61 cm) diameter at breast height (d.b.h.) can be grown on a 70-year rotation, but more often such trees are produced with rotations of 80 to 100 years. Annual growth for mature stands varies for 250 to 50 fbm (50 to 100 cubic feet) per acre (3.5 to 7.0 m^3/ha).

Principal insects and disease affecting hardwood species have been summarized (16). Currently, insects and diseases are not a significant factor in Appalachian mixed hardwood stands. However, this situation could change with gradual migration of the gypsy moth (*Lymantria dispar* Linnaeus) south from the northeast. Foliage of oaks, basswoods, American beech, red maple, sugar maple, birches, hickories, and black cherry are preferred food of the gypsy moth (1, 7). Initially, oak wilt (*Ceratocystis fagacearum* (Bretz) Hunt) was thought to be a major problem in the Appalachians, but its occurrence generally has stabilized and is limited to specific areas. However, oak borers, especially the red oak borer (*Enaphalodes rufulus* (Haldeman)), and associated decay cause serious damage, particularly with northern red oak (5, 13).

Sweet birch is readily attacked by several fungi and frequently becomes defective at an early age. Of all the pathogens that attack it, sweet birch is most susceptible to *Nectria* canker (*Nectria galligena* Bres.). Maple canker *Eutypella parasitica* Davids & Lorenz) is common in sugar maple. In general, sugar maple is not highly susceptible to insect injury, though the sugar maple borer (*Glycobius speciosus* Say) is a serious pest. Black cherry is defoliated by the eastern tent caterpillar (*Malacosoma americanum* (Fabricius)) and the uglynest caterpillar (*Archips cerasivorana* (Fitch)). Black knot fungus (*Apiosporina mobosa* (Schw.) von Arx) commonly occurs on black cherry. Cankers caused by *Strumella* and *Nectria* fungi are serious diseases of northern red oak. Trunk-boring insects seldom kill oaks, but they seriously degrade products cut from infected logs. Weevils (*Curculio* spp.) are a common pest of acorns. Neither white ash nor the basswoods have serious insect and disease enemies. However, basswoods, along with most species in mixed hardwood stands (particularly young stems), are highly susceptible to fire damage. Fires often result in wounds that serve as entry points for insects and disease.

Fire has been considered as a possible silvicultural tool, especially to control unwanted vegetation and to establish specific desirable species. Prescribed burning may be an option in certain limited situations. However, we must learn more about the role of fire in managing hardwoods before fire can be recommended (20, 24).

In cove hardwood stands there are a number of species that reproduce successfully following any regeneration cutting, thus reproduction usually is not difficult. However, species differences in shade tolerance and other silvical characteristics combined with site variation lead to changes in species composition. Species composition is affected by the silviculture and management systems used.

Even-aged and uneven-aged silvicultural practices have been used to manage Appalachian mixed hardwood stands. Even-aged practices such as clearcutting result in a greater variety of species and a higher ratio of intolerant to tolerant species than uneven-aged practices. The intolerant to intermediate species usually are fast-growing, high-value trees such as black cherry, black walnut, red oak, and white ash (32). Other fast-growing species include yellow-poplar and basswoods. Where uneven-aged practices are used, the tolerant, slow-growing, less valuable commercial species eventually dominate; these include American beech, sugar maple (high value), and red maple. Frequently, noncommercial tolerant species such as dogwood or striped maple are found in the understory. Their presence can result in costly silvicultural treatments to minimize their influence or to eliminate them from the new stand (30).

In stands where even-aged silviculture is practiced, one reproduction cut usually is done at the end of each rotation. As the new stand develops, thinnings are made at appropriate intervals until the next reproduction cut or clearcut. In stands where uneven-aged practices are used, regeneration and thinning occur concurrently at each cutting period. Intermediate cuttings may increase the yield of wood products by salvaging mortality. Time until final harvest is shortened by the increased diameter growth that results from these intermediate cuts. More quality trees may be available at final harvest.

There are three regeneration cutting practices to consider in even-aged management—clearcutting, shelterwood, and seed tree. Clearcutting generally is recommended to regenerate Appalachian mixed hardwood stands. Both intolerant and tolerant species are reproduced by this method, though the month in which a clearcut is applied can influence the amount of regeneration due to late seed germination, particularly with yellow-poplar (39). Planned clearcuts provide stands of differing ages in the forest; each stand contributes wildlife food and habitat which allows a variety of wildlife to prosper (12, 25). Clearcutting has a more immediate impact on the forest environment than any other cutting practice. Critics of clearcutting usually are concerned about the unsightly appearance of areas that have been clearcut. Methods to improve visual appearance such as blending clearcuts into the landscape, good planning and road maintenance, and follow-up post logging, felling and lopping, and seeding of logged areas, are being introduced. Most recreation areas are considered unsuitable for clearcutting—a notable exception is the use of clearcuts to provide scenic vistas.

Shelterwood cutting includes removing trees in the Appalachian mixed hardwood stands in two or more cuts, usually over a maximum period of 20 years. Shelterwood cutting may be promising for reproducing species of intermediate tolerance such as oaks. The method often is recommended where there is no desirable advance regeneration. However, the shelterwood system has not proven consistent in providing adequate advance oak regeneration, though periodic thinnings are recommended during the latter part of the rotation to maintain understory oaks in a vigorous condition (8). Effects of the shelterwood cutting depend on density and duration of the residual overstory. Results of current shelterwood studies in cherry–maple stands in northwest Pennsylvania may be applicable to even-aged Appalachian mixed hardwood stands. Regeneration research is

[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.

being conducted in mixed hardwood stands in the southern Appalachians (18); to date, shelterwood cuts and clearcuts have yielded similar results.

Regeneration by seed trees is seldom used or needed in these Appalachian mixed hardwood stands. Under most circumstances, regeneration comprising the new stand is already established or will become established the first growing season after cutting, regardless of the presence or absence of seed trees. Where seed trees are left in the stand, windthrow and loss of bole quality are of concern to foresters.

Regeneration methods to consider for uneven-aged management are single-tree selection and group selection. Single-tree selection results in least disturbance to the forest canopy and is used where a nearly continuous forest canopy is preferred, or when stand and site disturbance must be minimized (29). However, a selection method cannot be used if a high portion of intolerant species are desired for this practice encourages shade-tolerant trees and shrubs. Eventually, the mixed character of the cove hardwood stands will be reduced by the single-tree selection method to a few commercial tolerant species, such as sugar maple, American beech, and red maple (19, 28, 35). As species composition changes to more tolerant species, volumes per acre decrease and the number of years for trees to mature increases. Also, some wildlife species will be influenced by changes in nut, forage, and browse production and edge habitat (25). The use of single-tree selection cuts that remove enough trees to encourage regeneration and development of light-demanding, more valuable species poses the risk of reducing stand growth and quality through understocking and high grading (37). Single-tree selection is especially suitable in areas where esthetic or recreational values are high. This practice generally is less favorable than other cutting methods for increasing water yield or diversifying wildlife habitat (19). Also, potential logging damage to residual trees is a major concern.

Group selection provides a mixture of desirable tolerant and intolerant species in mixed hardwood stands, if the openings are at least 0.5 acre (0.2 ha) (31). Group selection is difficult to apply at periodically short intervals (25). If openings are small and well scattered, esthetic qualities remain high and group selection produces excellent wildlife habitat, forage, browse, edge, and mast-producing trees. However, quality of border trees can be reduced by epicormic branching. If deer populations are high, reproduction in small openings may be browsed severely, even eliminated. Group selection is well suited to small woodlots where occasional cuts are desired, but where regulation of yield is not important (25, 29).

Intermediate cuttings in immature mixed hardwoods provide a means of improving stands by removing undesirable species; increasing growth of more desirable, better quality species; and shortening the time until final harvest. There are no stocking guides specifically for mixed hardwood stands, although the Allegheny stocking guide (23) currently is being applied in West Virginia on the Monongahela National Forest. The yellow-poplar stocking guide is applicable to mixed hardwood stands dominated by yellow-poplar (4). Precommercial thinnings are questionable in even-aged Appalachian hardwood stands less than 10 years old, or with trees less than 25 ft (7.6 m) tall (11, 31). Thinnings should start at age 15 to 20 and continue at about 10-year intervals until age 60 or 70 (25). Thinnings should be intensive enough to provide rapid growth on leave trees, but not so intensive as to stimulate epicormic branching, early stem forking, or grapevine development. However, yellow-poplar stands can be thinned intensively without incurring serious butt-log degrade due to epicormic sprouting (10).

In Appalachian mixed hardwood stands where even-aged management is practiced, wild grapes and other vines can be a major problem to management of high-quality hardwoods. Vines bend, break, and kill young hardwood stems (40). Methods of controlling vines include herbicide treatments and cutting grapevines near ground level when the overstory canopy of young or mature stands is closed. When grapevine control is necessary, wildlife and recreation interest must be considered.

There is little evidence that conventional silvicultural practices will deplete nutrient levels in Appalachian mixed hardwood stands (22). Soil erosion and reduction of water quality are dependent on logging and road construction techniques rather than silvicultural practices. Also, the organic soil layers in these stands have an exceptional capacity for absorbing water and protecting soil against erosion (25). When erosion and consequent sedimentary runoff do occur on logged areas, the cause is usually poorly designed, constructed, and maintained haulroads and skidroads. Fish, especially trout, are sensitive to changes in water temperature. Protective tree borders can be left along streams to maintain prevailing stream temperature regimes and to minimize sediment before runoff water enters the stream (34). There are many species of wildlife in Appalachian mixed hardwood stands so it is necessary to maintain a variety of vegetation to provide diverse food and habitat (25). Silvicultural practices such as periodic regeneration cuts provide a forest with a variety of vegetative stages including seedlings, saplings, poles, immature sawtimber, and mature sawtimber. Silvicultural practices cannot be designated as beneficial or detrimental to birds per se (9). Certain practices may change habitats enough to decrease the total bird population of certain species; however, other bird species that are better adapted to the modified habitat will occupy the site (9).

Because Appalachian mixed hardwoods are found on good sites and generally contain a number of desirable species, these stands are highly productive. The rich mixture of species and the wide variation in silvical characteristics allow flexibility in applying silvicultural practices yet complicate management decisions. Even-aged management generally is recommended for maintaining Appalachian mixed hardwoods. Through this practice, intolerant and tolerant species can be retained together. But, there are so many forest stands, site conditions, and management objectives that there is no single silvicultural cutting practice that can be considered the most appropriate for managing the complex hardwood stands (27).

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Paper Birch

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Paper birch, Society of American Foresters forest cover type 18, occupies about 2.4 million acres (1.0 million ha) in New England, New York, and northern Pennsylvania, and in the northern portion of the Lake States. It also extends northward into Canada and westward across Canada into interior Alaska where it occupies 5.1 million acres (2.1 million ha) (6, 15). (See Interior Alaska White Spruce–Hardwoods type for information on silvicultural practices in Alaska.)

Paper birch (*Betula papyrifera* Marsh.) is a pioneer type that revegetates land disturbed by natural catastrophe such as wildfire or man-caused disturbance such as clearcutting. It grows best on deep, well-drained soils with good fertility, but is found on nearly any soil type and moisture regime. This forest cover type extends nearly to the limit of tree growth in the north and at high elevations on cool north- and east-facing slopes in the southern portions of its range (6). In general, paper birch is found where the climate has short, cool summers and long, cold winters (12). Annual precipitation varies greatly over the range, from 30 inches (760 mm) or less in the Lake States to as much as 60 inches (1520 mm) in northern New England. Typically, one-third to one-half of the precipitation falls as snow.

Large stands of pure paper birch are uncommon. Species commonly associated with the paper birch type include quaking and bigtooth aspen (*Populus tremuloides* Michx. and *P. grandidentata* Michx.), pin cherry (*Prunus pensylvanica* L.), yellow and gray birch (*Betula alleghaniensis* Britton and *B. populifolia* Marsh.), sugar and red maple (*Acer saccharum* Marsh. and *A. rubrum* L.), and in the northern parts of the range, spruce and balsam fir (*Picea glauca* (Moench) Voss, *P. mariana* (Mill.) B.S.P., *P. rubens* Sarg. and *Abies balsamea* (L.) Mill.). Young regenerating stands frequently contain abundant raspberries and blackberries (*Rubus* spp.), hobblebush (*Viburnum alnifolium* Marsh.), and elder (*Sambucus* spp.) (6).

In the absence of disturbance the paper birch type is replaced by tolerant types, commonly by northern hardwoods on well-drained mineral soils and spruce–fir on shallow or poorly drained soils. In Minnesota it is often replaced by communities dominated by shrubs, particularly beaked hazel (*Corylus cornuta* Marsh.), and scattered trees (11).

Paper birch normally reproduces from seed. Poor natural seed supplies may be supplemented by broadcasting additional seeds. Stumps of trees younger than about 60 years produce vigorous sprouts that can be counted on to supplement seedling regeneration (14). Where natural regeneration cannot be obtained or where introduction of genetically improved stock is desired, bareroot nursery stock or container grown seedlings can be planted (9). Site preparation to reduce competition is required, especially on old-field sites with heavy sod. Protection of planted seedlings from girdling by rodents and browsing by deer may be required (3).

Paper birch begins producing seed at about 15 years of age; optimum seed bearing age is 40 to 70 years. In the Northeast, good seed crops occur every other year, but some seed is produced every year, with a bumper crop 1 year in 10. In Wisconsin, the seed crop failed or was classed as poor for 5 consecutive years (8). Some seed may fall in July due to wind storms or birds feeding on catkins, but seedfall generally starts in August and continues through winter into spring. The bulk of the seed (about 90 percent) falls from September through November.

The light-winged seed of paper birch is readily dispersed by the wind. Some seed travels great distances, particularly when blown across the surface of snow. However, the majority of seed falls within the stand where it is produced, and the amount of seed dispersed into openings drops off rapidly with distance from stand edge. Two million seeds per acre (4.9 million/ha) would be adequate to regenerate openings up to 100 feet (30 m) wide; 8 million per acre (19.8 million/ha) would be adequate for openings 300 feet (100 m) wide (1).

Seed germination and seedling development are affected by soil moisture, soil temperature, light, and seedbed conditions. Best germination and early survival are on exposed mineral soil and in partial shade. However, growth is better on humus seedbeds and in 50 percent or greater sunlight. Scarification, disking, or light burning provide the best seedbeds (13).

Although paper birch is not known as a dry-site species, it is found on some droughty sites, particularly in the Lakes States. During drought, paper birch survives water stress by shedding foliage (7). It is generally wind firm despite its generally shallow root system. Often, the root system of trees blown over by the wind has been injured by a pathogen like *Armillariella mellea* (Vahl. ex Fr.) Karst. (17). Saplings and small poles bend under the weight of heavy wet snow or glaze, but most of the trees recover and straighten if the snow or ice falls off quickly.

Because of its intolerance, paper birch does not become established under dense forest canopies. In the early stages of suppression, paper birch most often requires release from aspen and pin cherry that overtop and threaten to suppress it. Unless suppressed trees are released early, they soon die. Intermediate trees survive longer, but gradually succumb after struggling for years at a low rate of growth (12).

Young paper birch grows rapidly but the growth rate declines with age, becoming negligible when trees reach maturity. The average diameter of trees in mature stands is 10 to 12 inches (25 to 30 cm), and the average height is 70 feet (21 m) (8, 12). On the best sites, an occasional tree in old stands may exceed 30 inches (76 cm) in diameter and 100 feet (30 m) in height. The diameter of trees of the variety *cordifolia*, mountain paper birch, can be as large as 40 inches (102 cm) (12).

Average yields at maturity (80 years) on good sites are about 3,500 cubic feet per acre (245.0 m^3/ha), a high proportion of which may be in sawlogs and veneer logs. Average yields on poor sites are about 2,000 cubic feet per acre (140.0 m^3/ha), of which few trees reach sawlog size (4). The bulk of the material can be used for pulpwood, fuelwood, or millwood. Yields in New England are higher than Ontario, especially on the poorer sites where yields from stands in New England exceeds those in Ontario by more than 80 percent.

Insects and disease attack only a small percentage of paper birch seed and seedlings (5, 17). Sapling and older trees may be attacked by several defoliating insects, including the forest tent caterpillar (*Malacosoma disstria* Hubner), the birch skeletonizer (*Bucculatrix canadensisella* Chambers), the birch leafminer (*Fenusa pusilla* (Lepeletier)), the birch casebearer (*Coleophora serratella* (L.)), the birch leafminimg sawflies (*Heterarthrus nemoratus* (Fallen) and *Profenusa thomsoni* (Konow)), and such general forest defoliators as the saddled prominent (*Heterocampa guttivitta* (Walker)) and the gypsy moth (*Lymantria dispar* (Linneaus)). Defoliation alone seldom kills otherwise healthy trees. However, growth is reduced and trees become susceptible to other damaging agents, particularly the bronze birch borer (*Agrilus anxius* Gory), which damages and kills substantial numbers of trees (5). Cambium miners such as *Phytobia* spp. attack healthy trees, and ambrosia beetles like *Trypodendron betulae* Swaine or *Xyloterinus politus* (Say) attack dying trees and recently cut logs, causing degrade and defects in paper birch wood (14).

Paper birch trees are very susceptible to discoloration and decay caused by microorganisms that enter the bole of the tree through branch stubs or wounds. A defect known as red heart (cause uncertain) is common in some areas. The wood is darkened, but may be sound enough for some uses. Principal decay-causing fungi include *Inonotus obliqua* (Pers. ex Fr.) Pilat, *Phellinus igniarius* (L. ex Fr.) Quel., *Pholiota* spp. Stem cankers that ruin a tree for timber purposes are often caused by *Inonotus obliqua, Inonotus glomeratus* (Pk.) Murr., and *Nectria galligena* Bres. (18). A condition known as collar crack sometimes arises when the root-rotting fungus *Armillariella mellea* (Vahl. ex Fr.) Karst. infects paper birch trees, cracking the bark at the base of the stem (17). Postlogging decadence, which sometimes develops following partial cutting in young birch sawtimber stands, causes premature mortality.

Browsing by white-tailed deer and moose in paper birch seedling stands can reduce the stocking of birch and impair the quality of surviving stems. The yellow-bellied sapsucker pecks rows of holes through the bark of upper stems of saplings to mature trees; these holes provide entry for discoloration and decay organisms and may cause ring shake (17). A dense band of holes will girdle the stem and kill most or all of the crown, leading to a weakened state that invites attack by the bronze birch borer or by decay organisms.

Wildfire has been responsible for the establishment of many paper birch stands. Controlled burning can be used to prepare sites for regenerating paper birch (2). Fire is a serious enemy of established stands of paper birch. Because the bark of paper birch is thin and highly flammable, even large trees can be killed by moderate fires (12).

Paper birch is an intolerant species and as a type can be established and maintained only under some form of even-age management. In the Northeast, blocks, strips, and small patches can be clearcut. In the Lake States, where summer drought is common and aspen reproduction often dominates large clearcuttings, regeneration methods that provide partial shade for several years are the best means of regenerating paper birch. Here, the shelterwood method, strip cutting, and small patches are most likely to succeed.

The arrangement and size of clearcuts depend on stand and site conditions as well as the manager's objectives. In the Northeast, block clearcuts of up to 40 acres (16 ha) can be used on sites that have gentle slopes and good soils where there are no watershed management conflicts. If a problem with seed supply is anticipated, 3 to 5 seed trees per acre (7 to 12/ha) should be left, or additional seed should be broadcast.

Regeneration cuttings using the progressive strip method, clearcutting in small patches of an acre or less, or the shelterwood method provide more protection to the site, partial shade for the regeneration, and a better seed supply than obtained with larger clearcuts. These methods can be used in the Lake States in general and in the Northeast on steeper slopes, droughty sites, or in any location where large clearcuts are undesirable. Although the shelterwood method is applicable for these conditions, there are little data for developing treatment prescriptions.

Small patch cuttings are difficult to fit together systematically to cover the entire area of a stand and result in administrative problems for subsequent stand management. However, patches are particularly useful for small-area management where esthetics are important. Patches also can be used to provide a birch component in stands of hardwoods managed by the selection system of uneven-age management (14).

Regardless of the regeneration method, seedbed disturbance is required. The goal of scarification should be to expose and mix mineral soil with the humus layers on about 50 percent of the regeneration area. Attempts to regenerate birch from young stands may be hampered by an abundance of other vegetation, such as *Rubus* and pin cherry arising from seed stored in the forest litter (10). Advance reproduction of tolerant species as well as shrub understories also may hamper reproduction attempts.

Most paper birch regeneration treatments result in stands with a mixture of species. To ensure survival and increase the growth of birch, cleaning and weeding and precommercial thinning treatments are often needed and desirable. These practices are only recommended for stands with site index 60 (18.3 m) or better (14, 19). Cleaning and weeding, if needed to insure survival, should be applied when the stands are 5 to 10 years old. To minimize costs, only about 150 crop trees per acre (370/ha) should be released (14). For rapid growth, one or more precommercial thinnings should be applied between ages 25 to 35. Approximately 250 to 300 paper birch crop trees per acre (620 to 740/ha) should be released (14). At later stages, a stocking guide (14) should be consulted for appropriate levels of residual stocking. In previously untreated old stands, two treatments about 5 years apart may be required to reach this level and avoid opening the stand to winter snow damage.

The attractive white bark and graceful form of paper birch make it esthetically pleasing. Single trees or sprout clumps are often transplanted as ornamentals and shade trees for landscaping. Stands of birch along roadsides and adjacent to campgrounds are attractive to hikers, campers, and tourists traveling the highways. Special practices to perpetuate stands in these locations include clearing in small patches, early cleaning and weeding, and favoring birch stump sprouts.

Young regenerating stands of paper birch and associated species provide prime browse and summer cover for deer and moose (16). Patches used in conjunction with uneven-age management create a diversity of vegetation and source of browse. Paper birch also is an important source of food for birds. The red poll, pine siskin, and chickadee feed on seeds and the ruffed grouse eats male catkins and buds during the winter (16).

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Loblolly Pine

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Loblolly pine (*Pinus taeda* L.) is the most important forest species in the southern United States, where it is dominant on about 29 million acres (11.7 million ha) and constitutes over one-half of the standing pine volume (6). Its natural range encompasses 14 States extending from southern New Jersey south to central Florida and west to eastern Texas (17). The range includes the Atlantic Plain, the Piedmont Plateau, and the southern extremities of the Cumberland Plateau, the Highland Rim, and the Valley and Ridge Provinces of the Appalachian Highlands (15). Loblolly pine is an adaptable species that has been successfully planted along the periphery of its natural range and has been introduced on other continents with varying degrees of success.

Loblolly pine occurs on a wide variety of soils, ranging from the poorly drained Aquults and Aquods of the coastal portion of the Atlantic Plain to the relatively dry Psamments, Udults, and Udalfs of the inland portion of the Atlantic Plain, Piedmont, and upland Provinces (27). Best growth is on moderately acid soils having imperfect to poor surface drainage, a deep medium-textured surface layer, and a fine-textured subsoil. These soils are common in the uplands of the Atlantic Plain and on floodplains and terraces of rivers and streams. Poorest performance is on shallow soils, eroded soils, and very wet sites.

The climate over most of the loblolly pine range is humid, warm-temperate with long, hot summers and mild winters. The frost-free period varies from 5 months in the northern parts of the range to 10 months along southern coastal States. Mean annual precipitation varies from 40 inches (1015 mm) in the northeastern and western extremes of the range to 60 inches (1525 mm) along the Gulf Coast.

The species is found in pure stands and in mixtures with other pines or hardwoods. When loblolly pine predominates it forms Loblolly Pine type 81 as described by the Society of American Foresters (9). Within their natural ranges, longleaf (*Pinus palustris* Mill.), shortleaf (*P. echinata* Mill.), or Virginia pine (*P. virginiana* Mill.), are frequent associates on well drained sites; pond pine (*P. serotina* Michx.) and spruce pine (*P. glabra* Walt.) are common associates on moderately to poorly drained sites. In the southern part of its range loblolly may be frequently found with slash pine (*P. elliottii* Engelm.).

Loblolly pine is a dominant pioneer arboreal species in secondary succession on the uplands; however, in later stages of succession it is commonly found with and often replaced by a broad spectrum of hardwood species when the successional trend is unchecked. While oaks, gums, and hickories are the most common associates, species composition varies by soil, moisture regime, and topographic position. The hardwoods are more shade tolerant than loblolly, and often form dense understories in pine stands. When the pines are harvested or die of natural causes, the understory hardwoods tend to dominate the site unless they are controlled.

Loblolly pine is easily regenerated by natural or artificial means. It is commonly regenerated by hand or machine planting 1-0 nursery-grown bareroot or containerized seedlings. Seedlings are generally planted at spacings to provide approximately 500 to 800 trees per acre (1240 to 1980 trees/ha), depending on landowner objectives and expected survival rates. Loblolly can also be reproduced on suitable sites by direct seeding 0.25 to 1.0 pounds per acre (0.3 to 1.1 kg/ha) of high quality bird- and rodent-repellent treated seed. Direct-seeding is especially suitable on inaccessible terrain or rocky soils. When artificial regeneration methods are used, attention should be given to the provenance or geographical origin of the seed. Unless better sources are known, an effort should be made to obtain seed from trees of native stock growing as close as possible to the planting site. In most cases, seed should be collected from good phenotypes that are within 100 miles (161 km) horizontally and approximately 1,000 feet (305 m) vertically of the point where it is to be used. When there is an adequate seed crop, a receptive seedbed, and adequate soil moisture, loblolly pine stands can be regenerated by natural seeding. Successful regeneration of loblolly pine by natural or artificial means usually requires site preparation where hardwood competition exists.

Seed production of loblolly pine varies by physiographic region, climatic factors, and tree or stand condition. In the southern coastal portions of the Atlantic Plain, loblolly is generally a prolific and consistent seed producer, but in some of the inland portions of the Atlantic Plain, the Piedmont, and in the western extremities of its range, seed production is often lower and more erratic. Even though year-to-year fluctuations in seed production occur, loblolly usually produces some seeds every year and good seed crops normally occur at intervals of 3 to 6 years. More than 80,000 sound seeds per acre (197 680 seeds/ha) is considered a good seed crop; 30,000 to 80,000 seeds per acre (74 130 to 197 680/ha) is an average crop, while less than 30,000 seeds per acre (74 130/ha) is considered marginal, depending on seedbed characteristic and weather conditions. During bumper seed years, more than a million sound seeds per acre (2.5 million/ha) are often produced. Seed production of individual trees increases with tree age, size, and freedom from crown competition. Enough seed may be produced in widely spaced stands by age 25 to regenerate a stand; however, trees at 40 years generally produce 3 to 5 times more seeds than those of 25 years. Rotations shorter than 30 years usually do not lend themselves to natural regeneration.

Loblolly pine seedfall usually begins in October with the bulk of the seeds being released in November and early December. Seedfall is hastened by dry, warm, windy weather and retarded by cool, wet weather. Seed dispersal in or adjacent to a stand varies with height and stocking level of the seed source trees, magnitude of the seed crop, terrain, and weather and wind conditions at time of seedfall. The effective seeding distance ranges from 200 to 300 feet (61 to 91 m) in a downwind direction from the seed source and 75 to 100 feet (23 to 30 m) in other directions. Viability of loblolly pine seeds varies with seed crop size and the month that the seed is dispersed. Seed viability is often lower in years of poor seed crops and in seeds dispersed late in the season.

Seed germination as well as seedling establishment and survival are strongly affected by weather conditions, soil moisture, seedbed condition, age of the seedbed, and soil texture. Seedbed preparation, either by scarification or burning, greatly increases seed germination and seedling survival. Scarifying the seedbed exposes mineral soil and increases contact of the seeds with moist soil surfaces. During years with good seed crops, soil disturbance from logging may be adequate, particularly when combined with a pre- or postharvest prescribed burn. Favorable seedbeds usually exist for only one year after disturbance, after which they rapidly deteriorate.

Loblolly pine is intolerant to moderately tolerant of shade. Its shade tolerance is similar to shortleaf and Virginia pines, less tolerant than most hardwoods, and more tolerant than slash and longleaf pines (9, 28, 29). Loblolly is moderately tolerant of drought. Extremely high summer temperatures and drought, expecially in areas of low summer rainfall and on sites that normally have high summer water tables, often cause mortality of seedlings and saplings and in some cases even larger trees are killed. Loblolly pine seedlings or saplings cannot withstand prolonged flooding. Complete inundation for more than two weeks during the growing season results in significant mortality. Larger trees are classed as moderately tolerant of flooding, since they can typically survive one season, but usually succumb during the second growing season if they are continuously in a flooded condition. Loblolly pine is basically a wind-firm species; however, some wind damage can occur in large dominant trees growing on shallow soils. Wind damage is more likely to occur in stands that have had a recent heavy thinning. Ice and cold damage can also be a problem in some parts of the loblolly range. Damage resulting from low or freezing temperatures is confined primarily to seedling injury or mortality. Sapling-size and larger trees are often damaged by ice or glaze storms in the form of branch and stem breakage, severe bending, and in some cases uprooting of trees. Ice damage is usually more severe in plantations that have been recently thinned or fertilized and in heavily stocked stands made up of slender, small-crowned trees. Even though loblolly pine occurs on a wide range of sites, there are soil-site limitations that affect its growth and development. For example, loblolly pine does not do well on deep, dry sands (sandhills), soils having a shallow hardpan but no clayey horizon (Spodosols), or extremely wet sites. The adverse properties associated with these sites result in stress that often leads to insect and disease problems.

Loblolly pine expresses dominance early, and various crown classes develop rapidly under competition on good sites; but in dense stands on poor sites, expression of dominance and crown differentiation are slower. Competition from hardwoods can seriously reduce merchantable volume in pine stands. For example, a study in North Carolina indicated that 10 square feet per acre (2.3 m^2/ha) of competing hardwood basal area at stand age 10 would reduce merchantable volume of pine more than 50 percent by age 20 (3). In Arkansas, understory hardwood competition in a 47-year-old pine stand has reduced cubic-foot volume growth by 43 percent and board-foot volume growth by 59 percent (11). Trees that have developed in a suppressed condition respond in varying degrees to release. Increases in diameter growth after release are related to live crown ratio and crown growing space, but trees of large diameter generally respond less than trees of small diameter (10). Trees with well-developed crowns usually respond best to release. Trees long suppressed may also grow much faster in both height and diameter after release but never attain the growth rate of trees that were never suppressed.

Dense natural stands of loblolly pines usually respond well to precommercial thinning (16). To insure the best volume gains, stocking should be reduced to 500 to 700 stems per acre (1240 to 1730 stems/ha) by age 5. Although commercial thinnings seldom increase cubic volume yields of loblolly pine, light thinnings that salvage suppressed or dying trees can increase net yields by 10 to 20 percent. When managing for sawtimber, thinnings increase diameter growth of residual trees and allow growth to be put on the better trees in the stand, thus maximizing sawlog volume growth and profitability. Thinnings also provide intermediate returns on investment.

Seedling height growth occurs annually in series of two to five growth flushes and is dependent on such variables as temperature, day length, soil moisture, nutrients, competition, and genetics. On the best sites, loblolly pine averages 3 to 4 feet (0.9 to 1.2 m) in height growth per year through the sapling stage.

Growth of loblolly pine stands, from sapling to maturity, is inherently good when compared to most hardwood competitors and on many sites doubles or triples the production of common associates (28). Individual trees tend to express dominance at an early age. The most vigorous individuals and those located in favorable microsite environments become dominants as the stand develops. In sapling stands, differences in growth rates of individual trees become evident when competition between the individual trees begins.

Diameter growth of individual trees generally increases as crown surface area and live crown ratio increase, with optimal diameter growth occurring when trees have at least a 40 percent live crown ratio. Annual diameter growth is greatest within the crown and decreases with increased distance below the crown. This phenomenon causes the bole of a loblolly pine tree to become cylindrical with increasing age.

Yield estimates for natural, even-aged loblolly pine in fully stocked stands were first made more than 50 years ago (1, 26). Additional estimates have been made in more recent years for stands of various stocking level (5, 7, 18, 19, 22, 23). Normal yields of natural, even-aged loblolly pine stands on good sites, such as those with a site index of 90 feet (27.4 m) at 50 years, have ranged from 1,900 cubic feet per acre (133.0 m^3/ha) in trees 3.6 inches (9 cm) diameter at breast height (d.b.h.) and larger at age 20 to 6,110 cubic feet per acre (427.7 m^3/ha) at age 60. Comparable board foot yields from trees 9.6 inches (24 cm) and larger in the same stands have ranged from 2,100 board feet (fbm) using the International ¼-inch rule (420 cubic feet)[1] per acre (29.4 m^3/ha) to 40,000 fbm (8,000 cubic feet) per acre (560.0 m^3/ha). Mean annual cubic volume growth generally culminates at about age 40 on these sites with appproximately 115 cubic feet per acre (8.0 m^3/ha). As a result of larger sawtimber merchantability limits, mean annual board foot growth culminates at about age 50 at a rate of 680 fbm (136 cubic feet) per acre (9.5 m^3/ha)[2].

Yields of planted loblolly pine vary with plantation age, site quality, number of trees planted, and interactions of these variables. Yields generally increase with age and site quality. Depending on the site and the product objectives, stands of lower densities or wider planting spacings often produce more sawlog volume and dollar value than stands with high densities. Closer spacings tend to produce higher total cubic

[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.

[2] Langdon, O. Gordon. Loblolly pine. 1981. Unpublished data: table supplied to author by O. Gordon Langden, North Carolina University, Raleigh, N.C.

volumes at younger ages than do wider spacings; however, average tree sizes are larger on wider spacings than on closer ones. If sawtimber is a primary management objective, then wider spacings or lower densities would be advantageous. In Arkansas, through intensive culture (heavy thinning, understory control, and pruning), an average d.b.h. of 15 inches (38 cm) and 13,000 fbm (International ¼-inch rule) (2,600 cubic feet) per acre (182.0 m^3/ha) were achieved in 27 years (8). Stands under conventional management produced 40 percent more cubic volume but 60 percent less board foot volume in the same period. Average yields of loblolly pine plantations with 750 seedlings per acre (1,850 seedlings/ha) on good sites for various locations within its range have increased from 880 cubic feet per acre (61.6 m^3/ha) at age 15 to 2,715 cubic feet per acre (190.0 m^3/ha) at age 30.[2] Mean annual increment for these stands have averaged 90 cubic feet per acre (6.3 m^3/ha).

Growth and yield in uneven-aged loblolly pine stands is dependent on stand structure, stocking, and site quality. On good sites in southern Arkansas, where the site index is 90 feet (27.4 m) at 50 years, managed uneven-aged loblolly pine stands that are well-stocked have averaged 3 square feet per acre (0.7 m^2/ha) of basal area growth (20), 80 cubic feet per acre (5.6 m^3/ha) of merchantable or 432 fbm per acre of sawlog volume growth per year for a 29-year period (21). On somewhat poorer sites in the Georgia Piedmont where the site index is 75 feet (22.9 m) at 50 years, annual growth has averaged 76 cubic feet per acre (5.3 m^3/ha) or 319 fbm per acre over a 21-year period (4).

Insects and diseases that affect loblolly pine at various stages of development are described by Baker (2) and Hepting (14). Loblolly pine serves as host to a multitude of insect pests. With few exceptions, the majority of the insects that attack loblolly are insignificant in terms of damage or mortality. The most serious insect pests are: bark beetles, particularly the southern pine beetle (*Dendroctonus frontalis* Zimmermann), whose attacks may result in extensive mortality, and pine engraver beetles (*Ips* spp.) which can cause death of isolated or small groups of trees; pine tip moths (*Rhyacionia* spp.) which often infest young trees; seedling debarking weevils (*Hylobius* spp. and *Pachylobius* spp.) which sometimes girdle and kill young seedlings up to 0.5 inches (1.3 cm) in d.b.h.; and cone and seed insects (*Dioryctria* spp. and *Leptoglossus* spp.) which can materially reduce seed crops. Loblolly pine is generally the preferred host of the southern pine beetle, which is the most destructive insect pest for this species (24). Most infestations originate in stands that are under stress because of poor site, adverse weather, overstocking, or overmaturity. Once a build-up of southern pine beetles occurs, adjacent well-managed stands may also be attacked. Preventive measures include avoidance of planting off-site and maintenance of vigorous stands through such silvicultural practices as controlling density through thinnings and harvesting trees at or before maturity.

The major disease problem in loblolly pine is fusiform rust (*Cronartium quercuum* (Berk.) Miy. ex Shirai f. sp. *fusiforme* Burds. & Snow). It is recommended that seedlings from rust resistant seed sources be used in areas of high fusiform incidence. Other diseases that can affect loblolly pine are: seedling susceptibility to black root rot (*Fusarium* spp., *Macrophomina* spp., and possibly others); root rot by *Heterobasidium annosum* (Fr.) Bref. in thinned stands; and heart rot in old stands with *Phellinus pini* (Thore ex Fr.) A. Ames in the bole and mostly *Phaeolus schweinitzii* (Fr.) Pat. in the butts.

Although young loblolly pine stands less than 12 to 15 feet (3.7 to 4.6 m) tall are highly susceptible to wildfire, prescribed fire, when used judiciously, is an excellent management tool for stands over 15 feet (4.6 m) tall. Prescribed fire is effective for manipulating understory vegetation, reducing excessive fuel (hazard reduction), disposing of logging slash, preparing planting sites and seedbeds, and improving wildlife habitat. Responses of the understory to prescribed fire varies with frequency and season of burning. Periodic winter burns will keep hardwood understories in check, while a series of annual summer burns will usually reduce vigor and increase mortality of the hardwood rootstocks. A series of prescribed burns, such as a winter burn followed by three annual summer burns prior to a harvest cut, has been more effective than disking in controlling competing hardwood vegetation and in improving pine seedling growth in the Atlantic Coastal Plain after establishment of natural regeneration (25).

Either even-aged or uneven-aged management systems can be used with loblolly pine. Even-aged stands can be established by natural or artificial regeneration methods. Uneven-aged stands are usually maintained by selection cutting methods that promote natural regeneration. Even-aged management is generally more practical and economically efficient on such large holdings as industry lands and the National Forests. Even-aged methods allow cultural operations to be concentrated in time and space and permit management areas to be easily defined and treated. The most common regeneration method used in the last decade on most southern forest lands has been clearcutting and planting. Planting has proven to be a reliable regeneration method for loblolly and has the advantages of providing control of spacing and stocking, providing for rapid and timely restocking, allowing the use of genetically improved seedlings, and permitting shorter rotations. Also, planting is not dependent on an on-site seed source. However, clearcutting, followed by site preparation and planting, is the most costly regeneration method. It requires a large capital investment and there is a long waiting period before financial returns can be realized from a given stand. But for large forest tracts, regulation of yields can be set up to provide a steady sustained flow of multiple forest products and income over time.

A variety of silvicultural systems are suited to loblolly pine. Reproduction cutting methods such as seed-tree, shelterwood, and clearcutting establish even-aged stands while selection cutting develops or maintains an uneven-aged forest.

Success of the seed-tree method depends on proper manipulation of the seed supply and seedbed conditions. The reproduction cut should be made prior to seed fall in a good seed year leaving 4 to 12 evenly distributed, well-formed trees per acre (10 to 30 trees/ha). The number of seed trees left depends on tree size and site conditions. The seed trees should be at least 10 inches (25.4 cm) d.b.h., but preferably 12 to 16 inches (30.5 to 40.6 cm) (31). Crown release of the seed trees 3 years before the main harvest cut can increase seed production of loblolly pines that have been grown in closed stands. Disking prior to seed fall or prescribed burning in advance of the reproduction cut will prepare a seedbed and assist in controlling small hardwoods. Larger hardwoods are often controlled with herbicides. Well-stocked stands usually result if adequate seed fall occurs within a year after seedbed preparation and the reproduction cut. Delayed seed fall may require the receptive seedbed to be maintained—normally by prescribed fire. The seed trees should be removed within 3 to 5 years after adequate reproduction has become well established. This would be approximately 1,000 well-distributed seedlings per acre (2470 seedlings/ha).

The shelterwood system has been most successful in the central and eastern parts of the range, where greater summer rainfall enhances seedling establishment. A two-cut shelterwood system is normally used in loblolly pine. In the first cut, all but 20 to 30 of the best seed trees per acre (49 to 74 trees/ha) are removed. The leave trees should comprise 20 to 30 square feet of basal area per acre (4.6 to 6.9 m^2/ha). Prescribed burning is the most practical method of site preparation and control of small hardwoods, and should be done before the first cut is made. The overwood, which helps retard the growth of competing hardwoods, is usually removed as the second cut within 5 years after establishment of reproduction.. Shelterwood cutting can result in too much reproduction, particularly when a good seed crop occurs following intensive site preparation. If overly dense stands develop they should be precommercially thinned within 3 to 5 years after overstory removal.

The clearcutting method can be used to naturally regenerate small blocks, patches, or narrow strips, if there is an available seed source from adjacent stands. The longer axis of the clearcut areas should be made perpendicular to the direction of prevailing winds and in most cases the clearcut should not exceed 300 to 400 feet (approximately 90 to 120 m) in width to insure adequate seeding over the entire area. Larger clearcut areas can be regenerated naturally with either seed- or seedlings-in-place. Seed-in-place involves clearcutting the stand after peak seedfall but prior to germination. It requires logging during the late fall and winter following a good seed fall.

Seedlings-in-place involves clearcutting the stand during the summer after seedlings have become established. Ample seed crops are necessary for successful use of these methods and a preharvest prescribed burn is often recommended. With clearcutting methods other than seed- or seedlings-in-place, a prescribed burn following logging is beneficial for slash disposal, site or seedbed preparation, and control of small hardwoods. The reproduction may also require additional release from hardwood competition within 2 to 5 years after establishment.

If the management objectives are to maintain an uneven-aged stand, where seedlings, saplings, pulpwood, and small and large sawtimber are all represented, and to harvest at relatively frequent intervals, selection cutting is the best alternative. The selection method involves periodic cutting, at 5 to 10 year intervals, of selected trees from all merchantable diameter classes. In fully stocked stands, harvest-cut volumes generally approximate growth for the cutting period or cutting cycle. In stands that are not fully stocked, only a portion of the periodic growth is cut. Trees selected for harvest can be single isolated trees or groups of trees. If regeneration is not necessarily needed following a particular harvest cut, single-tree selection is suitable. However, if regeneration is badly needed, the group selection or a combination of group and single-tree selection may be required. In many cases, site and seedbed preparation is achieved by the logging operation and the use of chemicals to control larger competing hardwoods. In some cases more intensive control of competing vegetation is required. This can be accomplished mechanically with chemicals and sometimes with prescribed fire. However, blanket application of prescribed burning or nonselective herbicides should be avoided where new regeneration is present. Throughout much of the loblolly pine range, uneven-aged management is an effective means of rehabilitating understocked stands and is especially suitable for small forest properties. It requires a low capital investment, provides periodic income without interruption for stand regeneration, permits net income to be spread out over time, and affords a reserve of large timber to take advantage of favorable market conditions.

Silvicultural systems that depend primarily on natural regeneration have some inherent shortcomings that must be accepted. Natural regeneration results in less control over spacing and initial stocking than does planting and some forms of direct seeding. The irregular stands that develop can cause problems with mechanical harvesting and provide poor access for fire equipment. If overly dense natural stands become established, precommercial thinning is often required to maintain maximum growth of crop trees and promote early sawlog production. In addition, managing for natural regeneration does not permit the use of genetically improved stock; however, it does permit leaving seed trees of good form, fast growth, and disease resistance, all of which contribute to stand improvement. Despite the shortcomings of natural regeneration systems, they can be used effectively and cheaply in many situations. For example, on those nonindustrial holdings or on sensitive sites where the vigorous and expensive site preparation measures required for artificial regeneration are not feasible, natural regeneration systems may be the only alternative.

Management of loblolly pine involves many important multiple-use opportunites such as maintenance of wildlife habitat, protection of rare and endangered species, urban forestry, soil stabilization and erosion control, and biomass and energy production.

Natural loblolly pine stands as well as intensively managed plantations provide habitat for a variety of game and nongame wildlife species. The primary game species that inhabit pine and pine–hardwood forests include white-tailed deer, gray and fox squirrel, bobwhite quail, mourning doves, wild turkey, and rabbits. Some of these species utilize the habitat through all stages of stand development while others are attracted for only a short time during a particular stage of development. A loblolly pine plantation can provide forage for deer, for example, only from the time of planting to crown closure. Without modifying management practices this usually occurs in 8 to 10 years. Management modifications such as wider planting spacings and early and frequent thinnings will delay crown closure and periodic prescribed burns will stimulate wildlife food production. Bobwhite quail tend to use the plantations until a decline in favored food species occurs. As the habitat deteriorates in plantations with crown closure, deer and quail usually move to mature pine or pine-hardwood forests (13), or to other newly established plantations. Pine seeds provide a major food source for many rodents and birds. Turkeys also inhabit upland pine and pine-hardwood forests, and do particularly well on large tracts of mature timber with frequent openings and where prescribed burning is conducted (13).

Loblolly pine and mixed pine–hardwood stands provide excellent habitat for nongame animals and birds. Pine lands are the chief habitat for some birds such as the pine warbler, brown-headed nuthatch, and Bachman's sparrow (12).

Old-growth loblolly stands are very important to the existence of the red-cockaded woodpecker. Large loblolly pine trees are favorite roosting places for many birds and provide an important nesting site for ospreys and the bald eagle.

Another important special use of loblolly pine is in urban forestry and specialty plantings. Loblolly pines are often used as shade trees, and for wind and noise barriers in urban areas throughout the South. It has also been used extensively for soil stablilization and erosion control in areas subject to severe surface erosion and gullying (32) as well as on roadbanks (30). Loblolly pine provides rapid growth and site occupancy and good litter production for these purposes.

In the future, loblolly pine may provide an important wood energy resource. Biomass for energy is presently being obtained from precommercial thinnings and from logging residue in loblolly pine stands. Utilization of these energy sources are predicted to increase, and loblolly pine energy plantations may become a reality.

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Longleaf Pine

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The natural range of longleaf pine (*Pinus palustris* Mill.) includes most of the Atlantic and Gulf Coastal Plains from southeastern Virginia, south to central Florida and west to eastern Texas, with extensions into the Piedmont, Ridge Valley, and Mountain Provinces of Alabama and northwest Georgia (9, 20). Longleaf pine forests may have occupied as much as 60 million acres (24.3 million ha) before settlement (25). Intensive exploitation since pioneer days and a lack of regeneration efforts have shrunk the once vast longleaf pine forests to less than 5 million acres (2.0 million ha) today. Much of the remaining forests are natural second growth that, mostly by chance, sprang up following logging of the old-growth timber. Longleaf pine remains a commercially important timber tree throughout much of its natural range, although close to 60 percent of the standing volume is found in Alabama, Florida, and Georgia (24).

Longleaf pine occurs on a wide variety of sites, from low, wet, poorly drained flatwoods near the coast to dry, rocky mountain ridges. Elevations extend from near sea level on the Lower Coastal Plain up to about 2,000 feet (610 m) in the Alabama mountains. For the most part, the species is found on the coastal plains at elevations between sea level and 600 feet (185 m). Soils are derived from marine sediments and range from deep, coarse, excessively drained sands of the sandhills and sand ridges to poorly drained clays. Throughout most of the coastal plains, surface soils are sandy, acid, low in organic matter, and relatively infertile.

Climate in the longleaf pine region is warm and wet, with hot summers and mild winters. Annual mean temperatures range from 60° to 74° F (15.6° to 23.3° C). Length of the frost-free period ranges from 210 days in North Carolina and North Alabama to more than 300 days in central Florida. Annual precipitation ranges from 43 to 68 inches (1090 to 1725 mm). Precipitation is the lowest, from 43 to 50 inches (1090 to 1270 mm), in the Carolinas and Texas and highest, from 59 to 68 inches (1500 to 1725 mm), on the Gulf Coast of Alabama, northwest Florida, Mississippi, and eastern Louisiana. Fall is the driest time of the year, although dry spells are common in the spring and may occur at any season.

The principal longleaf pine cover types, as described by the Society of American Foresters, are the Longleaf Pine (type 70), Longleaf Pine–Scrub Oak (type 71), and Longleaf Pine–Slash Pine (type 83) (14). Longleaf pine may also occur as a minor component of other forest types within its range. The longleaf pine forest is considered a fire subclimax type that has developed and maintained itself in close association with periodic fires. The species is resistant to fire. It is also very sensitive to competition, especially as seedlings. This has restricted longleaf largely to sites that have been periodically burned and to poor sites supporting only a sparse cover of competing vegetation. Longleaf pine is a pioneer species that, given an adequate seed source, can invade abandoned fields or areas cleared by a catastrophic event such as blowdown or severe wildfires (6, 14).

Once established, longleaf pine tends to perpetuate itself in areas where fires occur frequently. Needle litter from overstory pines support hot surface fires. These fires slow or prevent the encroachment of hardwoods and other pines; they also provide a favorable seedbed by removing accumulated litter and exposing mineral soil. Grass-stage longleaf seedlings are highly resistant to fire and can even tolerate growing season fires in the open or under light pine overstories. But under medium to heavy pine overstories, most seedlings cannot survive the combination of slow growth resulting from overstory competition plus hot fires fueled by abundant needle litter. Therefore, longleaf pine usually orginates in openings or under light parent overstories where less intense fires still suppress hardwoods but do little harm to vigorous longleaf seedlings.

Reduction in the frequency or exclusion of fire leads to substantial changes in the longleaf pine ecosystem. The open, park-like longleaf forests, with an understory comprised mainly of grasses and forbs, is invaded and eventually superceded by hardwoods as succession on these upland sites moves through pine-hardwood types toward eventual dominance by climax hardwoods. Dominance by other pines may precede hardwoods where presence of a slash pine (*Pinus elliottii* Engelm.) or loblolly pine (*P. taeda* L.) seed source permits these species to gain a foothold on longleaf uplands. In the absence of fire, the grass-stage of longleaf pine seedlings gives them a great competitive disadvantage in the presence of the fast-growing seedlings of other pines and hardwoods.

Longleaf pine has long been considered the most difficult of the southern pines to regenerate, either naturally or artificially. Although planning and care are required, the species can be and has been regularly regenerated naturally (13), by direct seeding (22), and also by planting (21).

Longleaf pine is a poor seed producer compared to the southern pines, and good cone crops are infrequent. Stand and site characteristics are most important in evaluating potential seed production (12). Tree size, crown class, stand density, site quality, and genetic predisposition are all important factors influencing seed production. Equally important are favorable weather conditions at critical periods to insure good seed crops. The best seed producers are dominant trees with well-developed crowns, a diameter at breast height of 15 inches (38 cm) or more, and a history of past cone production. Given an average site and the optimum number and quality of seed-bearing trees, seed crops adequate for regeneration should occur, on the average, once every 4 years (13). The best seedling establishment and survival is usually associated with the good seed years.

Longleaf pine has large winged seeds that are dispersed by wind. Seed fall begins in late October and continues through November, with most seeds shed over a period of 2 to 3 weeks. Dispersal range is short, with 71 percent of sound seeds falling within a distance of 66 feet (20.1 m) of parent trees.

Seeds require contact with mineral soil for satisfactory germination and establishment. Longleaf seeds, with their large wings, cannot easily reach mineral soil through a heavy cover of grass and litter. The accumulated material must be removed before seed fall, either mechanically or by burning. Seedbed burns within a year of seed fall will usually provide an adequate seedbed (13).

Seeds germinate soon after they are dispersed, often in less than a week, if moisture and temperature conditions are favorable. Prompt germination reduces the period of exposure to seed predators, although these seedlings are then exposed to other risks (13). Most seedling losses can be expected during the first year after establishment. Thereafter, risk of loss is substantially reduced.

Competition and brown-spot needle blight (*Scirrhia acicola* (Dearn.) Sigg.) are the two factors with the greatest impact on seedling development after the first year. Longleaf seedlings can survive for years, even under a dense overstory of parent pines, provided they are not burned before reaching a fire resistant size. Growth, however, is very slow (1). Once released from overstory competition, longleaf seedlings will respond promptly with increased growth (5). Brown-spot infection rarely reaches serious levels on seedlings under a pine overstory (4), and 10 to 20 percent of a natural seedling stand usually exhibits resistance to brown-spot (3).

Growth rate of longleaf pine seedlings varies considerably among individuals of the same age, and vigorous, brown-spot resistant seedlings express early dominance. A seedling stand will rapidly develop a range of size classes, reducing the risk of stagnation and consequent need for precommercial thinning. A low level of competition permits early initiation of height growth by grass-stage seedlings. Plantings on well-prepared sites can have the majority of seedlings in height growth by the end of the second growing season. Early initiation of height growth averts a brown-spot problem, as the disease usually takes 2 to 3 years to reach serious levels, and only grass-stage seedlings are affected. Seedling stands should be protected from livestock, as light-to-moderate cattle grazing causes some mortality plus reduced growth of survivors (2). Hogs can completely destroy a seedling stand (25).

Longleaf pine's reputation as a slow-growing tree may not be deserved. Growth on relatively poor sites can equal or exceed that of other pines. Natural stands on medium sites, where the site index is between 70 and 80 feet (21.3 to 24.4 m) at 50 years, can produce from 1.2 to more than 1.6 cords (108 to 144 cubic feet) per acre (7.6 to 10.1 m^3/ha) of mean annual increment to age 30, with 5-year periodic annual increments of 2 to 4 cords (180 to 360 cubic feet) per acre (12.6 to 25.2 m^3/ha) between ages 20 and 30. The optimum density range for maximizing early volume yield is 500 to 1,000 trees per acre (1240 to 2470 trees/ha) (16). Growth information on plantations is scarce. However, rate of height growth is strongly related to degree of competition on the planting site, and during the first 8 to 10 years it is much faster on old fields and prepared sites than on unprepared sites (8). If everything else is equal, yields for both planted and natural stands should be similar. Growth and yield tables for thinned, even-aged natural longleaf pine have been published (17).

Rotations selected for longleaf pine depend on management objectives, site quality, cultural treatments, and thinning schedules, but usually range from 60 to 80 years for sawtimber. Thinning is important if management objectives are sawlog-sized products. Some results indicate that on a medium site the periodic cubic-foot growth of 35- to 40-year-old longleaf pine does not increase much with increasing stand density above 60 square feet of basal area per acre (13.8 m^2/ha). Periodic thinning from below, to leave about 70 square feet per acre (16.1 m^2/ha) of best dominants, costs little in potential volume growth, concentrates growth on quality crop trees, and minimizes the investment in growing stock (15).

Longleaf pine is a low-risk species to manage. In addition to its fire resistance it is also rarely bothered by the serious diseases and insects that afflict the other major southern pines. Site requirements are not demanding, and it can grow well on droughty, infertile soils. Once out of the seedling stage, mortality is low. Suppressed trees may eventually die, but the greatest single cause of loss is lightning, frequently followed by bark beetle attack (*Ips* spp.). Mortality from all causes among dominant members of maturing longleaf stands has averaged about one tree per 2.5 acres (1 ha) annually, and for half of the observed stands averaged one tree or less per 5 acres (2 ha) annually (7).

The major management problems for longleaf pine, in common with other southern pines, are associated with stand regeneration, especially natural regeneration. Problems with artificial regeneration are less imposing, so this approach is preferred despite its high cost. Natural regeneration requires effective competition control and seedbed preparation, which can be achieved only through broadcast cultural treatments using mechanical equipment, chemicals, or fire. With the exception of fire in longleaf stands, such treatments are nearly impossible to apply to a management unit comprised of pines of all ages and sizes. Longleaf pine can tolerate prescribed fire at all ages, except for young seedlings less than about 0.3 inch (0.8 cm) in root-collar diameter. Therefore, this species should be better adapted to uneven-aged management than any other southern pine, as regular burning can be used to control hardwood competition. Although this type of management may best suit the goals of some landowners, especially those with a limited acreage, even-age management is, and undoubtly will continue to be, the predominant form of management for longleaf pine.

Most natural second-growth stands are even aged, dating back to the time the old-growth overstory was removed. The association of regeneration with a catastrophic event (land clearing, blowdown, logging, hot fire, etc.) led to the predominance of even-age stands, often of considerable extent. Since fire is such an integral part of longleaf pine management, the management unit, where an even-age stand is established and maintained, should also be a convenient burning unit, bounded by roads and streams, to minimize the length of maintained firebreaks.

Clearcutting, seed-tree, and shelterwood systems have all been applied to longleaf, but serious drawbacks have eliminated clearcutting and seed-tree systems as practical alternatives for natural regeneration (13). Clearcutting a mature stand can destroy much of the advanced reproduction, if any is present. Because of past difficulties in successfully planting longleaf pine, loblolly, slash, or sand pine frequently are substituted following clearcutting. Increasing success with containerized seedlings may overcome some of the planting problems.

The limited seed dispersal range requires that most of the cleared area be within 100 feet (30.5 m) of a seed source. If there is an extended wait for a seed crop, the growing space will be occupied by low quality hardwoods and brush that must be eliminated, at some cost, to prepare for a seed crop that may or may not be adequate to regenerate the area. With 8 to 10 scattered seed trees per acre (20 to 25/ha), the land is essentially out of production during the wait for a good seed crop. Even with periodic burning, the lower fire intensity resulting from a lack of heavy needle-litter fuels permits some encroaching hardwoods to regularly escape into a relatively fire-resistant size. When too much of this occurs, mechanical or chemical site preparation is required.

Early observations of longleaf regeneration in nature indicated that some form of shelterwood system for natural regeneration might be best suited to this species (10). Several advantages are immediately apparent. Final harvest of mature crop trees is delayed until adequate advanced reproduction is present on the site. This keeps the site in production with growth occurring to high-quality dominants while waiting for a seed crop. Shelterwood stands produce enough needle litter to fuel the hot fires needed to restrict hardwood and brush encroachment, and maintain an understory comprised largely of grasses and forbs. The presence of a shelterwood overstory also inhibits development of the brown-spot needle blight on established seedlings (4). An overstory of 30 to 40 square feet of basal area per acre (6.9 to 9.2 m^2/ha) maximizes seed production, and in a good seed year produces three times as many seeds as a seed tree stand.

The shelterwood system can be applied only in existing stands with sufficient dominant-codominant trees of seed-bearing size. Guidelines for use of the system have been published (6, 13). Briefly, either a two-cut or three-cut shelterwood system may be applied, the latter only in stands needing a thinning or improvement cut. The first cut in a three-cut system would be a preparatory cut. This should leave 60 to 70 square feet of basal area per acre (13.8 to 16.1 m^2/ha) in dominant and codominant trees. Removal of all other trees permits crown development on the residuals. A well-managed longleaf stand periodically thinned will not need a preparatory cut. The first cut in the two-cut system (second in the three-cut system) is the seed cut. This cut is made 5 or more years ahead of the planned harvest date and reduces stand density to about 30 square feet of basal area per acre (6.9 m^2/ha), leaving the best dominant trees. Residual large hardwoods are also removed. Even though stand density may be cut in half, per acre volume production of 50- to 70-year old trees would be reduced by only about one-third (17). Regular prescribed burning keeps down hardwoods. Growing season burns may be needed where brush is heavy. Usually, a seedbed burn the year before a good seed crop is the only site preparation that is needed.

Seed crop prospects are monitored through annual springtime counts of flowers and conelets on selected sample trees in the regeneration area. Normally 750 to 1,000 cones per acre (1855 to 2470 cones/ha) are needed for regeneration, although two or three successive lighter cone crops combined may do the job. Stocking surveys of established seedlings should be made annually, beginning after the seed cut. Sometimes an adequate stand of seedlings is already present on the site, so further measures to obtain regeneration are unnecessary.

The regeneration goal should be establishment of about 6,000 seedlings per acre (14 830 seedlings/ha) under the shelterwood overstory. Distribution should be such that 75 percent or more of milacre (0.001 acre or 0.0004 ha) sample plots are stocked with one or more seedlings. This number will allow for logging losses and still provide enough surviving seedlings so that the superior 10 to 20 percent can supply all the crop trees. Regeneration success must be based on seedlings at least one year old, due to the high risk of mortality during the first year after establishment.

Once an adequate seedling stand is established, the parent overstory can be removed. Prompt seedling release is not required for survival, so harvest of the overstory can be scheduled to meet the needs of management. Given a choice, overstory removal at seedling age 1 or 2 will have the least impact on the new stand (5).

The regeneration area should not be burned during the first 2 years after overstory removal, as accumulated logging slash and undecomposed litter can result in a fire too hot for newly released seedlings. After 2 years, seedling growth plus decomposition of organic debris reduces fire risk considerably. Prescribed burning can be resumed and applied as needed for control of brush and the brown-spot needle blight. A brown-spot survey sampling only crop seedlings will indicate if a burn is needed (11). If these seedlings have an average of 20 percent or more of their foliage destroyed by the disease, a winter brown-spot burn should be prescribed (13). Spring burns may be most beneficial to the seedling stand during the early years after release. These burns not only kill hardwoods more effectively than fires in any other season but also may stimulate longleaf seedling height growth more than either burns at other seasons or no burns at all (19, 23).

Precommercial thinning usually is not needed in longleaf stands, so the first commercial thinning brings the stand toward the desired density for optimum future growth. Dominant crop trees can be easily identified and leave trees marked for this and all subsequent thinnings. All other trees are removed during thinning if they have reached commercial size. Otherwise they are left until the next thinning.

All available information indicates that in the past, the longleaf pine forest type was maintained primarily as a result of wildfires that periodically burned through established longleaf forests. Exclusion of fire leads to serious regeneration problems, as past experience amply demonstrates. Management of longleaf forests should include prescribed fire at 2- to 5-year intervals through the rotation, as needed to prevent hardwood encroachment and excessive risk of wildfire damage through build-up of fuel on the forest floor.

Longleaf pine has long been recognized as an excellent timber tree, better suited than other pines to the whole range of forest products: sawlogs, poles, piling, posts, plywood, and naval stores. The needle litter has been harvested and even old stumps have been removed and destructively distilled for chemicals. The longleaf forest, regularly burned, has an open, park-like appearance often commented on by early travelers and settlers in the region. The forest provides an excellent habitat for game, especially deer, quail, and turkey. Quail hunting has long been associated with the longleaf forest. Cattle made themselves at home in the forest, beginning with the earliest settlement. On many sites, the understory can produce large amounts of forage for both cattle and deer (18, 26). A mature longleaf forest also provides a good home for the red-cockaded woodpecker and the fox squirrel.

The characteristics of longleaf pine make it highly adaptable to a range of management goals and silvicultural systems. This timber type is well adapted to multiple-use management because of the many forest products it supplies, the forage it produces, the wildlife it supports, and the recreation it affords.

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Shortleaf Pine

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Shortleaf pine (*Pinus echinata* Mill.) is the most widespread of any pine in the southeastern United States. It grows in 22 States over more than 440,000 square miles (1.14 million km^2). It extends from southeastern New York and New Jersey into Pennsylvania, southern Ohio, Kentucky, southwestern Illinois, and southern Missouri, south to eastern Oklahoma and eastern Texas, and east to northern Florida and Georgia. Its range extends from 41° 10′ to 30° O′ N. latitude and from 73° 50′ to 96° 0′ W. longitude.

The adaptability of shortleaf pine to a great variety of site and soil conditions partly accounts for its wide occurrence. The species' best growth rate, however, is on the South Atlantic and Gulf Coastal Plain soils. The most productive soils are the deep, well-drained sandy loams, such as those on flood plains. The least productive are the shallow, rocky upland soils. Site indices at age 50 on the better sites may exceed 100 feet (30.5 m) (21) and be as low as 33 feet (10.1 m) on poorer sites (11). Shortleaf pine does not grow well on soils having high pH values or high calcium content (9).

Shortleaf pine grows at elevations as low as 10 feet (3.0 m) in southern New Jersey, up to 1,000 feet (305 m) in Pennsylvania, and up to 3,000 feet (915 m) in the Appalachian Mountains. Its best development is attained at elevations of 600 feet (185 m) to 1,500 feet (455 m) in the Piedmont and 150 feet (45 m) to 1,000 feet (305 m) in Louisiana and Arkansas (9), although it grows up to 2,000 feet (610 m) in Arkansas, Missouri, and Oklahoma (7).

Over shortleaf pine's range, average annual temperatures vary from 48° F (8.9° C) in New Jersey to 70° F (21.1° C) in southeast Texas. The 50° F (10.0° C) average annual temperature isoline closely parallels the northern limit of shortleaf pine. Annual precipitation over the species range averages between 40 inches (1015 mm) on the western edge and 60 inches (1525 mm) at the southern tip of its range. Precipitation over the region of shortleaf pine's best development ranges from 45 to 55 inches (1145 mm to 1400 mm) and averages 50 inches (1270 mm). Average annual snowfall ranges from near zero in the southern sections to nearly 60 inches (1525 mm) in the northeastern parts of the species range, but averages less than 16 inches (405 mm). The average growing season ranges from about 140 days in the North to 280 days in the South (32). The average number of clear days varies from about 100 to 160 over the range of shortleaf pine.

Shortleaf pine is a major component of three forest cover types described by the Society of American Foresters: Shortleaf Pine (type 75), Shortleaf Pine–Oak (type 76), and Loblolly Pine–Shortleaf Pine (type 80). It is also a minor species in at least 15 other forest cover types, where it grows in association with at least 8 other conifer and 21 hardwood species. Major associated tree species include: loblolly pine (*Pinus taeda* L.), longleaf pine (*P. palustris* Mill.), Virginia pine (*P. virginiana* Mill.), eastern white pine (*P. strobus* L.), pitch pine (*P. rigida* Mill.), eastern redcedar (*Juniperus virginiana* L.), post oak (*Quercus stellata* Wangenh.), black oak (*Q. velutina* Lam.), northern red oak (*Q. rubra* L.), southern red oak (*Q. falcata* Michx.), white oak (*Q. alba* L.), chestnut oak (*Q. prinus* L.), bear oak (*Q. ilicifolia* Wangenh.), and blackjack oak (*Q. marilandica* Muenchh.) (7).

Shortleaf pine reproduces naturally from seed and may be artificially reproduced by direct seeding or planting. Good to excellent cone crops occur every 3 to 10 years in the Northeast and 3 to 6 years in the South. Some seeds are produced nearly every year, and significant amounts of seeds are likely to be produced during 3-year periods (40). Shortleaf pine seeds are dispersed by gravity and wind, beginning in late October or early November. About 70 percent of the seeds fall within a month after maturity and 90 percent within 2 months (6, 38). Some seeds continue to fall into April, and cones persist on the tree long after they are empty (9). Most of the winged seeds fall within a distance of about two times the height of the seed tree or the adjacent shortleaf pine stand seed source (38), but the distance may be affected by prevailing winds (17). Shortleaf pine cones contain 25 to 38 full seeds each or about 2 pounds (0.9 kg) of seed per 100 pounds (45.4 kg) of cones (15). The number of cleaned seeds averages about 46,300 per pound (102 070/kg). Releasing seed trees from competition may increase seed yields per cone and number of cones per tree (22, 39). In recent years, seed orchards have produced significant amounts of the seeds needed for nursery production of genetically improved shortleaf pine seedlings (33). Seeds that are to be sown in a nursery or seeded on regeneration areas in the spring are usually stratified for 15 to 60 days at 30° F (−1.1° C) to 41°F (5.0° C). Shortleaf pine seeds that lie on the ground during the winter are naturally stratified and germinate in early spring. Many of the seeds from natural seed fall are eaten by birds and small mammals and only about 1 percent actually germinate and produce seedlings (40).

Seedbed treatments which expose mineral soil tend to increase the initial establishment of seedlings. Scarification during logging and burning provide effective site preparation for natural regeneration. Control of hardwoods and other vegetative competition is also necessary to insure adequate survival of seedlings for full stocking, although some residual hardwoods provide the beneficial effect of shade and protection from drying winds, especially on southerly aspects during the first few years after establishment (16, 40).

Shortleaf pine seedlings may also be established by direct seeding. Its success depends on selecting suitable sites, providing suitable seedbeds, protecting seeds from birds and rodents, sowing sufficient seeds at the right time, and controlling competition. Seedbeds are prepared by mechanical methods such as disking, furrowing, or bulldozing, burning, or hand methods such as kicking or raking off litter (24). Hardwood competition is controlled by mechanical seedbed preparation or by properly timed herbicide application. For broadcast seedings, about 0.5 pound per acre (0.6 kg/ha) is recommended, although about one-half this amount is adequate for well-prepared seedbeds (4). Furrow seeding requires one seed per 9 to 12 inches (23 to 30 cm), while spot seeding requires at least five seeds per spot. It is better to sow at relatively high rates initially with any seeding method; then adjust rates for local conditions as experience dictates (24).

Shortleaf pine seedlings are commonly produced in nurseries and planted as 1–0 stock on prepared sites. Planting may be done by hand or machine at a rate of 450 to 2,000 seedlings per acre (1110 to 4940/ha), depending on management objectives and site characteristics. However, most forest land managers prefer to plant 750 to 900 trees per acre (1850 to 2220/ha). Seedlings may also be grown in various containers, such as tubes, blocks, and plastic molds, and may be planted with or without the container (2).

Shortleaf pine can be vegetatively propagated by rooting, grafting of scions, or air layering (5). Vegetative propagation is generally done for genetic control purposes; grafting of scions on trees of the same species is the most common method. Shortleaf pine seedlings and saplings sprout readily from the base after injury, as incurred following fire, cutting, or grazing (30).

Shortleaf pine seedlings grow slowly as the root system develops during the first year or two after establishment. Seedlings develop a taproot at an early age, which may become very massive if allowed to grow uninhibited (19). In much of the region where shortleaf grows, however, taproots do not develop because of shallow, rocky, heavy clay, or poorly drained soils. Lateral roots tend to grow near the soil surface and are generally concentrated in the upper 18 inches (46 cm) of soil. The developing seedlings and saplings attain most of their height growth early in the growing season, usually by early July. However, shortleaf pines will show growth response to late season rainfall if it is sufficient to substantially replenish soil moisture. Average annual height growth during the sapling stage ranges between 12 and 36 inches (30 and 91 cm) depending on locality and site conditions (9, 28).

Shortleaf pine is a shade intolerant species and does not survive or grow well when in the understory, although it can maintain dominance on most sites after it overtops competing vegetation. Overstory competition from other pines or hardwoods greatly reduces survival and growth of shortleaf pine seedlings (10, 16, 24). Elimination of such competition can increase survival and height growth of seedlings four or five times (9). Young trees in well-stocked shortleaf pine stands begin to compete with each other within a few years after establishment, and diameter growth rates decline (37). The species will, however, persist in very dense stands without stagnation. Natural pruning occurs as the canopies close, although it is slower than on loblolly or longleaf pines. Shortleaf pine responds well to release at all ages up to mature trees (9, 39).

On good sites, shortleaf pine trees attain heights of 100 feet (30.5 m) or more and diameters of 24 to 36 inches (61 to 91 cm). Heights of nearly 130 feet (39.6 m) and diameters of 48 inches (122 cm) have been recorded (9). However, growing trees to more than 70 years of age is uncommon in managed stands, because after that time net growth declines rapidly.

Despite the large acreages of natural even-aged shortleaf pine, the growth and yield information is essentially limited to that developed in well-stocked stands of the Piedmont (26), limited regional data (34), and some growth relationships for north Mississippi (37). Data are almost totally lacking for other circumstances.

Growth and yield of a given stand depends on the quality of the site, current number of trees, stand age, and silvicultural practices administered. Stand structure and yield data for unthinned shortleaf pine plantations in the highlands of Tennessee, Alabama, and Georgia show that mean annual increment for total volume culminates near tree age 30 on poor sites; on the better sites it culminates at about age 20. Mean annual increment of stands having a site index of 40 (base age 25) and planting density of 1,000 trees per acre (2470/ha) culminates at 75 cubic feet inside bark (i.b.) per acre (5.2 m^3/ha) at age 30. For the same site, age, and planting density, the standing volume is about 3,192 cubic feet per acre (223.4 m^3/ha). Basal area of this stand is 166 square feet per acre (38.1 m^2/ha), and the estimated number of trees is 621 (1535/ha). When the site index is 50 with the same planting density, the mean annual increment (i.b.) culminates at a maximum of 110 cubic feet per acre (7.7 m^3/ha) at age 25 (29). Culmination of mean annual increment will likely occur at older ages in natural stands, depending on stocking levels and site quality (3, 21).

Natural shortleaf pine stands in Missouri showed significantly greater net volume yields when thinned to about 90 square feet per acre (20.7 m^2/ha) or above than when thinned to lower densities. Unthinned stands had the highest net volume, 4,909 cubic feet per acre (343.6 m^3/ha), at age 51 (25). This yield is somewhat higher than would be calculated using regional natural stand yield data (21). In south Arkansas, annual growth of uneven-aged, shortleaf-loblolly pine stands thinned at three cutting cycles averaged 84 cubic feet per acre (5.9 m^3/ha) during a 24-year measurement period (23). Annual sawtimber growth of these stands averaged 432 board feet (fbm) (86 cubic feet)[1] per acre (6.0 m^3/ha).

Thinning in well-stocked stands will generally increase diameter growth rates of residual stems, and thus provide larger products over a specified period. However, the specific thinning levels and frequencies, as well as other silvicultural options selected, depend on management objectives.

Only a few insects are known to attack seeds and cones of shortleaf pine. Among these are the shortleaf pine cone borer (*Eucosma cocana* Kearfott) which occurs throughout shortleaf pine's range and the shortleaf pine cone beetle (*Conophthorus echinatae* Wood) occurring in Missouri (13).

Shortleaf pine seedlings are subject to damping off and root rot caused by several fungi, usually when soils have a pH above 6 and high water content. Foliage of shortleaf pine normally does not develop serious diseases, but several needle rusts are known to attack the species (14). Reproduction weevils, particularly pales (*Hylobius pales* (Herbst)) and pitch-eating (*Pachylobius picivorus* (Germar)) weevils, are the most serious insect pests of pine seedlings, reportedly killing 20 to 30 percent of seedlings planted in cut-over lands (8). Young shortleaf pines are also attacked by Nantucket pine tip moth (*Rhyacionia frustrana* (Comstock)). This insect has become a major pest in the eastern United States (1) and may have greater impacts than previously believed (8).

The southern pine beetle (*Dendroctonus frontalis* Zimmermann) is the most destructive insect pest of pine forests in 13 Southern and Southeastern States and parts of Central America and Mexico. When populations are epidemic, the beetles can kill healthy, vigorous trees. Outbreaks have upset management plans, reduced potential yields, and devastated many forest holdings. Where infestations are small and scattered, salvaging is impractical and less than half of total loss is recovered for use (31). The redheaded pine sawfly (*Neodiprion lecontei* (Fitch)) is the most destructive of the sawflies feeding on southern pines (8) and shortleaf is one of its preferred species (1). Other important insect pests include pine engraver beetles (*Ips* spp.), which are especially destruc-

[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.

tive during severe droughts, and the black turpentine beetle (*Dendroctonus terebrans* (Olivier)).

Shortleaf pine saplings and some older trees are moderately susceptible to attack by annosus root rot (*Heterobasidium annosum* (Fr.) Bref.), although losses have been only occasional. Littleleaf disease, associated with root destruction by *Phytophthora cinnamomi* Rands, is the most serious pathological threat to shortleaf pine, occurring on poorly drained soils from Virginia to Mississippi and south to the Gulf Coast (14). Red ring rot (*Phellinus pini* (Thore ex Fr.) A. Ames) may occur in older trees, but is rare in stands under 80 years old.

Shortleaf pine is generally fire resistant, although wildfires in young stands are very damaging, since they easily extend into the crowns. The crowns are usually killed, but shortleaf pine seedlings and small saplings can sprout from the base and form new stems (20). Larger trees may be killed by very hot fires, particularly if there is a large amount of fuel near the tree base. Fire-damaged trees are also more susceptible to attack by insects and diseases. After the trees grow to large sapling- or small pole-size, prescribed fire can be used to reduce both understory competition and wildfire hazards. Under proper conditions, fire can be used to improve wildlife habitat and is used extensively for site preparation for both natural and artificial regeneration.

Shortleaf pine is generally managed in even-aged stands, primarily because it is intolerant of shade. In the past, fire undoubtedly played an important role in establishing and maintaining the species. Both natural and artificial regeneration methods are used to establish even-aged stands. In recent years management has shifted from dependence on natural regeneration to planting and direct seeding. Artificial regeneration methods reduce the time required for establishment, provide better control of spacing, and allow establishment of genetically improved trees. Since fast-growing, better formed, pest-resistant strains of shortleaf pine are now generally available, artificial regeneration will likely predominate.

Even-aged stands of shortleaf pine are established artificially by planting or direct seeding. Both of these options require removal of all merchantable trees, control of competing vegetation, and, for direct seeding, removal of litter. The most common site preparation procedure following clearcutting is chopping or crushing of residual trees followed by a hot fire to control hardwoods, reduce ground cover, and expose mineral soil. Residual trees also may be sheared and burned or sheared and windrowed. The prepared sites are then machine- or hand-planted, or seeded.

Trees planted in cutover areas are susceptible to damage and loss by pales weevils. To avoid the problem, seedlings should be dipped in insecticide prior to planting, treated with insecticide at planting time or in late winter, or planting should be delayed 1 year. This delay, however, results in the loss of a year's growth and allows competing vegetation to develop 1 year ahead of regeneration.

Establishment of even-aged stands with natural regeneration may be accomplished by clearcutting strips or patches no greater than 200 feet (61 m) wide to allow seeding from nearby trees, felling the entire stand after seed fall or cone ripening, leaving seed trees, or shelterwood cutting (18). Of these natural regeneration methods, clearcutting of strips or patches is most compatible with the use of fire and heavy equipment to control competing hardwoods and prepare a suitable seedbed. A major disadvantage of depending on natural regeneration is the lack of adequate seed production every year, especially in the inland and westerly areas. Sufficient seeds must be available soon after site preparation or development of competing vegetation will necessitate retreatment of the area (18).

The second method, felling the entire stand in conjunction with cone and seed maturity, has been successful in some areas of the Southeast. Seedbed preparation is completed in advance of cutting, and seeds from the existing trees regenerate the area. One disadvantage of this method is that harvesting must be done after cone ripening and must be completed before seed germination in late winter or early spring. Seeds will be better distributed over the area if most are allowed to fall before harvesting. Regeneration can be obtained by cutting the trees between cone ripening and seed fall, since the cones usually remain in the slash instead of being removed during logging (18). A second major disadvantage is that the method can only be used when an adequate seed crop is present.

The seed-tree method involves leaving 10 to 16 of the best seed trees per acre (25 to 40/ha) to regenerate the area after harvesting. Where stands are dense, crown release of the seed trees about 3 years before the main harvest will improve seed production. Well-stocked stands should result in 1 to 3 years if seed fall is adequate. Mechanical site preparation can be used, but care must be taken to avoid damaging the seed trees, which could induce disease or insect attack. Prescribed burning can be done before or after the main stand is cut, but requires great care. Disturbance during logging may provide adequate seedbed preparation (40). Seed trees are also more vulnerable to loss or damage from lightning, wind, and insects than those in fully stocked stands. The loss may be substantial since these are high value trees and are the only source of natural regeneration.

The shelterwood system has been successful, particularly where summer rainfall usually is sufficient for good first-year survival and where half of the stand or approximately 50 to 60 square feet of basal area per acre (11.5 to 13.8 m^2/ha) remains. Prescribed burning is the most practical method of site preparation because the residual stand is too dense for easy operation of equipment. In many areas, litter decomposes rapidly, thus eliminating the need for burning. Chemical hardwood control, if needed, is usually easier to accomplish before the initial harvest, but may be done afterward.

Shortleaf pine can be managed in uneven-aged stands with the selection silvicultural system, an alternative that may be especially attractive to managers of small tracts (23, 36). The selection harvesting method utilizes natural regeneration and involves removal of trees singly or in small groups with the objective of achieving a balanced uneven-aged structure. This structure is determined by the selected basal area, diameter, and number of trees in each diameter class—all of which depend on the land manager's objectives, site quality, and other factors. Selection harvesting has been primarily used in understocked stands where cutting of trees and controlling hardwoods has created openings large enough for reproduction to become established (23). Usually, the primary product target is sawlogs, but smaller trees are removed to achieve the desired number of trees in each diameter class. The selection harvesting method could be used to grow smaller trees as a primary objective if enough trees (10 to 15/acre or 25 to 37/ha) of seed-bearing size are produced, although it would probably not be very efficient for simple fiber production. In general, the method is more difficult to use, requires more care, and may be economically less efficient than alternative methods.

Fire generally cannot be used with the selection harvesting method for seedbed preparation since seedlings in nearby openings would be killed. Openings may also be too small for efficient use of machines, therefore seedbed preparation is usually limited to disturbance during logging. Regeneration must be obtained promptly or expensive hand methods may be needed to maintain control of encroaching hardwoods.

Regeneration systems depending primarily on natural regeneration have several additional disadvantages. Loss of growth during the extended establishment time can be substantial, since seed crops may not occur for 3 to 4 years. Also, they are not amenable to establishment of genetically improved trees, and there may be problems with either too few or too many trees per unit area. Too few trees may require additional site preparation and artificial regeneration, while too many will likely require precommercial thinning.

Despite the shortcomings of natural regeneration systems, they can be used effectively and cheaply in some situations, and may be the best choice for small ownerships. Also, the greater expense and soil disturbance usually associated with artificial regeneration may not be justified on sensitive sites or those that have low productive potential.

The shortleaf pine and associated forest types are important for multiple-use considerations. During the early stages of stand development, regeneration areas provide forage for grazing and abundant food and shelter for a variety of wildlife species (12). Thinnings and prescribed burns increase the amount and palatability of wildlife food plants. Hardwood associates that occur as single trees, groups, or stringers add variety and quality to wildlife habitat. Size, shape, distribution, and timing of silvicultural treatments provide diversity to meet the habitat requirements of many wildlife species. Some shortleaf pine trees are managed in over-mature stands to provide special habitat requirements for endangered species, such as the red-cockaded woodpecker (27).

Shortleaf pine has been widely planted for erosion control, although it does not produce as much litter as its common associate, loblolly pine (35). The species does provide excellent watershed protection, as evidenced by the high quality of water flowing from shortleaf pine forests. Shortleaf pine stands with their diversity of associated species are esthetically pleasing to forest visitors and recreationists.

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Slash Pine

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Slash pine (*Pinus elliottii* Engelm.) occupies about 12.3 million acres (5.0 million ha) of commercial forest land in the southern United States.[1] Included in this total are natural and planted stands in which yellow pines make up at least one-half of the stocking, and slash pine is the predominant pine.

Slash pine occurs naturally within 150 miles (240 km) of the Atlantic and Gulf Coasts from Berkeley County, South Carolina, to Tangipahoa Parish, Louisiana, and throughout most of Florida (40). It is represented by two varieties: from central Florida northward by the common variety, typical slash pine (*P. elliottii* Engelm. var. *elliottii*), and in southern Florida by the South Florida strain (*P. elliottii* var. *densa* Little and Dorman) (41).

The commercial range of slash pine in the United States has been extended by planting to the Upper Coastal Plain of North Carolina, north central Georgia, central Alabama, northern Mississippi, western Louisiana, and eastern Texas.

Virgin stands of slash pine were largely confined to ponds or pond margins and to narrow strips along creeks, bays, and other minor drainages where ample soil moisture or standing water protected the young trees from wild fires, and to hummocks in the Everglades that provided sufficient elevation above the water level for pines to grow. With clearcutting of the virgin forests and protection from wildfire, slash pine spread naturally to better drained sites formerly occupied by longleaf pine (*P. palustris* Mill.). Extensive planting of the species has further extended the slash pine type so that it now occurs on a broad array of sites from poorly drained flat areas to droughty sandhills. Elevation ranges from sea level to a few hundred feet and topography from level to hilly.

Most of the soils supporting plantations or natural stands of slash pine are Alfisols, Entisols, Spodosols, or Ultisols. Frequently occurring suborders include Aqualfs, Udalfs, Aquents, Psamments, Aquods, Aquults, and Udults. Moisture regimes in these soils range from excessively wet to very dry.

Although slash pine adapts to a wide variety of soil conditions, it grows best on deep, well-aerated soils that supply ample quantities of moisture during the growing season. Generally, growth and site index increase with depth to a restrictive soil layer or seasonally high water table if these features occur within 20 to 30 inches (51 to 76 cm) of the soil surface. Where depth to a restrictive layer exceeds about 30 inches (76 cm), site index declines with increasing depth to a reliable source of moisture, such as a stable water table or a soil horizon with a large moisture storage capacity. Soil properties useful in estimating site index of slash pine include depth to grey mottles, depth to a spodic horizon, depth to the least permeable layer or to a fine-textured horizon, thickness of the A1 horizon, and texture of the least permeable or finest textured horizon (2, 14, 29, 39, 45, 52).

Slash pine growth on many sites is improved by application of phosphorus or nitrogen and phosphorous fertilizer (23, 34, 50). Additions of other nutrients are not normally required for satisfactory growth.

The climate within the natural range of slash pine varies from tropical in the Florida Keys to transitional between temperate and subtropical in the North (55). Summers are long, warm, and humid; winters are relatively mild. Mean January temperatures decrease northward from about 70° F (21.1° C) in south Florida to about 50° F (10.0° C) in Georgia and South Carolina. Mean July temperatures are less affected by latitude and average about 80° to 82° F (26.7° to 27.8° C) throughout the range. Length of the frost-free season ranges from 365 days in south Florida to 240 days in the North. Average annual precipitation varies from 44 inches (1120 mm) in portions of Georgia and South Carolina to 64 inches (1630 mm) or more in Louisiana, Mississippi, and southern Florida. Peak periods of precipitation in the northern portion of the range occur in late winter (February through March) and mid-summer (July through August). In the South, most of the rainfall occurs in mid-summer, and winter droughts are rather common. Stands found along coastal areas throughout the species' range are vulnerable to damage from hurricanes. The frequency of these storms is greater at the southern tip of Florida and along the Gulf Coast from Tampa westward than in other localities. Plantations in the extreme northern portions of the commercial range are subject to damage from ice storms.

Slash pine is a major component of four cover types recognized by the Society of American Foresters (20): Longleaf–Slash Pine (type 83), Slash Pine (type 84), Slash Pine–Hardwood (type 85), and South Florida Slash Pine (type 111). Associated tree species in these types vary with the site moisture regime. On well-drained upland soils they include longleaf, loblolly (*P. taeda* L.), and sand pines (*P. clausa* (Chapm. ex Engelm.) Vasey ex Sarg.); post (*Quercus stellata* Wangenh.), blackjack (*Q. marilandica* Muenchh.), southern red (*Q. falcata* Michx.), sand live (*Q. virginiana* var. *geminata* (Small) Sarg.), myrtle (*Q. myrtifolia* Willd.), bluejack (*Q. incana* Bartr.), and turkey (*Q. laevis* Walt.) oaks; hickories (*Carya* spp.); flowering dogwood (*Cornus florida* L.); yaupon (*Ilex vomitoria* Ait.); persimmon (*Diospyros virginiana* L.); and hawthorn (*Crataegus* spp.). Common associates on wetter sites are red maple (*Acer rubrum* L.), sweetgum (*Liquidambar styraciflua* L.), blackgum (*Nyssa sylvatica* Marsh.), swamp tupelo (*Nyssa sylvatica* var. *biflora* (Walt.) Sarg.), sweetbay (*Magnolia virginiana* L.), loblollybay (*Gordonia lasianthus* (L.) Ellis), southern redcedar (*Juniperus silicicola* (Small) Bailey), Atlantic white-cedar (*Chamaecyparis thyoides* (L.) B.S.P.), Carolina ash (*Fraxinus caroliniana* Mill.), American elm (*Ulmus americana* L.), cabbage palmetto (*Sabal palmetto* (Walt.) Lodd. ex J. A. and J. H. Schult.), pond pine (*Pinus serotina Michx.), pondcypress (Taxodium distichum* var. *nutans* (Ait.) Sweet), and water

[1] Unpublished data on file at U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station, Asheville, N.C. 1981.

(*Quercus nigra* L.), laurel (*Q. laurifolia* Michx.), and live (*Q. virginiana* Mill.) oaks. Baldcypress (*Taxodium distichum* (L.) Rich. var. *distichum*), pondcypress, blackgum, and water tupelo (*Nyssa aquatica* L.) also occur as associates on sites that are flooded periodically.

Slash pine is not a climax species. Without man's intervention and with the absence of fire or any other catastrophic event, natural succession will proceed to a mixed hardwood forest (47, 51).

Slash pine reproduces naturally from seed throughout its native range (16, 24), as well as in western Louisiana where it is an introduced species (43). It is reproduced artificially both by direct seeding and by planting. Vegetative propogation by grafting, air layering, and rooting of cuttings is used in seed orchards (19).

Slash pine is a relatively good seed producer and yields some seeds almost every year (59). Typical slash pine produces good crops about every 3 years; the South Florida variety will produce good seed crops every 1 to 5 years (33). Trees reach seed-bearing age in 7 or 8 years, but do not reach their full reproductive potential until much later. Yields greater than 200 cones per tree are not unusual for large, full-crowned trees in good seed years (58). Cone production may be more than doubled by stem injury, fertilization applied before flower bud initiation, or crown release after heavy thinning (30, 54).

Cones ripen in September and shed most of their seeds in October (16, 24). More than 90 percent of the seeds fall within 150 feet (45.7 m) of their source, but some may be carried by wind as far as 250 feet (76.2 m).

Seed viability is usually good, and germination may be rapid if soil moisture is adequate. Ordinarily, however, germination occurs over an extended period from November to April (16, 24). In years of heavy seedfall, many thousands of seedlings per acre may become established.

Seed germination and seedling survival may be increased several fold by burning or by any type of scarification that exposes mineral soil prior to seedfall (46, 48). Such treatments are recommended in direct seeding of slash pine (18). They may be necessary for natural regeneration only if a poor seed crop is anticipated (35) or the vegetative cover is very dense (36). Heavy understories of saw-palmetto (*Serenoa repens* (Bartr.) Small), gallberry (*Ilex glabra* (L.) A. Gray), or hardwoods should be controlled prior to regeneration by any method. Poorly drained sites where seeds or seedlings will be submerged for more than 1 or 2 weeks (18) need to be drained or have elevated seedbeds prepared for successful stand establishment.

Unprotected seeds are eaten by birds and small mammals and by a variety of insects. When direct seeding, repellent coatings are required to protect seeds from these predators (18). Insects, rabbits, and other animals also clip young seedlings, especially during late winter and early spring when other green vegetation is scarce.

Slash pine is considered intermediate in tolerance to shade by some authors (16, 24, 32, 36) and intolerant by others (35). It will reproduce naturally in small openings and will invade poorly stocked longleaf pine stands. But competition from overstory and understory vegetation reduces growth and causes much mortality.

The two varieties of slash pine differ in their patterns of growth. Typical slash pine makes excellent early height growth, whereas South Florida slash pine has a grasslike, almost stemless stage, that lasts from 2 to 6 years (41). Moreover, South Florida slash pine lacks the straight axis or leader characteristic of the typical variety and often develops forked boles with large branches and an open, spreading, irregularly shaped crown. In varietal trials at three locations in southern Florida, typical slash pine averaged 3 to 6 feet (0.9 to 1.8 m) taller at 10 years than South Florida slash pine (37).

Information is largely lacking on growth and development of South Florida slash pine under good forest management. The remainder of this section, therefore, applies primarily to typical slash pine, unless stated otherwise.

Slash pine is slow to express dominance in dense, even-aged stands. As a consequence, height growth is slower in very dense stands than in moderately or lightly stocked stands (7, 31).

Young stands respond promptly to thinning or release. Older stands whose height growth rate has declined and those in poor growing condition may respond slowly or occasionally fail to respond at all (4, 16, 24, 35). For these reasons, precommercial thinning before stand age 5 is recommended if densities exceed 2,000 trees per acre (4940 trees/ha), especially if the objective of management is the production of sawtimber, veneer logs, or naval stores (32, 35). Residual densities should be about 500 to 700 trees per acre (1235 to 1730 trees/ha). When sawtimber is to be produced and high initial density is not a problem, or if a precommercial thinning has been made, commercial thinnings will maintain good stand vigor, promote diameter growth, shorten the time required for individual trees to reach sawtimber-size, and concentrate volume on trees to be carried to rotation age. These thinnings should be initiated as early as economically feasible, at least by age 20. Commercial thinnings will increase diameter growth of residual trees. They will not increase total yields of stands managed for pulpwood on a 20- to 25-year rotation or those managed for sawlogs if the rotation is long enough for a majority of trees to reach sawtimber-size and competition for growing space has not caused excessive mortality (8, 13).

Rotation lengths vary according to product objective. The optimum pulpwood rotation may be about 25 years, as this age is intermediate among those at which mean annual cubic volume growth culminates. In unthinned plantations, this age increases to 30 from 23 years as density increases and site index declines (6). Site and stocking level also affect diameter growth and the age at which trees reach sawtimber-size. Available information (8, 22, 31, 42) suggests that on good sites, stands averaging 16 inches (41 cm) diameter at breast height (d.b.h.) can be grown in 45 to 55 years if initial dense stocking is adjusted before age 5 to about 500 to 700 trees per acre (1235 to 1730 trees/ha) and if commercial thinnings at about 5-year intervals reduce residual basal areas below 85 square feet per acre (19.5 m^2/ha).

Plantations and natural stands have similar rates of growth on sites of a given quality if they are comparable in genetic makeup, are maintained at comparable densities, and are given the same level of management (35).

Except as previously noted, product yields increase with density, age, and site index. Estimates of yields at 30 years for unthinned plantations on average sites where the site index is 60 feet (18.3 m), base age 25, range from 2,717 to 3,325 cubic feet per acre (190.2 to 232.8 m^3/ha) with 300 surviving stems per acre (740/ha) and from 3,291 to 4,097 cubic feet per acre (230.4 to 286.8 m^3/ha) with 500 survivors per acre (1235/ha) (9, 12, 15, 17). For managed natural stands on similar sites where the site index is 80 feet (24.4 m), base age 50, Bennett (5) estimated standing volumes at 50 years to range from 1,959 cubic feet per acre (137.1 m^3/ha) with a basal area stocking of 50 square feet per acre (11.5 m^2/ha) to 5,246 cubic feet per acre (367.2 m^3/ha) with a stocking of 150 square feet per acre (34.4 m^2/ha). Cubic volumes were computed using all trees 4.6 inches (12 cm) d.b.h. and larger to a 4.0 inch (10 cm) top outside bark.

Corresponding sawlog volumes were 6,253 and 11,682 board feet (fbm) (International ¼-inch Rule) (1,251 and 2,336 cubic feet)[2] per acre or 87.5 and 163.5 m^3/ha for trees 9.6 inches (24.4 cm) d.b.h. to an 8.0 inch (20.3 cm) top.

Numerous insects and diseases attack slash pine during its life cycle (1, 57). Only those that seriously affect establishment and management of plantations and natural stands will be discussed here.

Reproduction weevils, the pales weevil (*Hylobius pales* (Herbst)) and the pitch-eating weevil (*Pachylobius picivorus* (Germar)) are attracted by the odor of pine resin to recently logged areas where they lay their eggs in lateral roots of fresh pine stumps. Both the egg-laying adults and the emerging brood feed on the tender bark of seedlings. This damage can be avoided by delaying planting of cutover areas for at least 9 months or by treating seedlings with a suitable insecticide. Texas leafcutting ants (*Atta texana* (Buckley)) are serious pests of young seedlings on well-drained sites in western Louisiana and eastern Texas. The ants may completely defoliate and debark the stems of newly established pines during winter when other green plants are scarce. Control of the pest is by fumigation of the nest area.

Older stands are subject to attack by engraver beetles (*Ips* spp.), the black turpentine beetle (*Dendroctonus terebrans* (Olivier)) and the southern pine beetle (*D. frontalis* Zimmermann). Outbreaks of these insects are usually associated with wildfire, lightning strikes, and logging operations. The best protection against attack is to maintain vigorous, healthy stands through good forest management. Control is mainly by salvage and rapid removal of infested trees before new adults emerge from brood trees.

Fusiform rust (*Cronartium quercuum* (Berk.) Miy. ex Shirai f. sp. *fusiforme* Burds. & Snow) is the most serious disease of slash pine. Aside from planting rust-resistant families in high rust-hazard areas, there is no practical method of controlling the disease. Its impact on existing stands can be lessened by sanitation cuts to salvage high-risk trees if sufficient healthy stems remain after such operations to give an acceptable yield at rotation age (3).

Other important diseases of slash pine forests are annosus root rot (*Heterobasidium annosum* (Fr.) Bref.) and pitch canker (*Fusarium moniliforme* Sheld. emend. Snyd. and Hans. var. *subglutinans* Wollenw. and Reink.). Annosus root rot most frequently causes serious damage in thinned stands on sites having deep, well-drained sandy or loessial soils that lack an argillic horizon within 10 to 12 inches (25 to 30 cm) of the surface. On such sites it may be prudent to grow trees to rotation without thinning or to thin only during warm months when the disease is unable to compete with other wood-rotting fungi that destroy the stump. Prescribed burning before and after thinning may reduce severity of the disease. High-value stands can be protected by treating the freshly cut stumps (and other exposed wood) with borax. Harvesting of infected trees is about the only practical defense against pitch canker.

Fire is both an agent of destruction and a valuable tool in the management of slash pine. Young trees are quite susceptible to injury by fire until they are 10 to 15 feet (3.1 to 4.6 m) tall and have bark thick enough to insulate the cambium from lethal temperatures (27, 44). Even mature stands may be damaged by head fires in areas with large fuel accumulations (53). The principal uses of fire in slash pine management are for site preparation, hazard reduction, and control of understory vegetation. Fire also improves forage production for livestock and habitat for wildlife (32).

Slash pine may be regenerated naturally in uneven-aged stands by the group-selection method and in even-aged stands by either the seed-tree or shelterwood system. Regeneration can also be achieved in even-aged stands by clearcutting with seed- or seedlings-in-place (32, 35, 36). Because the species is intolerant, or nearly so, even-aged systems are preferred. Another reason for favoring even-aged systems is that they permit the use of prescribed fire to control stand composition and understory development.

Both the seed-tree and shelterwood systems entail removal of the overstory in two stages. They differ from each other only in the number of trees retained to regenerate the area, 6 to 10 trees per acre (15 to 25 trees/ha) in the seed-tree method and 25 to 40 trees per acre (60 to 100 trees/ha) in the shelterwood method. These trees should be full-crowned, disease-free dominants that are proven cone producers. They should be well spaced over the area to insure adequate seed dispersal.

Areas being regenerated by these methods should be prescribe burned prior to the harvest cut to control understory vegetation and prepare the seedbed. This burn should be made no earlier than the winter immediately preceding dispersal of a seed crop adequate to restock the area. Mechanical site preparation may be substituted for prescribed burning to ready the site for natural regeneration. But care must be taken to avoid injury to roots of the seed trees. Mechanical injury to roots renders the trees susceptible to attack by insects and disease organisms. Seedbeds deteriorate rapidly and must be refreshed if an adequate stand of seedlings is not established within about 2 years. The seed or shelterwood trees should be retained for 1 year after an adequate seed crop as insurance against drought losses during the critical first summer following germination. They should be harvested as soon thereafter as practical, certainly within 3 to 5 years, to insure vigorous growth of the new crop and to minimize logging damage to seedlings (21).

Occasionally an adequate stand of natural regeneration becomes established under lightly stocked mature stands where there has been no preparatory cut. Under these conditions the overstory should be harvested immediately to promote growth of the seedling stand. A variation of this clearcutting with seedling-in-place system is clearcutting with seed-in-place. In this method, the overstory is harvested during or immediately after seed dispersal. The system is less reliable than other even-aged systems, because the seed source is removed before the new stand is established. Widespread success in direct seeding of slash pine suggests that this disadvantage may not be serious if the seed crop exceeds approximately 5 pounds per acre (5.6 kg/ha) (18). Another disadvantage of this system is that seed crops must be estimated from flower or conelet counts unless the site preparation burn is made in late summer, after cones are fully grown.

Successful use of the group-selection method of uneven-aged management requires the harvesting of groups of mature trees to create openings about 1 acre (0.4 ha) in size. Larger openings are impractical because the seeds are not dispersed over large distances. Smaller openings are undesirable because the surrounding overstory trees retard seedling growth. Area-wide stand management treatments, such as prescribed burning, are not practical with uneven-aged management.

The preferred method of regenerating slash pine among large forest landowners is clearcutting followed by chemical or mechanical site preparation, then direct seeding or planting of nursery or container-grown stock. In 1981, plantations

[2] 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.

comprised 56 percent of the acreage in slash pine forest types in North Carolina, South Carolina, Georgia, and Florida.[1] The proportion of slash pine acreage established by artificial methods is probably higher in the Gulf region than in the Southeast because of widespread planting of the species north and west of its natural range. With increasing availability of genetically superior stock, planting should continue to be the preferred method of regeneration of slash pine.

Slash pine forests provide forage for domestic livestock, especially cattle, and food and cover for a variety of wildlife (10, 25, 38, 49). White-tailed deer is the major big-game species. Small-game species include bobwhite quail, mourning dove, eastern wild turkey, squirrels, and rabbits. Nongame animals include many species of songbirds, water birds, small mammals, amphibians, and reptiles. Competition between livestock and deer for food seldom occurs unless overstocking of cattle causes severe overgrazing, depleting the browse available for deer (56).

Herbage production may exceed 2,000 pounds per acre (2240 kg/ha) in sparse stands and newly established plantations. Production declines markedly as young stands close and may be no more than about 500 pounds per acre (560 kg/ha) by the time stands are large enough for a commercial thinning. If thinned and burned regularly, mature stands should produce about half as much forage as open, cutover range (26).

Slash pine 9 inches (23 cm) d.b.h. and larger may be worked for gum naval stores (11, 28). Yields average about 1 pound of gum per inch (179 g/cm) of face width per year. The most common practice is to work a tree for 4 years (2 years on each of 2 faces) immediately preceding the harvest cut. Since face widths are made equal to tree d.b.h., a full-crowned 9-inch (23 cm) tree should yield 36 pounds (16.3 kg) of gum and a 14-inch (36 cm) tree 56 pounds (25.4 kg) during the 4 years.

Slash pine may be planted to stabilize soil on eroding slopes and strip mine spoil banks.

Slash pine types provide habitat for several threatened and endangered species listed in the Endangered Species Act of 1973 (Public Law 93-205), as amended. The red-cockaded woodpecker forages extensively in slash pine forests and will use mature, living slash pines for nesting cavities. The bald eagle often uses large, dominant slash pines for nest trees, especially in Florida. The Florida panther ranges over extensive areas that include slash pine flatwoods. The eastern indigo snake uses a variety of habitats, including flatwoods of Florida, southern Gerorgia, and Alabama. The red hills salamander, the pine barrens treefrog, and the Mississippi sandhill crane are found within the natural range of slash pine, and are susceptible to habitat loss in areas converted to slash pine. Endangered plants within the natural range of slash pine include: Chapman rhododendron (*Rhododendron chapmanii* Gray), hairy rattleweed (*Baptisia arachnifera* Duncan), Harpers beauty (*Harperocallis flava* S. McDaniel), persistent trillium (*Trillium persistens* Duncan), and green pitcherplant (*Sarracenia oreophila* (Kearn.) Wherry).

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Virginia Pine

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Virginia pine (*Pinus virginiana* Mill.) is widely distributed in the northern Piedmont and the foothills and lower elevations of the Appalachian and Allegheny Mountains. It is also found on the western edge of the Coastal Plain in New Jersey and New York. The range extends from Pennsylvania southward through the Middle Atlantic States including Maryland, Delaware, Virginia, West Virginia, the Carolinas, Georgia, and westward to northern Alabama, eastern Tennessee, Kentucky, and Ohio.

In the Piedmont of the Carolinas and Virginia, Virginia pine is a pioneer species that rapidly invades abandoned agricultural lands or other disturbed sites. The Piedmont soils are predominantly clays with local variation in sand or loam content. In the Virginia and Maryland Coastal Plain, Virginia pine grows in pure or mixed stands on sandy loam soils. Up to 3,000 feet (915 m) on the low ridges of the Appalachian and Allegheny Mountains, Virginia pine successfully competes on abandoned fields and on dry ridges with a southern or western exposure. The upland and ridge sites are typically shallow soils derived from shales or sandstone and characteristically have low fertility and little organic matter (4).

Virginia pine is a very hardy species and tolerates weather extremes from $-10°$ to $100°$ F ($-23.3°$ to $37.7°$ C). Average summer temperatures are from 70° to 75° F (21.1° to 23.8° C) and winter temperatures are from 25° to 40° F ($-3.9°$ to 4.4° C). The growing season changes drastically from 225 days on the southern and eastern extent of the range to 160 days in the more mountainous northern and western portion. Average annual precipitation throughout the range is 35 to 55 inches (890 to 1395 mm) and is well distributed throughout the year. Seasonal droughts may occur throughout the range and are more severe on the shallow and rocky soils (10).

Virginia pine, classified as forest cover type 79 by the Society of American Foresters (4), is frequently associated with other conifers including shortleaf (*Pinus echinata* Mill.), Table Mountain (*P. pungens* Lamb.), pitch (*P. rigida* Mill.), and loblolly (*P. taeda* L.) pine, and eastern redcedar (*Juniperus virginiana* L.); it is also found with white pine (*Pinus strobus* L.) and eastern hemlock (*Tsuga canadensis* (L.) Carr.). Commonly associated hardwoods include many oak species—post oak (*Quercus stellata* Wangenh.), black oak (*Q. velutina* Lam.), northern red oak (*Q. rubra* L.), scarlet oak (*Q. coccinea* Muenchh.), chestnut oak (*Q. falcata* Michx.), and blackjack oak (*Q. marilandica* Muenchh.). Other hardwood associates are red maple (*Acer rubrum* L.), hickories (*Carya* spp.), blackgum (*Nyssa sylvatica* Marsh.), sweetgum (*Liquidambar styraciflua* L.), yellow-poplar (*Liriodendron tulipifera* L.), dogwood (*Cornus florida* L.), and sourwood (*Oxydendrum arboreum* (L.) DC).

Virginia pine is a precocious and prolific seed producer. Flower and seed production may begin as early as 3 to 4 years and continue until crown closure. Even dense even-aged stands normally produce some seed, but abundant production may be delayed until after dominance is expressed or mortality opens the stand to sunlight. Large dominant or open-grown trees are capable of producing over a thousand cones per year. Virginia pine produces some cones every year and does not appear to have a well-defined cycle of seed-producing years (7). Typically, there are good to excellent years between moderate to poor years. Annual seed crops of 48,000 to 996,000 seeds per acre (118 600 to 2 461 200/ha) have been observed in Maryland (6). Each cone has a seed capacity of approximately 90 seeds but this is normally reduced to about 35 to 45 due to losses from insects and other causes. Cones of Virginia pine normally are not serotinous but some trees will have cones that do not open readily. Normal seed dispersal begins in early November and continues through February or March; however, most of the seed is dispersed by the end of December. Germination occurs in late spring and seedling establishment is greatly enhanced by exposure of mineral soil.

Virginia pine is shade intolerant (11). The species will germinate and persist from 1 to 2 years under shaded conditions but continued shading will result in seedling mortality. Intolerance to shade and susceptibility to wind, ice, and snow damage are the most important silvical characteristics to bear in mind when choosing a management regime and reproduction method.

Timber production of Virginia pine is greatest on high-quality sites with full stocking (1, 8, 9). Yields at site index of 70 feet (21.3 m) for 30- to 40-year-old natural stands are from 3,200 to 4,360 cubic feet per acre (224.0 to 305.2 m^3/ha) and annual growth is approximately 90 cubic feet per acre (6.3 m^3/ha) per year (9). The regeneration ability of the species may result in overstocking and young stands of 40,000 (9) and even up to 100,000 seedlings (3) per acre (98 840 to 247 100/ha) have been observed. These overly dense stands may produce a relatively high total cubic-foot growth but merchantibility may be reduced because the average diameter is very small.

Virginia pine is not long lived. Suggested rotations are 30 to 40 years for pulpwood and 40 to 50 years for sawtimber. The mean annual growth increment culminates at about age 35 and is much reduced after 40 to 50 years when mortality begins to open the stand. By age 70, the stand may begin to deteriorate and the understory hardwoods to assert dominance.

Virginia pine is a rather hardy species with relatively few major pests. Cones and seeds are damaged by insects including *Dioryctria* spp., leaffooted pine seed bug *Leptoglossus* corculus (Say), shieldbacked pine seed bug *Tetyra bipunctata* (Herrich-Schaffer), *Laspeyresia* spp., and *Eucosma* spp. Insect pests during seedling growth and establishment include the pales weevil (*Hylobius pales* (Herbst)), pine webworm (*Tetralopha robustella* Zeller), and Nantucket pine tip moth (*Rhyacionia frustrana* (Comstock)). Although these insects are prevalent in young stands, the damage rarely results in economic losses. Virginia pine is a host for the eastern gall rust (*Cronartium quercuum* (Berk.) Miy. ex Shirai f. sp. *fusiforme* Burds. & Snow), which causes some mortality from stem cankers but heavy losses are not common.

The most serious insect problem, especially of intermediate-size trees, is the bark beetle, including the southern pine beetle (*Dendroctonus frontalis* Zimmermann) and engraver beetle (*Ips* spp.). These insects can cause severe losses and epidemic years result in mortality of a large number of trees. Other stress factors, such as drought, poor site, and overly dense stands, contribute to bark beetle attacks. Another important insect pest is the Virginia pine sawfly (*Neodiprion pratti pratti* (Dyar)). Pitch canker (*Fusarium moniliforme* Sheld. emend. Snyd. & Hans. var. *subglutinans* Wollen. & Reink.) and annosus root rot (*Heterobasidium annosum* (fr.) Bref.) are diseases that may attack Virginia pine stands of intermediate-size trees. As the stand reaches maturity, the red heart fungus (*Phellinus pini* (Thore ex Fr.) A. Ames) becomes a major disease and can cause serious wood volume loss.

Because of its silvical characteristics, Virginia pine should be grown in even-aged stands (11). Also, Virginia pine has thin bark and is easily damaged or killed by fire (3, 5, 9); therefore, fire normally cannot be used for seedbed preparation or hardwood control, except at the harvest cut under even-aged management.

For regenerating Virginia pine stands, clearcutting is best adapted to this species' silvical characteristics. Clearcutting allows full sunlight to reach the new trees, produces a stand of the same age and height that protects the trees from windthrow, and allows the use of fire in site preparation. The clearcut area can be planted, seeded, or reproduced by natural regeneration.

Like the seedlings of other southern pines, Virginia pine seedlings must be properly handled and planted and all necessary hardwood control completed (7). Direct seeding may also be used (12). For natural regeneration, Virginia pine's prolific seed crop is usually more than adequate and site preparation and hardwood control will increase regeneration success.

Clearcutting in strips or patches also can be used to regenerate Virginia pine. (Patch cutting can also be classified as group selection under uneven-aged management if the patches are small and cut out of the stand over a period of many years. Unless these conditions are met, this cutting method is considered even-aged management.)

In strip cutting, the stand is cut in 100- to 400-foot (30.5 to 121.9 m) wide strips. Slash on these cut areas can be burned and hardwood control measures applied. Seedbed preparation using logging equipment or fire is applied to the harvested strips. Seed is supplied by trees in the adjacent uncut strips. After 3 to 10 years the uncut areas are harvested. Regeneration of the uncut strips is more difficult. A light fire can be used to prepare a seedbed in the uncut strip but damage to residual trees may negate the benefit of the fire if mortality results (13).

Thinning uncut stands would stimulate production of seeds and establishment of advanced regeneration but risks of windthrow and ice damage would be increased. Perhaps the best procedure for regeneration of the uncut areas is to time the harvest cut in the fall or winter following a relatively good seed crop of the residual stand. Seed shed before harvest or from cones on logging slash provide seed for regeneration. Logging equipment provides some seedbed scarification and exposure of mineral soil to seed in the surface duff. Hardwood control in the uncut strips may be difficult, however, and requires weeding to reduce hardwood competition. Planting or direct seeding could also be used to ensure regeneration of the residual strips or patches.

Shelterwood or seed-tree cuts are generally not recommended for regenerating Virginia pine. The major reason is the susceptibility of Virginia pine to ice or windthrow when released after having been grown under relatively dense stocking levels.

Single-tree selection is not recommended for Virginia pine. As the species is shade intolerant, pure pine regeneration in small openings would not be expected but instead a single-tree cutting would undoubtedly favor hardwood invasion and gradual reduction of the pine-growing stock.

Group selection in the classical sense is also not recommended because the even-age structure of the stand would deteriorate into a gradual transition to hardwood species. Site and seedbed preparation, hardwood control, and thinning would also be difficult to manage.

Hardwood encroachment is a serious problem in the regeneration of Virginia pine. Virginia pine, as a pioneer species, achieves its best growth and development in old abandoned fields. The exposed mineral soil is an ideal seedbed and the competition from native grasses does not seriously restrict establishment. Initial stocking is frequently 1,000 to 3,000 stems per acre (2415 to 7415/ha) at age 3 with gradual reduction to 500 to 400 stems per acre (1235 to 990/ha) at age 40 to 50. Following establishment of Virginia pine on an old-field site, invasion of hardwood species begins as the litter depth increases. These associated hardwood species are relatively tolerant and, although they grow slowly as understory species, they respond to any openings in forest canopy. It is therefore important to exert hardwood control at the time of harvesting. If first-cycle Virginia pine stands are harvested without hardwood control, the second-rotation stand will be mixed pine-hardwood and further cutting of the pine will result in an almost pure hardwood stand.

Regeneration of ridge-top stands or stands that are growing on droughty, poor sites may not have serious problems with hardwood competition. These sites can be maintained by cutting all large hardwoods at the time of the harvest cut and allowing Virginia pine seedlings to compete with smaller hardwood sprouts and seedlings. On the very poorest sites, such as the shale barrens or rocky outcrops, Virginia pine may be one of the few tree species that survives the harsh environment. On these sites, Virginia pine serves primarily to protect the soil, and growth is so poor that the stands are rarely or never harvested.

Land use patterns throughout most of the Virginia pine range have recently changed so that agricultural land is rarely abandoned and allowed to revert to forest growth, and will probably remain for an extended period in crop or pasture production. In the Virginia Piedmont, Virginia pine growth normally exceeds that of shortleaf pine when the two species are found in mixed natural stands. On the poorer sites and more mountainous areas, Virginia pine remains the best suited species. Careful management, hardwood control, and regeneration strategy will be required to continue production from Virginia pine as a source of forest and related products.

Vigorous establishment of Virginia pine has severe limitations on future stand development. Even-age stands of several thousand trees per acre do not express dominance as clearly as other species and the major crop trees may appear as codominants at age 20 to 30 years. Thinning can be used to regulate stand density and to increase the average diameter of the stand (2). If thinning is done in Virginia pine stands, it is recommended that it be completed before age 12 to 15 years. This may be a precommercial thinning. Later thinnings apparently do not result in substantial growth increments on the residual trees. Thus, growth is primarily a function of basal area stocking and site index. On the better sites, relatively high basal areas up to 180 square feet per acre (41.3 m^2/ha) have been observed. Thinning these stands reduces the growing stock and net reductions in total volume can be expected. Residual trees do show a diameter response but total volume will not equal the unthinned stand (1, 9). Unless excessive stems per acre are present, no thinning is recommended for Virginia pine stands that are grown on a 40- to 50-year rotation for small sawlogs and pulpwood on the better Piedmont sites.

Similarly, improvement cuts after stands reach 30 to 40 years would be unlikely to show an economic gain. Stand appearance would be improved by partial cutting but the disadvantages of increased hardwood encroachment and susceptibility to damage by ice or windthrow probably more than offset any economic return. Sanitation cuts could include removal of trees damaged from bark beetles, ice, etc., but again, most forest managers would normally recommend clearcutting the stand if the damage was severe and otherwise avoid partial cuts before harvesting fully stocked stands.

Virginia pine stands provide food, cover, and protection for native wildlife species during periods of stand establishment, development, and maturity. During regeneration when stands are clearcut, the full sunlight required for pine establishment and development is very beneficial to small game species such as quail, rabbits, and numerous nongame birds and mammals. As the tree crown closes, light is reduced on the forest floor and food and ground cover species are crowded out. Even so, the dense stands of Virginia pine provide winter cover and protection for wildlife species such as deer. When understory plants such as honeysuckle (*Lonicera* spp.) are also present, deer frequently use Virginia pine stands during winter months. As stands mature, mortality may expose the forest floor once again and the Virginia pine gradually reverts to an oak-hickory forest. The mixed pine-hardwood forest is a favorable environment for numerous wildlife species.

The characteristic limby, dense growth of Virginia pine does not produce visually appealing parklike stands or much depth of vision. However, its bushy open-grown quality makes it esthetically desirable for some plantings, especially where early screening is desired.

Virginia pine is perhaps the best Christmas tree species to grow in the warmer areas of the South. Proper Christmas tree plantation management, including shearing, produces a desirable tree in 4 to 6 years. This use is increasing rapidly.

The aggressive pioneer characteristics of the species provide considerable protection to barren or exposed sites. The species is also frequently selected to reclaim mining areas, spoil banks, borrow pits, or other severely disturbed sites. Establishment of Virginia pine on these areas reduces erosion and further deterioration of the site.

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Sand Pine

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Sand pine (*Pinus clausa* (Chapm. ex Engelm.) Vasey ex Sarg.) is native to the droughty, acid, infertile, marine deposited sandhills of Florida and Baldwin County, Alabama. The largest concentration of the Ocala variety (*Pinus clausa* var. *clausa* D. B. Ward) is in the center of Florida on an area of rolling sandhills known as the Central Highlands. The Choctawhatchee variety (*P. clausa* var. *immuginata* D. B. Ward) is found along the Gulf Coast of northwest Florida from the Apalachicola River westward into Alabama (15). Both of these areas have similar climates with hot, humid summers, somewhat dry winters, and a long growing season of 269 to 312 days. Precipitation is abundant, 53 to 60 inches per year (1345 to 1525 mm), and fairly well distributed; however, because of the low moisture-holding capacity of the soils, drought conditions can exist within 2 weeks of a heavy rainfall. Surface temperatures of exposed soils may reach 140° F (60° C) on summer days (6).

Sand pine is the dominant species of the Society of American Foresters forest cover type 69 (9) on approximately 3 million acres in Florida and shows promise for converting much of the 8 million acres of scrub–hardwood dominated sandhill land to pine in the Southeastern States. It occurs as a minor component of type 70, Longleaf Pine, type 71, Longleaf Pine–Scrub Oak, and type 84, Slash Pine. The understory in Ocala stands is primarily evergreen shrubs 6 to 10 feet (1.83 to 3.05 m) tall with very little herbaceous ground cover (13). Typical understory species are sand live oak (*Quercus virginiana* var. *geminata* (Small) Sarg.), myrtle oak (*Q. myrtifolia* Willd.), Chapman oak (*Q. chapmanii* Sarg.), and palmetto (*Sabal* spp.). The understory of Choctawhatchee stands is primarily decidous shrubs with some herbaceous ground cover. Turkey oak (*Quercus laevis* Walt.), bluejack oak (*Q. incana* Bartr.), sand post oak (*Q. stellata* var. *margaretta* (Ashe) Sarg.), and pineland threeawn (*Artistida stricta* Michx.), commonly called wiregrass, are the major understory species (6).

Considerable differences exist between Ocala and Choctawhatchee seed production and cone characteristics. Although both commonly produce cones at an early age, about 5 years, Ocala trees have abundant annual cone crops while Choctawhatchee trees produce heavy crops only every 4 to 6 years with smaller crops between (1). Ocala cones are predominately serotinous and persist on the tree for many years. Most of the Choctawhatchee variety cones open in the fall when they reach maturity.

Although rated as moderately intolerant, sand pine is quite tolerant of shade and competition when young. Both varieties will survive underplanting among the scrub oak–wiregrass vegetation found on northwest Florida sandhills. Eventually they will overtop the competition and dominate the site (12). Once established, sand pine can endure considerable drought.

Trees on average sites, site index 60, are 10 to 12 inches (25 to 30 cm) in diameter at breast height (d.b.h.) and average 60 feet (18.3 m) tall at 50 years. Well-stocked natural stands of the Ocala variety will yield 900, 1,350, and 1,800 cubic feet per acre (63.0, 94.5, and 126.0 m^3/ha) on poor, average, and good sites, respectively, on a 40- to 45-year rotation (20). On a pulpwood rotation of 25 to 30 years, Choctawhatchee plantations are expected to yield 1,800, 2,700, and 3,600 cubic feet per acre (126.0, 189.0, and 252.0 m^3/ha) on poor, average, and good sites, respectively.

Insects, disease, and fire play a significant part in the development and management of sand pine. Bark beetles, primarily *Ips* (*Ips calligraphus* (Germar) and *I. grandicollis* (Eichhoff)), can be a problem after thinnings or partial cuttings. Ocala sand pine, especially in plantations outside its natural range (19) and natural stands over age 40, frequently suffer considerable mortality from mushroom root rot (*Armillariella tabescens* (Scop. ex Fr.) Sing.). Thus, the Ocala variety should not be planted outside its natural range and, within its native range, a maximum rotation age of 40 years is best. The Choctawhatchee variety is quite resistant to the root rot, except when planted offsite on poorly drained soils, and can be managed for sawtimber production with rotations as long as 50 years. On private ownerships, both varieties should probably be managed for pulpwood with rotations of 25 to 35 years (4).

Because of its thin bark, sand pine is relatively susceptible to fire-caused damage and mortality. The Choctawhatchee variety, however, with its typical sparse understory can be prescribed burned under proper conditions (2). The evergreen shrub understory of Ocala stands is usually dense enough to shade out grass and low herbaceous cover. Because of this lack of low base fuels, headfires are necessary to burn the understory, but these are too explosive to use without high risk of losing the entire stand. Thus, prescribed burning is impractical in the Ocala type (7).

Most natural stands of Ocala sand pine have originated from seed released by its serotinous cones following wildfires. Although the effects of fire regenerate the stand, it is undesirable because most of the original timber is lost. Some kind of disturbance is needed, however, to maintain the type; otherwise, these stands would gradually be taken over by the more tolerant scrub oaks.

Sand pine is best suited to even-aged management. Both form and branch pruning are considerably improved when trees are grown in dense, even-aged stands. Under natural conditions, stands are typically dense, pure, and single-storied, although uneven-aged stands do develop during the initial invasion stage of scrub-oak sites (2).

Choctawhatchee sand pine can be successfully regenerated by either seed-tree or shelterwood systems (2). In both methods of regeneration an initial cut is made to stimulate seed production, followed by a final harvest after adequate regeneration is obtained, normally 5 to 10 years. Disadvantages are the possible loss of trees from *Ips* beetle attacks after the initial cutting and damage to regeneration during the final cut. Density control can also be a problem with natural regeneration systems.

Because of its serotinous cones, the seed-tree and shelterwood systems are not suitable for regeneration of

Ocala sand pine. Attempts have been made to get natural regeneration by using the heat from the sun to open cones in logging slash, but stocking has been below acceptable levels (18). Burning logging slash to release seeds has also been tried but it gave poor results because available cones (and logging slash) were unevenly distributed and fire destroyed the seeds (8).

The most successful system for regenerating Ocala sand pine is clearcutting, site preparation, and direct seeding (18). Double chopping with a heavy, duplex brush chopper is the preferred method of site preparation because it gives good control of competition and adequate exposure of mineral soil. A prescribed burn may be applied between chops if slash is especially heavy. Broadcast seeding at a rate of 0.5 to 1.0 pound per acre (0.6 to 1.1 kg/ha) should be done from October through November when soil temperatures are the most favorable for seedling establishment. Some method of covering the seed with a layer of soil 0.25 to 0.75 inches (0.6 to 1.9 cm) thick should be used to reduce seed predation and increase germination. Ocala sand pine can also be planted, but due to its lack of dormancy, survival is generally poor (about 60 percent) and variable (6, 12).

Unlike Ocala, the Choctawhatchee variety is easily planted with high and consistant survival rates even on sites outside its natural range (3). Growth and survival on sandhill sites in Georgia and South Carolina indicate that sand pine will outperform other pine species normally planted on these deep sands (16, 17). Deep planting is recommended, with seedlings set to a depth that results in the lower branches remaining covered after the soil settles (4). Recommended planting densities for 25- to 35-year rotations are 500 to 550 seedlings per acre (1235 to 1360/ha) if no thinning is planned, and 725 to 775 per acre (1790 to 1915/ha) if an intermediate thinning at about age 20 is anticipated.

Overstocked stands of sand pine can result from regeneration by seed-tree, shelterwood, or direct seeding. Such stands should receive a precommercial thinning to prevent stagnation and growth loss. Mechanically thinning seedling-or small sapling-sized stands in strips using drum choppers or rotary mowers is the most practical method of reducing their density. Trees in older stands and plantations will respond to thinning (5). Thinning in the traditional manner can be used in older stands for regulation of product size. This is more applicable to the Choctawhatchee variety which has better form, smaller branches, and higher wood density, and thus is better suited to sawlog production than is the Ocala variety. Thinning should be done during the dormant season to lessen the risk of bark beetle attacks.

Many of the sites where sand pine currently is being established are scrub oak—wiregrass areas with no existing seed source. These sites can be converted by underplanting sand pine among the existing vegetation. Growth of seedlings can be substantially increased by release soon after establishment (3). This is an economically attractive strategy for landowners with small holdings who may not be able or inclined to make a large investment in stand conversion. On larger areas, double chopping followed by direct seeding or planting is more practical. Because spacing can be controlled, plantation establishment by planting the Choctawhatchee variety is the preferred procedure.

Site preparation for conversion of scrub oak—wiregrass sites reduces available wildlife foods. Some useful seed-producing species will invade and grow on these sites for a few years after chopping, but they soon give way to grasses (11). Undisturbed strips of scrub vegetation can be left in larger plantations to increase wildlife use (6). In some cases these can be provided along natural drainages. Even dense stands of Ocala sand pine contain many understory shrubs that provide mast and forage for wildlife. Production can be increased by clearcutting or thinning (10). Prescribed burning every 3 to 4 years will improve the quantity and quality of forage under Choctawhatchee stands (14).

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Oak – Pine

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The oak–pine type includes some 35 million acres of predominantly upland sites in the Southern and Eastern United States (33). Its range extends from southern New York and New Jersey to Pennsylvania, southern Ohio, Kentucky, southwestern Illinois and southern Missouri, south through Arkansas to eastern Oklahoma and east to northern Florida and north through the Atlantic Coast States to Delaware (6, 12, 14).

The several pine and oak species that comprise the oak–pine type are adaptable to a great variety of site and soil conditions. The type is found on all topographic positions from dry rocky ridges and steep slopes of the Appalachians and Ozarks to the gently rolling or flat terrain of the Piedmont or Atlantic and Gulf Coastal Plains. Ultisols are the dominant soils throughout the oak–pine range. Soils are derived from a wide variety of parent materials, including sedimentary and metamorphic rocks, marine terrace, and loess, and range from clays to sandy loams. The type is much less common on soils with high pH values or high calcium content (14).

The oak–pine type occurs at elevations as low as 10 feet (3 m) in southern New Jersey to 3,000 feet (915 m) in the Appalachians, although the type is most common at elevations of from 150 feet (45 m) in the Coastal Plain to about 1,500 to 2,000 feet (455 to 610 m) in the Piedmont and mountainous regions (14).

Climatic conditions vary widely throughout the oak–pine range. Annual precipitation averages 37 to 40 inches (940 to 1015 mm) in the northeastern and western portions of the range and 60 inches (1525 mm) along the Gulf Coast (31). Mean annual temperatures vary from 48° to 70° F (8.9° to 21.1° C), and the frost-free period ranges from 160 days in the north to about 250 days on the Gulf Coast.

The oak–pine type is composed of forests in which upland oaks and other hardwoods comprise 50 to 75 percent of the stocking and southern pines constitute the remainder (32). It encompasses the major pine–hardwood forest cover types as classified by the Society of American Foresters (12) including: Shortleaf Pine–Oak (type 76), Virginia Pine–Oak (type 78), and upland portions of Loblolly Pine–Hardwood (type 82). Pitch pine–oak variants of the Pitch Pine type (type 45) are common in the northeast and on poorer sites in the Appalachians, while Longleaf Pine–Scrub Oak (type 71) is common on the Atlantic and Gulf Coastal Plains. The oak–pine type is closely associated with and is most common within the geographic range of the Shortleaf Pine (type 75) and Loblolly Pine–Shortleaf Pine (type 80) forest types. Major oak species include white (*Quercus alba* L.), post (*Q. stellata* Wangenh.), black (*Q. velutina* Lam.), scarlet (*Q. coccinea* Muenchh.), northern red (*Q. rubra* L.), southern red (*Q. falcata* Michx. var. *falcata*), and chestnut (*Q. prinus* L.). Associated hardwoods include hickories (*Carya* spp.), yellow-poplar (*Liriodendron tulipifera* L.), sweetgum (*Liquidambar styraciflua* L.), black gum (*Nyssa sylvatica* Marsh.), and red maple (*Acer rubrum* L.). Major pine species are shortleaf (*Pinus echinata* Mill.), loblolly (*P. taeda* L.), Virginia (*P. virginiana* Mill.), and, to a lesser extent, pitch (*P. rigida* Mill.) (21).

Oak–pine represents a transitional stage of the successional pattern from an essentially pine-dominated forest to the climax forest types dominated by oaks and other hardwoods (25, 26). When farmlands are abandoned, southern pines become established on the open lands. Tolerant hardwood species invade the understory of pine stands and gradually increase in numbers, height, and basal area. Under heavy overstory shade, pine reproduction cannot compete successfully with the hardwoods for light and moisture, and few survive (18, 19, 35). Harvesting of large pines and losses by windthrow, insects, and disease create small openings in pine forests which are quickly occupied by oaks and other hardwoods already present in the understory. Over time, the pine-dominated stands are transformed to oak–pine stands, which in turn will be replaced by oak and other hardwood-dominated stands. Unless followed by adequate cultural treatments, repeated cuttings in pine stands will increase the amount of hardwoods and hasten the succession to oak–pine and then to oak–hickory (3, 4, 5, 34). By 1973, more than 70 million acres (28.3 million ha) of pine site lands were occupied by oak–pine or hardwood types (24), and the acreage has continued to increase through 1979 (3, 4).

Yield of oak–pine stands will vary with the amount of pine, but on upland sites yield will be intermediate between pine and oak–hickory types. For natural stands on upland sites in North Carolina and eastern Virginia, oak–pine yields at age 50 averaged about 2,600 cubic feet and 9,400 board feet (fbm) (International ¼-inch) per acre (182.0 and 131.6 m^3/ha, respectively)[1] on good sites and about 1,600 cubic feet and 2,700 fbm per acre (112.0 and 37.8 m^3/ha, respectively) on poor sites. Board foot volumes averaged about 50 percent less on both sites while cubic foot volumes were 25 percent less on good sites but were approximately the same as pure loblolly pine stands on poor sites. Upland hardwoods, primarily oak–hickory, produced the lowest average yields on all sites (16). Across the southern region, average loss in yield resulting from hardwood competition in natural pine stands has been estimated at 25 percent (13).

On better sites, oaks and associated species produce desirable stems and the succession from oak–pine to oak and other hardwood types should be encouraged. Also, hardwood species are aggressive on better sites and control is difficult and expensive. On medium to poor sites, the silvicultural objective for timber production in the oak–pine type is to increase the pine and reduce the hardwood components. Pines are favored over hardwoods because of the greater demand for pine products and because of faster growth, greater yields, and high quality and value of pines on most upland sites. On poorer sites, pine will produce moderate

[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.

yields of merchantable material while associated hardwoods are usually of poor quality, grow slowly, and produce lower yields.

The several pine species of the oak–pine type are intolerant of shade (14) and are best suited to an even-aged system of management. To obtain maximum pine stocking in future stands, harvest cuttings must be accompanied by intensive hardwood control methods such as prescribed burning, chemicals, or mechanical site preparation (7, 36, 37). Natural pine regeneration can be obtained with shelterwood, seed-tree, and patch or strip clearcut systems, providing suitable seedbed preparation and competition control measures are achieved (7, 20). Pure stands of pines (particularly loblolly) of excessive densities frequently become established by natural or broadcast seeding on well-prepared sites. Dense natural stands of southern pines usually respond well to precommercial thinning. To insure best volume gains, stocking should be reduced to 500 to 700 stems per acre (1240 to 1730/ha) by age 5 (15, 22).

Clearcutting followed by site preparation, hardwood control, and seeding or planting has been the most effective and desirable system to regenerate southern pines. This system results in more uniform stocking and spacing, permits introduction of superior planting stock or insect and disease resistant strains, and allows more flexibility in selecting the pine species most suitable to a particular planting site. Loblolly pine should be favored over shortleaf on sites where littleleaf disease (*Phytophthora cinnamomi* Rands) hazard is high (8). Planting or seeding also permits replacing loblolly with shortleaf in the northern part of the range where loblolly is susceptible to ice and snow damage and in the southern areas where loblolly is vulnerable to fusiform rust (*Cronartium quercuum* (Berk.) Miy. ex Shirai f. sp. *fusiforme* Burds. & Snow)(10).

Even-aged management with intensive site preparation and hardwood control measures will inevitably result in conversion of oak–pine to the pine forest types. Conversion measures are expensive and costs increase with the amount and size of the hardwood component (1). Such measures are feasible under a management system where timber production is the primary objective. However, nearly 70 percent of the oak–pine type is controlled by nonindustrial private owners whose management objectives for their forest land are varied and generally not oriented toward maximum timber production. Most nonindustrial landowners, for a variety of social and economical reasons, passively permit the more tolerant hardwoods to increase after the harvest of pines (4). Consequently, a high percentage of the oak–pine forest is in poor condition and has low stocking in trees that could be featured in management (17).

Although even-aged methods are preferred as the best timber management, the use of uneven-aged management with group selection cutting and natural regeneration can be used as an alternative to increase productivity over the exploitive cutting common to most nonindustrial private forest lands. Uneven-aged management can be effective on small ownerships and is adapted to both understocked and well-stocked stand conditions (38), and has been successfully applied to a limited extent in pine (7, 27) and hardwood forests (23). A combination of silvicultural practices—cleaning, improvement, liberation, and salvage cuts and thinnings when combined with group selection cutting—can effectively rehabilitate depleted oak–pine stands (30). Where better quality hardwoods occur on suitable sites, they should be favored. Yellow-poplar, like the southern pines, is intolerant of heavy shade and requires the same degree of overstory release and understory control as the pines for successful regeneration. Although intermediate in tolerance, desirable oak species also attain optimum growth under relatively open conditions, and openings of ½ acre (0.2 ha) or more are recommended. Adequate oak reproduction, as advance reproduction already established on the site or expected from stump sprouting, must be assured before the harvest cut (28). Feasibility of the more intensive rehabilitation treatments have been enhanced in the eastern portion of the oak–pine range by expanded markets for low value hardwoods and the increased use of whole-tree chippers. If a pine seed source is absent following a clean harvest operation, a mixed pine–hardwood stand can be established by planting pine. Establishment costs would be relatively low and the pine component can be increased with follow-up release (29).

Mixed uneven-aged oak–pine forests are esthetically pleasing and provide a diversity of habitat for many game and nongame wildlife species (9, 11). Mixed stands also have a lower incidence of attack by insects such as the southern pine beetle (*Dendroctonus frontalis* Zimmermann) (2). However, without some hardwood control in regeneration openings, the group selection system favors tolerant noncommercial hardwood species. Fire cannot be used for seedbed preparation, since seedlings in nearby regeneration openings would be killed. Group selection openings are generally too small for machine operation and sites must be prepared by scarification incidental with logging. If desirable reproduction is not obtained promptly, more expensive hand methods will be needed to control undesirable hardwoods that usually dominate the small openings.

Single tree selection cutting is not recommended for management in the oak–pine type because it discriminates sharply against the more light-demanding species. Openings created by removal of individual trees are usually too small to insure adequate reproduction of southern pines, yellow-poplar, and most upland oak species that dominate the oak–pine type. Successful regeneration of these species requires forest openings of at least 0.3 acre (0.1 ha) but preferably larger (14, 23, 28, 38).

Oak–pine stands with their diversity of species offer a variety of spring-flowering and fall coloration which are esthetically pleasing to forest visitors and recreationists. Regeneration cuttings in even-aged management and group selection cuttings in uneven-aged management, through the openings they create, provide abundant food and shelter for a variety of wildlife species. For rare and endangered species, silvicultural operations must provide the special habitat requirements that will ensure their continued existence. Impacts of well-planned silvicultural operations are minimal on water quality.

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Bottomland Hardwoods

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Bottomland hardwood forests encompass 19 forest cover types as described by the Society of American Foresters (5). They are scattered over 52 million acres (21.0 million ha) in 37 States (31). This area is bounded on the east by the Atlantic Ocean, on the south by the Gulf of Mexico, and on the north by Canada. The western boundary butts against the States of Montana, Wyoming, Colorado, and New Mexico.

Floodplains of rivers and streams, backwater and headwater swamps, and minor drainages all support bottomland hardwoods. Elevations are low, ranging from near sea level in coastal swamps to about 800 feet (245 m) above sea level in northern interior drainages. Annual precipitation ranges from about 30 inches (760 mm) in the western part of the range to 64 inches (1625 mm) along the Gulf Coast. Growing season varies from near 100 days in the North to 300 days along the Gulf Coast. A growing season of between 150 and 270 days is common for most bottomland forests. Temperature extremes range from −40° F (−40.0° C) in the far North to 110° F (43.3°C) in the deep South.

Bottomland forests include at least 70 different commercial species (28) that, for simplicity, will be discussed in three major groupings: cottonwood–willow, cypress–tupelo, and mixed hardwoods. The cottonwood–willow and cypress–tupelo groups are fairly specific with regard to species; the mixed hardwoods group is quite variable.

Cottonwood – Willow

Eastern cottonwood (*Populus deltoides* Bartr. ex Marsh.) and black willow (*Salix nigra* Marsh.), described as types 63 and 95 of the forest cover types of the Society of American Foresters (5), grow as pioneer species on recent alluvium, most extensively along major rivers such as the Mississippi, Ohio, and Missouri. Both species are very intolerant of shade and require bare mineral soil to become established (24). They are also intolerant of weed and vine competition. Natural stands are even-aged, nearly pure, and very dense. Eastern cottonwood grows on the higher, well-drained, coarser-textured soils, usually sandy loam or silt loam; black willow dominates on fine-textured, low lying soils subject to more frequent overflow. Both species will survive periodic growing season flooding and sediment, but black willow will tolerate more flooding and sediment than eastern cottonwood.

Eastern cottonwood is the fastest growing bottomland species, and black willow is second. Through a pulpwood rotation in the southern part of the range, annual diameter and height growth of crop trees should average 0.8 inch (2 cm) and 6 feet (1.8 m) for eastern cottonwood and 0.6 inch (2 cm) and 5 feet (1.5 m) for black willow. Mean annual increment in unmanaged stands peaks for both species at about 20 years—eastern cottonwood at about 250 cubic feet per acre (17.5 m^3/ha) and black willow at about 200 cubic feet per acre (14.0 m^3/ha) (33). The better unthinned eastern cottonwood stands produce about 27,000 board feet (fbm) (Doyle log rule) or 5,400 cubic feet[1] per acre (378 m^3/ha) in 35 years with codominant trees averaging 23 inches (58 cm) diameter at breast height (d.b.h.) and 134 feet (40.8 m) tall. Thinned stands have produced 32,000 fbm or 6,400 cubic feet per acre (448.0 m^3/ha) in 50 years; residuals averaged 34 inches (86 cm) d.b.h. and 146 feet (44.5 m) tall (14). Unthinned black willow stands produce about one-half the sawtimber volume of unthinned eastern cottonwood at 35 years (15). But the species only reaches sawtimber size along the Mississippi River and its tributaries.

When practical, light thinnings at 5- to 10-year intervals beginning at age 5 are recommended for natural stands. Mortality is forestalled, site utilization is more nearly complete, and total growth is distributed over fewer trees. Commercial thinnings usually begin when stands are 15 to 20 years old. After thinning, minimum basal areas where sawtimber is the objective should range from 40 square feet per acre (9.2 m^2/ha) in pulpwood stands to 90 square feet per acre (20.7 m^2/ha) in sawtimber stands.

Although eastern cottonwood on the best sites will remain healthy and have rapid growth for at least 75 years, when codominant trees will be 40 to 45 inches (102 to 114 cm) d.b.h. and approximately 150 feet (45.7 m) tall, most stands are harvested by age 50. Black willow is short lived and usually begins to deteriorate by age 35; final harvest should be complete by age 50.

Neither species provides dense shade, and therefore species more shade tolerant than cottonwood or willow become established in the understory. Because of their establishment requirements, neither species will succeed itself naturally. Mechanical site preparation has favored reestablishment of natural eastern cottonwood, but the system is highly dependent upon surface soil moisture (11). If advance reproduction other than eastern cottonwood or black willow is present and desirable, group selection, patch cutting, or clearcutting are the best regeneration systems. Successional species commonly following eastern cottonwood are hackberry (*Celtis occidentalis* L.), sugarberry (*C. laevigata* Willd.), American elm (*Ulmus americana* L.), green ash (*Fraxinus pennsylvanica* Marsh.), boxelder (*Acer negundo* L.), silver maple (*A. saccharinum* L.), sweet pecan (*Carya illinoensis* (Wangenh.) K. Koch), and occasionally sycamore (*Platanus occidentalis* L.), sweetgum (*Liquidambar styraciflua* L.), and Ohio buckeye (*Aesculus glabra* Willd.). Black willow stands normally succeed to sugarberry, American elm, green ash, overcup oak (*Quercus lyrata* Walt.), water hickory (*Carya aquatica* (Michx. f.) Nutt.), and sometimes noncommercial swamp-privet (*Forestiera acuminata* (Michx.) Poir.) (24).

Due to channel straightening and bank stabilization along major rivers, fewer new stands of eastern cottonwood and black willow are becoming established. Both can be successfully planted by cuttings or seedlings. Total site preparation and at least 1 year of intensive weed control is necessary to assure success (23).

[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.

Plantations of eastern cottonwood have yielded about 3,500 cubic feet per acre (245.0 m^3/ha) in 10 years and 5,500 fbm (Doyle) or 1,100 cubic feet per acre (77.0 m^3/ha) in 15 years (18). They have also provided excellent wildlife habitat for a number of game and nongame birds and animals (32).

Eastern cottonwood is frequently attacked by insect borers and defoliators as well as fungus stem cankers and leaf spots; damage has been most notable in monoculture plantings (26). Well-managed, vigorous stands are the least susceptible to injury from insects and diseases.

Cypress – Tupelo

Baldcypress (*Taxodium distichum* (L.) Rich.) and water tupelo (*Nyssa aquatica* L.) constitute the major species in types 100, 101, 102, 103, and 104 of the forest cover types of the Society of American Foresters. These two species dominate coastal swamps of several mid-southern States and in deep swamps of "red" and "black" water rivers (so called because of the sediment load they carry from their place of origin in the Piedmont and mountains and in the coastal plain) in the Southeast. Both species normally grow in pure, even-aged, densely stocked stands. Baldcypress is only moderately tolerant of shade; water tupelo is intolerant. Consequently, advance reproduction is sparse. Although both species may grow in mixture with other species, neither will tolerate overtopping competition. They will stagnate in dense stands but will respond to release. Both species are extremely tolerant of flooding. Baldcypress seed production is usually adequate; water tupelo produces good seed crops most years, with an occasional bumper crop and a few failures (6). The buoyant baldcypress and water tupelo seeds are dispersed by flood waters, and scattered by birds and animals. Both species may sprout from stumps, but sprouting is erratic and, for water tupelo, may be related to depth and duration of water, stump diameter and height, and tree vigor.[2]

In nonalluvial headwater swamps of the Southeast, swamp tupelo (*N. sylvatica* var. *biflora* (Walt.) Sarg.) is much more prevalent than water tupelo. Common associates of swamp tupelo and baldcypress include water tupelo, red maple (*Acer rubrum* L.), sweetbay (*Magnolia virginiana* L.), redbay (*Persea borbonia* (L.) Spreng.), Carolina ash (*Franxinus caroliniana* Mill.), and green ash. Seed crops of swamp tupelo are generally good to excellent, but the seeds do not float. Swamp tupelo is a fair stump sprouter. Sprouts may produce viable seeds in the second year (27).

Cypress–tupelo mixtures seem to thrive on water-saturated soils (17). Basal areas from 250 to 350 square feet per acre (57.4 to 80.4 m^2/ha) are common. Volumes of 6,100 cubic feet per acre (427.0 m^3/ha) have been reported for 70-year-old water tupelo stands (22). Annual volume production for water tupelo may be 90 to 100 cubic feet per acre (6.3 to 7.0 m^3/ha). Annual growth of 0.3 inch (0.8 cm) in diameter and 2 feet (0.6 m) in height may be expected from crop trees.

Unthinned baldcypress stands can produce 70,000 fbm (International ¼-inch) or 14,000 cubic feet per acre (980.0 m^3/ha) in 100 years. One such stand contained 303 square feet per acre (69.6 m^2/ha) of basal area; crop trees averaged 21.1 inches (53.6 cm) d.b.h. and 119 feet (36.3 m) tall (34). Baldcypress crop trees should have an annual growth of between 0.2 and 0.3 inch (0.5 and 0.8 cm) in diameter and about 2 feet (0.6 m) in height during the first 50 years.

Baldcypress will live for hundreds of years, far beyond a practical rotation age. However, the present practice is to harvest baldcypress and tupelos before they are 100 years old. For most stands, thinnings should begin between ages 20 and 30 at intervals of about 15 years. After thinning basal area should be between 80 and 100 square feet per acre (18.4 and 23.0 m^2/ha) (34).

Cypress–tupelo stands on very wet sites may be difficult to quickly regenerate under any silvicultural system. Seedling establishment requires that portions of a swamp be dry sometime during the growing season to allow for germination of seeds that may have been submerged for up to 2 years. Seedlings can be killed by 4 or 5 weeks of total submergence during the growing season, so a swamp should be essentially dry for 1 or 2 years following seedling establishment. The only way to assure a dry cycle is to control water levels—something that has seldom been done. Stump sprouts may provide some regeneration but seldom enough.

Since existing swamp stands are even-aged and support relatively shade intolerant species, an even-aged silvicultural system is required. Where there has been a drying trend, cypress–tupelo swamps usually support advance reproduction of mixed bottomland hardwoods. Also, where swamp tupelo stands are approaching rotation age and are less than fully stocked, advance reproduction of the species is likely present in adequate numbers. In either situation, patch cutting or clearcutting, coupled with brush control, is the recommended regeneration system.

In the absence of advance reproduction, a shelterwood of 30 to 40 trees per acre (75 to 100 trees/ha) will favor regeneration of swamp tupelo. However, harvesting under the shelterwood system is difficult and costly; strip clearcutting may offer a viable alternative. Another option, leaving 8 to 10 seed trees per acre (20 to 25/ha) may insure an adequate seed source to regenerate baldcypress and water tupelo. Established seedlings will resprout if they are broken during removal of seed- or shelterwood trees (8).

Cypress–tupelo swamps provide good habitat for fish and wildlife and therefore, good areas for recreation, as well as income from fishing and trapping. Commercial crawfish production is also important in many cypress– tupelo swamps, especially in southern Louisiana (4).

The forest tent caterpillar (*Malacosoma disstria* Hubner) is a major insect enemy to the tupelos and defoliates thousands of acres annually. Although repeated defoliations can kill trees, the main effect has been a significant reduction in growth and a loss of seeds (25).

Mixed Hardwoods

Most bottomland hardwood stands, scattered over types 39, 61, 62, 65, 87, 88, 91, 92, 93, 94, 96, and 108 of the forest cover types as described by the Society of American Foresters (5), are of mixed species that are site specific (7). Discounting the direct influence on the forest by humans, moisture is the key site factor to separation of species. While cypress and tupelo are extremely water tolerant, some hardwood species that grow on bottomlands are not water tolerant during the growing season and may survive less than 1 month of flooding. During the dormant season, however, all typical bottomland species can survive extended flooding.

Only a few bottomland species can survive and develop on either very wet or very dry areas, but most can grow satisfactorily on moist, well-drained sites. Thus, the best bottomland sites naturally support a variety of species that can be manipulated individually to maintain favored species. Many species that are not present can be introduced on such

[2] Kennedy, Harvey E., Jr. Growth and survival of water tupelo coppice regeneration after six growing seasons. Unpublished draft supplied to author by Harvey E. Kennedy, Jr., U.S. Department of Agriculture, Forest Service, Stoneville, MS. 1981.

sites by planting. Although good sites present the greatest challenge, they also offer the broadest range of silivicultural opportunities for those with the expertise to handle such complex communities.

Most desirable bottomland hardwoods are intolerant or moderately tolerant of shade. Some exceptions are hickories, American beech (*Fagus grandifolia* Ehrh.), elms, hackberry, sugarberry, red maple, and boxelder (10). Even moderately tolerant trees establish and develop slowly in small openings; they may become understory trees when the crowns of overstory trees close. Trees of tolerant and sometimes moderately tolerant species will respond to overhead release at ages greater than 20 years. Those of moderately tolerant species that start from seed in dense shade will usually die within 3 years if not released. Seedlings of intolerant species seldom occur in the understory; those that do will not survive the first year.

Differences in growth rates and growth patterns among species of the same stand are exemplified by fast and slow growers. Sycamore, river birch (*Betula nigra* L.), and silver maple are among the fast early growers. Sweetgum and green ash are characterized by intermediate growth; but like other hardwoods, sprouts of the two species grow rapidly the first 3 or 4 years. Oaks and hickories usually grow slowly until about age 10 or 15, then begin more rapid growth, especially in diameter. In 10 years, tree heights will vary by species from 10 to 50 feet (3.0 to 15.2 m) tall and from about 1 to 5 inches (3 to 13 cm) in diameter at breast height (d.b.h.). Over 50 years, crop trees should average between 0.2 and 0.5 inch (0.5 and 1.3 cm) diameter growth and from 1.5 to 2.5 feet (0.5 to 0.8 m) in height growth, depending on species and site (1).

Mixed bottomland hardwood stands seldom exceed 150 square feet of basal area per acre (34.4 m^2/ha) and most are between 110 and 130 square feet per acre (25.3 and 29.8 m^2/ha). Fully stocked stands of quality timber should yield between 15,000 and 20,000 board feet (fbm) (Doyle) or 3,000 and 4,000 cubic feet per acre (210.0 and 280.0 m^3/ha) at 60 to 80 years, depending on species mix and site (28).

Some of the bottomland species—sweetgum, sycamore, silver maple, green ash, and American elm—produce an abundance of lightweight seeds in most years. Light seeds are moved mainly by wind for 200 feet (61.0 m) or more, and sometimes for many miles by water. Oaks and hickories produce heavy seeds and have good crops about 1 year in 3 or 4. Heavy seeds are dispersed for only a few feet beyond the crown of the parent tree by gravity and for longer distances by birds, animals, and sometimes water. Light seeds require a seedbed relatively free of herbaceous plants and particularly sod; moist, bare soil is best. Most new seedlings in regeneration areas originate from light seeds. Of the heavy seeds, ones most likely to produce seedlings are found 1 to 2 inches (3 to 5 cm) deep in the soil. Good germination also occurs on moist surface soil when acorns are covered by leaves. A high proportion of both light and heavy seeds are lost to birds and animals each year.

Mixed stands were essentially even-aged and predominantly of the faster growing, light-demanding species before cutting practices and natural mortality modified stand structure and composition. Thus, even-aged management is recommended for maximum timber production. If adequate advance reproduction is present and if sprouting will be adequate, as it often is, clearcutting or patch cutting, the two systems found most favorable for fast development of desirable species, can be used to release the regeneration. Full release is essential; trees of commercial species greater than 2 inches (5 cm) d.b.h. should be cut, sheared, or otherwise brought back to ground level. Choppers have been successfully used, but the giant machines can destroy root systems. Deadening trees of unwanted species is recommended, but they may also be cut; stump sprouts will have rapid early growth, but trees of more desirable species will ultimately become dominant in the stand.

Where advance reproduction is inadequate, special attention should be given to stump sprouting. A high proportion of trees under 8 inches (20 cm) d.b.h. will produce satisfactory stump sprouts. Many species may produce sprouts from even larger stumps. Sweetgum stands alone as a prolific root sprouter (9). A general rule-of-thumb is that the poorer the site quality, the better the sprouting; best sprouting follows a November to March harvesting, but acceptable levels are usually obtained from growing season cuts (16).

The conditions likely to be found under dense stands of large trees would favor germination of light seeds in a situation where new seedlings are most needed. Some of these seeds may already be lying dormant and will germinate when the overstory is removed (3). Still, complete dependence on seed regeneration is a gamble.

The alternative to clearcutting and patch cutting in stands where regeneration may be a problem is a light shelterwood cut about 10 years before final harvest. Seedlings of moderately shade tolerant species, such as the oaks, can remain alive with only 2 or 3 hours of full daily sunlight. Thus, evenly dispersed openings that approximate the size following group selection should be adequate for establishment of the shelterwood. If openings are too large, boles of leave trees will develop epicormic branches. Removal of shelterwood trees, which should be done within 5 years after adequate reproduction is established, should pose no serious problems, since broken seedlings will resprout.

Under all regeneration systems, the reproduction of most mixed stands will be composed of the same species as those in the overstory, but proportions will differ. Within a few years, however, shade intolerant species, which are usually the most commercially desirable, will die unless steps are taken to provide ample sunlight. Small openings created through single tree selection will thus ultimately result in a stand of more shade tolerant species unless openings are enlarged within 10 years. Development of reproduction in openings of less than half an acre (0.2 ha) is generally much slower than in openings of 2 acres (0.8 ha) or more. Group selection is a suitable compromise system, but only the interior of openings will favor more shade intolerant species with a tree development rate near to that in clearcuts. The seed-tree method is seldom successful because of the conditions required to establish new seedlings.

Where possible, smaller trees should be left around the perimeter of regeneration cuts to shade the boles of surrounding crop trees and thus reduce epicormic branching. Openings of a size that will allow tree development in bottomland forests are quickly covered by lush vegetation. Vines will not prevent well-stocked reproduction stands from developing, but they do tend to equalize development rates of all species.

When natural regeneration appears unsatisfactory, planting is a viable alternative. There are commercial plantings of sweetgum, sycamore, green ash, Nuttall oak (*Quercus nuttallii* Palmer), water oak (*Q. nigra* L.), cherrybark oak (*Q. falcata* var. *pagodifolia* Ell.), and willow oak (*Q. phellos* L.) in bottomlands of the Southern and Southeastern United States. At least six other commercially important species have been established in test plantings. A disadvantage to hardwood plantations is the high cost, due to the necessity of 1 to 5 years of intensive competition control (12).

Another possible option for artificially regenerating bottomland hardwoods is direct seeding. But, with one exception, guidelines are unavailable. Nuttall oak has been successfully direct seeded in 3-acre (1.2-ha) site-prepared openings in a natural forest (13). As for the future, oaks seem to offer the best potential for direct seeding.

There is little opportunity for improvement cuts in many mixed bottomland hardwood stands. A history of stand abuse resulting from high grading has left little to improve among residual trees. Reducing the stand to ground level to favor seedling and sprout regeneration or to convert to a better species composition through planting is often the course to follow. No cutting at all is usually better than premature harvest of a large component of desirable growing stock. Stands where improvement cutting may help are those with scattered overmature, damaged, and dying trees of marketable size and quality (24). Even in these stands some growing-stock trees may have to be harvested to make openings for regeneration and to provide enough timber to entice buyers. After an improvement cut, large culls and trees of undesirable species should be killed to enlarge openings for reproduction. Unmerchantable trees of desirable species up to 8 inches (20 cm) d.b.h. should be cut rather than deadened to stimulate stump and root sprouting. This will also reduce disease loss in the stand.

Wider spacing between trees and control of competitors has increased diameter growth in plantation research (29). Thus, one precommercial thinning and weeding in developing natural stands seems warranted. However, guidelines for such treatments are unavailable, as are associated economics.

The first treatment of even-aged groups or stands is usually a commercial thinning when codominant trees average 8 to 10 inches (20 to 25 cm) d.b.h. Thinning removes diseased trees and those of low vigor and should leave approximately 60 to 70 square feet per acre (13.8 to 16.1 m^2/ha) of basal area. At least two or three more thinnings are recommended at intervals between 7 and 15 years, depending on species and site. After thinning, basal areas will gradually increase as trees grow larger. At final harvest, most stands should not exceed 120 to 130 square feet per acre (27.6 to 29.8 m^2/ha).

Of all bottomland hardwoods, those of low vigor are most susceptible to injury from insects such as wood borers and defoliators. Practices that promote tree vigor help to minimize losses (30). Canker diseases cause defects, allow decay, and can kill trees (21). Dutch elm disease (*Ceratocystus ulmi* (Buism.) C. Mor.) and elm phloem necrosis (*Morsus ulmi* Holmes) have killed most elms in the northern and central parts of the range. Oak wilt (*Ceratocystus Fagacearum* (Bretz) Hunt) is serious in some areas (20). Fire has been detrimental to bottomland hardwoods and has had no favorable role in their management (28). Beavers kill trees by girdling and, according to recent surveys, have impounded water on 532,384 acres (215 450 ha) in six southern States.[3] This is detrimental, since 1 to 4 years of continuous flooding will kill trees of most bottomland hardwood species (2). Even first-year plantings have been destroyed by beavers (19).

Some of the most productive and valuable fish and wildlife habitats in the United States are found in bottomland hardwood stands. Food and cover are provided for a number of game and nongame birds and animals. Uncommon wildlife species that dwell in the bottomlands are the swallow-tailed kite, river sturgeon, southern black bear, ringed sawback turtle, and American bald eagle.

Stands absorb much of the pressure of river floods, reducing damage to populated areas and croplands. The ecosystem may also absorb and process pesticides and other chemicals (4).

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Yellow-Poplar

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Yellow-poplar (*Liriodendron tulipifera* L.) grows throughout the Eastern United States from southern New England, west through southern Ontario and Michigan, south to Louisiana, then east to north-central Florida. It is most abundant in the valley of the Ohio River Basin and on the mountain slopes of North Carolina, Tennessee, Kentucky, and West Virginia.

Because of its wide geographic distribution, yellow-poplar grows under a variety of climatic conditions. Low temperature extremes vary from severe winters in southern New England and upper New York with a mean January temperature of 19° F (−7.2° C) to almost frost-free winters in central Florida with a mean January temperature of 61° F (16.1° C). Average July temperature varies from 69° F (20.6° C) in the northern part of the range to 81° F (27.2° C) in the southern. Rainfall varies from 30 inches (760 mm) to more than 80 inches (2030 mm) in some areas of the southern Appalachians. Average number of frost-free days varies from 150 to over 310 days within the north-to-south range of yellow-poplar.

Effects of temperature and moisture extremes are tempered somewhat by local topography. At the northern end of its range, yellow-poplar is usually found in valleys and stream bottoms at elevations below 1,000 feet (305 m). In the southern Appalachians, it may grow on a variety of sites, including stream bottoms and coves, and moist slopes up to an elevation of about 4,500 feet (1370 m). Toward the southern edge of the range, where high temperatures and soil moisture probably become limiting, the species is usually confined to moist, but well-drained stream bottoms. Optimum development of yellow-poplar occurs where rainfall is well distributed over a long growing season. The best growth usually occurs on north and east aspects, on lower slopes, in sheltered coves, and on gentle, concave slopes.

Yellow-poplar thrives on many soil types varying widely in physical properties, chemical composition, and parent material. Exceptionally good growth has been observed on alluvial soils bordering streams, on loam soils of mountain coves, on talus slopes below cliffs and bluffs, and on well-watered, gravelly soils (15). In general, where yellow-poplar occurs naturally and grows well, the soils are moderately moist, well drained, and loose textured; it rarely does well in poorly drained, or very dry situations. It is a vigorous competitor on the most productive sites in eastern North America.

Yellow-poplar is a major species in four Society of American Foresters forest cover types (12): Yellow-poplar (type 57), Yellow-poplar−Eastern Hemlock (type 58), Yellow-poplar−White Oak−Northern Red Oak (type 59), and Sweetgum−Yellow-poplar (type 87); it is also found as a minor species in 11 other cover types.

On bottom lands and better drained soils of the Coastal Plain, yellow-poplar occurs in mixture with baldcypress (*Taxodium distichum* (L.) Rich. var. *distichum*), oaks (*Quercus* ssp.), red maple (*Acer rubrum* L.), sweetgum (*Liquidambar styraciflua* L.), and loblolly pine (*Pinus taeda* L.). In bay heads and branch bottoms of the Coastal Plain, an ecotype of yellow-poplar is associated with swamp black tupelo (*Nyssa sylvatica* var. *biflora* (Walt.) Sarg.), green ash (*Fraxinus pennsylvanica* Marsh.), sweetbay (*Magnolia virginiana* L.), and baldcypress. In the Piedmont, associated species include oaks, sweetgum, blackgum (*Nyssa sylvatica* Marsh.), red maple, loblolly pine, shortleaf pine (*Pinus echinata* Mill.), Virginia pine (*Pinus virginiana* Mill.), hickories (*Carya* spp.), flowering dogwood (*Cornus florida* L.), sourwood (*Oxydendrum arboreum* (L.) DC.), and eastern redcedar (*Juniperus virginiana* L.).

At lower elevations in the Appalachian Mountains, yellow-popular is found with black locust (*Robinia pseudoacacia* L.), eastern white pine (*Pinus strobus* L.), eastern hemlock (*Tsuga canadensis* (L.) Carr.), hickories, oaks, black walnut (*Juglans nigra* L.), shortleaf, Virginia, and pitch (*Pinus rigida* Mill.) pines, flowering dogwood, sourwood, sweet birch (*Betula lenta* L.), American basswood (*Tilia americana* L.), and Carolina silverbell (*Halesia carolina* L.). At higher elevations, associated species include northern red oak (*Quercus rubra* L.), white ash (*Fraxinus americana* L.), black cherry (*Prunus serotina* Ehrh.), cucumbertree (*Magnolia acuminata* L.), yellow buckeye (*Aesculus octandra* Marsh.), American beech (*Fagus grandifolia* Ehrh.), sugar maple (*Acer saccharum* Marsh.), and yellow birch (*Betula alleghaniensis* Britton). Trees associated with yellow-poplar in non-mountainous areas of the North and Midwest include white oak, black oak (*Quercus velutina* Lam.), northern red oak, white ash, beech, sugar maple, blackgum, flowering dogwood, and hickories.

The successful regeneration of yellow-poplar by natural means requires adequate seed, a seedbed of exposed mineral soil, and direct sunlight (17), or trees capable of producing stump sprouts.

The first requirement, adequate seed, is seldom a problem on sites capable of growing yellow-poplar where even a few seed-producing trees are available. Large seed crops of up to 1.5 million seeds per acre (607 030/ha) are produced annually in yellow-poplar stands (17). Viable seed is disseminated from mid-October to mid-March; the percentage of viability, which ranges from 5 to 20 percent, is about equal throughout the seedfall period. The individual winged samaras may be scattered by the wind to distances equal to four or five times the height of the seed-bearing tree. Distribution of seed is usually satisfactory up to 3 chains (198 ft, 60 m) from a good seed tree in the direction of the prevailing wind and 1.5 chains (99 ft, 30 m) in all other directions (29). In addition, seed may be stored in the forest floor for up to 8 years and germinate and grow when proper conditions of light and moisture are created (8).

Scarification and fire, which puts seed in contact with mineral soil, significantly increases the number of seedlings as compared to an undisturbed forest floor (11, 14, 21, 29). However, under normal conditions, the site disturbance caused by harvesting a mature stand is the only seedbed preparation needed to provide enough yellow-poplar seedlings for a new stand. The amount of regeneration obtained increases directly as the intensity of the harvest cut, with complete stand removal yielding the highest stocking.

After germination, several critical years follow. Although rated intolerant of shade, yellow-poplar seedlings reach maximum or near-maximum photosynthetic efficiency at relatively low-light intensities (17, 18). During the establishment period, protection from dying, frost heaving, and flooding may be more important than light requirements. After the first few growing seasons, vegetative competition may become the most important factor affecting survival and growth.

Prolific sprouting from stumps adds considerably to the ability of yellow-poplar to reproduce. Percentage of stumps sprouting and the number of sprouts per stump decreases with increasing age and size of stump. However, trees of the age and size being harvested in second-growth stands can be expected to produce at least one stem that is of low origin, well anchored, vigorous, and capable of producing a high-quality tree (1, 26, 27, 28).

Because of its seed-production characteristics and its sprouting ability, yellow-poplar is readily regenerated by natural means (15). Growth characteristics of yellow-poplar indicate that it can best be grown under even-aged stand conditions although there is considerable leeway in choosing regeneration methods (5). On suitable sites where yellow-poplar is present, harvest of the mature stand by clearcutting, small patch cuts, group selections, or shelterwood cuts will usually ensure establishment of yellow-poplar regeneration. The minimum-size opening that can be used to establish yellow-poplar seedlings is fairly small. Research has shown little difference in number of seedlings per acre in openings ranging from 0.125 to 5 acres (0.1 to 2.0 ha) in size (20). However, opening size has a significant effect on growth of seedlings after establishment. Both diameter and height were found to be significantly smaller in openings less than 0.5 acre (0.20 ha) in size than in larger openings (22, 23). All openings, regardless of size, are bordered by a zone where growth of reproduction is retarded; this zone may extend from 10 to 30 feet (3.0 to 9.1 m) from boles of surrounding trees. Thus, the percentage of the area in the restrictive zone increases greatly for openings smaller than about 0.5 acre (0.2 ha).

Although the shelterwood cut can be used to establish yellow-poplar, height growth is severely limited by the remaining overstory (16, 20). Rapid height growth does not begin until the overwood is removed, and the removal of overwood should probably be made within 5 years of seedling establishment.

The seed-tree method can be used to regenerate yellow-poplar; however, the method has little to recommend it. Plentiful seed are usually present on the site or blown in from surrounding stands. The seed trees afford limited protection to the site and provide uneconomical logging conditions for tree removal. Regeneration cutting by single-tree selection is not a suitable method for regenerating yellow-poplar. Although some reproduction will become established, it will not develop satisfactorily under fully stocked stands.

Treatment of stems left after commercial logging is essential to successful development of yellow-poplar reproduction. Some stands that have carried high stocking up to the time of the final harvest cut may have relatively few unmerchantable stems left after logging where a good pulpwood market is available. But, in the typical case, there will be numerous stems of the more tolerant understory species such as dogwood, red maple, and hornbeam (*Carpinus* L.) left after commercial logging. This residual material can significantly reduce growth of yellow-poplar (30).

Cull and nonmerchantable stems may be controlled before, during, or after the commercial logging operations. A wide range of techniques is available that may vary from simple felling nonmerchantable stems with saws, chemical control by injection or basal spray, and mechanically knocking down leftover material with bulldozers. Burning is also a viable option. Complete elimination of competition is not necessary. Cutting back, or top-kill, is usually sufficient to allow yellow-poplar seedlings to get ahead of the competition. Where yellow-poplar sprouts are abundant, less competition control is needed.

Although yellow-poplar has not been planted on a large-scale, commercial basis, it is biologically and technically feasible to do so with procedures widely used for other species (19). Key requirements for planting yellow-poplar are: selection of suitable sites; adequate control of competing vegetation; and use of the best planting technology, including high-quality seedlings, careful stock handling, and choice of appropriate seasons and methods of planting.

Yellow-poplar expresses dominance well and seldom, if ever, stagnates because of excessive stand density. It prunes very well in closed stands, and while it will produce epicormic sprouts when the bole is exposed, this is a minor problem compared with many hardwood species. The problem of epicormic sprouts can be further minimized by favoring vigorous trees that show little tendency toward epicormic development before thinning. Because of these growth charactertistics, yellow-poplar stands can develop and produce considerable quantities of large, high-quality products with no intermediate stand management (2).

In the seedling-sapling stage, dominant and codominant trees are little affected by thinning or cleaning (13, 24). Intermediate or overtopped trees of good vigor will respond to release in both diameter and height growth (30). However, cultural treatment of seedling-sapling stands is seldom needed or justified except for removal of vines where they are a problem (9, 25).

By the time stands reach pole size at 20 to 30 years of age, the peak rates of growth and mortality are past and the crown canopy is closed. Crown size on surviving trees is reduced and diameter growth is considerably slowed. Thinnings done to salvage or prevent mortality, increase the growth of residual trees, shorten rotations based upon tree size, and increase the yield of high-value timber products are practical cultural operations in intermediate stand management. The net result of numerous thinning experiments is that residual yellow-poplar trees rapidly utilize space and accelerate diameter increment (3, 4, 6, 17). Response will occur across a wide range of sites and stand ages, even in stands as old as 80 years that have never been thinned. Total cubic-volume growth is greatest at the highest densities and cubic yields would be maximized by very light, frequent thinnings that salvage anticipated mortality. Mean annual increment in total cubic volume ranges from 75 to 165 cubic feet per acre (5.2 to 11.5 m^3/ha) on sites 82 to 115 feet (25.0 to 35.1 m) respectively, at culmination of approximately 70 years. On the other hand, board-foot volume growth is maximum at densities well below those that maximize cubic-foot volume growth.

Board-foot growth is near maximum over a wide range of densities. Thus, there is considerable leeway to manipulate stocking levels to achieve diameter growth and quality goals without sacrificing volume growth of the high-value products (5).

There are numerous insects and disease organisms that can damage or kill yellow-poplar throughout its lifespan. However, except in rare instances, they are of insufficient importance to appreciably alter management practices. Fire and vines are particularly damaging to young stands and may require special protection measures and treatment (24). Glaze damage occurs in many areas and may alter management practices in zones where glaze storms are prevalent (7).

Yellow-poplar has nominal value as a source of wildlife food when compared to many of the species with which it is associated. Its seeds are eaten by a variety of animals and birds but it is not considered a critical food supply for any of them. Deer will browse yellow-poplar but it is not a highly preferred species (10), however, it has distinctive value as a source of nectar for honey bees. Yellow-poplar is an excellent ornamental for parks and for landscape plantings where there is adequate space to accommodate its large size. Its green leaves and distinctive flowers and seed clusters complement its statuesque appearance.

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Glossary

Definitions contained in this glossary are based on those that appear in the 1971 edition of *Terminology of Forest Science, Technology, Practice and Products*, published by the Society of American Foresters and prepared in conjunction with the Joint Food and Agriculture Organization/ International Union of Forestry Research Organizations Committee on Forestry Bibliography and Terminology.[1] In rare instances where definitions were not available from *Terminology of Forest Science, Technology, Practice and Products*, composites were prepared from other sources.

A silvicultural system is sometimes confused with the regeneration cutting after which it is named. The following excerpt explains why this confusion is so prevalent in the literature, regulations, and legislation concerning silvicultural practices.[2]

> "The main—but not the only—treatments making up silvicultural systems, involve the cutting or felling of trees. Cuttings are commonly divided into those that help to reproduce forest stands (reproduction or harvest cuttings) and those that maintain vigor and desired composition and structure of the stands in terms of tree species, ages, and size classes (intermediate cuttings).
>
> Reproduction cuttings have such a great influence on the character and management of the new stand—and the forest as a whole—that silvicultural systems are generally named after them. The major systems used in the United States are clearcutting, seed-tree, shelterwood, single-tree selection, and group selection. Each system includes reproduction cuttings to establish seedlings and intermediate treatments to culture the developing stand."

Advance growth—Young trees that have become established naturally before regeneration cuttings are begun, or a clearcutting is made.

All-aged—A condition of a forest or stand that contains trees of all, or almost all, age classes.

Area regulation—An indirect method of controlling (and roughly determining) the amount of forest produce to be harvested periodically on the basis of stocked area.

Basal area—The area of the cross-section of a tree inclusive of bark at breast height (4.5 feet or 1.37 meters above the ground) most commonly expressed as square feet per acre or square meters per hectare. For a stand, basal area is computed from all living trees.

Biomass—The total quantity, at a given time, of living organisms of one or more species usually expressed in weight per unit area.

Cleaning—Elimination or suppression of competing vegetation from stands not past the sapling stage (2 to 4 inches (5 to 10 centimeters) in diameter as measured 4.5 feet or 1.37 meters above the ground); specifically, removal of (a) weeds, climbers, or sod-forming grasses, as in plantations or (b) trees of similar age or of less desirable species or form than the crop trees which they are, or may soon be, overtopping.

Clearcutting—The cutting method that describes the silvicultural system in which the old crop is cleared over a considerable area at one time. Regeneration then occurs from (a) natural seeding from adjacent stands, (b) seed contained in the slash or logging debris, (c) advance growth, or (d) planting or direct seeding. An even-aged forest usually results.

Climax forest—A plant community that represents for its locality and its environment the culminating stage of a natural succession. When the culminating stage is influenced by topography, it is termed a topographic climax and when maintained by regular fires, it is termed a fire climax.

Co-dominant—A tree with its crown in the upper forest canopy but less free than the dominant trees and freer and taller than the intermediates and suppressed trees. A crown class.

Composition—The representation of tree species in a forest stand, expressed quantitatively as percent by volume or basal area of each species, or as percent by number only in seedling stands.

Coppice—A regeneration method in which standing trees are cut and subsequent crops originate mainly from adventitious or dormant buds on living stumps but also as suckers from roots and rhizomes.

Crop—The major woody growth on a forested area.

Crop tree—A tree that forms, or is selected to form, a component of the final crop, specifically, one selected to be carried through to maturity. Also known as a final crop tree or growing stock tree.

Crown class—Any class into which trees of a stand may be divided based on both their crown development and crown position relative to crowns of adjacent trees. Commonly used crown classes are dominant, co-dominant, intermediate, and suppressed.

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[1] Society of American Foresters. Terminology of Forest Science, Technology, Practice and Products. Washington, DC: Society of American Foresters; 1971. 349 p.

[2] Society of American Foresters. Choices in Silviculture for American Forests. Washington, DC: Society of American Foresters; 1981: 2–3.

Culmination of mean annual increment—For a tree or stand of trees, the age at which the average annual increment is greatest. It coincides precisely with the age at which the current annual increment just equals the mean annual increment of the stand and thereby defines the rotation of a fully stocked stand that yields the maximum volume growth.

Cutting method—Describes cuttings used either to help reproduce forest stands (reproduction or harvest cuttings) or to maintain their vigor and desired composition and structure in terms of tree species, ages, and size classes (intermediate cuttings).

Dominant—A tree with its largely free-growing crown in the uppermost layers of the forest canopy. A crown class.

Epicormic—A type of branch or shoot arising from an adventitious or dormant bud on a stem or branch of a woody plant. Also called an epicormic branch, epicormic shoot, or water sprout.

Even-aged management—The application of a combination of actions that results in the creation of stands in which trees of essentially the same age grow together. The difference in age between trees forming the main canopy level of a stand usually does not exceed 20 percent of the age of the stand at maturity. Regeneration in a particular stand is obtained during a short period at or near the time that a stand has reached the desired age or size for regeneration, and is harvested. Cutting methods producing even-aged stands are clearcut, shelterwood, or seed-tree.

Even-aged—The condition of a forest or stand composed of trees having no, or relatively small, differences in age, although differences of as much as 30 percent are admissable in rotations greater than 100 years of age.

Fire climax—(See **climax forest.**)

Group selection—The cutting method which describes the silvicultural system in which trees are removed periodically in small groups resulting in openings that do not exceed an acre or two in size. This leads to the formation of an uneven-aged stand in the form of a mosaic of age-class groups in the same forest.

Growing stock—All the trees growing in a forest or in a specified part of it, generally expressed in terms of number or volume.

Habitat type—The aggregate of all areas that support or can support the same primary vegetation at climax.

Habitat type series—All plant associations having the same potential dominant plant species at climax. Under forested conditions, trees are the dominant vegetation.

Harvest cutting—The felling of the final crop of trees either in a single cutting or in a series of regeneration cuttings. Generally, the removal of financially or physically mature trees, in contrast to cuttings that remove immature trees. Also referred to as main felling and major harvest.

Improvement cutting—The elimination or suppression of less valuable trees in favor of more valuable trees, typically in a mixed, uneven-aged forest.

Individual (single) tree selection—The cutting method that describes the silvicultural system in which trees are removed individually, here and there, each year over an entire forest or stand. The resultant stand usually regenerates naturally and becomes all-aged.

Intermediate—A tree of the middle canopy dominated by others in the dominant and co-dominant crown classes. A crown class.

Intermediate cutting—Any removal of trees from a stand between the time of its formation or establishment and the harvest cut. Generally taken to include cleaning, thinning, liberation and improvement cuttings, increment felling, and sometimes even salvage and sanitation cuttings.

Intolerance—Trees unable to survive or grow satisfactorily under specific conditions, most commonly used with respect to their sensitivity to shade but also to conditions such as wind, drought, salt, and flooding.

Mean annual increment—The total increment of trees in a stand up to a given age divided by that age, usually expressed in annual cubic feet of growth per acre (cubic meters of growth per hectare).

Nurse crop—A crop of trees, shrubs, or other plants naturally occurring or artifically introduced to foster another, and generally more important crop, during its youth by protecting it from frost, insolation, or wind.

Overstory—The trees in a forest of more than one story that form the upper or uppermost canopy layer.

Pioneer—A plant capable of invading bare sites (that is, a newly exposed soil surface) and persisting there until supplanted by successor species. A species planted to prepare a site for such successor species and therefore, a nurse crop.

Preparatory cutting—The removal of trees near the end of a rotation, which permanently opens the canopy and enables the crowns of seed bearers to enlarge, to improve conditions for seed production and natural regeneration. Typically done in the shelterwood system.

Progressive clear-strip cutting—A shelterwood system with clearcutting in strips (usually not wider than the height of adjoining trees) generally progressing against the prevailing wind.

Quadrat—A small, clearly demarcated, sample area of known size (usually a square decimeter, a square meter, or a milacre (43.56 ft^2 or 4.05 m^2) on which ecological observations are made.

Regeneration—The renewal of a tree crop whether by natural or artificial means. Also the young crop itself which commonly is referred to as reproduction.

Regeneration cutting—Any removal of trees intended to assist regeneration already present or to make regeneration possible.

Release—Freeing a tree or group of trees from competition by cutting or otherwise eliminating growth that is overtopping or closely surrounding them.

Salvage cutting—The exploitation of trees that are dead, dying, or deteriorating (e.g., because they are overmature or have been materially damaged by fire, wind, insects, fungi, or other injurious agencies) before their timber becomes worthless.

Sanitation cutting—The removal of dead, damaged, or susceptible trees done primarily to prevent the spread of pests or pathogens and so promote forest hygiene.

Scarification—Loosening of the topsoil of open areas, or breaking up the forest floor, in preparation for regenerating by direct seeding or natural seedfall.

Seed cutting—Removal of trees in a mature stand to effect permanent openings in the canopy (if not done in a preparatory cutting) and thereby provide conditions for securing regeneration from the seed of trees retained for this purpose. Also the first of the shelterwood cuttings.

Seed-tree—The cutting method that describes the silvicultural system in which the dominant feature is the removal of all trees in one cut except for a small number of seed bearers left singly or in small groups, usually 8 to 10 per acre (20 to 25 per hectare). The seed trees generally are harvested when regeneration is established. An even-aged stand results.

Selection—(See **group selection** and **individual (single) tree selection.**)

Serotinous—A term applied to plant species or individuals that flower or fruit late in the season and to fruit or cones that remain on the tree without opening for one or more years (as the serotinous cones of jack pine, lodgepole pine, and the Ocala variety of sand pine).

Shelterwood—The cutting method that describes the silvicultural system in which, in order to provide a source of seed and/or protection for regeneration, the old crop (the shelterwood) is removed in two or more successive shelterwood cuttings. The first cutting is ordinarily the seed cutting, though it may be preceded by a preparatory cutting, and the last is the final cutting. Any intervening cutting is termed removal cutting. An even-aged stand results.

Silvicultural system—A process whereby forests are tended, harvested, and replaced, resulting in a forest of distinctive form. Systems are classified according to the method of carrying out the fellings that remove the mature crop with a view to regeneration and according to the type of forest thereby produced.

Single tree selection—(See **individual tree selection.**)

Site—An area considered in terms of its environment as determined by the type and quality of the vegetation it can carry.

Site class—A measure of the relative productive capacity of a site based upon the volume or height (dominant, co-dominant, or mean) or the maximum mean annual increment of a stand that is attained or attainable at a given age.

Site index—A measure of site class based upon the height of the dominant trees in a stand at an arbitrarily chosen age, most commonly at 50 years in the East and 100 years in the West.

Stand—A community of naturally or artificially established trees of any age sufficiently uniform in composition, constitution, age, spatial arrangement, or condition to be distinguishable from adjacent communities thereby forming a silvicultural or management entity.

Stand density—A measure of the degree of crowding of trees within stocked areas, commonly expressed by various growing-space ratios such as crown length to tree height, crown diameter to diameter at breast height (4.5 feet or 1.37 meters above the ground), or crown diameter to tree height, or of stem (triangular) spacing to tree height.

Stocking—A measure of the proportion of the area in a stand actually occupied by trees expressed in terms of stocked quadrats or percent of canopy closure (as distinct from their stand density).

Structure—Of a forest, crop, or stand, the distribution and representation of age and/or size (particularly diameter) classes, and of crown and other tree classes.

Succession—The gradual supplanting of one community of plants by another.

Suppressed—One of the four main crown classes. Very slowly growing trees with crowns in the lower layer of the canopy and leading shoots not free. Suppressed trees are subordinate to dominant, co-dominant, and intermediates in the crown canopy.

Thinning—A felling made in an immature stand primarily to maintain or accelerate diameter increment and also to improve the average form of the remaining trees without permanently breaking the canopy. An intermediate cutting.

Thinning from above—A thinning that favors the most promising (not necessarily the dominant) stems, with due regard to even distribution over the stand, by removing those trees that interfere with them.

Thinning from below—A thinning that favors the dominants or selected dominants more or less evenly distributed over the stand by removing a varying proportion of the other trees.

Topographic climax—(See **climax forest.**)

Understory—Trees and woody species growing under an overstory.

Uneven-aged management—The application of a combination of actions needed to simultaneously maintain continuous high-forest cover, recurring regeneration of desirable species, and the orderly growth and development of trees through a range of diameter or age classes. Cutting methods that develop and maintain uneven-aged stands are single tree selection and group selection.

Uneven-aged—The condition of a forest, crop, or stand composed of intermingling trees that differ markedly in age. In practice a minimum age difference of 25 percent of the length of the rotation usually is used.

Volume regulation—A direct method of controlling and determining the amount of timber to be periodically cut by calculations based upon growing stock volume and increment, disregarding area.

Yield—The amount of forest produce that may be harvested periodically from a specified area over a stated period in accordance with the objectives of management.

English to Metric Conversion Factors

English Unit	×	Conversion Factor	=	Metric Unit
inch	(in)	25.4000	millimeter	(mm)
		2.5400	centimeter	(cm)
foot	(ft)	0.3048	meter	(m)
yard	(yd)	0.9144	meter	(m)
mile	(mi)	1.6093	kilometer	(km)
ounce (avdp)	(oz)	28.3495	gram	(g)
pound (avdp)	(lb)	453.5924	gram	(g)
		0.4536	kilogram	(kg)
ton	(ton)	0.9072	tonne	(t)
ounce (fluid)	(oz)	0.0296	liter	(1)
pint	(pt)	0.4732	liter	(1)
quart	(qt)	0.9464	liter	(1)
gallon	(gal)	3.7854	liter	(1)
square inch	(in^2)	6.4516	square centimeter	(cm^2)
square foot	(ft^2)	929.0341	square centimeter	(cm^2)
		0.0929	square meter	(m^2)
square yard	(yd^2)	0.8361	square meter	(m^2)
acre	(acre)	0.4047	hectare	(ha)
cubic inch	(in^3)	16.3871	cubic centimeter	(cm^3)
cubic foot	(ft^3)	0.0283	cubic meter (stere)	(m^3)
square feet per acre	(ft^2/acre)	0.2296	square meter per hectare	(m^2/ha)
board feet per acre	(fbm/acre)	0.0140	cubic meter per hectare	(m^3/ha)
cord per acre (cord = 90 ft^3)	(cord/acre)	6.2975	cubic meter per hectare	(m^3/ha)
cubic feet per acre	(ft^3/acre)	0.0700	cubic meter per hectare	(m^3/ha)
pound per square inch	(lb/in^2)	70.3067	gram per square centimeter	(g/cm^2)
pound per square foot	(lb/ft^2)	4.8824	kilogram per square meter	(kg/m^2)
pound per cubic foot	(lb/ft^3)	16.0185	kilogram per cubic meter	(kg/m^3)
pound per cubic yard	(lb/yd^3)	3.9543	kilogram per cubic meter	(kg/m^3)
pound per acre	(lb/acre)	1.1208	kilogram per hectare	(kg/ha)

Lists of Common and Scientific Names

Birds[1]

Common Name	Scientific Name
(American) bald eagle	*Haliaeetus leucocephalus* (Linnaeus)
(American) osprey	*Pandion haliaetus* (Linnaeus)
American Swallow-tailed kite	*Elanoides forficatus forficatus* (Linnaeus)
American woodcock	*Scolopax minor* (Gmelin)
Bachman's sparrow	*Aimophila aestivalis* (Lichtenstein)
Bay-breasted warbler	*Dendroica castanea* (Wilson)
Black-and-white warbler	*Mniotilta varia* (Linnaeus)
Black-backed woodpecker	*Picoides arcticus* (Swainson)
Black-throated green warbler	*Dendroica virens* (Gmelin)
Blackburnian warbler	*Dendroica fusca* (Muller)
Bobwhite	*Colinus virginianus* (Linnaeus)
Brown-headed nuthatch	*Sitta pusilla* (Latham)
Cape May warbler	*Dendroica tigrina* (Gmelin)
Chickadee	*Parus* species (Linnaeus)
Chipping sparrow	*Spizella passerina* (Bechstein)
Clark's nutcracker	*Nucifraga columbiana* (Wilson)
Common yellowthroat	*Geothlypis tricha* (Linnaeus)
Common redpoll	*Carduelis flammea* (Linnaeus)
Crossbill	*Loxia* species (Linnaeus)
Ducks	*Anas* species (Linnaeus)
Great gray owl	*Strix nebulosa* (Forster)
Kinglet	*Regulus* species (Cuvier)
Kirtland's warbler	*Dendroica kirtlandii* (Baird)
Magnolia warbler	*Dendroica magnolia* (Wilson)
Merriam's turkey	*Meleagris gallopavo merriami* (Nelson)
(Mississippi) sandhill crane	*Grus canadensis pratensis* (Meyer)
Mourning dove	*Zenaida macroura* (Linnaeus)
Nashville warbler	*Verminvora ruficapilla* (Wilson)
Northern parula warbler	*Parula americana* (Linnaeus)
Peregrine falcon	*Falco peregrinus* (Tunstall)
Pheasant	*Phasianus colchicus* (Linnaeus)
Pileated woodpecker	*Dryocopus pileatus* (Linnaeus)
Pine grosbeak	*Pinicola enucleator* (Linnaeus)
Pine siskin	*Carduelis pinus* (Wilson)
Pine warbler	*Dendroica pinus* (Wilson)
Red-breasted nuthatch	*Sitta canadensis* (Linnaeus)
Red-cockaded woodpecker	*Picoides borealis* (Vieillot)
Ruby-crowned kinglet	*Regulus calendula* (Linnaeus)
Ruffed grouse	*Bonasa umbellus* (Linnaeus)
Song sparrow	*Melospiza melodia* (Wilson)
Spruce grouse	*Dendrogapus canadensis* (Linnaeus)
Turkey	*Meleagris gallopavo* (Linnaeus)
Veery	*Catharus fuscescens* (Stephens)
Waxwing	*Bombycilla* species (Vieillot)
White-throated sparrow	*Zonotrichia albicollis* (Gmelin)
Yellow-bellied sapsucker	*Sphyrapicus varius* (Linnaeus)

[1] Sources: American Ornithologists' Union. Checklist of North American Birds. Fifth edition. Lawrence, KS: American Ornithologist Union; 1957. 691 p. and Association of Systematics Collections. Checklist of Birds of the United States and the U.S. Territories. (Prepared for the U.S. Department of the Interior, Fish and Wildlife Service, Office of Biological Services.) Lawrence, KS: Association of Systematics Collections. 31 p.

Animals[2]

Common Name	Scientific Name
Abert's squirrel	*Sciurus aberti aberti* (Woodhouse)
Antelope (pronghorn)	*Antilocapra americana* (Ord)
Beaver	*Castor canadensis* (Kuhl)
Black bear	*Ursus americanus* (Pallas)
Canadian lynx	*Lynx canadensis* (Kerr)
Chipmunk	*Tamias striatus* (Linnaeus)
Coyote	*Canis latrans* (Say)
Deer mouse	*Peromyscus maniculatus* (Wagner)
Elk	*Cervus* species (Linnaeus)
Fisher	*Martes pennanti* (Erxleben)
Florida panther (puma)	*Felis concolor coryi* (Bangs)
Fox	*Urocyon* species (Baird) or *Vulpes* species (Bowdich)
Fox squirrel	*Sciurus niger* (Linnaeus)
Gray squirrel	*Sciurus carolinensis* (Gmelin)
Gray wolf	*Canis lupus* (Linnaeus)
Grizzly bear	*Ursus arctos* (Linnaeus)
Hare, snowshoe	*Lepus americanus* (Erxleben)
Kaibab squirrel	*Sciurus aberti* (Woodhouse)
Marten	*Martes americana* (Turton)
Meadow vole	*Microtus pennsylvanicus* (Ord)
Moose	*Alces alces* (Linnaeus)
Mountain beaver	*Aplodontia rufa* (Rafinesque)
Mule deer	*Odocoileus hemionus hemionus* (Rafinesque)
Opossum	*Didelphis virginiana* (Kerr)
Pine marten	*Martes americana* (Turton)
Pocket gopher	*Thomomys* species (Wied)
Porcupine	*Erethizon dorsatum* (Linnaeus)
Rabbit	*Sylvilagus* species (Gray)
Racoon	*Procyon lotor* (Linnaeus)
Red squirrel	*Tamiasciurus hudsonicus* (Erxleben)
Red-backed vole	*Clethrionomys gapperi* (Vigors)
Rocky Mountain elk	*Cervus elaphus* (Linnaeus)
Skunk	*Mephitis* species (E. Geoffrey St. Hilaire and G. Cuvier) or *Spilogale* species (Gray)
Squirrel	*Sciurus* species (Linnaeus)
Timber wolf	*Canis lupis* (Linnaeus)
Tree squirrels	*Sciurus* species (Linnaeus)
White-footed mouse	*Peromyscus leucopus* (Rafinesque)
White-tailed deer	*Odocoileus virginianus* (Zimmerman)
Wild horse	*Equus* species (Linnaeus)
Woodrat	*Neotoma* species (Say and Ord)

[2] Sources: Hall, E. Raymond. Mammals of North America. New York, NY: John E. Wiley and Sons. 1981. 1,175 p. and Association of Systematics Collections. Checklist of Mammals of the United States and the U.S. Territories. (Prepared for the U.S. Department of the Interior, Fish and Wildlife Service, Office of Biological Services.) Lawrence, KS: Association of Systematics Collections; 1982. 31 p.

Amphibians and Reptiles[3]

Common Name	Scientific Name
Eastern Indigo snake	*Drymarchon corais couperi* (Holbrook)
Pine Barrens treefrog	*Hyla andersoni* (Baird)
Red Hills salamander	*Phaeognathus hubrichti* (Highton)
Ringed sawback turtle	*Graptemys oculifera* (Baur)

Fishes[4]

Common Name	Scientific Name
Arizona or Apache trout	*Salmo apache* (Miller)
Gila trout	*Salmo gilae* (Miller)
Lake sturgeon	*Acipenser fulvescens* (Rafinesque)
Trout	*Salmo* species and/or *Salvelinus* species

[3] Sources: Collins, J. T.; Huheey, J. E.; Knight, J. L.; Smith, H. M. Standard Common and Scientific Names for North American Amphibians and Reptiles. Lawrence, KS: Society for the Study of Amphibians and Reptiles. 1978. 36 p. and Association of Systematics Collections. Checklist of Reptiles and Amphibians of the United States and the U.S. Territories. (Prepared for U.S. Department of the Interior, Fish and Wildlife Service, Office of Biological Services.) Lawrence, KS: Association of Systematics Collections; 1982. 33 p.

[4] Source: American Fisheries Society. A List of Common and Scientific Names. Names of Fishes from the United States and Canada. Fourth Edition. Special Publ. No. 12. Bethesda, MD: American Fisheries Society; 1980. 174 p.

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