Silvicultural Systems
for the Major Forest Types
of the United States

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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 for each of 37 major forest types in the United States the silvicultural systems that appear biologically feasible on the basis of present knowledge. Supporting information is given on the occurrence of the 37 forest types, the cultural requirements of the component species, and the biological factors that control the choice of silvicultural options. The text is arranged in regional sections suitable for reprinting.

Oxford: 221, 228, 231. Key Words: silviculture, forest types, species, multiple use.

Cover Photo: Even-aged management in the Pacific Ponderosa Pine type by the Seed-tree System (Challenge Experimental Forest, California).

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INTRODUCTION

The forests of the United States are coming under increasing pressure to provide more and better products and benefits to more and more people. This pressure has accelerated the development of procedures for multi-purpose 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 for each of 37 major forest types the silvicultural systems that appear biologically feasible on the basis of present knowledge.

Great public interest now 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 suitable 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. This system is esthetically pleasing, but is difficult to apply successfully unless the stand structure is favorable. The two types of selection are uniform or individual tree selection and group selection.

a. *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.

b. *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.

All of the remaining 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. 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 which perpetuate any of these species are more acceptable.

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 THAT INFLUENCE 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]

Wildlife requirements and problems are important in the choice of cultural measures, and also in the choice of silvicultural systems. 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 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. But protection against insects, such as shoot weevils of certain pines, is aided by 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

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[1] U.S. Department of Agriculture, Forest Service. 1965. Silvics of Forest Trees of the United States. U.S. Dep. Agric. Handb. 271, 762 p. U.S. Gov. Printing Off., Wash., D.C. $8.25.

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 which 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 manpower, equipment, and capital, and also 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 remainder of this publication 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.

PACIFIC NORTHWEST TYPES

Western Hemlock–Sitka Spruce
Coastal Douglas-fir
Mixed Conifers of Southwestern Oregon
True Fir–Mountain Hemlock
Mixed Pine–Fir of Eastern Oregon and Washington
Northwestern Ponderosa Pine
Interior Alaska White Spruce
Interior Alaska Hardwoods

WESTERN HEMLOCK–SITKA SPRUCE

by Robert H. Ruth and A. S. Harris
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Hemlock–spruce forests occupy a coastal strip 2,000 miles long, extending from northern California to Prince William Sound, Alaska. The portion within the United States (Alaska, Washington, Oregon, and California) totals about 10 million acres. Toward the south, there is an admixture of redwood, Douglas-fir, red alder, western redcedar, Pacific silver fir, and lodgepole pine; toward the north and west, Alaska-cedar and mountain hemlock. Coastal forest stands are very dense, and timber volumes per acre in natural stands are among the highest in North America.

Climate within the coastal hemlock–spruce forest type is characterized by moderate temperatures, heavy precipitation, prolonged cloudiness, and frequent summer fog. Extended summer droughts are lacking. Average annual temperature and length of growing season decrease northward, as does fire hazard. Storm winds often sweep in from the Pacific Ocean causing repeated wind damage. Uprooting of trees is severe where a high water table, impervious soil layer, or thin soil over bedrock causes trees to be shallow rooted. Other high-hazard areas exist where topography constricts the wind and increases its velocity.

Western hemlock, the main component of the type, is a prolific seeder. In Oregon and Washington it produces some seed most years with heavier crops every 3 to 4 years. In Alaska a heavy crop occurs every 5 to 8 years. The seed is very small and is disseminated considerable distance by the wind. Germination under forest conditions is excellent on such diverse material as moss, humus, decaying litter, and mineral soil.

Sitka spruce is also a good seed producer. Some seed is produced nearly every year. Substantial crops develop every 3 or 4 years in Oregon and Washington, and 5 to 8 years in Alaska. Dissemination of the seed is wide. Sitka spruce will germinate on almost any kind of seedbed, including organic

substances, if moisture is abundant; but germination is best on mineral soil *(9)*. However, on young soils low in organic matter or clay content, subsequent survival and growth may be low.

Western hemlock is very shade tolerant. Sitka spruce is less shade tolerant and tolerance probably decreases northward. In general, hemlock responds well to release after long periods of suppression. Sitka spruce responds well in diameter growth but may not respond as well in height growth. Hemlock–spruce is often considered to be a climax type, but western hemlock probably represents the true climax *(9)*.

Clearcutting in units of 25 acres to several hundred acres is the most commonly used harvest-cutting system. Prompt natural forest regeneration usually follows with full stocking or overstocking of tree seedlings on harvested areas. Most seedlings originate after cutting from seed disseminated by surrounding stands. However, some seedlings, usually western hemlock, become established under the mature stand before cutting, survive the logging operation, and are released by it, thereby gaining a head start on the next rotation. Artificial regeneration by seeding or planting is used only in special situations, for example, to increase the proportion of spruce or to add a component of Douglas-fir. Control of competing vegetation plus planting may be necessary in some areas *(2, 4)*.

Large clearcuts decrease the length of cutting boundary exposed to the wind relative to the area clearcut and facilitate selection of windfirm stand borders. Progressive strip cutting toward storm winds helps to reduce wind damage in high-hazard areas *(6, 8)*. The present trend is to select carefully the location, reduce the size, and vary the shape of clearcuts to improve the appearance of harvest-cutting areas. Smaller clearcuts may also provide better wildlife habitat.

In areas where dwarf mistletoe is prevalent, understory hemlock seedlings are infected by a shower of seed from mistletoe in the crowns of overstory trees. In these situations, complete removal of the overstory and destruction of infected seedlings are needed to control the parasite *(7)*.

Even-aged coastal stands in Oregon and Washington can be regenerated by the shelterwood system *(5, 10)*. Of the main species, hemlock is the most shade tolerant; thus the leaving of an overstory, as in shelterwood cutting, is more favorable to hemlock than to spruce regeneration. Such cutting minimizes the reproduction of the moderately shade-tolerant Douglas-fir and the light-demanding red alder and lodgepole pine; it also provides some natural control of competing shrubs and herbaceous plants that spring up under full sunlight. In Alaska, experience with shelterwood cutting is lacking, but other partial cuttings have resulted in extremely dense regeneration, primarily western hemlock. Growth rate of western hemlock and Sitka spruce seedlings is far slower under partially cut stands than on clearcut areas; Sitka spruce, especially, is suppressed *(1)*.

In areas of high public use where esthetics are important, the shelterwood system has an advantage over clearcutting. However, the application of shelterwood cutting to areas of steep topography should await availability of improved logging techniques and equipment that will permit repeated operations in the residual stand without causing excessive damage. Areas having high blowdown hazard should be avoided unless repeated thinnings have developed windfirmness in the stand. Use of the shelterwood

system is limited in defective stands where cull logs become a physical obstacle to logging operations, and its use is not suited to areas infested with dwarf mistletoe. The shelterwood system is not yet feasible in Alaska because of the species composition, climate, terrain, and large proportion of overmature and defective trees.

The presence of seedlings in uneven-aged climax stands where individual trees or small groups have died is evidence that the selection system might be used in certain situations where timber production is not the major concern. Limited experience, however, has shown that old-growth hemlock–spruce stands have not responded well to selection cutting *(3)*. Nonetheless, selection cutting may have application where it is necessary to maintain a continuous forest canopy. Examples are campgrounds and other areas of high recreation use, scenic areas, streamside stands, and stands along highways. In these situations, individual mature trees as well as defective and diseased trees should be cut. Periodic removal of selected trees in reserved strips along streams can minimize blowdown across the streams.

The seed-tree system generally is impractical because exposed trees tend to uproot during late fall or winter storms.

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COASTAL DOUGLAS-FIR

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Coastal Douglas-fir is one of the world's most productive forest types. Within the United States, this type is generally restricted to areas west of the Cascade Range in Washington and Oregon, but it is also found on a more limited area in northwestern California. In total it covers about 17 million acres in areas which are humid or subhumid except for dry summers.

Coastal Douglas-fir requires moderate temperatures and mesic regimes, as shown by its presence commonly on southerly slopes in the northern portion of its range, and on northerly slopes in the southern part. Almost pure stands are more common in the central portion of its range than toward the periphery. The associates western hemlock and western redcedar appear more frequently in the west and north; true firs and mountain hemlock are more abundant at higher elevations *(9)*. To the south the type merges into the mixed conifers of southwest Oregon and California.

Douglas-fir rates as intermediate in shade tolerance but demands more light than its associates. It is usually a subclimax species. Left untouched, old-growth stands of Douglas-fir are usually replaced by more shade-tolerant trees, especially western hemlock, unless natural catastrophes such as wildfires and windthrow intervene. It is called a "fire" species because wildfire has often been involved in its natural regeneration. Fire may stimulate seed production, cause the release of seed from cones, eliminate competitors, and create a more suitable seedbed. Historically, wildfires have burned large areas, giving rise to extensive even-aged stands.

Poria root rot is the most important disease of coastal Douglas-fir. The disease occurs in patches up to an acre or more where affected trees die or are blown over alive *(1)*. Dwarf mistletoe, a very injurious parasite in many areas, is not a problem in coastal Douglas-fir, but is sometimes injurious to associated hemlock.

Occasionally, serious epidemics of the Douglas-fir bark beetle decimate large areas. This destructive insect often gets started in areas of heavy blowdown and then spreads to other stands.

Douglas-fir produces heavy seed crops at 5- to 7-year intervals and light to medium crops more frequently. Seed dissemination is variable and hard to predict *(9)*. Regeneration practices can mitigate extremes in temperature and light and assist in conserving moisture required for survival and growth of coastal Douglas-fir seedlings. Broadcast burning or scarification bares mineral soil which is the best seedbed for Douglas-fir *(5)*. Lethal soil surface temperatures are common on southerly slopes in the middle and southerly parts of the Cascade Range in Oregon *(2, 7)*. Height growth of seedlings increases with increasing amounts of light in partially cut stands *(3, 8)*. New seedlings benefit from light shade but once established, coastal Douglas-fir grows best in full sunlight *(9)*.

Silvical characteristics and regeneration requirements of coastal Douglas-fir all point toward use of even-aged management and a silvicultural system adapted to it: Clearcutting, seed-tree, or shelterwood. Clearcutting in

patches is the most commonly used system for harvesting coastal Douglas-fir. Under this system, slash disposal is easy, suitable seedbeds can be readily created for regeneration, and adequate light is provided for seedling development.

Failures in natural restocking have occurred, however, especially on hot dry south slopes and on areas where frost is a hazard or where seed source is inadequate *(6)*. Therefore, almost all clearcuttings are now regenerated artificially, and shelterwood cutting is used where stand and site conditions are suitable. Planting presents an opportunity to introduce genetically improved seedlings which are becoming increasingly available. Clearcutting in 50-acre patches or less favors big game by providing needed browse while still maintaining suitable cover in adjacent uncut areas. The present trend is to reduce the size of clearcuttings and to delineate cutting boundaries that blend with the landscape. These esthetic aspects are especially important in mountainous areas where recreational use has increased.

Recent trials of the shelterwood system have been successful in providing natural regeneration in portions of the high Cascades in Oregon, including some areas where regeneration, both natural and planted, has failed after clearcutting. Thus far, survival of residual stands has been excellent. In the few cuttings that are old enough for seedlings to have become established and the overstories removed, adequate regeneration has survived the removal. If natural regeneration is relied upon, preparation of mineral soil seedbeds is necessary to avoid conversion to less desirable associated species. Plantings may be necessary on steep ground where seedbed preparation is extremely difficult and on certain other sites where seedlings encounter a particularly hostile environment. Brush competition is more harmful to Douglas-fir than to the more shade-tolerant species; therefore, site preparation, even in planted areas, may be necessary. Shelterwood cuttings have special appeal where esthetics are important. They can be used effectively near areas of high recreation use, in scenic zones, and along major travel routes. Shelterwood stands should invariably consist of the most vigorous dominants and codominants. Shelterwood density should vary according to the protection requirements of seedlings, wind hazard, and esthetic requirements.

The seed-tree system, seldom used in coastal Douglas-fir, has little to recommend it. Its only advantage over clearcutting is more certainty of seed supply. Where seed crops are doubtful, artificial regeneration—planting or broadcast seeding—has been relied upon to obtain prompt regeneration. A major shortcoming of this method is the general susceptibility of Douglas-fir seed trees to windthrow or wind breakage, because seed-tree stands are so open that trees lack mutual protection from wind.

Extensive trials some 30 years ago, clearly showed that the selection system used in uneven-aged management cannot be applied successfully to old-growth coastal Douglas-fir *(5)*. Slash disposal is difficult because there is risk of killing standing trees, mortality in residual stands is high, and insufficient light is provided for Douglas-fir reproduction. The result is that stands are converted to more shade-tolerant and less desirable species *(4, 6)*. The method may have limited applicability in recreation areas if one is willing to accept these species.

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MIXED CONIFERS OF SOUTHWESTERN OREGON

by Don Minore

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Mixed conifer forests occupy about 4 million acres in southwestern Oregon *(7)*. They are located in a complex transition zone where the Douglas-fir forests of northwestern Oregon meet and mingle with the pine forests of northern California and eastern Oregon. Douglas-fir is the most abundant tree in most of this zone, but it seldom grows in pure stands, and associated species differ from north to south. In the north western hemlock is a common associate. Sitka spruce is also common in the north along a narrow coastal belt, and Port-Orford-cedar is present along the southern coast. In the interior, ponderosa pine, sugar pine, and incense-cedar become increasingly frequent from north to south *(6)*. Grand fir is an associate at low and moderate elevations but is replaced by white fir at high elevations. The less common Jeffrey pine, knobcone pine, California black oak, and canyon live oak appear with increasing frequency southward in the interior. Oregon white oak is present in the central valleys, and tanoak is common in the southwest.

The climate, topography, and geology of southwestern Oregon are as complex and varied as the composition of its forests. Annual precipitation varies from 70 to 100 inches along the coast to less than 20 inches in some interior valleys; mean July temperatures vary from 58° to 72° F. *(6)*. Mountains are responsible for much of this climatic variation. The Coast Range in the west, the Cascade Range in the east, and the Siskiyou Mountains

in the south isolate a lowland coastal belt and surround the interior valleys. Mountain topography is particularly steep and broken in the southwest. Large, infertile serpentine intrusions and pumice plateaus are examples of the extreme variations in parent material and soil type throughout the area *(4, 8, 14)*.

Moisture and temperature, not light, seem to be the limiting environmental factors that most influence stand composition and forest succession in southwestern Oregon. Moisture is particularly important *(5)*. Most of this area is dry, and the light-demanding but drought-resistant Douglas-fir reproduces and grows well in partial shade, usually without being overtopped by more shade-tolerant but less drought-resistant species. This contrasts with the coastal Douglas-fir type farther north where conditions favor shade-tolerant but moisture-demanding species such as western hemlock, Pacific silver fir, and western redcedar—often to the exclusion of Douglas-fir. In southwestern Oregon Pacific madrone and Oregon white oak often form nurse covers for Douglas-fir *(4, 12)*.

Observations on forest succession indicate that madrone and Oregon white oak are replaced by conifers. Among the conifers, ponderosa pine is replaced by Douglas-fir, and Douglas-fir is replaced by grand fir *(3)*. Grand fir seems to be the climax conifer where its moisture requirements are met. On drier sites, Douglas-fir probably is climax. On very dry sites a ponderosa pine climax occurs *(2)*.

The silvical characteristics and requirements of southwestern Oregon tree species differ greatly. Ponderosa pine is very intolerant of shade, and is drought resistant *(5)*. Sugar pine and Douglas-fir are more shade tolerant, but less drought resistant than ponderosa pine. Sugar pine will outproduce Douglas-fir in many environments *(7)*, but it is very susceptible to white pine blister rust. Douglas-fir is highly infested with dwarf mistletoe in many stands, particularly in the South Umpqua River drainage and south into northern California. Incense-cedar, commonly found with sugar pine and Douglas-fir, grows more slowly than either. It is more shade tolerant than sugar pine and Douglas-fir, but less so than grand fir *(13)*. Port-Orford-cedar is also more shade tolerant than either sugar pine or Douglas-fir, but less tolerant than grand fir *(1)*. It is very susceptible to root rot caused by *Phytopthora lateralis (11)*, which limits its future management in southwestern Oregon.

Similar species mixtures are present in dissimilar sections of the area, and climate and topography, more than species composition, dictate silvicultural practice. Therefore, no single silvicultural system or prescription is applicable throughout the mixed conifer forests of southwestern Oregon.

In the interior where seasonal frosts and drought are common, regeneration of tree seedlings is difficult to obtain when the overstory is completely removed. Except on unusually moist slopes below 4,000 feet, natural regeneration on clearcuts is unsuccessful, and there have been repeated plantation failures. Generally, clearcutting should be avoided; nor is seed-tree cutting suggested. Seed trees do not provide enough protective overstory, and are subject to windthrow. Moderate slopes in most of this interior area facilitate shelterwood cutting, which usually results in adequate regeneration. This method should be employed wherever the topography is suitable. Basal areas of at least 80 square feet per acre should be maintained

in the overstory until regeneration is established. Selection cutting is appropriate where continuous forest cover is needed. Selection cutting also provides an opportunity to leave oaks and other species desirable for wildlife. Tractor logging is usually practical where slopes do not exceed 35 percent; cable logging is recommended for steeper slopes. Shade should be provided wherever Douglas-fir is planted on hot, dry sites *(10)*.

In areas along the southern coast and in the western Siskiyou and southern Coast Range mountains, soil moisture is less limiting, and seasonal frosts are less serious. Here clearcutting followed by planting is successful. Dense brush understories, poor seed crops, and a high rodent population may eliminate the natural regeneration resulting from adjacent uncut stands or from seed-tree cutting. Planting and repeated herbicide treatments or other brush control measures are required. Tanoak understories greatly retard seedling growth if not removed by cutting or chemical treatment. Where Port-Orford-cedar is to be favored, clearcutting should be done in small units not more than 10 chains (660 feet) across *(9)*. The abundant brush cover and mild climate permit year-round animal activity, and deer, hare, and rabbit damage is a serious problem in this area. Control of animals as well as brush may be needed. Steep slopes and dense brush in the understory usually make shelterwood cutting and single-tree selection impractical, but if advance regeneration is present careful overstory removal can reduce subsequent planting requirements.

In areas along the northern coast and in the central Coast Range, slopes are less steep and brush problems less severe than farther south. Site quality is higher here than elsewhere in southwestern Oregon *(4)*. Most harvesting is accomplished by clearcutting, but shelterwood and selection systems are feasible in many stands and should be used where esthetic values are high. Seed-tree cutting is impractical here—exposed trees are often uprooted by winter storms. Regeneration is relatively easy to obtain, and planting usually is successful.

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TRUE FIR–MOUNTAIN HEMLOCK

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The true fir–mountain hemlock type is a diverse collection of subalpine forest types found on upper slopes of the Cascade Mountains and the Coast Range of the Pacific Northwest. They cover about 4 million acres over a broad spectrum of environmental conditions incorporating many species and stand conditions *(1, 2)*. Typically, the forests are overmature mixtures of three to eight species, with some long-lived pioneer species persisting in the overstory.

The more important tree species are noble fir, Douglas-fir, western white pine, Pacific silver fir, western hemlock, mountain hemlock, Shasta red fir, subalpine fir, and Engelmann spruce. The first three require considerable sunlight and mineral seedbeds to reproduce well *(7)*. Pacific silver fir and western hemlock, however, are shade tolerant and often form abundant advance regeneration under old-growth stands. The remaining species are generally intermediate in light requirements. Seed production does not appear to be a major problem in natural regeneration *(3)*, but the heavy true fir seeds have relatively short dispersal distances.

Pathogens, insects, and climate are significant constraints in the choice of silvicultural systems and of species to favor in management. Major insect and disease hazards are the balsam wooly aphid, which attacks Pacific silver and subalpine firs but not noble fir *(5)*, dwarf mistletoe (primarily on the

hemlocks), root rots, and white pine blister rust. Due to heartrots, western hemlock is highly defective, especially in the High Cascades *(1, 2)*. Heavy winter snowpacks and late spring and early fall frosts shorten the growing season and cause severe damage to regeneration. Warm, dry summers, particularly in high elevations of the Cascade Range in Oregon and southern Washington, accentuate climatic problems related to regeneration.

True fir–mountain hemlock forests can be managed either under even-aged or uneven-aged systems depending on the species composition and health of the stand. Where the more light-demanding trees predominate, the even-aged system is indicated. If the more shade-tolerant species are the more important, then either even-aged or uneven-aged management is possible provided the stand is not defective. Thus the choice will depend on stand and site conditions and management objectives.

Under even-aged management the most consistently satisfactory silvicultural systems are shelterwood and clearcutting in strips or patches. Noble fir, Douglas-fir, Shasta red fir, and western white pine are all well suited to shelterwood techniques which can be designed to provide sufficient light and seed for their regeneration, yet avoid the severe climatic conditions, such as frost, associated with clearcutting. In many mixed stands, foresters can favor establishment of desired species over their associates by selection of reserved trees and seedbed preparation. Where stand or physiographic conditions are unfavorable to shelterwood, as on steep slopes, narrow strip or small patch clearcuttings can be used for most species and, if properly practiced, will provide necessary conditions for seedling establishment. Small patch cuttings on gentle topography sometimes create frost pockets that damage regeneration; group selection cutting may prove superior in such areas, provided the stand structure is suitable.

Larger clearcuts, of 20 to 40 acres, may also be appropriate provided (1) dependable techniques are available for artificial regeneration of the desired species or (2) sufficient advance reproduction of acceptable species can be preserved during logging and slash disposal. Large clearcuttings in the true fir–mountain hemlock type followed by broadcast burning aggravate extremes of temperature and moisture, minimize seed supply, destroy advance regeneration, and sometimes result in brush problems. Regeneration failures have been more common in the High Cascades *(2)* and near the upper limits of continuous forests. Advance regeneration of most species responds well to release *(4, 6)* and can serve as insurance against reforestation failure even when planting or seeding is planned.

Forests of the more shade-tolerant Pacific silver fir and hemlocks are adapted to either even-aged or uneven-aged management. Thus, any standard silvicultural system (except reproduction by sprouts) can be used. Selection cutting may be especially applicable in areas where recreational and scenic values are high. Shelterwood cutting has very broad application, although clearcutting of such forests may also be appropriate in some areas provided that advance regeneration is present and will not be destroyed during logging and slash disposal. Techniques which leave a scattered overstory of Pacific silver fir are undesirable; this species, and to a lesser extent western hemlock, is subject to heavy mortality following exposure.

Stands near the upper edge of closed, continuous forests containing substantial amounts of mountain hemlock are relatively low in productivity

and harsh environmental conditions make regeneration very difficult to obtain. Scenic and watershed values, however, may be high. Where these conditions and values prevail, the option of leaving the stands uncut should be considered.

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MIXED PINE–FIR OF EASTERN OREGON AND WASHINGTON

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The principal species in the mixed pine–fir type of eastern Oregon and Washington are ponderosa pine, lodgepole pine, Douglas-fir, grand fir, and western larch. This type covers about 6 million acres in these two States on the east side of the Cascade Mountains and other ranges to the east. Stand structure and species composition of these forests are extremely variable, depending upon site, logging history, insect and disease attacks, and wildfire. At lower elevations, mixtures of ponderosa pine and Douglas-fir are common. Farther up the slope western larch and lodgepole pine form mixed stands, with or without grand fir or Douglas-fir in the understory. At higher elevations, this type gradually merges into the mountain hemlock–subalpine fir type.

The most important natural factor affecting present composition of these forests in wildfire. As a result of past fires, the present forests are generally even-aged; or at least two- or three-aged, having even-aged overstories and one or two age classes in the understory. In addition to bringing about even-aged forests, fire has retarded natural plant succession by

creating conditions favorable for the establishment of a diversity of pioneer plant species.

A disturbance such as fire or blowdown, which creates open areas, results in the establishment of light-demanding pines and larch. As succession proceeds, these species are gradually replaced by the more shade-tolerant Douglas-fir. At higher elevations, true firs will eventually form climax vegetation in absence of further disturbance since they are the most shade tolerant tree species in this type.

Silvical characteristics *(6)* of the species in this type and the natural trend of plant succession indicate general guidelines for obtaining regeneration. However, in such a variable forest type, each stand will present a somewhat different silvicultural problem. Thus, the prescription for its treatment must be developed for the specific area, integrating the existing physical, biological, economic, and social conditions.

Silvicultural systems which result in even-aged stands should be used in this forest type if timber production is an important objective. The ecological requirements of the pines and larch, the increasing markets for smaller material, and the necessity of removing large amounts of diseased timber, all indicate that even-aged management should be applied. This means that clearcutting, shelterwood, or seed-tree systems may be used when regeneration cuttings are needed, depending on the individual stand conditions.

The presence of dwarf mistletoe in many stands creates problems which limit the manager's choices *(7)*. If one or more species are uninfected, a seed-tree or shelterwood method may be used favoring the disease-free species. If all species are heavily infested in both the overstory and understory, there are two alternatives. The first, which can be used where there is little or no difficulty obtaining regeneration by planting, is to clearcut, prepare the site, and plant. Where esthetic conditions and wildlife are important, the clearcut areas should be small and shaped to the landscape. The second alternative appropriate for areas that are difficult to regenerate, is to use shelterwood to enhance seedling establishment. The final removal cut is made after the seedlings become established but before they become infected with dwarf mistletoe.

Another common condition in the mixed pine–fir type are stands having an overstory of larch or lodgepole pine with a true fir understory. In these situations, the regeneration is already established and the overstory can be removed in one or more cuts (similar to the final cuts in a shelterwood system) without destroying or damaging the understory. Unfortunately, removing the overstory using present logging methods is hazardous to the understory. Many of the trees not killed are damaged and may develop heart rot *(1, 3)*. Thus, in this forest type, improved logging techniques will have to be developed to utilize effectively the shelterwood system and to avoid excessive damage to the regeneration. Improved techniques will also be required to practice shelterwood cuttings on steep terrain with a minimum of soil disturbance.

In a healthy mature stand composed of several species having different degrees of shade tolerance, considerable flexibility exists for choice of silvicultural systems, depending on management objectives. If a considerable amount of larch or pine is desired in the new stand, clearcutting in small patches or the seed-tree or shelterwood method together with site preparation

by burning or scarifying would be suitable in order to provide sufficient light and mineral soil for these species *(4, 5)*. On the other hand, to favor Douglas-fir or true fir regeneration, shelterwood cutting that leaves a heavier residual density is indicated, particularly on adverse sites where heat or frost damage can be expected. Douglas-fir seedlings become established best in partial shade but grow best in full sunlight. Therefore, the overstory should be removed as soon as possible after the regeneration has become established *(2)*.

In areas of high recreational value such as around campgrounds or roadsides, the selection system could be used in disease-free stands if stand structure and composition are suitable and the conversion to more shade-tolerant species is not objectionable.

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NORTHWESTERN PONDEROSA PINE

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The ponderosa pine type in the Northwest covers about 12 million acres in eastern Oregon and Washington and additional areas of quite similar forest in northeastern California. Its range encompasses great diversity in climate, topography, and site quality, and consequently a wide variety of opportunities for regeneration and wood production exists. Ponderosa pine is found in pure stands or as a major component with lodgepole pine, grand fir, white fir, Douglas-fir, or western larch. Jeffrey pine is an important associate in California. Changes in stand composition are associated with climatic changes. Ponderosa pine in the Northwest can grow in areas of extremely low rainfall at the desert edge to areas of high precipitation in the Cascade Mountains. Precipitation comes mainly in winter; summers are dry.

With increasing elevation and precipitation, there is generally a gradual transition from pure ponderosa pine to the mixed pine–fir forest.

Ponderosa pine is commonly a climax type when found in pure stands east of the Cascade Mountains. Where it occurs with true firs at higher elevations in eastern Oregon and Washington and in mixed conifer stands in the Coast Range of southwestern Oregon, it is not climax *(9)*.

Fire has played a very important part in development of plant communities within this pine type. Young ponderosa pine seedlings are readily killed by fire, but older trees with the protection of thick bark survive. Species such as grand fir and Douglas-fir are less fire resistant *(6)*. Ponderosa pine has survived in areas where fire has prevented other species from becoming dominant. Early fire followed by periods of protection has promoted the development of brush species or of a dense carpet of tree seedlings.

Ponderosa pine can be a prolific seed producer in the Northwest *(2)*, although good cone crops occur only about once every 7 years. Stands are present because of a series of favorable events–a good seed year preceding a mild spring, followed by a wet, cool summer, plus minimal depredation from birds and small mammals *(4)*. Many years may pass before all these factors occur in the right combination to produce a well-stocked stand. As a result, some areas have not regenerated for decades. In other areas, where heavy seed crops have followed ground fires and favorable weather, dense stagnated stands of reproduction are often found.

Because of past fires, seed crop periodicity, and climatic factors climax ponderosa pine forests tend to be even-aged by tree groups rather than uneven-aged throughout the stand *(6)*. Because of this trend, the species may be managed by promoting even-aged groups of second-growth timber. Thus, complete overstory removal in a single cutting and thinning of the even-aged understory are practiced in some areas although partial cutting is still being done *(7)*, especially in areas enjoyed by the public.

In pure stands of ponderosa pine at higher elevations, where soil moisture is plentiful, there are several alternative opportunities for regenerating the stand. These include seed-tree, shelterwood, and group selection methods. In areas of lower rainfall, regeneration is difficult by any method because good seed crops and suitable climatic factors seldom coincide. To insure prompt restocking, it is necessary to plant nursery-grown trees rather than to rely on natural seeding.

Much of the pure ponderosa pine type on the east side of the Cascades has abundant pine regeneration beneath mature trees. This regeneration is dense and suppressed, but it is capable of responding to overstory removal and thinning *(1)*. Harvesting these stands involves carefully removing the old trees and preserving the small understory trees for the future crop.

Preserving suitable trees in the understory is difficult. Large numbers of dead limbs and trunks accumulating on the ground from past partial cuttings, natural mortality, and the present cut make conditions ideal for catastrophic fire. This fuel must be utilized, burned, or buried; moving it destroys young trees, sometimes reducing stocking below adequate levels.

Some ponderosa pine stands are severely infested with dwarf mistletoe *(3)*. If mature trees have this parasite, small trees in the understory often become badly infected. Where this situation prevails in areas that are difficult

to regenerate by shelterwood or seed tree methods, then clearcutting, site preparation, and planting to rid the area of dwarf mistletoe are needed. However, on sites that are easy to regenerate, shelterwood cuttings should be made. The overstory should be completely harvested (final cut) after the seedlings become established but before they become infected with dwarf mistletoe.

Brush species sometimes dominate the understory, suppressing pine reproduction. Here shelterwood cutting in conjunction with site preparation by controlled broadcast burning or by tractor piling and burning the brush is a useful method *(8)*. If adequate stocking occurs underneath brush, chemical sprays may be used to release seedlings *(5)*. Where there are no seedlings and too few overstory trees for the shelterwood or seed-tree method, bulldozing brush in strips and machine planting the vegetation-free areas is one way to obtain restocking of the land.

Mountain and western pine beetles are major obstacles to ponderosa pine management west of the Rockies. Converting old-growth stands to younger stands, harvesting on a shorter rotation before trees become overmature, and removing decadent or injured trees before they become infested can be expected to reduce volume losses attributable to these beetles.

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INTERIOR ALASKA WHITE SPRUCE

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The white spruce type covers about 13 million acres in interior Alaska *(1)*. It occurs on a wide range of sites but attains its best development on river bottoms and south-facing slopes *(2)*. Major factors in the formation and composition of these forests have been fire and the natural processes of stream erosion and deposition. Stands may be either pure, even-aged white spruce or mixtures of spruce with paper birch, quaking aspen, balsam poplar, black cottonwood, and in the Kenai Penninsula, mountain hemlock.

White spruce, one of the hardiest conifers of North America *(4)*, is more shade tolerant than the associated hardwoods and may be the climax species on many interior sites. However, such factors as aspect, soil temperature, thickness of organic layers, presence or absence of permafrost, and past fire history complicate the successional status of spruce *(3, 5)*.

Major considerations in achieving natural regeneration of white spruce forests in interior Alaska are seed supply and seedbed conditions. Excellent seed crops occur infrequently—only every 10 to 12 years—and interim poor to good crops are often completely destroyed by red squirrels. Moreover, dense moss and thick layers of undecomposed organic material beneath the stands prevents establishment of regeneration.

Except near population centers, little timber harvest has taken place in these forests. Thus few observations have been made of the results of various silvicultural systems. Clearcutting and shelterwood cutting have been commonly used in white spruce in Canada and should also be useful in Alaska. At least in a general way, these methods simulate conditions under which Alaskan spruce forests developed—that is, in the absence of a forest canopy or under variable canopies following forest fires and during primary plant succession. However, site degradation related to cold soils, the presence of permafrost, and development of moss-organic layers *(5)* may be unique or of greater importance in subarctic forests than in spruce forests farther south. Because of the shade tolerance of white spruce, the selection system might be successfully used where seedbed conditions permit, or where logging adequately disturbs the moss-organic layer. Because of the depth of this layer, however, post logging site preparation would be required *(6, 7)* but this is rarely feasible in combination with selection cutting.

Outbreaks of spruce beetle sometimes develop in over-mature stands. Butt rot and blowdown are potential problems in these stands and the affected trees provide a habitat favoring buildup of spruce beetle populations.

Currently, clearcutting and shelterwood cutting appear to be the best systems to use in these subarctic white spruce stands, with site preparation where necessary and with careful observance of other constraints imposed by local environmental conditions.

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INTERIOR ALASKA HARDWOODS

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Interior Alaska's hardwood forests cover nearly 10 million acres. This complex is composed of paper birch, quaking aspen, balsam poplar, and black cottonwood growing in pure stands or in mixtures with one another or with white spruce and black spruce *(2)*. Fire has played an important role in the perpetuation of this forest. The component species are intolerant of shade, are prolific seed producers, and are able to reproduce vegetatively. Thus after fire they promptly restock the land *(3)*. Compared to white spruce which may be an associate, they grow more rapidly in the juvenile stage but are shorter lived *(1)*.

Although these species are present in mixtures, they appear to occupy specific physiographic positions. Paper birch stands predominate on northeast and northwest facing slopes; most stands appear to have originated from seed *(1, 3)*. Quaking aspen grows on the driest, warmest sites. These are typically southern exposures; stands appear to be primarily of root-sucker origin *(1, 3, 4)*.

Less is known about the silvics of balsam poplar–black cottonwood stands in this region. These species attain their best development on river bottom sites. These stands are mostly of seed origin. However, balsam poplar is known to sprout and, more importantly, to sucker prolifically after fire *(3, 5)*. Because of its thick bark, this species is more resistant to fire than other trees of the type.

These pioneer species form even-aged stands on land disturbed by fire or on relatively recent river bottom sites. This would indicate that some form of clearcutting, as has been shown throughout the species range, is a

compatible and perhaps the only silvicultural system to employ in their management. If regeneration through natural seeding is to be relied upon, some form of site preparation may be required.

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PACIFIC SOUTHWEST TYPES

Redwood
Red Fir–White Fir
California Mixed Conifers
Pacific Ponderosa Pine

REDWOOD

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The redwood type–that forest in which redwood is predominant–was, in 1968, estimated to cover 915,000 acres.[1] Of the total, 820,000 acres are available for commercial timber production and 95,000 acres are reserved in parks. The type contains two principal management categories, old growth and young growth. Old-growth stands–those over 100 years old, including both virgin and partially cut stands–are present on 240,000 acres. The young-growth stands comprise 580,000 acres, some of which are now being harvested. These stands will be the principal source of redwood timber in a few decades.

Redwood is adapted to the environment of a narrow strip of land 450 miles long and 5 to 35 miles wide, along the north coast of California and extending into extreme southwestern Oregon *(10)*. Here the climate is mild and humid, with winter rains and summer fogs. Major associated species are Douglas-fir, Sitka spruce, grand fir, western hemlock, and Port-Orford-cedar. The type changes to Douglas-fir along the eastern fringes and higher elevations. The topography, ranging from near sea level to an elevation of about 2,500 feet, is often broken and is moderate to steep. Redwood grows principally on loam and clay loam soils *(6)*; a common feature is that these soils are deep and have moderate to high moisture-storage capacity.

One habitat classification proposed for redwood is based on soil moisture, soil nutrients, light, and temperature *(11)*; another classification relies on herbaceous plants as indicators *(2)*. However, easily recognized broad habitat differences exist between the alluvial flat and slope redwoods. The almost pure, world-renowned groves, most of which are in State and National Parks, are mainly on alluvial flats. Redwood on slopes seldom forms pure stands, giving way usually to Douglas-fir as elevation and dryness increase.

[1] Personal communication, April 19, 1971, from Melvin E. Metcalf, Project Leader, Forest Survey, Pacific Northwest Forest and Range Experiment Station.

Although redwood seedlings can endure heavy shade, they are scarce on undisturbed seedbeds in timber stands. This is probably because of destruction by root rot and damping-off fungi *(7)*. Juvenile growth is best in full sunlight. New redwood seedlings require more moisture for survival than do seedlings of most associated species *(10)*. Therefore, evaporational stresses caused by low humidity or exposure deter redwood establishment.

Redwood's ability to sprout, a characteristic possessed by no other western commercial conifer, provides excellent regeneration potential after fire, wind damage, and cutting *(10)*. The sprouts start from dormant buds at any time of the year. Those that grow from the root crown position are generally favored for tree crops.

Seed production by redwood and associates is fairly regular *(4, 7)*. Proportion of sound seed is low, but germination of sound seed is excellent. Mineral soil is the best seedbeed for establishment because of rapid germination and low losses from fungi. Although many redwood stumps sprout *(1, 8)*, the spacing of old-growth stumps is such that resulting tree reproduction is apt to be poorly distributed. Additional seedling regeneration is, therefore, needed to complete a full stand. The associated species, especially Douglas-fir, supplement the natural stocking of redwood seedlings commensurate with seed source available.

For prompt regeneration of conifers, it is essential not to allow other vegetation to gain control of the site. In the northern part of the redwood area, red alder and several shrub species may dominate severely disturbed sites. Tanoak and blueblossom ceanothus are potential threats if either species was present in significant amounts before cutting. Blueblossom is especially aggressive in the southern redwoods, and slash burning may increase its density.

Redwood is extremely longlived, and the old-growth stands differ greatly from young stands in their structure and management needs. Consequently the management of these two stand types is discussed separately.

Culture of Old Growth

Reproductive habits of redwood permit different management and silvicultural options in old-growth stands. Clearcutting, seed-tree cutting, and shelterwood cutting create even-aged stands as a result of sprout or seedling regeneration. But in clearcuttings that exceed 30 to 40 acres, even with those having surrounding seed sources, some supplemental seeding or planting is needed in central positions of the cut area where seed distribution may be inadequate *(3)*.

On seed-tree and shelterwood cuttings, the reserved seed trees should have cones and should be dominant or codominant trees. Small and suppressed redwoods are poor seed trees because they bear few or no cones and fruiting improves very slowly after release *(4)*. Any improved cone production from trees in the intermediate crown class would benefit only the later cuts in a shelterwood system. Seeding is needed 1 to 3 years after harvesting, while the seedbed is still favorable. Once seedlings are established, seed trees are usually cut; this logging may reduce stocking of small seedlings up to 25 percent. Sprouting of cut seed trees, however, will replace some seedling losses.

Gradual harvesting of virgin old-growth redwood by the selection system is possible in special situations where a continuous forest cover is desired. Such cuttings can be used to create an uneven-aged stand structure. Logging of large old trees during the first few cuts will, however, destroy much advance reproduction.

There are many mixed old-growth–young-growth stands that developed following partial cuttings by tractor logging after the mid-1930's *(5)*. Some of these were seed-tree operations; others approached a shelterwood condition. In these stands the objective usually should be to harvest the scattered older trees with minimum disturbance to the well-stocked young growth. These second cuttings will create even-aged young stands. Some areas may require seeding or planting to improve stocking.

Culture of Young Growth

Young-growth stands will need thinning one or more times before they are ready for the final harvest cut at age 50 to 90 years. Many of these stands, now well stocked, originated primarily from early clearcutting. Other stands are inadequately stocked because of heavy burning to eliminate debris or to convert the forest to grass *(5)*. On recent thinnings most redwood stumps have sprouted. Many of these sprouts will grow into crop trees in the new stand. Regeneration of redwood and associated species occurs also on disturbed surfaces after thinning. Although moderate to severe competition from other vegetation, especially in the more northerly areas, may cause heavy mortality, many seedlings will survive as advance reproduction. Thus, the nucleus of a new stand will be present on many areas when the present young stands mature and are harvested.

Coppice selection is an optional method applicable to young stands. The unique sprouting ability of redwood and the high quality of the sprouts make them a remarkably dependable, acceptable, and durable contribution to regeneration after any kind of cutting *(9)*. Additionally, the advance growth from seedlings of redwood and associated species will contribute to constant replacement of harvested trees. The objective of coppice selection is to maintain an uneven-aged stand by removing selected redwood and fostering the development of smaller sprouts and natural seedlings. Careful logging is necessary to minimize destruction of advance regeneration. The techniques of coppice selection remain to be tested and developed.

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RED FIR–WHITE FIR

by Donald T. Gordon and Douglass F. Roy
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Mixed forests of California red fir and white fir cover nearly 3 million acres and are found most commonly between elevations of 5,500 and 6,500 feet in the Sierra Nevada and southern Cascade Range, and in the northern Coast Range of California. At lower elevations, red fir is absent and white fir becomes a component of the ponderosa pine–sugar pine–fir type. At higher elevations–those between 6,500 and 7,000 feet–white fir generally is absent from the stand, and red fir is the dominant species up to about 8,000 feet. Here it sometimes borders a thin band of mountain hemlock lying just below timber line.

Relatively pure fir stands occupy much of California's prime mountain recreation areas, and fir forests, expecially red fir, cover much of the high-elevation snow belt. These forests are extremely productive of timber. Many well stocked old-growth stands contain 100,000 to 150,000 board feet per acre.

White fir grows with red fir in dense stands that may contain little or no underbrush or advance regeneration. Both species are shade tolerant, however, and each will reproduce naturally under stands of both species, especially in old stands that have opened up. Common associated species are Jeffrey pine, western white pine, lodgepole pine, and mountain hemlock *(1, 3)*.

Heavy cone crops of white fir are produced at 3- to 9-year intervals; every 5 years is about average. Red fir seed crops appear every 2 or 3 years

(3). Thus considering both firs there is at least a medium cone crop in any 4-year period. Most fir seed falls within one tree height of its source, usually beginning in mid-October. When seed fall is delayed until after the winter snowpack has formed, most seeds are wasted because they germinate in the snow. These potential seedlings die from dessication or high surface temperature after the snow melts *(1)*.

For establishment, natural fir reproduction requires seedbeds of loose mineral soil. In the absence of an overstory of trees, fir seedlings begin to grow rapidly within 3 or 4 years if they are established before grass or brush occupy the site.

Red fir–white fir timber stands are more subject to windthrow and breakage than conifers growing at lower elevations. Of the two species, red fir is more vulnerable because it grows at high elevations along exposed ridges and in saddles where strong direct winds or extraordinary turbulence prevail.

A variety of forest pests sometimes attack red fir and white fir singly or in combinations. Dwarf mistletoe commonly parasitizes these firs reducing their vigor. Most severely affected are old stands of red fir. The weakened trees often fall prey to bark beetles and fungi. The fir engraver beetle is at times exceedingly destructive in white fir stands, and root rots contribute significantly to mortality by windthrow. Generally, old fir stands are quite defective.

The structure of fir stands and their silvical characteristics indicate that red fir and white fir can be managed in either even-aged or uneven-aged forests. Any area having a good distribution of size classes probably can be managed as an uneven-aged unit if dwarf misteltoe is not an overriding factor.

Even-aged stands of natural regeneration can be established by clearcutting dense mature forests. The narrow dimension of opening should not exceed 4 chains (about 260 feet). Strips and small patches regenerate best if the main axis of each is at right angles to the direction of normal fall winds. This orientation benefits seed dispersal and decreases wind damage. Clear-cuttings of small size and proper orientation also increase snow deposition and delay snow melt.

Shelterwood cuttings, which leave one-fifth to one-half of the old stand for seed and shelter, also seem feasible and are being tested as a means of obtaining natural regeneration. Where advance reproduction is already established under a scattered stand of old trees, a release cutting that will liberate the thrifty trees of any size under 12 inches in diameter usually can be successful if carefully logged. Such shelterwood and release cuttings will form new even-aged stands.

Stands can also be regenerated slowly by removing a few large, old trees singly or in groups in cutting cycles of 5 to 20 years, as under the selection system. Such cutting creates minimum visual impact and should be considered for areas having high recreational or esthetic value. Its disadvantages are that it increases possibilities of dwarf mistletoe infection of new trees if the stand is infested and that competition from old trees retards seedling growth. Both selection and shelterwood cuttings require logging with special care to minimize injury to residual trees.

If an area is dedicated to maximum timber production, regeneration cuttings under any system should require removal of over-story trees or adjacent timber before seedlings are 3 feet high *(2)*. Normally, this means 8 to

10 years after the regenerated unit has been cut. Otherwise, dwarf mistletoe in the mature timber will infect the seedlings, and competition from the old trees will significantly retard seedling growth.

Lodgepole pine, most often an associate of red fir, presents a special problem under all systems, especially the even-aged systems. An aggressive pioneer, it captures areas on fir sites that have been disturbed by fire, wind, severe logging, or road-building. Initial growth is faster than fir, but fir becomes established under the lodgepole and eventually overtops it. This sequence is an expensive way to maintain fir dominance. A solution is to remove potential lodgepole pine seed trees when harvesting fir during regeneration cutting.

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CALIFORNIA MIXED CONIFERS

by Douglass F. Roy and Philip M. McDonald
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The sugar pine–fir–ponderosa pine forest type, often called "mixed conifer" in California, is a complex association with ponderosa pine, sugar pine, Douglas-fir and white fir, any of which may predominate. Incense-cedar also is a component, although scattered in distribution and not prominent in the dominant canopy. Generally, the five conifer species are intermixed either as single trees or as small groups. Vertical mixing also is common with one to three species in the overstory and one or two species in the understory *(5)*.

In northern California the five-species mixture of conifers grows on east-facing slopes of the Coast Range and on west-facing and high-elevation east-facing slopes of the Cascades and Sierra Nevada. This forest extends northward into Oregon and southward into the Transverse and Peninsular Ranges of southern California. It occupies about 4.5 million acres of commercial forest land in California *(2)*.

Heavy cutting was common in the past and resulted in stands that are now largely young growth. Pine was the preferred species; white fir and incense-cedar were left behind. However, these latter species are increasing in use and are being logged intensively. Artificial regeneration efforts have involved ponderosa pine almost entirely, because planting stock was available and initially it survived well.

The mixed conifer forest occupies productive forest land at middle elevations were precipitation is high and the growing season long. Elevational

limits of the forest are 2,000 to 7,500 feet in northern California and 4,000 to 10,000 feet in southern California. In the Sierra Nevada the type grows mainly between 3,000 and 6,000 feet. Below this range of elevation is Pacific ponderosa pine; above, the red fir–white fir type. But long irregular fingers of the mixed conifer forest extend into adjacent cover types, sometimes complicating stand delineation and management.

Wide geographical and altitudinal ranges of the mixed conifer forest type, with attendant variations in soils, topography, and climate, cause great variability in stand composition and structure. For example, ponderosa pine tends to dominate warmer and drier sites, while white fir prevails on cool and moist northern exposures. Douglas-fir is prominent in the mixed conifer type in the Coast Ranges and in the northern Sierra Nevada, but it is absent in the southern Sierra Nevada. The amount of ponderosa pine increases rapidly at lower elevations, white fir at higher. Sugar pine is prevalent throughout the mixed conifer forest and is associated mostly with white fir. Slow-growing incense-cedar often occupies edaphic and topographic areas unfavorable to the other species *(6)*.

The overall successional stage of the mixed conifer forest is climax. However, internal shifts in species composition continuously take place, especially following fire, storm, and insect attack. These disruptive agents generally favor ponderosa pine, while their absence favors white fir, sugar pine, and incense-cedar. The extent of mixed conifer forest also expands and contracts. Freedom from disruption enables expansion into lower elevational cover types, while disruptions, particularly fire, cause the type to recede.

The mixed conifer forest comprises a mosaic of small stands differing in species composition, age class, seed producing ability, and amount of brush. These small homogeneous units, usually ranging in size from 2 to 10 acres, are recognized and accurately delineated as the bases for silvicultural prescriptions.

Silvicultural treatments in the California mixed conifer forest are derived individually for each small stand identified during mapping. Treatment is governed by the conditions in the stand and fitted to the characteristics that determine regeneration, survival, and growth of the species desired. Most pertinent characteristics are those related to seed production and dispersal, seedbed requirements, the ability of seedlings to compete with other vegetation, and the species adaptation to particular environmental conditions. The species' relative tolerance to shade is an important consideration.

White fir and incense-cedar are tolerant of shade; sugar pine and Douglas-fir are intermediate in tolerance; and ponderosa pine is intolerant *(1)*. Hence, heavy cuttings favor the pines and Douglas-fir; light cutting and no cutting favor white fir and incense-cedar.

Significant differences exist between the species in their ability to regenerate and survive. White fir seedlings become established and grow where litter and shade exclude pines *(4)*. Unless cutting is heavy enough to create essentially open conditions, white fir regenerates aggressively and produces seedlings that survive and eventually (within 30 years) overtop and suppress shrubs even in dense brush *(6)*.

Pines, on the other hand, require a mineral soil seedbed, and cannot become established in dense brush. Pine seedlings generally grow well when

they have an even start with brush, but pine reproduction, whether by natural or artificial seeding, or by planting, often fails unless sites are prepared by exposing mineral soil and eliminating vegetation that competes for soil moisture.

Many agents exhibit a differential impact on species regeneration and survival. Cutworms, which are most active in recently disturbed soil, damage white fir and incense-cedar seedlings more than seedlings of other conifers *(3)*. Spring frosts, common in forest openings, damage white fir seedlings most, sugar pine seedlings next, and affect seedlings of other species least. Deer browsing is most severe on white fir and Douglas-fir. Douglas-fir seedlings are the most sensitive to heat injury.

The western and mountain pine beetles, by repeated but generally limited attacks, may eventually take a heavy toll of sugar pine and ponderosa pine. The Douglas-fir tussock moth affects Douglas-fir and true firs. Spot kills by this insect are typically ringed by top-killed trees which are susceptible to disease and bark beetles.

Sugar pine is vulnerable to white pine blister rust except in the southern part of its range. Tree improvement programs, however, should eventually produce resistant strains of sugar pine. In the meantime, silvicultural treatments should probably discriminate against this species, particularly where blister rust is virulent and widespread. No other serious insect or disease problems are anticipated in thrifty young-growth mixed conifer stands.

In general, open cutover areas create environmental conditions that inhibit regeneration of white fir and to a lesser extent Douglas-fir and sugar pine. Such conditions favor ponderosa pine regeneration if brush is controlled. Where pines are preferred, the most satisfactory silvicultural systems are patch clearcuttings and seed-tree cuttings, fitted to appropriate stand conditions, and, where necessary, accompanied by site preparation to eliminate brush and expose mineral soil.

The shelterwood cutting system, leaving about 12 trees per acre, is an attractive silvicultural alternative. It assures a large and well-distributed seed supply, and the heavier residual stand which provides overhead shade allows Douglas-fir and sugar pine to become established while still favoring ponderosa pine.

Selection cuttings leading to uneven-aged stands are possible, but individual tree selection favors white fir and incense-cedar and discriminates against pines. To maintain a pine component, group selection can be used in stands of suitable structure. Selection cuttings can be used on recreational, scenic, and roadside areas where maintenance of a tree cover is desired. The selection system also fits low-quality sites where timber production is not an important consideration.

Artificial regeneration of species other than ponderosa pine is still uncertain. The development of better nursery procedures for the production of healthier and hardier seedlings will permit successful planting of white fir, Douglas-fir, and sugar pine on small clearcuttings and increase the silvicultural alternatives available.

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PACIFIC PONDEROSA PINE

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The Pacific ponderosa pine type occupies between 1 and 1 1/2 million acres of the west slopes of the southern Cascades and the Sierra Nevada, east slopes of California's northern Coast Ranges, and west slopes of the Transverse and Peninsular Ranges of southern California. The most important part of the type is a belt of high site quality land stretching along the lower west slopes of the Sierra Nevada from Shasta County to Fresno County.

This timber type lies above Digger pine and oaks (mainly blue and California black oaks) and below the mixed conifer type. Its elevational limits increase from north to south. Lower limits range from 500 feet in the north to 5,000 feet in the Peninsular Range near the Mexican border; upper limits range from 1,000 feet in the north to 8,000 feet in the south.

Stand composition is determined largely by available moisture. At lower elevations the type is essentially pure, although oaks often are minor stand components. With increasing elevation, and on better sites, sugar pine, Douglas-fir, white fir, and incense-cedar are common associates, but these species never total more than 20 percent of the stand *(8)*.

At lower elevations ponderosa pine grows best on north- and east-facing exposures in shaded draws and canyons. It also develops well at the base of slopes where soils are deeper and soil moisture is more abundant. As elevations increase, sites favorable to ponderosa pine also increase. Thus, the species grows well on all exposures at elevations between 2,500 and 5,000 feet in the northern part of its range and between 4,000 and 6,000 feet in southern California. At ponderosa pine's upper elevational limits, where north and east exposures are occupied by sugar pine and firs, its best growth is on south- and west-facing exposures.

Cutting in the type began in the 1850's to provide lumber for gold mines and settlements. Only the best trees were utilized, but the logging process was destructive. Most areas were burned at least once. Much of the

timber existing today developed naturally on these heavily cut, grazed, farmed, or burned areas. Only small areas of old-growth timber remain.

Regeneration over much of the Pacific ponderosa pine type began in the 1870's. Seedlings periodically restocked the ground naturally in waves. Seedling establishment required a good seed crop followed by favorable soil moisture. The first wave of reproduction was the most effective because seedlings in following waves had to compete with older trees and other vegetation.

The most destructive agents threatening Pacific ponderosa pine are fire and the western pine beetle. The latter breeds in trees weakened by drought, stand stagnation, or fires. When epidemic, this beetle becomes aggressive and kills vigorous trees over 6 inches in diameter *(4)*. Control of fires and western pine beetle attacks is enhanced both by vigilance and cultural treatments which keep the forest clean and healthy. Fomes root rot and shoestring root rot are other potential threats *(10)*. Porcupines severely damage young ponderosa pine locally.

Ponderosa pine is intolerant of shade; sugar pine and Douglas-fir are intermediate; incense-cedar and white fir are tolerant *(1, 9)*. The Pacific ponderosa pine type, in the main, however, is climax. If timber is removed and not successfully regenerated, many areas, particularly those at lower elevations, will remain for a long time in subclimax stages of the chaparral, oak woodland, Digger pine and oak, or California black oak types. Along the upper elevational margin of the type many areas would convert gradually to the mixed conifer type if logging and fires were excluded.

Seed production records for the Pacific ponderosa pine type are few, but in one area records were kept for 15 years. In this period seed crops were heavy twice; and medium three times. In these crops sound seed production by uncut stands (trees over 20 inches in diameter averaged 30 per acre) ranged between 20,000 and 110,000 per acre.

Pines require mineral soil seedbeds for natural regeneration. And pine seedlings often fail unless site preparation has eliminated vegetation which competes for soil moisture, but, if given an even start with brush, pines generally grow well. Ponderosa pine seedlings possess the ability to withstand prolonged drought *(3)*.

Compared to other California forest types the Pacific ponderosa pine forest is relatively homogeneous and is even-aged. A given silvicultural treatment, therefore, can be applied to fairly large units. Clearcutting with prompt site preparation and planting, or in some cases seeding, is recommended. Cuttings can be as large as 30 acres. Sugar pine, which is free of blister rust at elevations below 3,000 feet, could be planted on clearcut areas at lower elevations with ponderosa pine to avoid a monoculture. Sugar pine grows rapidly and produces high volumes at an early age.

Seed-tree cuttings leaving 4 to 8 trees per acre and shelterwood cuttings leaving about 12 trees per acre are other systems which have successfully regenerated ponderosa pine naturally. Seed trees should be removed as soon as suitable regeneration has been obtained. If seedlings are small and care is used in logging, loss of regeneration will be minimal *(5)*.

Lumber products from young-growth Douglas-fir and white fir are equal in quality to old-growth material of the same grade. But, lumber from young-growth ponderosa pine is inferior to that from old-growth trees

because of differing textures *(2, 7)*. The probable consequence in the foreseeable future is that young-growth Douglas-fir, white fir, and sugar pine grown on high sites of the Pacific ponderosa pine type will be more valuable than young-growth ponderosa pine. Land managers, therefore, might choose to favor Douglas-fir, white fir, and sugar pine where these species are stand components through either single tree selection or group selection cutting.

Selection cutting methods which encourage establishment and growth of white fir and Douglas-fir rather than pines in this type are well adapted to strips along scenic roadways and streams where contrast, variability, harmony, and beauty are desired *(6)*.

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NORTHERN ROCKY MOUNTAIN TYPES

Ponderosa Pine and Rocky Mountain Douglas-fir
Western Larch
Western White Pine and Associated Species
Engelmann Spruce–Subalpine Fir
Lodgepole Pine

PONDEROSA PINE AND ROCKY MOUNTAIN DOUGLAS-FIR

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Ponderosa pine and Rocky Mountain Douglas-fir forests cover about 20 million acres of the interior Northwest–Montana, Idaho, and northeastern Washington. They include pure forests of ponderosa pine or Rocky Mountain Douglas-fir and those with either of these two species as the major constituents mixed in various combinations with the other and with grand fir, western larch, and lodgepole pine.

Where there is a mixture, comparative shade tolerance of the various species plays a considerable role in stand behavior and development. Larch and lodgepole pine are light-demanding trees, ponderosa pine somewhat less so, while Douglas-fir and especially grand fir can withstand considerable shade *(5)*. These forests, however, include a number of different ecological situations. In some, ponderosa pine is the climax species, in others grand fir is climax, and over most of the type Douglas-fir is climax. In this area summers are dry; most of the precipitation occurs in winter.

Seed production, of course, directly influences regeneration and the system of silviculture that may be applied. Ponderosa pine is a poor seeder west and a fair seeder east of the Continental Divide in Montana. Most seed falls within 130 feet of the parent tree. Douglas-fir is somewhat more prolific, and effective dissemination distance is more than twice as great as it is with ponderosa pine *(5)*.

The potential of understory trees to respond, grow, and become a vigorous forest once the overstory trees are cut is most important in deciding on a cutting method in each forest type. Some stands contain understory trees that are healthy and able to grow rapidly once the overstory is removed. However, other mature stands contain small but old understory trees that do not possess the vigor to grow when released from competition. Many trees, though alive, are infected with heart-rot fungi, dwarf mistletoe, or other disease and are thus unsuitable for further management.

Depending on the stand condition, the ponderosa pine–Douglas-fir forest offers more options in the choice of regeneration methods than any

other forest type in the interior Northwest. In pure ponderosa pine stands which occupy mainly southerly facing lower slopes and the valley bottom fringes of the type, the land manager usually has an opportunity to choose any one of several methods—selection, shelterwood, seed tree, or clearcutting. The choice, however, is complicated by dwarf mistletoe. Ponderosa pine stands in western Montana are practically free of this disease, allowing freer choice. Many stands in Idaho and eastern Washington, however, are badly infected, which often limits the choice to clearcutting in order to control the disease.

Prompt natural regeneration in pure ponderosa pine stands usually is difficult to obtain no matter what system is used because the combination of good seed crops and moisture conditions favorable for survival of seedlings is infrequent. Hence, mechanical site preparation often is required *(2, 7)*. Without site preparation, natural reproduction may become established, but usually at a very slow rate.

Where ponderosa pine is in mixture with Douglas-fir, choosing a cutting method is more complicated. If a merchantable stand of ponderosa pine and Douglas-fir is vigorous and relatively free of dwarf mistletoe, a seed-tree or a shelterwood system may be used to favor the pine. In ponderosa pine-Douglas-fir mixtures that are free of dwarf mistletoe and that already contain several age classes, the selection system may be used. This type of cutting will favor Douglas-fir over pine in the long run *(1)*.

In many of these mixed stands the Douglas-fir is infected with dwarf mistletoe. If the infection is heavy, it will seriously reduce growth and may eventually kill the tree *(3, 4, 6)*. In addition, this species frequently is infested and weakened by western budworm. In stands where most of the Douglas-fir trees are badly infected with dwarf mistletoe and little, if any, understory is present, a silviculturally satisfactory method is to clearcut the merchantable trees, dispose of remaining trees, prepare the site with mechanical equipment, and establish a new stand by planting ponderosa pine. In lightly infected stands, any partial cutting should be accompanied by cutting or killing infected trees.

Pure Douglas-fir stands in the interior Northwest offer somewhat less latitude for choice of a cutting method than ponderosa pine—Douglas-fir mixtures. Where Douglas-fir is badly infected with dwarf mistletoe, the only reasonable recourse is to clearcut if the timber is to be utilized. Also, only clearcutting is feasible for some Douglas-fir stands that have been badly damaged by western budworm. Old growth, pure Douglas-fir stands are particularly susceptible to Douglas-fir beetle attack. Fires and inadequate age-class distribution in these stands perpetuate this susceptibility. Partial cutting may reduce losses from beetle attack. If the merchantable stand is vigorous and relatively free of dwarf mistletoe, a shelterwood or selection system of cutting may be used, depending on the age and structure of the stand.

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WESTERN LARCH

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Western larch grows only in the upper Columbia River Basin of the interior Northwest. As a timber type, it occupies 3 1/2 million acres, mainly in the northern Rocky Mountains. Western larch, a pioneer species with a wide ecological amplitude, grows in mixture with several other pioneer, subclimax, and climax species. Depending on the ecological situation, certain associated species such as Rocky Mountain Douglas-fir, grand fir, western hemlock, western redcedar, and subalpine fir, all more shade tolerant than larch, replace it in forest succession.

Western larch is a very light-demanding tree and has been maintained over the years by wildfire. The thick basal bark on the mature larch protects the tree from fire, and a few surviving trees or groups of trees quickly provide seed for reestablishing the species *(4)*. Larch is also quick to seed after clearcutting. Larch seeds are light in weight and are dispersed long distances—up to 1,000 feet—into clearcuts or other openings. Some seed is produced almost every year and good crops occur every 4 or 5 years. Thus larch, as a seed producer, is more than adequate *(6)*. At maximum distances, however, the quantity of seed dispersed may not always be sufficient for adequate regeneration in a given seed year.

Western larch has capacity for rapid initial height growth, particularly when growing in the open, and it is a long-lived species. Although generally windfirm, overmature trees are susceptible to root rot and subject to

windthrow. Dwarf mistletoe is found in much of the larch type and severely damages larch where infections are heavy *(3)*. The western budworm damages both shoots and cones *(1, 2)*, and the introduced larch casebearer, a defoliating insect, seriously reduces growth and threatens the future of western larch *(5)*. Larch has special landscape value as the foliage turns yellow in the autumn and provides striking contrast to the dark green of non-deciduous associated species *(4)*.

Western larch, because of its silvical characteristics, can best be maintained by any of the even-aged silvicultural systems: Seed-tree, shelterwood, or clearcutting in patches.[1] Site preparation by burning or mechanical scarification is required to create favorable seedbeds for regeneration. Clearcutting is the best method to cope with the dwarf mistletoe disease.

Because larch is very intolerant of shade, uneven-aged systems will convert western larch stands to more shade-tolerant species. The composition of the ensuing stand will vary according to the ecological habitat type. One uneven-aged system, group selection, appears feasible and may be desirable in areas where esthetic values are a major consideration and where an increase in the more shade-tolerant species is not objectionable.

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WESTERN WHITE PINE AND ASSOCIATED SPECIES

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Western white pine forests occupy nearly 3 million acres in northern Idaho, western Montana, and eastern Washington. It is essentially a mixed

[1]Roe, Arthur L., Raymond C. Shearer, and Wyman C. Schmidt. Ecology and silviculture of western larch forests. USDA, For. Serv., Tech. Bull. (In preparation).

forest type of several species ranging from the very light-demanding western larch and lodgepole pine to the somewhat less light-demanding western white pine and Rocky Mountain Douglas-fir to the shade-tolerant grand fir, western redcedar, western hemlock, Engelmann spruce, and subalpine fir *(4)*.

Over the centuries fire has maintained western white pine, western larch, and lodgepole pine in northern Rocky Mountain forests. As a result, stands tend to be even-aged. Without disturbances such as fire, stands of this type progress from rich mixtures of many species toward climax forests of a few species. Grand fir is the climax species on the drier sites; western redcedar and western hemlock are climax in more moist, cooler situations; and subalpine fir on cool, moist sites.

Insects and diseases have important effects on silvicultural practices. The overriding disease is the introduced blister rust on western white pine. All attempts to control it have failed. As a result, the disease continues to kill western white pine in present stands *(3)*. Genetically resistant western white pines are being developed by painstaking research and development effort *(1)* and will increasingly be available for planting on selected areas.

Old-growth stands of western white pine type frequently contain large numbers of defective, unmerchantable live trees and many unmerchantable dead trees. The Indian paint fungus causes severe heart rot in western hemlock and grand fir. Many white pines and western redcedars are unmerchantable because of heart rots and butt rots. White pine blister rust and the mountain pine and Douglas-fir beetles kill many trees. The defective, unmerchantable live trees and large numbers of dead trees add up to a serious residue accumulation that must be considered in choosing methods for cutting and site preparation.

All silvicultural systems have been studied in the western white pine type *(2)*. Any of the even-aged systems are applicable when the objective of management is to perpetuate species that require considerable light, such as western larch, Douglas-fir, and lodgepole pine. The seed-tree, shelterwood, and clearcutting methods have all been used successfully to obtain natural regeneration. The shelterwood system has been used successfully to regenerate species of the type in stands that do not contain great amounts of unmerchantable residues. Clearcutting followed by burning has often proved to be the most satisfactory method to dispose of residues and prepare cut areas for regeneration where conditions favor this approach.

When the objective of management is to perpetuate shade-tolerant species such as grand fir, western hemlock, and western redcedar, the selection method either by individual trees or groups offers promise. This system should be considered where continuous forest cover is needed for esthetics or other purposes. Any type of partial cutting, however, may increase damage by heart rot in such species as grand fir and western hemlock. In addition, disposal of logging slash and other unmerchantable residues is very difficult when the selection system is used. As a consequence, the method has greater potential for use in future stands that will contain very much less unmerchantable residues and a higher proportion of trees of good vigor than present old-growth stands.

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ENGELMANN SPRUCE–SUBALPINE FIR

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Engelmann spruce and subalpine fir forests occupy nearly 10 million acres on cool, moist sites in the upper valleys and plateaus of the Rocky Mountains. These forests are on areas of generally high timber productivity, water yield, scenic beauty, recreational potential, and wildlife use. Much land now covered with lodgepole pine, aspen, or other pioneer and subclimax species also has the potential to grow spruce and fir *(7)*. Of the two main species in the type, Engelmann spruce rates as shade tolerant and subalpine fir as very tolerant. Spruce is also longer lived *(10)*. With such characteristics, spruce and fir eventually replace shorter-lived and less tolerant species such as lodgepole pine and aspen in the main forest cover after the pine and aspen mature, decline in vigor and die, or are killed by bark beetles, dwarf mistletoe, or other causes.

Cutting methods that are applicable in spruce–fir forests depend on the ecological habitat, the condition of the present stand, and the objectives of the manager. Spruce and fir grow in a number of climax or near climax associations, but because most existing spruce–fir forests developed after fires, beetle epidemics, or other disturbances, they do not have the typical all-aged structure of true climax forests. Instead, most stands are clearly of a single age class or may be made up of two or even several distinct age classes which may be recognized by the storied appearance of the forest *(3, 4, 6)*.

A large proportion of the present forests are overmature and have little potential for future growth. Windfall is common after any kind of initial partial cutting in spruce–fir forests, and is frequently heavy if the entire stand is opened up. However, regardless of how stands are cut, windfall is greater on some topographic locations than others *(2)*.

Old-growth spruce is especially susceptible to damage by the spruce beetle *(5)*. Epidemics have been associated largely with extensive blowdowns,

but beetles thrive in cool shady situations. Excessive cull material left after logging and trees windthrown after heavy partial cuttings can produce heavy broods and induce outbreaks *(11)*. Heart rot is common in subalpine fir, and is particularly serious in trees injured by logging during a partial cutting operation.

Spruce–fir forests are frequently difficult to regenerate either naturally or artificially, particularly at the higher elevations, in the lower latitudes of its range, and on southerly aspects *(9)*. Seed supplies are modest, and the small first-year seedlings are not resistant to heat or drought.

If timber harvest is an objective of management and the risks of windfall, beetle attack, and disease are high, there is little choice but to clearcut and start a new stand. Openings, however, should be kept small so that they will regenerate naturally, and slash disposal should be limited to the extent necessary to provide suitable seedbeds *(9)*. Where esthetic and watershed considerations preclude clearcutting, stands must often be left uncut. If windthrow and insect and disease problems are not critical, a selection system is possible in broad-aged, multi-storied stands *(3)*. Where there is only one age class, or even two or three, the shelterwood system can be used if the trees are uniformly spaced *(3, 8)*. Group selection can be used in those stands where the trees are clumpy to take advantage of the natural arrangement of trees *(1, 3)*. The initial cuts under any of these partial cutting systems should be light in order to minimize wind losses *(8, 9)*. Use of the seed-tree method is seldom possible because spruce and fir are not windfirm and seed trees are soon blown over by the wind.

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LODGEPOLE PINE

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The lodgepole pine type extends over 15 million acres on a wide range of sites principally in the Rocky Mountains but also in areas further west. Lodgepole pine is a pioneer species and most stands are the result of catastrophic fires. Many areas have burned so extensively that large acreages are nearly pure lodgepole pine. In many situations in the northern Rocky Mountains, however, there is some mixture of other conifers: western larch, Rocky Mountain Douglas-fir, grand fir, subalpine fir, western redcedar, western white pine, Engelmann spruce, western hemlock, and mountain hemlock. In the central Rocky Mountains, Engelmann spruce and subalpine fir are the primary associates.

Since lodgepole pine is a very light-demanding tree the associated species, all of which are more shade tolerant except western larch, replace it in the process of forest succession. But in those areas where lodgepole pine exists in extensive pure stands, there is no seed source of the associated species and replacement of the lodgepole pine is, of course, very slow. Lodgepole pine may also represent an edaphic-topographic climax in some situations *(16)*. Each ecological situation requires special consideration in determining silvicultural practices.

Lodgepole pine is a prolific seed producer. Good crops are produced at 1- to 3-year intervals with light crops intervening. Moreover, cones bearing viable seed are produced at a very early age.

Lodgepole pine varies greatly in its cone habit. Throughout much of the Rocky Mountains, the seed produced for many years are stored in closed cones that open and shed seed only when exposed to relatively high temperatures *(3, 8, 15)*. Many dense lodgepole pine stands have resulted when abundant seed was shed on receptive seedbeds after wildfires killed the standing trees but did not damage the cones. The closed cone characteristic can also be utilized with proper silvicultural practices to reproduce cutover areas. In some areas, cones open at maturity and seeds are dispersed the same as other conifers. In such situations, only small disturbances are likely to result in restocking to dense stands.

Insects and diseases also play a vital role in lodgepole pine forests. Many stands are opened up by the activity of the mountain pine beetle which attacks and kills the largest diameter trees *(11)*. Dwarf mistletoe *(9)* and Comandra rust are common diseases of lodgepole pine. Western gall rust also causes serious losses *(10)*.

Seed-tree, shelterwood, and selection systems of cutting are frequently not applicable to lodgepole pine for several reasons *(1, 4)*. Dense lodgepole pine stands are seldom windfirm and many trees blow down when these stands are opened up by partial cutting. The trees have short crowns, and their vigor and growth are poor. Partial cutting also encourages the spread and intensification of dwarf mistletoe *(5)*. Finally, the disposal of logging slash and unmerchantable material is difficult and reserve trees are damaged by partial cutting. Clearcutting is, therefore, usually the most practical method of harvesting many lodgepole pine forests *(2, 6, 7, 12, 14)*. Where management considerations preclude clearcutting, the choice may be limited to leaving the area uncut.

Exceptions do occur. There are examples of partial cutting on research plots *(2)* and of old cuttings for railroad ties where part of the stand was removed in what resembles a shelterwood. In these operations, windthrow in the residual stand was not excessive and the openings regenerated. It is possible to make similar cuttings in stands where the visual and environmental impact of clearcutting is unacceptable, if mistletoe is light or absent and the risk of windfall low. Also, in some lodgepole stands that are open grown or have been opened up by fire, wind, disease, or beetle attacks, the more shade-tolerant climax species have become established as an understory *(13)*. In these stands, it is possible to remove the overstory of lodgepole pine and release the understory.

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CENTRAL AND SOUTHERN ROCKY MOUNTAIN TYPES

Southwestern Ponderosa Pine
Southwestern Mixed Conifers
Rocky Mountain Aspen
Black Hills Ponderosa Pine

SOUTHWESTERN PONDEROSA PINE

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Southwestern ponderosa pine covers about 10 million acres, mostly in New Mexico, Arizona, and Colorado. The type exists mainly as a climax forest *(6)* in pure irregular uneven-aged stands consisting of small even-aged groups varying in size from a few trees to several acres *(9)*. Past cuttings involved a variety of selection methods that tended to preserve the uneven-aged structure. However, some present stands are essentially even-aged where clearcuttings, open areas, and burns have regenerated. In the Southwest, ponderosa pine generally forms fairly open stands with occasional meadows and parks; one-fourth to one-half of the stands have less than 40 percent stocking, accounting in part for the low average stand volume in the type.

Ponderosa pine, a light-demanding species, cannot regenerate under low light intensity and cannot tolerate heavy root competition. Thus, pine seedlings do not establish themselves in adequate numbers under dense stands of timber *(5)* or in dense grass *(3, 8)*. However, areas heavily grazed and then protected from grazing have often regenerated well *(5)*.

Natural regeneration depends on an ample seed supply and adequate moisture for germination. Adequate seed crops occur only once in 4 to 5 years *(4)*. Although favorable moisture conditions occur at about the same frequency, these conditions do not usually coincide *(5)*. Springs are usually very dry and summer rains come too late to be effective. Therefore, long intervals between good seedling years are the general rule.

Among the diseases affecting ponderosa pine in the Southwest, dwarf mistletoe is the most widespread and damaging. Some stands are so heavily infected that they should be clearcut and planted *(2)*. Where planting is called for, complete site preparation is needed to insure success. Planted areas should not be seeded to grass or grazed by domestic livestock until tree seedlings are about 2 feet high, and sheep should be excluded from plantations until tree terminals are out of reach. Some low-density stands with an adequate understory can be treated for dwarf mistletoe by clearcutting the infected overstory and then thinning and pruning the understory *(1)*.

The roundheaded pine beetle periodically infests ponderosa pine over thousands of acres in the Southwest. During endemic periods infestation occurs in dense stands on ridge tops or poor sites or where trees are infested by other bark beetles. They may build up rapidly and spread to stands on better sites.

Uneven-aged stands of southwestern ponderosa pine can be managed by the group selection system. Under this system old decadent groups are harvested and the area regenerated naturally. Immature and mature groups are cut lightly to remove defective trees and to improve spacing. Groups should range from about 1/2 to 2 acres. Groups smaller than 1/2 acre can be combined, whereas larger groups may be subdivided in the present cut or future cut.

Even-aged stands are managed most effectively by the two-cut shelterwood system with removal of the overstory after adequate seedling establishment. In using the shelterwood or the selection system, protection of advanced reproduction is essential. Precommercial thinning of even-aged sapling stands and groups prior to harvest cutting has effectively reduced damage to younger trees during harvest cutting *(7)*.

In areas where it is difficult to get natural regeneration, site preparation and planting are required. The harvest method here should be clearcutting on areas large enough for efficient site preparation and planting.

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SOUTHWESTERN MIXED CONIFERS

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Southwestern mixed conifers occupy about 2 million acres of highland forest in Arizona, New Mexico, and southwestern Colorado. These forests vary greatly in species composition and include Rocky Mountain Douglas-fir, white fir, corkbark fir, Engelmann spruce, blue spruce, ponderosa pine, southwestern white pine, and quaking aspen. All grow together in some stands; in some others only two or three are found. Douglas-fir usually predominates. In shade tolerance, Engelmann spruce and corkbark fir rank highest, followed in approximate descending order by white fir, Douglas-fir, blue spruce, white pine, ponderosa pine, and aspen.

Most mixed conifer associations seem to have been initiated by wildfires *(9)*. Initial stages are usually forbs, aspen, or Gambel oak. Ponderosa pine sometimes restocks such burns. If grass is seeded or becomes established naturally, coniferous invasion is usually slow *(2, 6, 9)*. If a seed source is available, Douglas-fir or white fir invade pioneer pine stands. In the absence of a coniferous seed supply, aspen may persist for centuries. In the presence of a coniferous seed source, it is rather quickly invaded, mainly by species other than ponderosa pine. A similar succession takes place with Gambel oak *(8)*. Mixed conifers dominated by Douglas-fir and white fir seem to be near climax. On cooler moister sites, Engelmann spruce and corkbark fir are probably climax *(7)*.

Southwestern mixed conifers differ in seed production. In most years few ponderosa pine cones are produced. In contrast, blue spruce produces frequent heavy crops; other conifers are intermediate. Rodents eat much of the seed *(6, 8)*. Aspen, the main deciduous associate, reproduces almost entirely by root suckers rather than by seed *(1, 11)*.

In the Southwest, spring is a dry season so most mixed conifers do not germinate until summer rains begin. White fir and corkbark fir, however, germinate only in the spring, mainly on moisture from snowmelt. These newly germinated seedlings are exposed almost at once to the spring dry season, an especially difficult period for shallow-rooted corkbark fir.

Seedlings of white fir, Douglas-fir, Engelmann spruce, and especially corkbark fir are subject to heavy early losses when exposed to full sunlight. Ponderosa pine, white pine, and aspen, however, are well adapted to full light. Frost heaving and washing can virtually eliminate a seedling crop of shallow-rooted species in the open. In stands with a substantial mixture of aspen, burning or heavy cutting may result in prompt occupation of the site by aspen root suckers. In the open, aspen root suckers grow rapidly from the start while early growth of blue spruce and Engelmann spruce seedlings is very slow, with only about 2 1/2 inches of root penetration in the first year. Corkbark fir and Douglas-fir do little better. White fir, white pine, and ponderosa pine show the best seedling root growth *(7)*.

Dwarf mistletoes have particular silvicultural significance for this forest type *(3, 5)*. They are widespread and infect trees of all sizes. Each dwarf mistletoe tends to be restricted to certain host species. Ponderosa pine is most affected by the disease, followed by Douglas-fir. Engelmann spruce has dwarf

mistletoe in some areas. Western budworm periodically causes serious die-back and sometimes mortality of white fir and Douglas-fir.

In areas with high deer populations, browsing has caused a significant regeneration problem, especially where stands have been heavily opened. Elk and cattle *(4)* also cause damage. Ponderosa pine, aspen, and the true firs are browsed most heavily; spruces are seldom seriously affected. Small clearcuttings are more attractive to deer and elk than large ones *(10, 12)*. Regenerating small patch clearcuttings with ponderosa pine may be a severe problem with even moderate big game and cattle populations.

Silvicultural prescriptions need to consider non-timber factors as well as silvical characteristics and other factors affecting regeneration. Esthetic and recreational considerations may require the maintenance of a continuous high cover; an overstory may also be needed to reproduce shade-tolerant conifers. On the other hand, clearcutting may increase water yield, favor livestock use, and benefit certain kinds of wildlife.

Southwestern mixed conifer stands have a preponderance of shade-tolerant or moderately tolerant species and tend to become uneven-aged as they mature.

For well stocked uneven-aged stands with a good distribution of age classes and healthy seedlings and saplings, a combination of the group selection and single-tree selection systems seems appropriate. Selection cutting serves both timber production and scenic objectives. If, however, dwarf mistletoe infection is serious or the stand has been badly damaged by the western budworm, even-aged management with clearcutting may be necessary. Clearcuttings also may be desired to meet wildlife, water yield, or livestock objectives. For esthetic reasons shape of openings should be made to blend with the landscape. Clearcut openings are difficult to regenerate. Thus, if the desire is to maintain the area in forest, advance regeneration should be protected from logging damage, and clearcut areas should be planted within 2 years after cutting unless abundant aspen suckers restock the areas.

Poorly stocked uneven-aged stands on southerly aspects pose a difficult regeneration problem. Harvest should be by the selection system and unstocked openings planted. Interspersed patches of Gambel oak or New Mexican locust should be retained as cover and food for deer and turkey.

In some areas, even-aged overstories of ponderosa pine dominate an understory of more shade-tolerant species. Such a situation favors even-aged management—either by the clearcutting or selection system. If ponderosa pine predominance is to be maintained, patch clearcutting is recommended with retention of groups of larger understory trees in the otherwise clearcut patches for wildlife cover and esthetic variety. The patches should then be planted with ponderosa pine. If the understory is to form the new stand, then an overstory removal in one cut or a series of partial harvests is suitable, with logging constraints, to minimize damage to the understory. If windthrow or too sudden exposure of the site are special hazards, a series of partial harvests under the shelterwood system may be advisable. Where the understory shows severe die-back from western budworm attack or is badly infected with dwarf mistletoe, the defective understory should be destroyed before or during the first cut to prepare the site for new regeneration.

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ROCKY MOUNTAIN ASPEN

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Native aspen in the western United States belongs to a single variable species, quaking aspen. Aspen forests occupy more than 6 million acres extending from New Mexico to Montana, but two-thirds of this area is in Colorado and Utah. The aspen cover type is found throughout most of the altitudinal range of forests and is widespread in the mountains and high tablelands on a wide variety of soils. It may form the forest border with lower elevation scrub types. At the other extreme, aspen grows as deciduous islands in the Englemann spruce–subalpine fir zone and occasionally as a sprawling shrub at timberline.

Aspen is a pioneer species, but on some sites it seems to be climax or at least a fire climax *(1, 9, 11)*. It is very intolerant of shade *(1, 14)* and where the site is well suited to invasion by conifers and a substantial coniferous seed source exists, aspen stands may last only through a single generation. Where

the site is ill-suited to invasion by conifers, aspen seems to last indefinitely. In the absence of disturbance or coniferous invasion, scattered root suckers develop as the old canopy gradually breaks up, giving rise to a fairly uneven-aged replacement stand, commonly of somewhat crooked trees *(1)*. Heavy use by wildlife or sheep in such areas can prevent replacement, and if continued long enough can convert aspen to grassland.

Aspen seldom regenerates from seed. The great preponderance of regeneration originates as root suckers. Following fires or clearcutting in aspen, or of stands of conifers with scattered aspen, aspen root suckers may promptly occupy the site. Juvenile growth is fast *(8)*, and on many sites growth exceeds that of associated conifers for decades *(1)*. Stands often survive for 150 years or more, barring fire, and occasionally exceed 200 years. Good clones on good sites surpass 100 feet in height, but on poor sites, old stands may be less than 60 feet tall and the trees may not reach commercial size.

In the southern part of the range of aspen, outbreaks of the Great Basin tent caterpillar may repeatedly defoliate extensive areas, severely reducing growth and causing heavy top kill. Stands may be destroyed, most of the trees killed, and the remainder left with only lower branches living *(13)*. Following such stand destruction root suckers tend to be sparse and weak.

The most significant disease, white trunk rot *(3)*, destroys much wood, weakens stems, and contributes to wind breakage *(4)*. A variety of canker diseases are second only to heart rots in the damage they cause to aspens *(5, 6, 12)*. Root rot caused by *Fomes applanatus* is also widespread and results in considerable windthrow *(3)*.

Aspen suckers are readily browsed by elk, deer, cattle and sheep, and repeated heavy browsing for several years can eliminate aspen regeneration on an area. Sheep are particularly destructive *(1)*.

Aspen has outstanding multiple use potentials. Aspen forests are highly regarded esthetically and where forests are mostly coniferous, or where Gambel oak scrub and sagebrush–grassland types are extensive, the scenic variation offered by aspen is especially appreciated. Aspen stands without coniferous understories often provide considerable forage for livestock and big game. Following clearcutting or forest fire, aspen suckers provide abundant browse until they grow out of reach or succumb to overbrowsing. On deep soils aspen uses more water than grass cover *(2, 7)*, thus reducing runoff and protecting watersheds well against erosion, particularly on very steep slopes. On favorable sites it produces considerable wood, although in time conifers will outproduce aspen *(1)*. Markets for aspen wood are still very limited in the Rocky Mountains, however. In contrast to conifers, aspen regenerates immediately after clearcutting. Finally, most coniferous species regenerate more rapidly under aspen than in the open *(1, 10)*.

It may sometimes be desired to convert aspen forest to conifers. Where there is no coniferous understory, the stand may be underplanted with shade-tolerant conifers, which can be released or partially released after they have become well established. If there is an established coniferous understory, the aspen will largely disappear when the old trees die, leaving the site occupied mostly by conifers. If the aspen is logged carefully to minimize damage to the understory, the resulting stand will be a conifer–aspen mixture.

In other cases the objective may be to perpetuate the aspen forest. Where there is no coniferous understory and if subsequent browsing is not excessive *(1)* this can usually be accomplished simply by clearcutting or burning. Establishment of well-stocked vigorous sucker stands is favored by cutting or killing unmerchantable aspen *(1, 15)*. Cutting small irregular strips or patches can improve the appearance of the harvest areas. If aspen is to be perpetuated despite a coniferous understory, the stand can be harvested in a way that maximizes destruction of the understory, or it can be burned. However, esthetic, economic, or air pollution considerations may require that no harvesting or burning be undertaken in certain stands.

If conversion of aspen to grassland is desired to increase yields of water or grass, or for other reasons, the aspen can be clearcut and sheep allowed to browse the area for three consecutive summers *(1)*.

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BLACK HILLS PONDEROSA PINE

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The ponderosa pine forests of the Black Hills of South Dakota and Wyoming, covering about 1 million acres, form a small unique segment of the vast interior ponderosa pine type. In addition to being isolated from the rest of the type by wide expanses of non-forested land, the pine forests of the Black Hills are distinctive in two important respects: (1) They reproduce themselves readily and prolifically, and (2) they are free of dwarf mistletoe. This fortunate combination both simplifies and enhances success of cultural efforts.

Essentially pure, climax stands of ponderosa pine dominate most forest sites in the Black Hills, imparting the appearance of a monotypic forest. Actually, a variety of other tree species are native to the area, but in total they represent only minor components. Characteristically, ponderosa pine is of much smaller stature in the Black Hills than in some other parts of its range; the average site index is less than 60 feet at 100 years.

Because it reproduces prolifically as a result of frequent seed crops and dependable precipitation in late spring and early summer, Black Hills ponderosa pine typically grows in dense, uniform, even-aged stands *(3)*. In rare instances, however, uneven-aged stands can be found where pine has gradually invaded grassy upland parks or old fields, where there has been prolonged protection from wildfires. Transitional two-aged stands, composed of a light overstory or residual old-growth trees above dense second growth, are present on more acres than any other structural class. Even-aged stands, free of overstory and mostly immature, occupy most of the remaining forest acres.

The most damaging insect pest is the mountain pine beetle. Periodic epidemics still require direct control, but the beetle threat will likely diminish as susceptible, overstocked stands are converted to more thrifty stands by intermediate harvests. Western red rot and associated decay fungi cause large volume losses in old-growth timber, but impact of these diseases will be less in faster grown, managed stands *(1)*. These pests may at times influence cutting priority but not the method.

In contrast to most other areas supporting ponderosa pine forests, no research has been done on harvest cutting in the Black Hills—simply because post-harvest natural regeneration has been so readily obtainable. Much has been learned by experience, however, during nearly a century of persistent harvesting which has (1) encompassed all of the options from selection to clearcutting, (2) touched nearly every harvestable acre at least once, and (3) led to the successful replacement of the mature and overmature old-growth stands by well-stocked, manageable stands of second growth.

The most obvious lesson taught by this varied harvest experience is that no standard silvicultural system can be considered wrong or wholly inapplicable in Black Hills ponderosa pine. The same experience, however, has clearly demonstrated that even-aged management is most compatible with the species' strong natural tendencies in the Black Hills, and that the shelterwood system is the best choice in most harvest situations. This method combines the advantages of continuous protection of the site, assurance of an adequate well-dispersed seed supply, some control over development of competitive

ground cover vegetation, good control over accumulation of unsightly and hazardous logging residue, and of an esthetically acceptable appearance—if the harvest job is skillfully planned and carried out. A two-cut shelterwood is efficient and silviculturally desirable, but a three-cut shelterwood may be used where residue buildup and logging damage to reproduction pose unusual problems.

The other even-aged methods, seed-tree cutting or clearcutting, may be acceptable options in special situations, but each lacks one or more of the advantages of shelterwood harvest. Selection cutting could be used in stands where esthetic considerations are overriding and the stand structure is suitable.

Ponderosa pine reproduction in the Black Hills, irrespective of the silvicultural system employed, is apt to be superabundant. As a result, overstocked young stands present a problem *(4)*. Because natural thinning is normally too slow to be effective, stands that are initially crowded usually stagnate by the time they reach sapling size if left untreated *(2)*. Therefore, periodic thinnings are essential in immature stands to relieve stagnation and grow merchantable timber crops on a reasonably short rotation.

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NORTH CENTRAL TYPES

Lake States Northern Hardwoods
Red Pine
Jack Pine
Black Spruce
Lake States Aspen
Oak–Hickory

LAKE STATES NORTHERN HARDWOODS

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The northern hardwood forest type of the Lake States covers about 10 million acres and varies greatly in composition and density depending on soil drainage, past cutting practices, and fire *(1, 3)*. Characteristic species are sugar maple, yellow birch, and eastern hemlock. Sugar maple is a very shade-tolerant tree; yellow birch is intermediate; and hemlock is highly tolerant of shade, slow growing, and very long lived *(13)*. American beech, which grows in the mixture in some areas, is also very shade tolerant. Sugar maple, beech, and hemlock are principal components of the northern hardwood climax forest *(8)*. In places American basswood, an intermediate in light requirements, occupies an important position in the type. Other associated species of less importance are the shade-tolerant balsam fir, the moderately tolerant American elm, red maple, eastern white pine, and white ash; and the very intolerant paper birch. Present stands have a high proportion of younger ages and smaller size classes. Well-drained and poorly-drained sites differ in species composition. Thus, different silvicultural prescriptions are needed.

Well-drained Sites

Sugar maple forest types are usually 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.

Advance regeneration on most sites is composed of shade-tolerant long-lived species, most commonly sugar maple. Although good seed crops occur frequently in all species, site preparation and adequate light are required for establishment of the less tolerant species *(11, 12)*. Most species are vigorous sprouters, but only basswood sprout regeneration is considered desirable.

Most disease problems are associated with overmature stands *(3)*, although defects due to discoloration or decay may occur in lumber cut from younger trees. A major damage by insects is that caused by bud miners; these

kill the terminal buds resulting in multiple forking of the main stem, especially in maple *(4)*. Reproduction may be damaged by high deer populations in limited situations. However, the upland sugar maple types are capable of supporting relatively high wildlife populations without serious injury to the forest *(7)*.

In the upland sugar maple types the forest owner has the choice of several silvicultural systems depending on his management objectives.

All-aged management by selection cutting is well suited for continuous production of high-quality veneer and sawlogs from shade-tolerant species such as sugar maple *(1)*. Adequate advance reproduction of shade-tolerant species is almost always present. Periodic thinnings can develop a desirable distribution of size classes and concentrate growth on the more desirable species and the larger trees having long clear boles. The selection system of cutting results in stands with a good proportion of larger trees but provides minimal habitat for most wildlife species. Wherever recreational and esthetic demands require a continuous cover of sizeable trees, the selection system is favored.

Even-aged systems of silviculture are necessary to encourage the more light-demanding and valuable species such as yellow birch *(12)*. Simply removing the overstory, however, will not automatically result in a higher proportion of these species. Inadequate natural regeneration has, in the Lake States, followed clearcuttings in immature stands or on sites with impeded or excessive drainage *(9)*. Some even-aged methods cause temporary esthetic damage but have the advantage of immediate improvement of wildlife habitats *(10)*, especially for deer and grouse.

Shelterwood cuttings provide the greatest flexibility and consistency of results for establishing even-aged stands *(12)*. The amount and composition of the 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 prior to logging encourage the establishment of light-demanding species; without such understory treatment, tolerant species will continue to dominate the new stands *(12)*. Normally only one cutting is required in upland stands of seed-bearing age to assure adequate seeding. Removal of the remaining overstory can be accomplished in stages to develop regeneration slowly or in a single cut after suitable regeneration is fully established *(10)*.

Poorly-drained Sites

In addition to those types where sugar maple is a dominant species, the northern hardwood forest includes types classed as hemlock, hemlock–yellow birch, or black ash–American elm–red maple. These are mostly long-lived subclimax types, usually growing on wetter areas *(2)*. The ash–elm–maple type is probably climax on the wettest areas. The hemlock, hemlock–yellow birch, and ash–elm–maple types commonly grade into each other and into variations of the maple types. 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.

Good seed crops for species common to the more poorly drained sites occur frequently. Hemlock and yellow birch, however, do not regenerate well

in forest duff and compete poorly with sugar maple, a common associate. Establishing hemlock and birch regeneration requires removal of competing vegetation and, in addition, site scarification. Planting has not been very successful. Nearly all species are shallow rooted especially on the wetter sites. Both red maple and American elm develop vigorous sprouts, particularly younger trees growing under open conditions. On the wetter sites, trees of sprout origin are subject to rot and many have poor form.

These types provide food and cover for many species of game. Yellow birch, hemlock, and red maple are preferred browse species for white-tailed deer. High deer populations may cause severe damage to seedlings, especially where poor tree-growing conditions exist *(6)*.

Selection cutting is a feasible system to favor tolerant hardwoods in these types, but because of the danger of windthrow and postlogging decadence, the first cutting should leave relatively high stocking levels *(1)*. After 5 years a second cut should be made to reduce the stands (trees 10 inches and larger in diameter) to 70 square feet basal area per acre; succeeding cuts should be to this stocking level also. Where Dutch elm disease is prevalent, heavier cuts of elm may be necessary in anticipation of mortality. However, cutting to less than 50 square feet basal area (trees 10 inches and larger in diameter) reduces volume growth and quality development of the remaining stems *(5)*, and regeneration may be spotty because undesirable shrubs and grasses invade the stand.

Regeneration following complete clearcutting is unpredictable on these sites in the Lake States *(11)*. Grass-shrub-herb stages can result and last for several decades before they are replaced by desirable tree species. Clearcutting without advance regeneration and when appreciable numbers of red maple and American elm are present usually results in undesirable fast-growing sprouts which suppress seedling stems *(6)*. However, clearcutting in small patches enhances game habitat by providing browse and nesting sites.

Group selection cutting is possible in the hemlock types and is used with site preparation to favor regeneration of yellow birch *(3)*. The method 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. When group cuttings are combined with selective removal of individual trees in the adjacent areas, some of these disadvantages are overcome *(1)*.

Shelterwood treatments that include removal of advance growth or scarification before the seed cut can be used to increase the proportion of yellow birch and hemlock *(1, 12)*. 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 depend on the abundance of the regeneration, stand age and decadence, soil depth, and on other factors related to wind firmness and post-logging mortality.

In abused stands, 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 *(1)*. Where the major portion of the stand is defective or undesirable, shelterwood treatments may be used for regeneration as soon as desirable species reach seed-producing age.

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RED PINE

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Red pine was an important component of the extensive Lake States pine forests that were cut about the turn of the century. Logging was generally followed by burning, either accidental or intentional to reduce the risk of wildfires. The widespread fires caused an increase in aspen and jack pine at the expense of red pine and white pine. Although the area of natural red pine forest is small, the type has been considerably expanded by planting to a total area that is now about 1 million acres. Currently, red pine is the most intensively managed coniferous type in the Lake States.

Red pine grows both in pure and mixed stands. Associated species on the coarser, drier soils are jack pine, aspen, paper birch, and northern pin oak. On the fine sands to loamy sands, associates include eastern white pine, red maple, northern red oak, and white spruce–balsam fir mixtures *(5)*.

Red pine, although a light-demanding tree, can endure more shade than jack pine, bigtooth and quaking aspens, and paper birch, but not as much as white pine or its other common associates *(5)*. The generalized ecological succession of these species in the Lake States is from jack pine to red pine to white pine and, in some instances, to northern hardwoods or spruce–fir. The rate of succession is more rapid on the better sites *(3)* and essentially stops at an intermediate stage on the poorer sites *(5)*. Red pine is most common on fine to loamy sands with level to gently rolling topography or on low ridges adjacent to lakes and swamps. It grows best on moist, well-drained soils but can withstand moderate droughts.

Heavy seed crops occur at irregular and infrequent intervals of 10 to 12 years or more; light to medium seed crops are produced every 3 to 7 years *(3)*. Although seeds can germinate on the organic forest floor, relatively few seedlings survive because the deep litter dries rapidly. Exposed mineral soil or disturbed seedbeds increase the chances for seedling success. Shrub competition may limit seedling establishment especially on the better sites. Thus, natural regeneration is not very dependable because it requires a combination of good seed production, seedbed preparation, and favorable precipitation during germination and seedling establishment. For these reasons, more reliance is currently placed on artificial regeneration–seeding or planting.

Because of its intolerance to shade, red pine grows best in even-aged groups or stands *(3)*; thus, it is adapted to even-aged management. Usually the management objective is to grow red pine in essentially pure stands, removing other species such as jack pine in intermediate cuttings *(5)*.

Clearcutting followed by machine site preparation and then by seeding or planting is the system most commonly used. In areas where esthetic considerations are important, clearcut areas must be kept small. Narrow strip cuttings that limit disturbance to 25 percent or less of the forest area can be used for harvesting timber in sensitive areas such as scenic zones and recreational areas. Strips may be curved along type boundaries to blend with the landscape. Such cuttings also enhance wildlife habitat *(6)*.

The seed-tree system received an extensive trial in Minnesota over a number of years. Regeneration was successful only when harvest cuttings coincided with good seed years or when abundant advance reproduction was present prior to cutting *(3, 4)*. The method is not now in use.

The shelterwood system has utility in the red pine type *(3, 4)*. Since regeneration is established before the mature stand is completely removed, the method is compatible with the maintenance of landscape values. Because of the uncertainty of natural regeneration, however, supplemental seeding or planting is sometimes required. This is usually preceded by mechanical site preparation or adequate surface disturbance through logging. Competition from shrubs may necessitate release of seedlings a few years after establishment.

A harvesting pattern now undergoing test is clearcutting strips 50 feet wide and leaving intervening 16-foot strips of mature trees. The cleared strips are then planted. After the planted trees become established the 16-foot

reserve strips are harvested. These narrow strips will provide access throughout the life of the stand for mechanized cultural operations and other purposes *(1)*.

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The jack pine type, characteristic of very sandy areas, is found on more than 2 million acres in the Lake States. Jack pine grows in both pure and mixed stands. Common associates in mixed stands are red and eastern white pine, aspens, paper birch, oaks (mainly northern red oak and northern pin oak), and spruce–balsam fir mixtures. The type is usually found on level to gently rolling sand plains, mainly of glacial outwash, fluvial, or lacustrine origin *(6)*. It also grows on eskers, sand dunes, rock outcrops, and ridges.

Jack pine, a rather small short-lived species, establishes readily on recently burned areas, especially on exposed sandy sites. It is less shade tolerant than any of its principal associates except quaking aspen and paper birch. Thus, jack pine is a temporary type that on the better sites is replaced by more shade-tolerant species when natural succession is not interrupted by fire. Fire results in the reproduction of jack pine at the expense of the more shade-tolerant associated species *(3)*, except for the oaks which sprout vigorously. On poor sites, such as light sandy soils where other commercial species do poorly, jack pine is more permanent. Here it tends to grow in pure stands but sometimes with northern pin oak. The poorest jack pine sites are largely free of shrubs; medium sites are characterized by low shrubs such as blueberry, sweet fern, and dwarf honeysuckle; and the better sites often have a dense undergrowth of American and beaked hazel, alder, red-osier dogwood, and willows *(6)*.

Jack pine seed is produced nearly every year in stands over 30 years of age, with good crops at 2- to 4-year intervals. Over most of its range, the seed is borne in serotinous cones that retain viable seeds for many years. In the more southerly areas of its range, however, the cones of some trees open and release seeds soon after they mature *(3, 6)*. But the seeds in tightly closed serotinous cones accumulated on the trees are not released until the cones are opened by relatively high temperature, as with fire. Cones in scattered logging slash also will release seeds if they are close to the ground.

To perpetuate the type, jack pine stands require even-aged management. This may be accomplished by clearcutting, seed-tree cutting, or shelterwood cutting at rotation age. Recommended rotations are 50 years for fiber products and 60 to 70 years for larger products on the better sites *(5)*. Trees grown under short rotations are less likely to be damaged by insects and diseases.

Most jack pine stands are harvested by a clearcutting system. Regeneration is most easily obtained on mineral soil seedbeds free of competing vegetation *(1, 4)*. Prescribed burning and many kinds of mechanical equipment have been used to prepare seedbeds on which jack pine has been successfully regenerated by scattering cone-bearing branches or by sowing repellant-treated seed. On better sites, competition from dense shrubs and other tree species may require treatment to release the jack pine seedlings between the third and fifth years. Brush competition on the best jack pine sites may become severe enough to warrant planting of seedlings to increase chances of successful regeneration.

Both seed-tree and shelterwood cuttings *(2)* have been moderately successful. In stands where the serotinous cone habit prevails, slash is broadcast burned to produce the heat necessary to open the cones in standing trees. Such prescribed burning has the disadvantage that it kills most of the seeds in cones in the logging slash.

The shelterwood system has also been used in limited areas where some cones open freely on trees *(2)*. The method involves removal of the stand in two or three cuts after reproduction is established. Where applicable, the shelterwood system tends to preserve landscape and wildlife values. A disadvantage is that the jack pine budworm causes problems in two-storied stands—the larvae fall from the overstory to the reproduction and may defoliate and kill seedlings.

Management of jack pine to provide suitable nesting habitat for the Kirtland's warbler, an endangered species, requires regenerating rather large patches on a rotation basis in order to keep enough area in young stands where branches reach the ground.

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BLACK SPRUCE

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The black spruce type occupies about 2 million acres in the Lake States, chiefly in Minnesota. It grows mainly in pure stands, principally on organic soils of old lake beds, but may also be mixed with tamarack, northern white-cedar, and balsam fir. To a lesser extent, black spruce also is found on mineral soils where it may form pure stands but more often is mixed with black ash, red maple, quaking aspen, paper birch, the pines, and white spruce *(7)*.

Black spruce is generally a rather small, slow-growing tree; heights of dominant trees at 50 years range from 15 to 50 feet. On good sites mature stands yield high volumes of pulpwood but the poorest sites produce only small Christmas trees *(5)*. Growth rate on organic soils apparently is related to the amount of nutrients received in ground water flowing from adjacent areas of mineral soil *(1)*.

Most black spruce stands in the Lake States originated after wildfires and so are, or once were, even-aged. Black spruce is a good seed producer and seed crops seldom fail *(7)*. It reproduces successfully after fire because mature trees (even if killed) bear persistent cones that disseminate viable seed. Seedlings grow much faster in open areas created by fire than under a living overstory. In the absence of fire, black spruce is succeeded by northern white-cedar and balsam fir which are more tolerant of shade *(7)*. Brush invades black spruce stands on the best sites, especially on organic soils.

In areas long undisturbed by fire, black spruce stands begin to open up as overstory trees die and new trees become established. Such uneven-aged stands are more common on the poorest sites, which have a low fire hazard and burn less frequently. Here trees are continuously reproduced vegetatively by layering where branches become buried in moss and develop adventitous roots *(7)*.

The shallow root system of black spruce makes it notably susceptible to uprooting by wind *(7)*. Wind breakage is common in older stands because of butt rot. Both uprooting and breakage occur along stand edges exposed to the prevailing wind. Opening up of the stand by any partial cutting system increases the risk of windthrow or breakage. However, wind damage is not heavy on poor sites where trees are short.

Seedling establishment requires a moist seedbed free from competing vegetation. Establishment is generally successful on slow-growing sphagnum

moss or where the surface layer is removed by fire or compacted by machines as in skid roads *(4)*. Natural regeneration takes place in clearcut openings where seeding is effective up to 260 feet from the windward edge of a mature stand and up to half that distance from the leeward edge *(3)*. Regeneration also occurs under partial cover, as in shelterwood cutting, but growth is slower than where full sunlight is available *(4)*.

In some stands dwarf mistletoe is a serious disease. Besides causing witches'-broom, it kills many trees and reduces volume growth on others. The pest is probably best controlled by broadcast burning *(2)*.

Black spruce is well adapted to even-aged systems. Best yields of pulpwood and better environment for wildlife can be sustained by managing black spruce in fairly large stands. Under such management the alternative silvicultural systems to consider are seed-tree, shelterwood, or clearcutting. Seed-tree and shelterwood cuttings result in much wind damage through uprooting or breakage in the reserved stand. Moreover, under shelterwood, growth of reproduction is slow and dwarf mistletoe infestations are not controlled. Therefore, clearcutting has much to recommend it. Stands should be clearcut at maturity, either in progressive strips to be seeded naturally or in larger blocks followed by artificial seeding *(4)*. The choice between these two methods will depend on the stand's shape, area, condition, and location.

The establishment and growth of new stands will be favored by broadcast burning of the slash if any of the following conditions exist on the clearcut area: Dwarf mistletoe is abundant, brush is abundant, sphagnum seedbeds are poorly distributed, or heavy slash covers the area *(4)*. Normal drainageways should be kept open to prevent damage from flooding *(6)*. Visual impact of clearcut areas can be reduced by making their boundaries follow natural site or forest type lines.

Uneven-aged management is applicable on poor sites. Here partial cutting by group selection with a cutting cycle of about 10 years can be used for producing Christmas trees.

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LAKE STATES ASPEN

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Aspen forms the largest and most widely distributed forest type in the Lake States, covering about 13 million acres. There are smaller areas of the type in the northeastern United States. The dominant species, quaking aspen, a small to medium-sized tree, may grow in essentially pure stands, but other species are usually present in varying numbers. Common associates in the far north are paper birch, jack pine, balsam fir, spruces, northern white-cedar and balsam poplar. Farther south and east, aspen stands may include sugar maple, red maple, American basswood, northern red oak, paper birch, bigtooth aspen, red pine and eastern white pine *(12)*.

Over its wide range, aspen grows on a diversity of soils and sites. Growth rate varies with soil fertility and available moisture—tree heights at age 50 range from 90 feet on deep, fertile, high-calcium loams to 40 feet on dry sands and rock outcrops or water-logged mineral soils and peats *(8, 9)*.

The light-demanding aspen cannot reproduce successfully under its own shade, so it forms a temporary forest type that is replaced by other species where the natural ecological succession is not interrupted by fires, logging, or windstorms *(7)*. On relatively dry sites, aspen often is succeeded by red pine, red maple, or oaks. On moist fertile soils, aspen is followed by some of the northern hardwoods, balsam fir, white spruce, or white pine, and on the wetter sites by balsam fir, black spruce, or northern white-cedar.

Although aspens produce good seed crops every 4 or 5 years *(12)*, few seedlings become established. Instead, regeneration depends primarily on the abundant root suckers that develop after aspens of any age are cut or killed *(6, 13)*. Vigorous suckers grow fast enough to overtop competing vegetation of comparable size, but they cannot persist under the shade of brush or taller hardwood reproduction. Although aspen stands continually produce suckers, these seldom survive long under the canopy.

Aspen is aptly described as the "Phoenix tree"; it has persisted in natural stands largely because of fires *(6)*. Even where it is a minor component of the stand, aspen's ability to produce abundant root suckers often enables it to become the dominant species after a succession of fires. Where aspen is already dominant, it easily reestablishes itself after logging, especially where cutting is followed by fire that kills back the other vegetation.

In general, the number of suckers produced is proportional to the degree of cutting; from 5,000 to 10,000 suckers per acre often appear after a complete clearcutting. Although natural thinning rapidly reduces this high stocking, crop trees are essentially the same size after 15 years regardless of initial stocking *(11)*.

Complete clearcutting is the most effective method for regenerating aspen stands. However, a commercial harvest followed by cutting or killing the remaining unmerchantable overstory is also satisfactory if the followup operation is not delayed too long. Excessive brush or advance reproduction of other species should also be killed back by prescribed burning or treatment with acceptable herbicides to provide favorable conditions for aspen sucker

development. In areas of high scenic quality or those having heavy recreational use, the size of clearcuttings may need to be restricted for esthetic reasons. Small clearcuts are also best for wildlife. During all stages of their development, aspen stands provide highly desirable food and shelter for ruffed grouse. Newly regenerated stands are an essential source of browse for deer and moose. Numerous well-distributed aspen stands of all ages thus provide favorable habitat for the most important wildlife species in the region.

In stands containing a substantial mixture of longer lived and more valuable species—in particular northern hardwoods or balsam fir as an understory—the aspen is removed in a single release cutting to hasten conversion to another type having greater potential. Where the mixture is of low-quality species such a release cutting is not advocated.

Aspen stands may be periodically defoliated by the forest tent caterpillar and other leaf feeders; the major effect usually is decreased growth rate during infestations. Control of the insects is seldom feasible *(4)*. Trees of any age can be attacked by the aspen borer, but infestations seem most frequent in poorly stocked or thinned stands *(5)*. Hypoxylon canker is the most serious aspen disease; it results in death or breakage of many trees *(2)*. Infections may be reduced by maintaining well-stocked stands *(1)*. Because losses to decay fungi increase rapidly in overmature stands, harvest should not be unduly delayed *(3, 10)*.

To minimize losses from insects and disease, this easily regenerated, light-demanding type should be grown in well-stocked, even-aged stands and harvested promptly at maturity. Recommended rotations for aspen stands range from about 30 years on poor sites to 50 or 60 years on the best sites. A single thinning from below is sometimes made on good sites at age 30 to 35 years where large high-quality trees are desired in the final harvest.

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OAK–HICKORY

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The oak–hickory forest is the most extensive timber type in the United States. It covers 116 million acres, nearly one-quarter of the total forest area in the country *(16)*, and extends from the prairie borders in Oklahoma, Kansas, and Minnesota through the Appalachian Mountains into the Piedmont and southern New England. This forest is best developed and most continuous in the Ozark and Ouachita Highlands *(2)*, where it exists on all upland sites from the driest ridges to the coolest slopes and protected coves. Farther east, the type tends to be replaced by mesic species on the more fertile and moist sites. The great geographic and climatic range of the type results in wide variation in stand composition.

White, northern red, and black oak are found throughout the type. Other common oaks are scarlet and chestnut oaks in the Appalachians and adjoining areas, northern pin and burr oaks in the northern and western parts of the range, and post, blackjack, and southern red oaks to the west and south. Although the oaks are more abundant, the hickories—especially shagbark, pignut, mockernut, and bitternut—are consistent components. Associated species vary widely and may include aspens, ashes, blackgum, yellow-poplar, elms, sugar and red maples, sassafras, black cherry, black locust, black walnut, and many other hardwoods. On suitable sites, shortleaf, pitch, white, and Virginia pines, and eastern redcedar may also be present.

The more valuable species of the oak–hickory forests are intolerant to moderately intolerant of shade *(17)*. However, maples, blackgum, elms, beech, and understory species such as dogwood, eastern redbud, and many shrubs are much more shade tolerant than oaks or hickories. These tolerant species reproduce from seed and seedling sprouts; they persist for long periods under a canopy, and grow rapidly when released. Two light-demanding species, yellow-poplar and white ash, consistently produce good seed crops and the seeds remain viable in the litter for several years *(3, 6)*. Where

adequate seed is present, rapidly growing seedlings of these valuable species follow overstory removal and on suitable sites provide a strong component in the new stand.

In most years, essentially all oak and hickory seeds are destroyed by insects, fungi, birds, or animals. When the infrequent bumper crop is produced, enough seed escapes damage to provide abundant seedling reproduction. Few seedlings survive long under a dense canopy, however, because of inadequate light and moisture. Even without competition, new oak seedlings grow very slowly for several years. Such seedlings cannot be depended upon to reproduce oak–hickory stands. Unless released through cultural operations, they cannot compete with rapid-growing seedlings and sprouts of other species that follow overstory removal or heavy partial cutting. Although oaks can also be planted on suitable sites *(12)*, the cost of subsequent cultural operations makes oak planting a marginal operation at present.

Because of its strong sprouting ability, oak and hickory reproduction survives the effects of browsing, breakage, drought, and fire. Top dieback and resprouting may occur a number of times *(7, 8)* with each successive shoot reaching larger size and developing a stronger root system than its predecessors. By this process, oak and hickory reproduction gradually accumulates and grows larger under moderately dense canopies, especially on sites dry enough to restrict the development of reproduction of more tolerant but more fire- or drought-sensitive species. Oak advance reproduction should be at least 4 feet tall and 1/2 inch in diameter at the root collar before it can compete effectively with other reproduction when the overstory is removed *(13)*. For sprouts to compete effectively, they must come from stems of at least this size. Thus, oak–hickory stands are regenerated before, not after, the harvest cut *(4)*.

In much of the area covered by the oak–hickory forest, shade-tolerant hardwoods are climax, and the trend of succession toward this climax is very strong. Although most silvicultural systems when applied to the oak type will maintain a hardwood forest, the cutting method used affects the rapidity with which other species may replace the oaks and hickories. Results vary by site condition, location, type of other species present, and response of the various species to the light and moisture conditions created by silvicultural operations. If the management objective is to perpetuate the oaks, these species can best be reproduced and grown in even-aged groups or stands *(5, 14)*.

Harvesting single trees as they mature is not a suitable silvicultural system for managing oaks *(1, 10)*. Although some oak reproduction will become established and persist for long periods under selection cutting, it will not develop satisfactorily under a uniform canopy even as low as one-third full stocking *(11)*.

Group selection cutting is a good system for regenerating light demanding species *(9, 14)*. With small and well-dispersed groups, the landscape appears to retain a permanent forest cover. Although the size of group cuttings has little effect on density and composition of reproduction, trees grow slower on the edges than in the center of openings. To minimize the proportion of the area affected, openings should be at least 1/2 to 1 acre in size *(14, 15)*. Application of the group selection technique over large areas

creates many small stands of varying age classes; these are difficult to identify and treat in subsequent cultural and harvesting operations. At some arbitrary point, group selection cutting and clearcutting grade into each other in appearance and silvicultural response. The choice between the two systems is thus based less on silvical principles than on management objectives and what is administratively feasible.

Where adequate oak–hickory advance reproduction is present, clearcut areas, of any size or shape, will reproduce rapidly-growing new stands containing oaks, hickories, other light-demanding species, and usually a few shade-tolerant species. The better the site quality, the greater the diversity of the associated species.

In the absence of adequate oak and hickory advance reproduction, clearcutting tends to eliminate these species except for sprouts from the stumps of cut trees. On medium and poor sites such sprouts will usually provide an oak component in the new stand, but there will be fewer oaks in the new stand than in the old. On good sites in the eastern part of the region, clearcutting without adequate oak advance reproduction will convert the stand to shade-intolerant species other than oaks, typically yellow-poplar. This is desirable where yellow-poplar is the objective. Oak and hickory are desirable components in this type for their wildlife values, but it is difficult to obtain advance reproduction of these species.

If oaks and hickories are especially desired in the new stand, but advance reproduction of these species is inadequate, no final harvest cuts should be made. Cutting should be deferred altogether or light thinning used to promote development of oak advance regeneration.

Shelterwood cutting has no advantage over clearcutting where adequate oak–hickory reproduction exists. Where advance regeneration is inadequate, shelterwood cutting should theoretically be useful for creating it. However, shelterwood cuttings often fail to regenerate oaks. Several cuttings are apparently needed to create a shelterwood that will provide the right combination of light and moisture over the period necessary for large advance reproduction to develop. Shelterwood cutting can also favor reproduction of more tolerant species, and the proper overstory density may well differ according to site quality. The shelterwood system may have some utility where esthetics are important.

Seed-tree cutting has little value as a reproduction method for oaks and hickories. The heavy seeds are poorly distributed, and the small seedlings grow slowly and are often overtopped by other vegetation. Although leaving seed trees might reduce the esthetic impact of heavy cutting while providing some mast for wildlife, this objective is better achieved by restricting the size of clearcut areas, adjusting the shape to blend with natural features, and retaining stands of mast-bearing trees on one or more edges of the clearing.

Insects and disease have little impact upon the choice of silvicultural systems for oak–hickory management. No really practical control measures exist for either defoliating insects or oak wilt; thus, the silvicultural practices must be aimed at maintaining stands in a healthy vigorous condition, salvaging losses as feasible. Borers, an important cause of quality loss, seldom successfully attack vigorous trees. For these reasons and to maintain rapid growth rates on crop trees, periodic thinnings are needed in oak–hickory stands regardless of the regeneration system used.

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NORTHEASTERN TYPES

Northeastern Spruce–Fir
Eastern White Pine
Northeastern Northern Hardwoods
Cherry–Maple
Appalachian Mixed Hardwoods

NORTHEASTERN SPRUCE–FIR

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Red spruce, white spruce, and balsam fir are the predominant species in the northeastern spruce–fir type. Black spruce is also a minor component. Altogether there are nearly 11 million acres of the type in New England and New York. Depending on site conditions, stands may contain only the spruces and fir or spruce–fir in various combinations with other conifers and hardwoods. These other conifers include northern white-cedar, eastern hemlock, eastern white pine, and tamarack; and the hardwoods include red maple, paper birch, the aspens, white ash, American beech, sugar maple, and yellow birch (*4*). Red spruce, white spruce, and balsam fir will grow on a variety of soils, including those that are poorly drained (*5*). Black spruce is generally confined to bogs and muck soils.

Red spruce produces good seed crops every 4 to 8 years, white spruce every 2 to 6 years, and balsam fir every 2 to 4 years (*6*). All three species are tolerant of shade but require considerable light for rapid growth and development. In more northerly sections of the Northeast, white and red spruce develop pure stands on old-field sites (*4*). All three species may form physiographic climaxes on poorly drained sites, but on the better soils are subclimax to and often mixed with hardwoods such as sugar maple and beech (*2, 7*).

Spruce–fir stands normally reproduce readily and have remarkable recuperative capacity (*1*). Advance spruce–fir reproduction under many older stands may assure new spruce–fir stands after the overstory is harvested, unless fire occurs. If left undisturbed, most stands of the type will contain a number of age classes because the species, particularly balsam fir, will survive under heavy shade. However, the main canopy of many stands is even-aged because they developed after depredation by insects, hurricanes, fires, and clearcutting of mature stands around 1900 (*2*).

The major pests of the spruce–fir type include spruce budworm, balsam wooly aphid, and fungi which cause balsam fir butt rot. Serious outbreaks of the defoliating budworm occur about every 20 years; aphid infestations are worst along the coastline; and butt rots result in windthrow and stem breakage, especially in stands older than 50 to 70 years.

The spruce–fir type in the Northeast is suited to either even-aged or uneven-aged management, and depending on stand conditions, the type is amenable to all of the silvicultural systems except seed-tree harvesting (*4*, *7*). The spruces and firs are generally shallow rooted, and windthrow of seed trees can be serious on all except the most protected sites.

Clearcutting is the most commonly used harvesting system for even-aged stands that are mature or overmature and on sites where windthrow is a problem (*3*, *4*, *7*). Harvesting should be done in narrow strips or small patches so the adjacent uncut stand can provide partial shade for advance regeneration and a seed source if advance regeneration is missing (*7*). Small clearcut openings benefit wildlife, particularly white-tailed deer, by stimulating production of browse. Clearcutting, except where the most advanced mechanical harvesters are used, results in dense accumulations of slash that inhibit the survival and growth of advance regeneration. Also, very large clearcuts may result in high surface temperatures and excessive drying that kill seedlings or delay the development of regeneration until the area is covered with herbaceous vegetation.

Selection cutting is applicable to those stands that tend to be uneven-aged (*1*). Single trees or groups of trees are removed at relatively short intervals of 5 to 20 years (*4*). In using the selection system, thinning must be an integral part of all harvesting operations (*1*) in order to maintain proper distribution of age and size classes. The system is ideal for obtaining regeneration and is particularly applicable where site protection, esthetic values, and recreational use are dependent on a healthy continuous forest cover.

The shelterwood system in which the overstory is removed in two or more cuttings is applicable to most stands of the spruce–fir type except those on shallow soils or very exposed sites. The system provides a seed source, protection for regeneration, and rapid quality growth on the residual trees. Length of time between cuts is determined by the development of regeneration and the growth objectives for the residual trees.

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EASTERN WHITE PINE

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Eastern white pine is an important forest type in the Northeast covering about 7 million acres. It also extends into the Lake States and southward along the Appalachian Mountains. White pine is found on a wide variety of sites: From wet swamps to dry sand plains or rocky ridges, and from moist stream bottoms and coves to dry upper slopes and ridgetops. Because of its wide range and its adaptability to varied site conditions, eastern white pine is a major component of four forest types and an associate in 14 other types. Common associates of white pine include nine other conifers and at least 18 hardwood species (*13*).

White pine is often a pioneer and it forms either relatively pure stands or mixtures with other pioneer species in abandoned fields and pastures. Natural white pine regeneration frequently follows major disturbance such as windthrow and wildfire. Fire, in particular, played a major role in establishing essentially even-aged stands of white pine in the original forest by eliminating competition (*2, 8*). However, too frequent or too severe fires eliminate white pine as well (*7*).

On sandy and relatively dry sites white pine stands may form a physiographic climax. On fertile and relatively moist soils white pine eventually is displaced by more shade-tolerant species, usually hardwoods. Throughout its range, however, white pine is a minor component of the climatic climax forest. Although white pine may play an ecological role similar to some 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 of full sunlight. Thus, white pine can reproduce under partial shade where it can survive and grow slowly for a long period. Eventually it will die or become deformed unless released from the overstory. Once established, optimum growth occurs under full sunlight (*13*).

The most important disease of white pine is the white pine blister rust. On some sites in the Lake States, white pine cannot be grown successfully because of this disease. However, on other sites and in other sections, as the southern Appalachians, blister rust is a minor problem.

The most important insect pest in the Northeast and northern Lake States is the white pine weevil, whose larvae kill the terminal shoots (*9*). Methods of natural control include the use of shelterwood or other systems that provide some shade to sapling pines (*5*); maintenance of high young-stand densities to minimize damage (*5, 6*); or groupwise mixtures with other species, especially hardwoods (*9*). Weevil damage in the Southern Appalachians is minor compared to that in the Northeast and Lake States.

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Good seed crops generally occur every 3 to 5 years but may be as infrequent as 7 or more years. Seed will travel at least 200 feet within a white pine stand and more than 700 feet in the open (*13*).

The condition of the seedbed is an important factor in regenerating white pine. In full sunlight, favorable seedbeds are moist mineral soil, 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 (*10, 11, 12*). Partial shade, mechanical scarification, and burning improve the seedbed.

Growth characteristics of white pine indicate that it can best be grown under even-aged stand conditions although there is considerable leeway in choosing regeneration methods. Indeed, white pine has been successfully regenerated by a wide variety of methods, including clearcutting in blocks and strips, seed tree, shelterwood, and group selection (*1, 3, 4*). Single-tree selection cutting has usually not proven satisfactory (*7*).

If abundant advance regeneration is present, it can be released by cutting the remaining trees. Clearcutting during or just after a heavy seed crop often results in well-stocked stands on light soils (*3, 6*). Clearcutting in small patches or strips with seed dispersed from adjacent stands is also possible (*4*). However, little or no regeneration may develop after a harvest cut due to the periodic nature of the seed crops and to competition from other vegetation. Therefore, mechanical site preparation and planting are necessary at times.

The seed-tree method, while feasible, has little to recommend it (*4*). The sporadic nature of seed crops and susceptibility of white pine to windthrow can mean inadequate seed for regeneration. Also, the seed trees offer little protection to the site or to the developing seedlings.

White pine has been successfully regenerated by the group selection method (*1, 3, 4*). However, any of the regeneration requirements provided by group selection usually can be provided more economically by other methods, especially where mechanical means are used to improve seedbed conditions or eliminate competition. Where esthetics are important, group selection cutting may have merit.

Probably the most versatile system for regenerating white pine is shelterwood cutting. 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, to hold down weevil attacks, and to help suppress competition from herbaceous vegetation and hardwood sprouts (*3, 4*). Three or more cuts spread over a number of years may be used, but white pine can be successfully regenerated with a two-cut shelterwood system. The seed cut should be timed to take advantage of a good seed crop, but considerable leeway exists in timing the final cut (*3, 4*).

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NORTHEASTERN NORTHERN HARDWOODS

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The northern hardwood forests in the northeastern United States, covering nearly 15 million acres, are characterized by sugar maple, American beech, and yellow birch. In older stands these three species may dominate, but younger stands also contain paper birch, white ash, red maple, and other hardwoods. Conifers such as eastern hemlock, balsam fir, and red spruce grow with the hardwoods, especially on cool steep slopes and on poorly drained soils at the lower elevations. Repeated cuttings, sometimes followed by wildfires, have favored a variety of stand conditions. Consequently, numerous combinations of stocking levels, age classes, and species are present. Yellow birch, sugar maple, paper birch, and white ash are the most important hardwoods for timber production; in many areas, paper birch is the most valuable tree not only for timber but also for esthetic considerations.

Northern hardwood sites in the Northeast are found up to elevations of about 2,000 feet on land that is rolling to mountainous. The hardwoods occupy a zone between white pine and spruce types in the river valleys and the spruce–fir type at higher elevations of the mountains. Hardwood soils are usually stony and podzolic, but the most productive soils are deep and well to moderately well drained.

Species in the type differ in shade tolerance, longevity, and growth rate. Yellow birch tolerates shade moderately well but usually has the slowest growth. White ash and red maple are also intermediate in shade tolerance, but 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 of shade. Sugar maple, beech, hemlock, and red spruce are all shade-tolerant, long-lived species. Sugar maple and beech have moderate growth rates, while hemlock and red spruce are slow growing. Sugar maple, beech, and hemlock are the principal components of the northern hardwood climax forest (*10*).

The highly shade-tolerant reproduction of sugar maple and beech dominate the understories of most northern hardwood stands. In contrast, yellow and paper birches need some overhead light and seedbeds of humus or mineral soil for their early establishment and development (*12*). Paper birch must become dominant in the stand early in life to survive to maturity.

Northern hardwoods have several natural enemies that influence the application of silvicultural treatments. Beech bark disease is a lethal disease of beech (*8*). Birch dieback has caused heavy mortality in both yellow and paper birches, and although the disease has subsided, a recurrence is possible. A similar condition, postlogging decadence, often develops in birches excessively exposed by heavy partial cutting. Cankers caused by the sugar maple borer 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 (*9*). Eutypella canker can result in severe degrade.

Suitable silvicultural systems in the northern hardwood type of the Northeast vary with species composition, age distribution, site productivity, deer browsing pressure, and management objectives.

One applicable system is the selection system which is used to develop an uneven-aged forest. Trees are harvested singly or in small groups. Repeated use of selection cuttings perpetuates or increases the proportion of shade-tolerant species—sugar maple, beech, hemlock, and red spruce (*4*). This method is favored wherever recreational and esthetic demands are such that a continuous forest cover is desired, such as special zones along roads, lakes and streams. In the selection system, several cuts may be needed to develop a balanced distribution of size classes and to improve the stand quality by removing diseased and defective trees, including those badly damaged by sap suckers (*7*). Additional cultural work is often necessary in the smaller size classes to favor the more valuable sugar maple over beech.

In contrast, even-aged management is needed wherever intermediate or light-demanding species are desired as the major component in the future stand (*1, 2, 6*). In even-aged management some form of clearcutting is used in the final harvest cutting, often combined with site preparation, to favor reproduction. Clearcutting will result in a mixture of species having varying degrees of shade tolerance in the reproduction and thus is indicated for light-demanding species (*5*). This clearcutting may be done in irregular patches, progressive strips, or by blocks. To provide a seedbed for the birches, additional scarification besides that provided by logging is often needed (*3*). Scarification not only prepares a desirable seedbed, but eliminates much competing vegetation. Stands extensively affected by diseases must be clearcut. Clearcutting stimulates production of food for deer to a greater

extent than selection cutting. In areas having high deer populations regeneration may be damaged or eliminated by browsing. This is true particularly if the cleared areas are small. Restricting the size of areas and creating irregular cutting boundaries to blend with the landscape tend to ameliorate the temporary unsightliness of clearcut areas.

Sheterwood cutting can probably be used as well as clearcutting for establishing even-aged stands of northern hardwoods in the Northeast, but this method has not been used in practice because appropriate silvicultural guidelines based on results of experimental cutting or other trials are not yet available.

The productivity of even-aged stands in the Northeast is increased considerably and rotations shortened by periodic thinnings. Stocking guides based on mean stand diameter and basal area per acre, coupled with stand prescriptions, are used for determining when and how much to thin and when to make the final harvest cutting (*4, 11*).

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CHERRY–MAPLE

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The cherry–maple or Allegheny hardwood type, covering about 12 million acres, is a second-growth forest type found on the Allegheny Plateau of Pennsylvania and New York. It owes its origin to the lumbering and fires of the 1890-1920 era that destroyed stands that were originally part of the vast hemlock–white pine–northern hardwoods region of eastern deciduous forests (*2*).

The type is composed primarily of black cherry, red maple, and sugar maple, with white ash, yellow and sweet birch, American beech, and eastern hemlock as common associates (*7, 9*). Within this type, black cherry is by far the most valuable species for timber production, its value averaging two or three times higher than that of the other important species. Of all species in the country, black cherry ranks second in timber value, being exceeded only by black walnut. Although black cherry grows over a wide geographic area in the eastern United States, it is much more abundant in the Allegheny hardwood area than elsewhere. The type is also important for its production of ash and maple.

Of the important species within the type, black cherry, white ash, and red maple seed abundantly at frequent intervals. Moreover, cherry seeds are stored in the surface layer of the soil for several years. Sugar maple produces good seed crops every four or five years. Black cherry and white ash are intolerant of shade, red maple is intermediate in tolerance, and sugar maple is highly tolerant (*14*). However, very young seedlings of black cherry, white ash, and red maple endure more shade than older trees. As a result, 1- to 3- or 4-year-old seedlings of these species are often found beneath the canopy of older stands. Unlike sugar maple seedlings, which may survive and grow under shade, these cherry, ash, and red maple seedlings soon die unless the overhead cover is removed. Nevertheless, these advance seedlings provide a reservoir from which a new stand of trees may be formed when the overstory trees are removed by cutting or natural catastrophe.

Excessive browsing of tree seedlings by deer, the result of an unusually high deer population that has existed in Allegheny hardwood forests since the 1920's, delays and often prevents successful regeneration (*1, 10, 13*). Damage to reproduction is especially severe in small cutover areas where the deer can easily consume all new growth as quickly as it appears. But deer influence regeneration even in uncut areas: 20 years of vegetation records show that deer browsing in a virgin hardwood–hemlock natural area has virtually eliminated all reproduction except beech (*6*).

The choice of silvicultural systems in Allegheny hardwood forests would be wide were it not for the unusual deer pressures on regeneration. Second-growth cherry–maple stands are even-aged and are made up primarily of light-demanding species, except for sugar maple. Sugar maple grows well in even-aged stands if it gets a slight headstart on the other species by originating as an advance seedling or sapling prior to the regeneration cutting. Because of the light requirements of cherry, ash, and red maple, the type can be perpetuated only through some form of even-aged silviculture.

In the absence of deer, clearcutting of mature stands that were not subjected to fire has generally resulted in very satisfactory regeneration (*4, 7, 8, 11*). Clearcutting in small patches or strips provides conditions favorable to reproduction but currently such methods are not in use because deer tend to concentrate in small openings and kill the young seedlings through overbrowsing (*3, 5, 8*). Clearcutting is the only currently available cutting method that will provide desired regeneration, and clearcutting will work only in stands that have an abundant understory of advanced seedlings. In general, the more seedlings present per unit area and the larger the area cut, the less the damage to reproduction by deer. At present, however, in stands that lack abundant advance seedlings, the only way to insure reproduction after cutting is to erect a protective fence around the clearcut area.

Because very young cherry, ash, and red maple seedlings grow better in shade than do older trees, the shelterwood system may provide even better conditions for early establishment and survival than clearcutting. The shelterwood system, however, has not been used because of lack of knowledge of cutting intensity and timing.

Although uneven-aged silviculture as exemplified by the selection system cannot be used in the cherry–maple type to perpetuate a high proportion of the light-demanding species, it could be used to hasten succession toward the climax beech–hemlock–sugar maple type if it were not for the persistent deer problem. With the current deer populations repeated selection cutting would eventually result in complete removal of the present trees without replacement by seedlings or saplings. Instead of a climax forest composed of beech, hemlock, and sugar maple, the end result would be a stand dominated by beech (*12*) and very likely lacking in tree cover of any type in many spots. However, if deer populations are brought into balance with their range, selection cutting will provide an optional silvicultural system where esthetic or scenic values preclude heavier cutting methods and where the reduced timber values and deer browse production of this forest type are acceptable.

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APPALACHIAN MIXED HARDWOODS

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The Appalachian mixed hardwoods, commonly known as cove hardwoods, comprise one of the most productive hardwood types of the North Temperate Zone. The type is found in the coves and on the moist slopes of the central and southern Appalachian Mountains and adjacent portions of the Allegheny and Cumberland Plateaus. The acreage involved is substantial but no accurate estimate of the total is available. Stands are characterized by a large number of dominant and subdominant species and by the great diversity of their mixture (*1*). The species and their proportions vary considerably because of differing past treatments or natural stand disturbances on sites of different quality, aspect, elevation, and latitude.

Cove hardwoods are highly productive, typically occupying good and excellent sites; 65 to 90 feet on the oak site index scale (*7*) and 90 to 120 feet on the yellow-poplar site index scale (*3*). Soils on these sites normally are fairly deep, medium textured, and well drained; annual precipitation is ample, ranging from about 40 to 55 or more inches and is well distributed throughout the year. On these rich sites, major species are long lived and can grow to very large sizes.

Species composition ranges from almost pure northern red oak to pure yellow-poplar, but more typically is a mixture that may contain 20 or more commercial species. Important components are yellow-poplar, northern red oak, sugar and red maples, white oak, American beech, white ash, American basswood, black cherry, cucumbertree, sweet and yellow birches, hickories, yellow buckeye, and black locust. Many other species occur occasionally, including a few conifers–eastern white pine, red spruce, and especially

eastern hemlock. On good sites at high elevations, the type merges in many places with northern hardwood–black cherry mixtures. On drier situations with shallow soils, the type gives way to oak–hickory.

Among major Appalachian mixed hardwood species, tolerance to shade varies widely, from the very tolerant American beech, eastern hemlock, and sugar maple, to the intermediate shade-tolerant oaks, hickories, birches, and white ash, to the intolerant black cherry, black locust, and yellow-poplar. The intermediates and intolerants will not reproduce and survive under a closed canopy. In West Virginia, however, the intolerants can reproduce and grow satisfactorily in small (1/4 to 1/2 acre) openings (*11*). It seems likely, therefore, that the oaks and less tolerant species were present in old-growth stands only because wildfires, windstorms, or other catastrophes created suitable openings.

The regenerative potential of the Appalachian hardwood type is very strong. All of the hardwoods sprout vigorously when small (*12*). Advance reproduction of the shade-tolerant species, especially sugar maple and beech, develops prolifically even under closed canopies. Advance reproduction of species of intermediate tolerance usually follows any moderate opening of the canopy, and on these moist sites can persist for several years. Seed of species requiring moderate to full sunlight–white ash, yellow-poplar, and black cherry–remain viable through several years' storage in the forest floor (*2*, *4*, *14*) and germinate when light, temperature, and moisture are favorable, as when the canopy is removed.

The variety of species and favorable reproductive mechanisms involved result in abundant tree reproduction following any system of cutting. Different degrees of shade tolerance among the species, however, lead to changes in the proportions of the species present depending on the silvicultural systems employed.

The selection system of cutting causes the least disturbance in the forest canopy and may be used where a continuous forest cover is required as may be necessary in some areas for landscape considerations. It discriminates sharply against the more light-demanding species. Selection cutting reduces the mixed character of the original forest to stands composed largely of a few shade-tolerant species, predominantly sugar maple and beech (*9*). Making selection cuttings heavy enough to encourage the regeneration and development of light-demanding species runs the risk of reducing stand growth through understocking and of impairing stand quality through high grading.

Group selection cuttings offer a good means of obtaining desirable species and of providing favorable habitat for wildlife. Openings as small as a quarter of an acre result in reproduction of a wide range of species, including the desirable intolerants (*6*, *11*). One disadvantage of this type of cutting is quality loss on border trees around the openings due to epicormic sprouting (*8*). Another disadvantage is that in areas of heavy deer population, browsing may excessively damage reproduction in the small openings.

Shelterwood cuttings appear to be a promising method for reproducing species of intermediate shade tolerance, but little research has been done on this method of regeneration in Appalachian hardwoods, hence guidelines are lacking.

The seed-tree method appears not to be needed for regeneration of Appalachian hardwoods. Present evidence indicates strongly that no need exists to retain seed trees as a seed source for new stands.

Clearcutting, which lends itself only to an even-aged system, offers the greatest potential for successful practice of intensive forest management. It provides for the maximum reproduction of desirable light-demanding species (*5, 10, 13*). Such practice in the past has provided many of the best of our present stands. This method is easy to regulate for timber, wildlife, and water yield. However, in scenically sensitive locations, esthetic objections to the appearance of newly clearcut areas may preclude its use or limit it to small areas.

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SOUTHEASTERN TYPES

Oak–Pine
Longleaf and Slash Pine

Atlantic Oak–Gum–Cypress

OAK–PINE

by David F. Olson, Jr. and Robert G. McAlpine
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The oak–pine type occupies about 27 million acres in scattered areas from southern Pennsylvania southward through the northern and central sections of the southeastern and southern States of Texas and Oklahoma. It is composed of forests in which hardwood trees (mostly upland oaks) make up over half of the stands, and upland southern pines 25 to 49 percent (*11*). The major oaks involved are white, northern red, scarlet, black, chestnut, and southern red. Associated hardwoods include yellow-poplar and sweetgum. The pines are primarily loblolly, shortleaf, and Virginia pines. The type is closely associated with the loblolly–shortleaf pine type.

Oak–pine, if left undisturbed, will develop into a forest of predominantly oak and other upland hardwoods (*4, 7*). When farmlands are abandoned, or forest openings are created by windthrow or other major disturbance, southern pines seed in on the open lands. After 20 to 30 years the pine stands are invaded by hardwoods, which are more tolerant of shade than the pines and which compete so strongly with pine reproduction for light and moisture that few pine seedlings are able to survive (*3, 5, 6*). Thus, mature stands of pine commonly contain a dense understory of young hardwoods.

Harvesting of large pines and losses of pine trees by windthrow, insects, diseases, and fire create openings in the pine forest which are quickly occupied by oaks and other hardwoods already present in the understory. In this way, the stands of pine gradually are transformed into oak–pine forests. As this process continues the oak–pine forest is ultimately replaced by the oak–hickory type. The change from forests predominantly pine to an oak–pine mixture or to an oak–hickory forest is hastened by heavier cutting of mature pines than of mature hardwoods (*13*), unless appropriate cultural methods are used to promote pine reproduction, survival, and growth.

Except on the best sites, the silvicultural objective for timber production in the oak–pine type usually is to increase the pine and diminish the hardwood components. Pine is favored over the hardwoods because of the greater demand for pine lumber, pulpwood, and veneer throughout the region and because of the faster growth and better yields of pine on most upland sites. Pines grow satisfactorily and produce moderate amounts of wood even

on thin, eroded soils, whereas on such sites the hardwoods are of poor quality, grow slower, and produce lower yields.

Pine bark beetles attack oak–pine stands particularly where pine predominates, stands are overdense, or pines come under stress from drought, littleleaf disease or man-caused disturbances. Management systems which minimize stress or overdense conditions will reduce insect-caused losses in the pines. Hardwoods, therefore, are favored only on the better sites stocked with species having the potential to grow high-value products.

Shortleaf and loblolly pines are intolerant of shade (*10*), and therefore, require the use of even-aged management for their regeneration. The more valuable hardwoods in the oak–pine type, such as yellow-poplar and northern red oak, are also relatively intolerant of shade and thus regenerate best under even-aged systems. To obtain maximum pine stocking in future stands, harvest cuttings must be accompanied by vigorous methods of hardwood control such as prescribed fire, use of herbicides, or mechanical site preparation (*1, 8, 9*).

Although all of the even-aged systems of regeneration (clearcutting, shelterwood, and seed-tree) have been used successfully, the most effective has been clearcutting followed by hardwood control, site preparation, and planting or direct seeding of pine. This method favors loblolly pine over shortleaf pine, which is desirable in areas where shortleaf pine is heavily attacked by littleleaf disease (*2*). It also permits replacing loblolly pine with shortleaf pine in the northern sections of the type where loblolly is damaged by ice and snow and in parts of the southern Piedmont where loblolly is susceptible to fusiform rust (*12*). Clearcutting and planting will probably increase as genetically improved insect and disease-resistant strains of pine become more readily available.

Oaks and certain other hardwoods are favored over pine by uneven-aged management in which the selection system (single-tree or group selection) is used. Without hardwood control, group selection cutting will convert oak–pine stands, especially in the easterly and southerly sections of the range, to hardwood stands favoring the more shade-tolerant species but also containing some intolerant hardwoods such as yellow-poplar and sweetgum in the mixture. With vigorous hardwood control, group selection cutting has been successfully used to regenerate pine in oak–pine forests in Arkansas (*8*). However, prescribed burning and mechanical methods of hardwood control are expensive to apply on small, dispersed areas, and there is risk of damage to the residual stand.

Single-tree selection cutting provides too little light for survival and growth of pine and intolerant hardwood seedlings, and it will eliminate these seedlings from the stands (*3*). If timber production is not an important factor, such cutting can be used to maintain a permanent forest canopy. However, stand composition will shift to the shade-tolerant hardwoods present, usually hickories, and the most tolerant oak species, especially white oak.

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LONGLEAF AND SLASH PINE

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In the virgin forests, slash pine was confined to the lower Coastal Plain from South Carolina to Louisiana with an extension into southern Florida of the variety South Florida slash pine. Longleaf pine in general overlapped slash pine but had a much wider range in a broad belt along the Coastal Plain from Virginia to Texas with an extension northward into the Appalachian foothills of Alabama and Georgia (*20*).

Although they overlapped in range, the two species rarely occupied the same sites; longleaf pine grew on the drier sites while slash pine was confined to the poorly drained portions of the middle and lower Coastal Plains (*20*). Wildfire played a dominant role in this distribution. Longleaf pine, being highly fire resistant, maintained itself on the drier sites which burned more

frequently, whereas the less fire-resistant slash pine was confined to the more moist situations where fire was less prevalent. With modern fire protection, slash pine has seeded into many former longleaf pine sites (*5*). Also, attempts have been made to extend the range of this type by seeding and planting. Currently there are nearly 19 million acres of the longleaf–slash pine type.

Neither pine is a climax species; in the absence of fire, succession in these forest types proceeds toward mixed hardwood tree species (*14*, *17*). When fire is excluded, herbaceous and shrubby species together with forest litter, build up into a highly flammable understory. When wildfire occurs it can be disastrous. Prescribed burning for hazard reduction at 3- to 5-year intervals, now a common practice, has greatly reduced incidence, acreage, and damage of wildfires.

Longleaf and slash pine differ in silvical characteristics such as seeding habit and juvenile growth but the silvicultural prescriptions for the two species are similar.

Longleaf Pine

Longleaf pine grows on a broad range of sites from poorly drained flatwoods soils to excessively drained sandhill soils characteristically low in organic matter. It is very intolerant of shade. Not a prolific seeder, longleaf pine produces good seed crops only at 5- to 7-year intervals (*22*). Longleaf seed requires a mineral seedbed for best germination. An exposed seedbed, however, may increase seed depredation by birds and rodents. Burning the seedbed, especially when followed by mechanical scarification, usually increases seedling catches (*4*).

Although the mature tree is fire resistant, longleaf pine is susceptible to fire shortly after germination before entering the grass stage and again on emergence from that state 3 or 4 years later. Under severe competition, height growth may be delayed for many years, but seedlings will survive under older trees for at least 9 years (*2*, *21*).

The principal disease of longleaf pine is brown spot needle blight which attacks seedlings in the grass stage and seriously inhibits growth. Prescribed fire is commonly used for controlling the disease (*6*, *19*). Incidence and severity of the disease are lower on seedlings growing under an overstory (*2*). Since woods hogs and cattle also damage many seedlings, regeneration areas must sometimes be fenced (*3*).

Even-aged management is recommended for longleaf pine (*22*, *13*) because of its intolerance of shade, the slow growth of regeneration in the presence of an overstory, and the need to control seedling needle blight and to reduce hazardous fuels by prescribed fire.

The seed-tree system is one choice for obtaining natural regeneration (*22*) under even-aged management, but it is not much used because of the uncertainty of seed supply. The shelterwood system is the preferred method for obtaining natural regeneration because it provides a more dependable seed source, lowers brown spot needle blight infection rates, and reduces regeneration time (*7*). The shelterwood trees also help control or inhibit brush competition during the regeneration period. Clearcutting is not likely to result in natural regeneration, unless done after an excellent seed crop. The general practice is to clearcut the stand and regenerate it by seeding or planting.

Slash Pine

Slash pine is a relatively good seed producer with some seed being produced each year (*23*). Heavy cone crops occur about every 3 years. Seed production may be stimulated by crown release, stem injury, or fertilization (*20*). Slash pine is not as exacting as longleaf pine in its requirements for a mineral soil seedbed. However, burning or disking increase seedling catches severalfold (*15*). Reduction of ground cover by site preparation is necessary where vegetative cover is very dense.

Typical slash pine of north Florida and southeast Georgia makes excellent height growth in its early years as contrasted with longleaf pine and South Florida slash pine, both of which have grass stages. Because of injury to young seedlings, prescribed fire cannot be used in young slash pine stands until they are 12 to 15 feet tall (*8*). South Florida slash pine is much more fire resistant in its seedling and sapling stages than typical slash pine (*10*).

Slash pine is plagued by two diseases: fusiform rust and annosus root rot. Fusiform rust is the more serious because of the large growth loss in infected trees and because many of the trees not killed are seriously deformed. No rust control measures have been found. Incidence of annosus root rot is related to cutting operations, especially those made in late fall and winter (*18*). Proper timing of thinning, prescribed burning, and the application of chemical protectants (e.g. borax) or fungal competitors to cut stumps will help to control annosus root rot (*9, 11*).

Slash pine can be managed either in uneven- or even-aged stands. Under the former, the group selection system is applicable because slash pine is intermediate in shade tolerance and will reproduce in small openings (*12, 16, 20*). However, overstory or ground cover competition greatly reduce height growth (*1*). There may be also an undesirable build-up of fuels, especially in the sawpalmetto-gallberry understories of the lower Coastal Plain.

Even-aged management is more widely used because: (1) Growth of regeneration is not greatly curtailed by overstory trees; (2) even-aged stands can be carefully burned for fire hazard reduction, wildlife habitat improvement, and forest range improvement; and (3) they can be harvested in one operation, which reduces the incidence of annosus root rot.

Several silvicultural systems may be used to obtain regeneration under even-aged management. Under extensive, low-cost management natural regeneration is very acceptable; the recommended methods for supplying the seed source are to either leave seed trees (6 to 10 per acre) or shelterwood trees (25 to 40 per acre) at the time the main portion of the stand is harvested. In either case prescribed burning should precede the harvest cut in order to control understory vegetation and to prepare the seedbed. An alternative to prescribed burning is mechanical site preparation. The seed or shelterwood trees are harvested after seedlings become established, which usually occurs within 2 or 3 years. Under intensive culture the commonly used regeneration method is clearcutting followed by mechanical site preparation and either seeding or planting.

With the development of improved strains of both slash and long leaf pine that grow faster or that are more resistant to disease and insects, planting will increasingly become the main method of regeneration. Planted stands also lend themselves to intensive cultural practices, such as cultivation and

fertilization, which are necessary to take full advantage of gains from genetically improved seedling stock. All these measures work best under even-aged management.

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ATLANTIC OAK–GUM–CYPRESS

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Within the southeastern Atlantic Coastal Plain from Maryland through Florida, there are 13 million acres of oak–gum–cypress forests. These forests naturally divide into two broad types: Tupelo–cypress swamps and mixed bottom land hardwoods (*16*). Most sites of these forests are characterized by a profuse supply of water and include both alluvial and residual soils.

The best sites are the bottoms of major rivers that originate in the Piedmont and mountains. They are called "red water" rivers because of the color of their silt-laden muddy waters. Within a bottom land the soil texture is correlated with flooding: the more frequent and prolonged the flooding, the heavier the soil. Bottom lands in "black water" rivers, darkly stained with organic matter and originating in the Coastal Plain, are a smaller version of the major bottom lands. Soils are lighter textured and less fertile, and support a slightly different mixture of tree species.

Besides the alluvial soils there are broad interstream areas of tupelo–cypress swamp where soils range from heavy clays to coarse sand, to peats and mucks. Site quality is extremely variable. Finally, many swamp tupelo–cypress ponds are generally of low productivity.

Tupelo–Cypress Swamps

The deep swamps of red water bottoms are strongly dominated by water tupelo and baldcypress, with a small admixture of red maple, swamp cottonwood, green ash, and many understory species. Water tupelo is intolerant of shade and cypress only moderately tolerant; consequently, advance reproduction is sparse. Water tupelo produces good seed crops most years, occasional local bumper crops, and some complete failures (*18*). Baldcypress seed production seems to be generally adequate. Water tupelo and baldcypress seeds both float well and are dispersed by flood waters; they are also scattered by birds and animals. Both species sprout vigorously from stumps (*18*).

In non-alluvial headwater swamps, swamp tupelo is much more prevalent than water tupelo. Associates include red maple, sweetbay, redbay,

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and Carolina ash (*16*, *18*). Seed crops of swamp tupelo are generally good to excellent, but the seeds do not float. Swamp tupelo sprouts prolifically unless the stumps are cut quite low (*4*).

The three species that characterize these swamps—water tupelo, baldcypress, and swamp tupelo—do not merely tolerate saturated soils and flooding, they thrive on them (*10*). Tupelo–cypress types are stable and will regenerate usually to what they were before cutting, although willow may temporarily dominate cutover areas (*1*). Additionally, it seems that following logging of old growth, the tupelos have gained at the expense of baldcypress for reasons unknown. Seedling establishment requires that a swamp not be flooded deeply or for any extensive period during the growing season. Tupelo and cypress seeds will not germinate under water (under natural conditions), and seedlings must grow tall enough to avoid long submergence during the growing season.

To regenerate mature swamp stands, an even-aged silvicultural system is indicated by the silvical characteristics of the tupelos and cypress. Also, existing stands are even-aged. Almost all swamps in the Southeast have been commercially clearcut at least once; little growth remained except large cull trees. Logging left good seedbed conditions provided the swamp became sufficiently dry and the cutting reduced competing shrubs and small trees. Virtually all logged areas have regenerated well; indeed, many have sapling densities far in excess of optimum.

For water tupelo and baldcypress, similar clearcutting is recommended but with the provision that cull trees be deadened. Seed will be provided by floating in if only the downstream part of a swamp is cut. Also, seed in place may remain viable for about 2 years. Germination occurs when waters recede.

Swamp tupelo–baldcypress swamps also require even-aged management. In contrast to water tupelo swamps, however, advance regeneration of swamp tupelo is often present (*13*). These swamps can be clearcut. If advance reproduction is scanty or lacking, provision should be made for a continuing supply of these non-floating seeds (*8*). Leaving a heavy shelterwood of 30 to 40 trees per acre will accomplish this. If there is a brush problem, chemical control may be necessary. When regeneration becomes established, logging of the remaining shelterwood can be accomplished with inconsequential damage to the seedlings because they sprout vigorously (*11*).

In swamps that flood deeply during the growing season, planting after clearcutting shows promise, but it is not yet on a solid operational basis. The seed-tree method is of doubtful utility in either subtype. Uneven-aged systems seem wholly unsuited to tupelo–cypress types.

Mixed Bottom Land Hardwoods

In alluvial bottom lands of major rivers, first bottoms (the sites lying immediately above swamps) support mixed stands principally of overcup oak, water oak, laurel oak, willow oak, sweetgum, water hickory, green ash, sugarberry, river birch, elms, American sycamore, and red maple. Overcup oak and water hickory are relatively more important on wetter sites having heavier soils, and sweetgum in drier areas. In addition, there is an understory composed of a variety of minor tree species and shrubs. In undisturbed stands

of even moderately good density, the shrub layer is not dense nor are vines generally prolific (*18*).

In second bottoms, flooded less often and for shorter duration, cherrybark oak, swamp chestnut oak, white oak, various hickories, and white ash predominate. Loblolly pine may also be present. Among smaller associates are winged elm, boxelder, and American holly. On terrace sites, rarely flooded, American beech and yellow-poplar may be abundant. Second bottom and terrace sites are highly productive. There are, in addition, a number of other physiographic sites of varying productivity and more than 70 species to consider. The wealth of species with diverse requirements results in efficient utilization of the wide array of sites.

Most mixed bottom land species are light demanding or intermediate in shade tolerance. Very shade-tolerant exceptions are beech, small understory tree species, and shrubs. Shade tolerance will not guarantee successional trends as many stands are edaphic climaxes. Light-seeded species produce seed in abundance and that for heavy-seeded species is generally adequate for regeneration. Moreover, yellow-poplar and white ash seed remain viable for several years in the forest litter (*2*). All species produce excellent sprouts from damaged seedlings; sweetgum also sprouts prolifically from roots (*12*).

As with swamps, these mixed bottom land hardwoods are essentially even-aged—one age class in the dominant stand, perhaps another in scattered saplings and advanced reproduction. Light-demanding species predominate in these forests, thus even-aged management is in order. If adequate advance reproduction is present, as it generally is, clearcutting can be used to release it. A main consideration is that the cutting should be complete; all cull trees and other poor growing stock should be cut or deadened.

Many stands that were high-graded in the past, but not cut cleanly, now have a brush problem. Excessive brush needs to be controlled mechanically or chemically so that the reproduction can compete successfully. This can be accomplished most easily before the stand is cut. However, care must be used in treatment, as in bulldozing, which at times has resulted in an area clear of competition but also bereft of desirable reproduction. These forests are key habitats for certain species of wildlife; wildlife needs should be considered in determining cutting systems.

In the unusual situation where advance reproduction is not adequate, several options are available. If the stand is dominated by light-seeded species and they are desired, the stand may be clearcut after a good seed crop. Where sweetgum predominates, cutting can be done at any time because of prolific sprouting. If oaks are to be favored, or cutting cannot be scheduled to follow a good seed year, the shelterwood system can be used. Twenty or more of the best trees per acre of the favored species should be left (*3*). As soon as regeneration is adequate, the shelterwood should be removed, because the tolerant brush species will fare better under this partial shade than will the desirable tree species. Oak reproduction may require release from faster growing species to enable it to pull through.

If for some reason the size of regeneration areas must be kept small, the group selection system may be used. This has the disadvantage that regeneration will not develop as rapidly as in larger clearings; also epicormic sprouting occurs around the edges of clearcut groups with loss in timber quality (*6, 15*). In addition, where deer populations are heavy, reproduction

in small openings is more prone to damage (*14*). Group selection, however, may have utility along roadsides and larger streams where clearcutting is esthetically objectionable.

Single-tree selection is not adapted to the southeastern bottom land types as it does not result in satisfactory development of seedlings and favors less desirable but shade-tolerant species (*9, 17*). The seed-tree method also is not recommended because in most cases seed from the residual trees is superfluous (*7*) and in others, as when oaks are favored, it is insufficient. Regeneration through planting cleared sites is rather difficult in mixed hardwoods. Competition on these rich soils is intense and natural regeneration often outgrows planted seedlings (*5*).

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SOUTHERN TYPES

Loblolly–Shortleaf Pine Oak–Gum–Cypress in the Midsouth

LOBLOLLY–SHORTLEAF PINE

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The loblolly–shortleaf pine type is the most widespread forest type in the South. It extends from Delaware along the Atlantic and Gulf Coastal Plains to Texas and Oklahoma; it includes most of the Piedmont region and parts of the Ouachita Mountains area in Arkansas. This type was once limited by repeated wildfires, but with improved fire protection it has spread gradually southward onto sites formerly dominated by longleaf pine. It now occupies about 58 million acres *(11)*.

The type grows well on soils ranging from heavy clays to sandy loams and differing broadly in moisture conditions *(1)*. Growth is best along the margins of streams where surface drainage is often slow, but a deep, permeable surface layer affords good internal drainage. Poorest performance is on shallow, eroded soils.

Where intermixed, loblolly pine usually predominates and outgrows shortleaf on the more moist soils. Shortleaf is apt to be more numerous on the dry, infertile soils prevalent in the Piedmont and on thin, rocky, droughty mountain soils in Arkansas *(12, 13)*. Both are light-demanding species.

The loblolly–shortleaf pine type is replaced by a broad spectrum of hardwood species when the successional trend is unchecked *(6)*. While oaks, gums, and hickories are the most common associates, composition varies by soils, moisture, and topographic position. These hardwoods are more shade tolerant than the pines, and often form dense understories in pine stands. When the pines die or are cut, the hardwoods dominate the site unless it is prepared and the understory is controlled *(4)*.

Unwanted hardwoods are relatively easy to control when stands are clearcut and pines are regenerated by planting or seeding. In many situations prescribed fire will do the job inexpensively *(2)*. Where the hardwoods are too large or fuels are sparse, disks, choppers, or shearing blades prepare the site effectively. On many soils, mechanical site preparation improves growth as well as survival of planted or seeded pines. None of these treatments eradicate hardwoods, which sprout prolifically and thereby increase available browse for deer. Because hardwoods are an important wildlife habitat component in this type, they should be considered when developing a cultural program.

Regeneration of the loblolly–shortleaf pine type can be obtained by artificial or natural methods. In recent years, management has shifted from dependence on natural regeneration to planting and direct seeding. These

methods of artificial regeneration reduce the time needed for restocking, provide control of spacing, and enable land managers to establish genetically improved pines. As fast-growing, pest-resistant strains of pines become increasingly available, artificial regeneration will probably predominate.

Natural regeneration may be obtained by (1) clearcutting patches or strips small enough to allow seeding from nearby trees, (2) felling the entire stand after seedfall or when cones are ripe, (3) leaving seed trees, (4) shelterwood cutting, and (5) group selection cutting. All of these methods require hardwood control. None allows for full genetic improvement of the new crop, which requires introduction of genetically improved pines by planting. However, all of these silvicultural systems are compatible with wildlife management, provided openings and seed-tree areas are kept to about 40 acres—near optimum for deer *(3)*.

Of the several methods, clearcutting is most compatible with the use of fire and machines to control competing hardwoods and to prepare a mineral soil seedbed. Burns can be severe and heavy equipment can be operated freely. Where dependence is placed on natural regeneration, a major disadvantage is the erratic occurrence of seed crops, especially in inland and westerly areas of the type. Success frequently requires timing of site treatment with seed production. Without timely seed crops, weeds take over the prepared sites and necessitate expensive retreatment *(9)*.

Clearcutting coincident with cone ripening has been successful in the Southeast. Seedbed preparation is completed in advance of felling, and seed from tree tops regenerates the area. However, the time between cone ripening and cone opening is only about 4 weeks, limiting use of this method to a short period.

Trees planted in heavily cutover areas are highly susceptible to weevil damage and loss. In such cuttings, planting should be delayed for approximately 9 months or, if hardwood encroachment is a problem, seedlings should be dipped in insecticide prior to planting *(8)*.

Success of the seed-tree method depends on proper manipulation of the seed supply and the seedbed conditions *(5, 14)*. Well-stocked stands usually result if adequate seedfall occurs within a year or two after the seedbed is prepared. Crown release of the seed trees 3 years before the main harvest cut will considerably increase the seed production of loblolly pines that have been grown in closed stands *(14)*. Prescribed burning, which can be done before or after the main stand is cut, requires great care. The fires must be hot enough to kill back most of the hardwoods but not so severe that pine seed trees are damaged. Mechanical site preparation is also restricted somewhat, because scraped trunks and severed roots may induce infestations of bark beetles.

The shelterwood system has been most successful in the eastern part of the range, where the greater summer rainfall is usually sufficient for good first-year survival and where some seed is produced almost every year. Prescribed burning is the most practical method of site preparation, because with a shelterwood too many pines are left standing for efficient operation of large equipment. Again, timing of site preparation with seed production is usually the key to success.

Group selection cutting has been used primarily in understocked stands, where removal of a few pines and the control of adjacent hardwoods often

creates an opening large enough for reproduction to become established *(7)*. The system has been applied in fully stocked stands but with less success. Fire cannot be used for seedbed preparation, since seedlings in nearby openings would be killed. Openings are too small for machine operations. Consequently, sites are prepared mostly by scarification coincidental to logging. If reproduction is not obtained promptly, expensive hand methods are needed to kill the hardwoods that quickly dominate the small openings. The selection system may have special utility in or around recreation areas, where esthetic values are highly important, and on steep erodible slopes.

Systems depending primarily on natural regeneration have several additional disadvantages. Foremost is the loss of pine growth while awaiting a seed crop. Seeding may be adequate only every third or fourth year; thus, several years' growth may be lost in each rotation. Also, seed trees are vulnerable to damage by lightning, wind, and insects. Since only high-value trees are reserved for seed, the loss may be considerable *(10)*.

Another problem is the variation in stocking that can occur. With a bumper seed year, as many as 25,000 seedlings per acre may be come established, whereas in a lean seed year stocking may be insufficient. Also, natural regeneration systems seldom are consistently effective on droughty sites.

But despite the shortcomings of natural regeneration systems, they can be used effectively and cheaply in some situations. For example, on small ownerships where the vigorous and expensive site preparation measures required for artificial regeneration are not feasible, natural regeneration systems may be the only alternative.

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OAK–GUM–CYPRESS IN THE MIDSOUTH

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Oak–gum–cypress, a combination of several types and subtypes, extends over some 20 million acres in the Gulf States, Tennessee, and Arkansas *(8)*. Forests of this type grow both on alluvial soils where the bottom land associations predominate and in swamps. These two groups are quite different in species composition and in silvicultural requirements of the stands.

Bottom Land Forests

About 60 to 70 commercial species are included in the type as it exists in a varying pattern on the major and minor stream bottoms of the Midsouth *(7)*. Eastern cottonwood and black willow grow as pioneer species on recent alluvium deposited along waterways, most extensively along the Mississippi River. Both species are extremely intolerant of shade and require bare mineral soil to become established *(10)*. They are also intolerant of weed and vine competition. New stands are always even-aged and are very dense but thin themselves under natural conditions. Because of river channel straightening and bank stabilization, few new stands of cottonwood and black willow are now becoming established. These two species will not succeed themselves.

Cottonwood grows on the higher, well-drained, coarse-textured soils, usually sandy loam or silt loam. It is succeeded by the riverfront sub-type–American sycamore, sweet pecan, sugarberry, and elm. These species persist in the understory or in small openings but do not grow rapidly in partial shade. In many areas, the shade-enduring boxelder, a major component of the understory, attains dominance when the overstory is removed. Pioneer stands of black willow become established on fine-textured, low-lying soils subject to overflow. Sugarberry, elm, ash, and frequently swamp-privet succeed willow. All are shade tolerant and can survive flooding even for short periods during the growing season. Privet, the only noncommercial species in this group, may dominate the site once the willow is removed.

On older alluvium, forests tend to be somewhat uneven-aged but in small even-aged groups in a varying mixture of species. Primary genera present in the overstory include oaks, ashes, elms, hickories, and maples. Other

associates are sugarberry, sweetgum, sycamore, and yellow-poplar. Oaks may persist in small openings in the understory for 15 to 20 years. But once the overstory closes, most oak reproduction dies. Oaks, such as Nuttall and overcup, are common to poorly-drained soils; they persist longer than Shumard and cherrybark oaks that grow on coarser-textured, better-drained soils. Only occasionally do new stands of oak seed in, and advance regeneration must be present in the understory to enable oak to become a major component of the new stand. Shade-tolerant hickories, ashes, and maples become established in the understory. Since they sprout prolifically from both stumps and roots, they are among the easiest hardwoods to regenerate. The elms and sugarberry, shade-tolerant trees, also become established in the understory. They will sprout from stumps but less so than the former group. Where ash, sweetgum, and maples are present in the overstory, sprouts will be part of the regneration that follows cutting *(3)*. However, sprouts alone are usually insufficient to provide an adequate stand.

Sweetgum is found on a wide range of soils with varying moisture conditions. It is probably the most prolific sprouter of any of the species in the oak–gum–cypress type, but it will reproduce from seed under exacting conditions. It needs only a bare seedbed within an opening in the overstory. Being relatively intolerant of shade, sweetgum will usually survive in an understory for no more than 2 or 3 years. The light-demanding sycamore and yellow-poplar usually become established as seedlings on a seedbed void of herbaceous competition *(4)* Seedlings may persist for several years in small openings but to maintain vigor they.require full sunlight.

The species composition and silvicultural needs of the several million acres of hardwood stands along streams that meander through the southern pine forest are not unlike those of the bottom land forests in the oak–gum–cypress complex. Thus, the principles outlined in this paper for species groups apply whether species are growing in major or minor bottom lands. In the past, many forest managers have converted minor bottoms from hardwoods to pine. However, this not an easy task. More importantly, these areas generally provide the best wildlife habitat in the pinelands and are suitable for quality hardwood production. A major, still unsolved, question in minor bottoms in how far up the slopes hardwoods should be favored. Judgment, based on performance of existing hardwood trees, may be the best indicator.

The choice of cutting system for the oak–gum–cypress type depends on the composition and density of the advanced regeneration, on the sprouting characteristics of the trees to be cut, and on whether the stand is even-aged or uneven-aged. Among the systems adapted to even-aged management, clearcutting provides the best growing conditions for regeneration of most species and especially for those intolerant of shade. Where advanced reproduction is lacking, it is still possible to establish an adequately stocked stand after clearcutting provided: (1) an adequate proportion of good sprouting species exists in the overstory, or (2) overstory trees of desirable light-seeded species are in sufficient numbers to seed in large areas, and a good seedbed is available. The best seedbed is bare mineral soil, but one void of most trees, vines, and herbaceous cover will suffice *(4)*. In mixed stands of this forest type, clearcutting has the disadvantage of destroying potentially valuable intermediate-sized trees.

Clearcutting has application to cottonwood stands, which should be clearcut in blocks or patches. Deadening the undesirable boxelder understory following cutting is necessary to favor the better species. Occasionally, the understory contains too few trees to constitute a new stand. In such areas clearcutting followed by planting of cottonwood has proven very successful. Plantings must be handled similarly to an agronomic crop, and genetically improved planting stock is now available. Willow, likewise, should be clearcut. Reproduction must be very dense to shade out competing vines and develop properly. Willow brakes are difficult to regenerate artifically.

Of the conventional systems, seed-tree cutting is least useful on alluvial sites. It may succeed with a light-seeded, light-demanding species like yellow-poplar, but it requires a combination of plentiful seed, a good seedbed, and favorable micro-environment. This set of conditions does not occur regularly and, unless a catch is obtained the first year, the site is usurped by vines and brush.

The shelterwood system is more widely applicable. It provides enough seed for advanced reproduction and has some suppressing effect on unwanted understory vegetation. With species intolerant of shade, such as yellow-poplar, sycamore, and sweetgum, the overstory must usually be removed within 5 years. With shade-tolerant species, release can be delayed much longer. Many present-day stands are examples of unplanned shelterwood management. That is, repeated cuttings have broken up the overstory, but the remaining trees have provided seed for advance reproduction. In this situation, a reasonably good new stand can often be obtained merely by removing the remaining overstory.

The selection system has application in certain stands in the type where the intention is to maintain or create an uneven-aged condition. Single-tree selection in which mature, suppressed, or damaged trees are removed at frequent intervals has been used in the past in oak–gum–cypress *(6)*. The system opens a stand gradually and tends to favor development of less desirable shade-tolerant species. It is not now considered to be a desirable method of reproducing the type. Group selection, however, is a desirable system in suitable stands. In such cuttings the overstory is removed in small groups, the size of which depends on the structure and composition of the stand. Establishment of light-seeded species is favored if a seed source exists within 200 feet of the opening. Advance reproduction is fully released, and sprouts are free to develop. In some localities, removal of the old stand must be complete to rid the forests of trees of shade-tolerant subcommercial species that may constitute an intermediate stand class.

On the wettest alluvial sites, as flats that are under standing water for long periods of the year, the existing type is a subclimax and usually will be perpetuated regardless of the silvicultural system employed. Thus, on these sites bitter pecan and overcup oak usually dominate the overstory; they are virtually the only species that can be regenerated naturally.

Swamp Forests

Cypress and tupelo are the predominant species in the swamps of southern Louisiana, Mississippi, and Alabama. Both species normally grow in pure, even-aged, densely stocked stands which tend to stagnate. Most existing stands are second growth.

Both cypress and tupelo will reproduce from seed when specific conditions are met. Seedlings become established on the rare occasions when the water recedes to below ground level during the germination period. Low water for the balance of the first spring and summer is also essential, for at this early stage seedlings cannot tolerate more than 2 or 3 weeks of submergence. After the first season, however, the young trees can survive inundation during much of the winter, provided they have not leafed out *(5)*. Seedlings of both species are relatively intolerant of shade and will not persist in the understory for more than 2 or 3 years.

Stump sprouts are important to the regeneration of cutover cypress and tupelo stands. Sprouts that originate above the standing water level during the growing season have the best chance to survive *(2)*.

Unless the swamps are drained or water distribution within them is changed, the silvicultural systems that favor coppice regeneration are probably most suitable for the cypress-tupelo stand.

Silviculturally Related Aspects

Oak–gum–cypress forests are recognized as the most productive wildlife habitat in the South. Overpopulations of deer will, however, negate the opportunity to reproduce hardwood stands under any silvicultural system, since the animals will browse and eventually kill young trees of most species. Beavers destroy some trees by felling but greater mortality results from year-long flooding caused by the dams they build. Most hardwood species cannot tolerate continuous flooding for more than a year or two *(1)*.

Fire, in addition to killing trees of all sizes, may severely wound the survivors, thus opening the way for heart rot *(9)*. Even one wildfire in 10 years makes it impossible to manage hardwoods. Research in prescribed burning is incomplete, but fire appears to have very limited use in the silviculture of the oak–gum–cypress mixture.

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GLOSSARY

All-aged

A condition of a forest or stand that contains trees of all or almost all age classes.

Area regulation

A method of planning for sustained yield which relies on control of the area harvested in a given period under even-aged management.

Basal area

The area of the cross section of a tree at breast height; for a stand, the total basal area per unit of area, usually per acre.

Cleaning

The elimination of competing vegetation from stands not past the sapling stage; i.e., removal (a) of weeds, climbers, or sod forming grasses--as in plantations, or (b) of trees of similar age or of less desirable species or form than the crop trees which they are or may soon be overtopping.

Clearcutting system

A silvicultural system in which the old crop is cleared from a considerable area (generally more than a few acres) at one time. Regeneration is generally artificial but natural regeneration is sometimes possible (a) from adjacent stands by seeding or from seed already on the ground (or from that in conebearing slash), or (b) from advance growth.

Climax forest

A plant community that represents for its locality and its environment the culminating stage of a natural succession.

Coppice selection

A silvicultural system for young-growth redwood, in which selected redwood are removed, permitting the development of an uneven-aged stand from smaller sprouts and seedling trees.

Epicormic

A type of branch or shoot arising from an adventitious or dormant bud on a stem or branch of a woody plant.

Even-aged

A class of forest or stand composed of trees of about the same age. The maximum age difference admissible is generally 10 to 20 years.

Group selection system

(see selection system)

Individual tree selection system

(see selection system)

Overstory

The trees in a forest of more than one story that form the upper or uppermost canopy layer.

Patch cutting

A type of clearcutting used for even-aged management in which the cleared area may be as small as a few acres in size.

Pioneer

A plant capable of invading bare sites (e.g., a newly exposed soil surface) and persisting there until supplanted by successor species.

Progressive strip cutting

Clearcutting progressing against the prevailing wind in strips that are generally not wider than the height of the adjoining trees.

Release (release cutting)

Freeing a tree or group of trees from competition by cutting or otherwise eliminating growth that is overtopping or closely surrounding them.

Seed-tree system

Removal in one cut of the mature timber from an area, except for a small number of seedbearers per acre left singly or in small groups.

Selection system

Individual (single) tree selection

An uneven-aged silvicultural system in which trees are removed singly and periodically throughout the stand, leading to the formation of a mixture of age and size classes by individual trees.

Group selection

A modification of the selection 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 a mosaic of age-class groups in the same forest.

Serotinous cones

Cones that remain closed long beyond the time of maturing without allowing dissemination of seeds.

Shade tolerance

The ability of a tree to grow satisfactorily in the shade.

Shelterwood system

An even-aged system in which a new stand is established under the protection of a partial canopy of trees. The old stand is removed in a series of two or more harvest cuts, the last of which removes the shelterwood when the new even-aged stand is well established.

Silvicultural system

A process whereby forests are tended, harvested, and replaced resulting in production of a forest of distinctive form. Systems are classified according to the method of harvest cutting employed when the stand is reproduced.

Single-tree selection system

(see selection system)

Site index

A measure of site quality based on the height of the dominant trees at an arbitrarily chosen age.

Structure

The distribution and representation of age, size, crown, or other tree classes in a stand or forest.

Succession

The gradual supplanting of one community of plants by another.

Understory

Generally, those trees and woody species growing under an overstory.

Uneven-aged

A class of forest or stand composed of intermingled trees or groups of trees that differ markedly in age.

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LIST OF COMMON AND SCIENTIFIC TREE NAMES[1]

Common Name	Scientific Name
Alaska-cedar	*Chamaecyparis nootkatensis*
Alder, red	*Alnus rubra*
Ash, black	*Fraxinus nigra*
Carolina	*Fraxinus caroliniana*
white	*Fraxinus americana*
green	*Fraxinus pennsylvanica*
Aspen, bigtooth	*Populus grandidentata*
quaking	*Populus tremuloides*
Baldcypress	*Taxodium distichum*
Basswood, American	*Tilia americana*
Beech, American	*Fagus grandifolia*
Birch, paper	*Betula papyrifera*
river	*Betula nigra*
sweet	*Betula lenta*
yellow	*Betula alleghaniensis*
Blackgum (black tupelo)	*Nyssa sylvatica*
Blueblossom	*Ceanothus thyrsiflorus*
Boxelder	*Acer negundo*
Buckeye, yellow	*Aesculus octandra*
Cherry, black	*Prunus serotina*
Cottonwood, black	*Populus trichocarpa*

[1] Names follow the "Check List of Native and Naturalized Trees of the United States" (U.S. Dep. Agr., Agr. Handb. 41, 472 p. 1953), with minor revision. That reference cites authors of the scientific names, also synonyms and other common names in use.

Common Name	Scientific Name
eastern	*Populus deltoides* var. *deltoides*
swamp	*Populus heterophylla*
Cucumbertree	*Magnolia acuminata*
Dogwood, flowering	*Cornus florida*
red-osier	*Cornus stolonifera*
Douglas-fir	*Pseudotsuga menziesii*
coastal	var. *menziesii*
Rocky Mountain	var. *glauca*
Elm, American	*Ulmus americana*
winged	*Ulmus alata*
Fir, balsam	*Abies balsamea*
California red	*Abies magnifica*
corkbark	*Abies lasiocarpa* var. *arizonica*
grand	*Abies grandis*
noble	*Abies procera*
Pacific silver	*Abies amabilis*
Shasta red	*Abies magnifica* var. *shastensis*
subalpine	*Abies lasiocarpa*
white	*Abies concolor*
Hackberry	*Celtis occidentalis*
Hemlock, eastern	*Tsuga canadensis*
mountain	*Tsuga mertensiana*
western	*Tsuga heterophylla*
Hickory, bitternut	*Carya cordiformis*
mockernut	*Carya tomentosa*
pignut	*Carya glabra*
shagbark	*Carya ovata*
water	*Carya aquatica*

Common Name	Scientific Name
Holly, American	*Ilex opaca*
Incense-cedar	*Librocedrus decurrens*
Larch, western	*Larix occidentalis*
Locust, black	*Robinia pseudoacacia*
New Mexican	*Robinia neomexicana*
Madrone, Pacific	*Arbutus menziesii*
Maple, red	*Acer rubrum*
sugar	*Acer saccharum*
Oak, black	*Quercus velutina*
blackjack	*Quercus marilandica*
blue	*Quercus douglasii*
bur	*Quercus macrocarpa*
California black	*Quercus kelloggii*
canyon live	*Quercus chrysolepis*
cherrybark	*Quercus falcata* var. *pagodaefolia*
chestnut	*Quercus prinus*
Gambel	*Quercus gambelii*
laurel	*Quercus laurifolia*
northern pin	*Quercus ellipsoidalis*
northern red	*Quercus rubra*
Nuttall	*Quercus nuttallii*
Oregon white	*Quercus garryana*
overcup	*Quercus lyrata*
post	*Quercus stellata*
scarlet	*Quercus coccinea*
Shumard	*Quercus shumardii*
southern red	*Quercus falcata* var. *falcata*
swamp chestnut	*Quercus michauxii*

Common Name	Scientific Name
water	*Quercus nigra*
white	*Quercus alba*
willow	*Quercus phellos*
Pecan (sweet)	*Carya illinoensis*
bitter	*Carya x lecontei*
Pine, Digger	*Pinus sabiniana*
eastern white	*Pinus strobus*
jack	*Pinus banksiana*
Jeffrey	*Pinus jeffreyi*
knobcone	*Pinus attenuata*
loblolly	*Pinus taeda*
lodgepole	*Pinus contorta*
longleaf	*Pinus palustris*
pitch	*Pinus rigida*
ponderosa	*Pinus ponderosa*
red	*Pinus resinosa*
shortleaf	*Pinus echinata*
slash	*Pinus elliottii*
South Florida slash	*Pinus elliottii* var. *densa*
southwestern white	*Pinus strobiformis*
sugar	*Pinus lambertiana*
Virginia	*Pinus virginiana*
western white	*Pinus monticola*
Poplar, balsam	*Populus balsamifera*
Port-Orford-cedar	*Chamaecyparis lawsoniana*
Redbay	*Persea borbonia*
Redbud, eastern	*Cercis canadensis*
Redcedar, eastern	*Juniperus virginiana*
western	*Thuja plicata*

Common Name	Scientific Name
Redwood	*Sequoia sempervirens*
Sassafras	*Sassafras albidum*
Spruce, black	*Picea mariana*
blue	*Picea pungens*
Engelmann	*Picea engelmannii*
red	*Picea rubens*
Sitka	*Picea sitchensis*
white	*Picea glauca*
Sugarberry	*Celtis laevigata*
Swamp-privet	*Forestiera acuminata*
Sweetbay	*Magnolia virginiana*
Sweetgum	*Liquidambar styraciflua*
Sycamore, American	*Platanus occidentalis*
Tupelo, black (blackgum)	*Nyssa sylvatica*
swamp	*Nyssa sylvatica* var. *biflora*
water	*Nyssa acquatica*
Tamarack	*Larix laricina*
Tanoak	*Lithocarpus densiflorus*
Walnut, black	*Juglans nigra*
White-cedar, northern	*Thuja occidentalis*
Willow, black	*Salix nigra*
Yellow-poplar	*Liriodendron tulipifera*

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