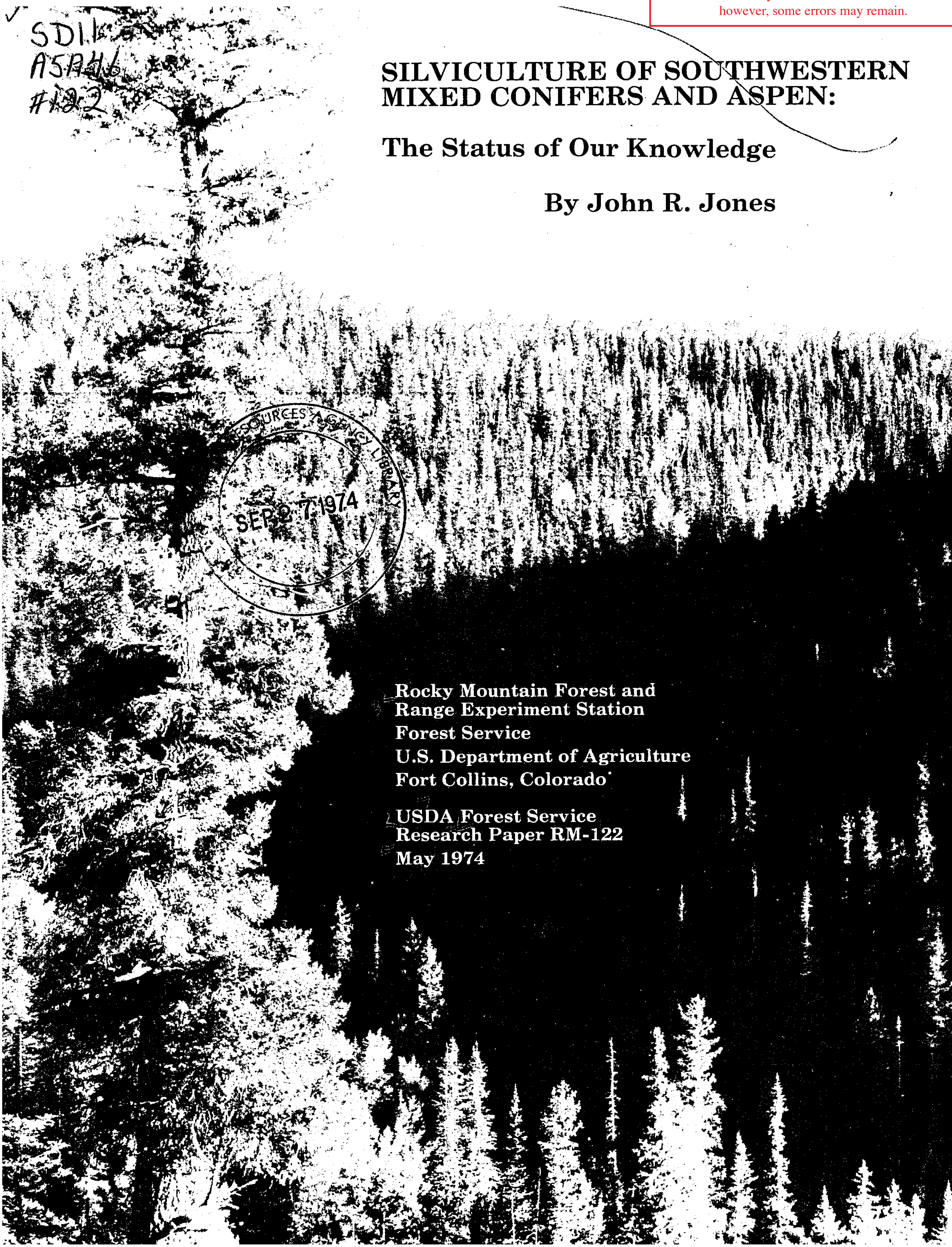
SILVICULTURE OF SOUTHWESTERN MIXED CONIFERS AND ASPEN:

The Status of Our Knowledge

By John R. Jones



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ABSTRACT

Describes the status of our knowledge about mixed conifer silviculture in the interior Southwest. Ecological background is reviewed first, followed by description of silvicultural methods. Relevant literature is discussed, along with observations, experience, and results of unpublished research. Contains unpublished input by subject-matter specialists and southwestern forest managers, largely as feedback from their reviews of a working draft. Research needs are also considered. Aspen forests are included; in the Southwest they are usually succeeded by mixed conifers.

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by
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PREFACE

In any field there is a periodic need to describe the status of available knowledge — to gather unpublished information and that which is scattered in various reports, and organize it in one set of covers for easy reference. That has been done here. Recommendations will often be somewhat tentative and less than precise. While there is much we still need to find out about the silvics and silviculture of mixed conifer land in the Southwest, there is much we already know.

Although reference is made here and there throughout the paper to management for other purposes, it is directed toward the growing of timber. Other writers are summarizing the water, wildlife, and range aspects of forest management. Much of the silvical discussion here, however, and many of the silvicultural methods described, are directly applicable or readily adaptable to management for purposes other than growing timber.

Early sections of the paper describe the Southwestern mixed conifer forests and their silvics. Later sections discuss their silviculture. A final brief section looks at needed research.

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GENERAL DESCRIPTION OF THE MIXED CONIFERS

Mixed conifer forests occupy sites more moist than those usually occupied by pure stands of ponderosa pine.[2] Pinyon-juniper woodlands and the variable mixtures of Chihuahua pine, Apache pine, and evergreen shrubs are not mixed conifer forests within this definition. The common overstory species in mixed conifer forests are Douglas-fir, ponderosa pine, white fir, Engelmann spruce, aspen, southwestern white pine, blue spruce, and corkbark fir, often in more or less that order of abundance. In some mixed conifer areas of the Southwest, one or more of those species may be absent. Corkbark fir is replaced by the closely related subalpine fir on the Kaibab Plateau. In this paper, Southwest means Arizona, New Mexico, and the San Juan Basin of southwestern Colorado.

Mixed conifer forests may be any one of a diversity of mixtures. Various combinations of the above species can be found, with as few as two or as many as all eight growing intermixed. Mixed conifer stands have this in common: the moisture regime has permitted the more or less abundant establishment of coniferous species whose seedlings are more sensitive to drought than are ponderosa pine seedlings. At one extreme the overstory may be almost pure ponderosa pine, with other species abundant only in the understory. At the other ecological extreme, the stand may be predominantly Engelmann spruce and corkbark fir.

Ordinarily, stands of mixed Engelmann spruce and corkbark fir without other species are not considered mixed conifer forest. They form a distinctive and easily defined cover type logically regarded as an extension and variant of the Engelmann spruce-subalpine fir forests farther north, whose management is described in detail in another publication (Alexander 1974). In the Southwest, however, Engelmann spruce-corkbark fir stands intergrade with mixed conifer stands. They are ecologically similar to them in important respects, are often associated with them, and both component species are also elements in mixed conifer forests. In this paper, therefore, Engelmann spruce-corkbark fir forests will occasionally be considered. For convenience, they will be referred to simply as spruce-fir forest. Some foresters and related specialists in the Southwest extend the term spruce-fir forest to include mixed conifer forests that contain spruce. In this paper the term will be used in the more usual sense and not be applied to stands with appreciable mixtures of other species except for groups of aspen.

Aspen forests in the Southwest typically tend to be replaced in time by mixed conifer or spruce-fir forest, and often have a mixed conifer or spruce-fir understory. Aspen management is therefore closely tied to mixed conifer and spruce-fir management, and for that reason will also be discussed here.

A discussion of succession and climax in mixed conifer forests can best follow a discussion of ecological factors. For now let it suffice to say that, following destruction of mixed conifer forest by fire, epidemic, or clearcutting, succession commonly begins with aspen, meadow, or shrub communities. Eventually the area returns to mixed conifer forest, and some mixed conifer forests evolve into spruce-fir forest.

[2] *Scientific names of plants and animals mentioned are listed on page 44.*

DISTRIBUTION

The principal mixed conifer forest areas (fig. 1) include about 2½ million acres of mixed conifer forest broken by associated grassland, aspen forest, ponderosa pine forest, and brushland. As mapped, they include the spruce-fir areas of New Mexico and Arizona but not of southwestern Colorado.

In addition to the areas mapped — areas where mixed conifer forest predominates — mixed conifer stands are scattered in areas predominantly of ponderosa pine forest, where higher elevations, protected north-facing slopes, and the bottoms of canyons and draws provide suitable moisture regimes.

Mixed conifer stands can be found below 6,000 ft in canyon bottoms and on steep north slopes, but most occur at elevations above 8,000 ft. Pure ponderosa pine stands can also be found well above 8,000 ft, probably most often because seed sources of other species are inadequate for effective invasion.

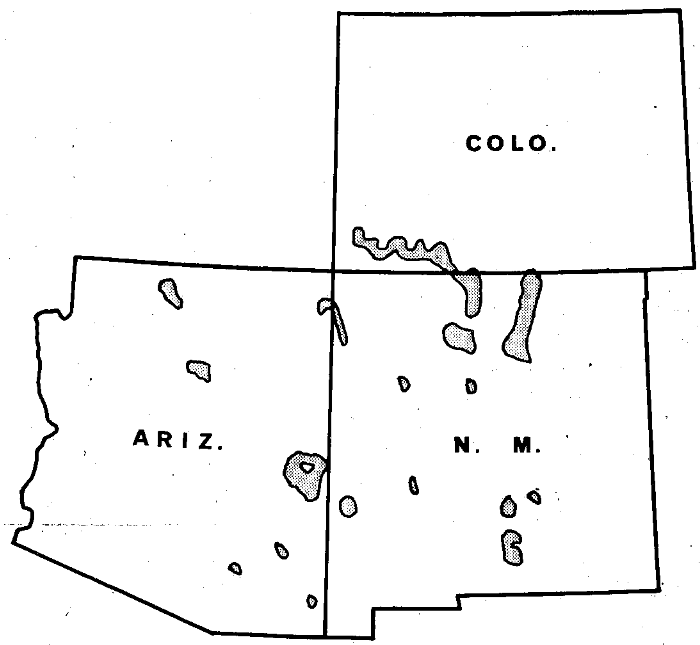

Figure 1.—Main mixed conifer areas in the Southwest.

Mixed conifer stands are largely replaced by spruce-fir at elevations a little below 10,000 ft. Coniferous species other than Engelmann spruce and corkbark fir persist above 10,000 ft mainly as scattered individuals on south slopes or exceptionally rocky ridge tops. Spruce-fir stands can also be found as low as 8,500 ft, primarily on northerly slopes and usually with some slight mixture of other conifers.

Spruce-fir forest may extend to 12,000 ft on favorable sites. Corkbark fir seldom if ever persists to timberline.

ECOLOGICAL FACTORS INFLUENCING SILVICULTURE

Ecological processes tend to be complex interactions of various organisms and assorted physical factors. A single factor may or may not dominate. It is convenient and useful, however, to consider factors individually, with the understanding that they operate jointly.

Moisture

At winter's end, mixed conifer soils are wet. During the following spring-early summer dry season, varying degrees of soil moisture stress develop (Embry 1971). These moisture stresses apparently are not severe enough to critically affect established seedlings or larger trees except where competition is severe (Jones 1972). On southerly slopes or level sites, a heavy stand of grass will lower soil moisture to critical or fatal levels for tree seedlings. These levels may extend from the soil surface to a depth of at least 16 inches (Embry 1971) and presumably more. On northerly slopes, drying under grass is less severe. In contrast, drying of bare loam soils commonly is severe only in the upper inch or two; there is usually considerable moisture 3 or 4 inches beneath a bare surface, even on southerly slopes (Embry 1971).

Studies with various conifers outside the Southwest indicate that soil moisture stress slows seedling height growth substantially when the soil still contains considerable available moisture (Brix 1962, Glerum and Pierpoint 1968, Jarvis and Jarvis 1963, Stransky and Wilson 1964). Mixed conifers achieve most of their height growth in the Southwest before the summer rains begin, using winter moisture stored in the soil.

Summer rains, which usually begin the first half of July, rewet the soil. Moisture stresses, even under a grass cover, are unlikely to become severe again on mixed conifer sites until autumn. Autumn is often dry, but herbaceous cover has largely cured by then so soil drying is less severe than in spring. Also, trees have stopped growing except for root tips, and seem to be relatively drought resistant in autumn.

Some seedbeds, especially duff, dry out quickly. In years and locations where rains are sporadic in July, this drying may delay germination and kill newly emerged seedlings. On the other hand, a thin layer of needle litter on mineral soil may act as a mulch, and may also reduce the foraging efficiency of seed-eating rodents. If seeds are naturally or artificially covered by a thin layer of mineral soil they are less subject to drying, and therefore germinate quicker and survive better.

Temperature

During the period of active stem elongation, primarily the month of June, nighttime temperatures are still quite cool — commonly in the 30° F range. Soil warming is retarded. Physiological studies with various species indicate that seedling growth under these conditions is considerably restricted. Where cold air collects at night, severe frosts in June may also kill back new growth (Ronco 1967).

Sequences of freezing and thawing when the soil is wet and bare of snow often result in extensive frost heaving of seedlings. Freezing without alternating thawing causes much less severe heaving. Deeply rooted seedlings frost heave less than those with shallow roots. In a large spot-seeding study in clearcuttings with free air drainage, blue spruce was seeded as a sun-tolerant species with shallow seedling roots, and white pine was seeded as a sun-tolerant species with deep seedling roots. Many of the blue spruce seedlings that survived the first growing season were subsequently frost heaved, while relatively few white pine seedlings were frost heaved. Had air drainage been poor at night, frost heaving presumably would have been even more severe.

Juvenile roots of Engelmann spruce are about as shallow as those of blue spruce, and seedlings are easily frost heaved. Corkbark fir and Douglas-fir seedlings root a bit more deeply their first year. White fir, white pine, and ponderosa pine seedlings, which root much more deeply, are relatively resistant.

When Douglas-fir tubelings were planted on a clearcutting, they all frost heaved, with their 3-inch tubes, although frost heaving on adjacent white pine seedspots was not serious.

Frost heaving requires a soil texture suited to the upward movement of water in response to weak moisture gradients. Sands do not frost heave. Soils with a high silt content are especially susceptible.[3] Many Southwestern forest soils are silt loams or silty clay loams.

Prolonged snow cover on north-facing slopes protects seedlings from alternate freezing and thawing, and therefore reduces frost heaving. In contrast, on some south-facing slopes the snow may melt even in midwinter, saturating the surface soil and exposing it to alternate freezing and thawing.

Shade not only prolongs snow cover; it considerably reduces both the daytime thawing of bare ground and the incidence of ground freezing in early autumn and late spring when there is no snow cover (Graber 1971).

Light

Open sunlight is always sufficient for good growth (Hodges 1962). There may, however, be too much light. In the Southwest, Engelmann spruce, corkbark fir, Douglas-fir, and white fir do not readily invade openings except in shade, commonly of fallen timber, aspen regrowth, or a forest edge (fig. 2). These observations coincide with research results in southern New Mexico (Krauch 1956) and elsewhere in the interior West (LeBarron and Jemison 1953, Ryker and Potter 1970).

Work in Colorado showed that unshaded Engelmann spruce seedlings, planted in the open at age 4, suffered very heavy **overwinter** mortality. Matched seedlings shaded during the summer with upright shingles suffered few overwinter deaths. A process called solarization, taking place within exposed seedlings during the summer, caused them to die under the snow (Ronco 1967, 1970a, 1970c). A comparable process may occur in Douglas-fir (Zavitkovski and Woodard 1970) and other species.

One-yr-old seedlings were planted in Arizona to learn whether solarization operates in mixed conifer forests here. Ponderosa pine and aspen were not included. Unfortunately, the study was compromised by two consecutive winters with record low snowfall and relatively short periods of snow cover; the hypothesized process hardly had a chance to become critical. Nonetheless, shaded seedlings of all species survived considerably better than unshaded seedlings. All unshaded corkbark fir seedlings and almost all unshaded Douglas-fir died, although few died over winter. Whether solarization was involved or not, shade was clearly very beneficial.

Healthy seedlings grown for 2 or 3 yr in a nursery and properly planted in the field are much more resistant to the drying and heating effects of exposure to full sunlight than are recently germinated seedlings. If a species is subject to solarization, however, seedlings several years old can still be quite susceptible. In Colorado and New Mexico, a number of plantations of 2- and 3-yr-old Engelmann spruce

[3]*Personal communication from L. J. Heidmann, Rocky Mountain Forest and Range Experiment Station, USDA Forest Service, Flagstaff.*

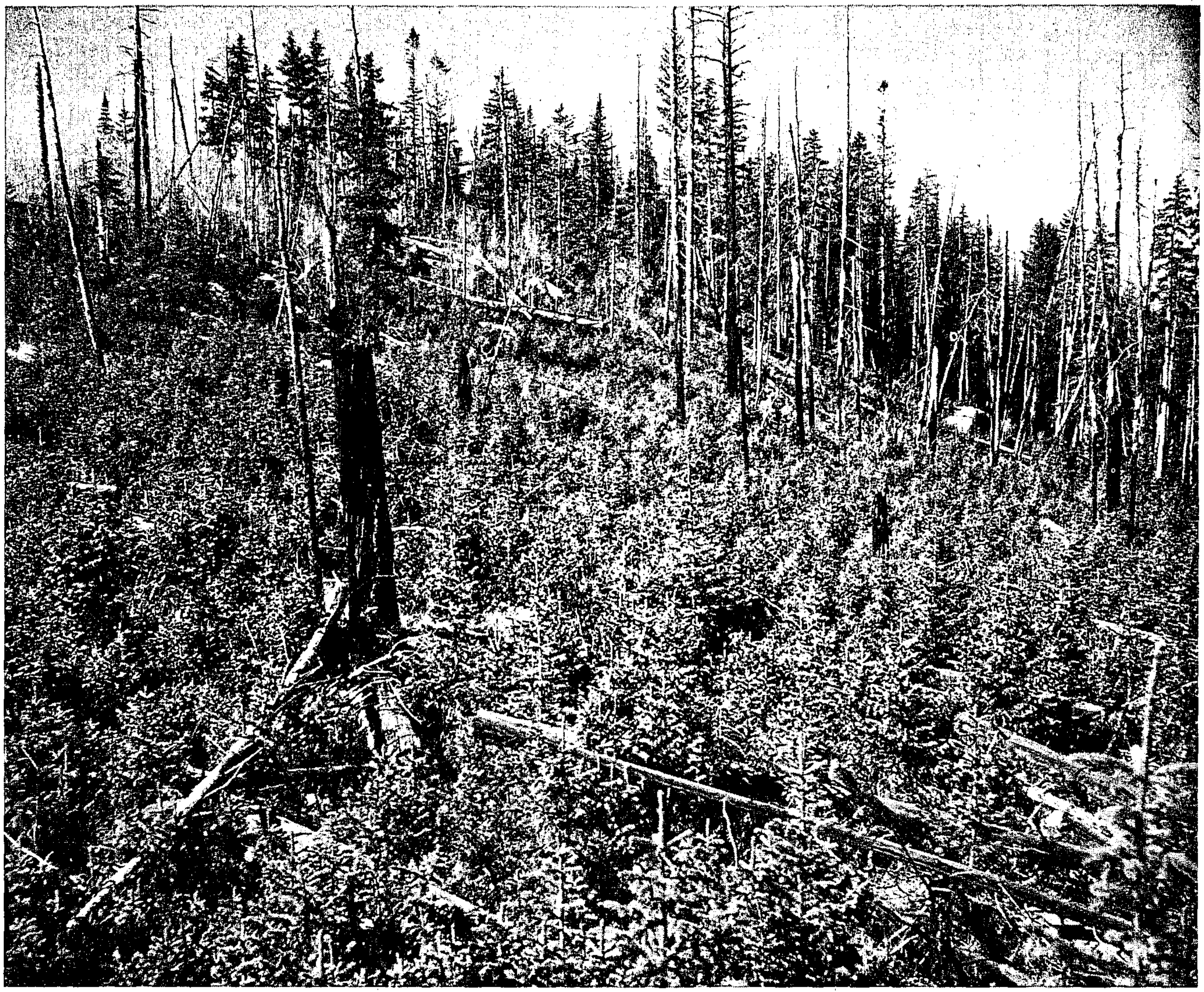

Figure 2.—Dense Engelmann spruce regeneration that came up in the shade of jack-strawed blowdowns after a fire. Apache National Forest.

have failed, apparently because of solarization. A few unshaded Engelmann spruce plantations, including one in Arizona, have survived and grown well. The reasons for these exceptions are not known.

In some regions and types, heat girdling causes heavy losses of newly germinated seedlings on bare southerly slopes. Radiant heating of the ground surface kills juvenile tissues in the hypocotyl. Seedlings more than 8 to 12 weeks old usually are no longer susceptible (Baker 1929, Keijzer and Hermann 1966). Seedspot studies suggest that heat girdling is not a major source of seedling deaths in southwestern mixed conifers that germinate after the summer rains begin. The rainy season is cloudy and the soil, usually wet at or near the surface, probably seldom heats severely. Heat girdling may be significant among new seedlings of corkbark and white fir because they germinate in the sunnier spring.

Because of poor heat conductivity and low moisture content, sandy soils are more likely than loams or clays to reach critically high temperatures (Chang 1958).

Wind

Wind blows down trees, distributes seed, contributes to drying, and influences plant and ground temperatures.

WINDFALL

Windfall is a function of windspeed, tree form, firmness of rooting, and strength of stem.

Alexander (1964, 1967b) studied factors influencing blowdown along the margins of clearcuttings in Colorado. Many of the same factors are pertinent to blowdown in partially cut or uncut timber (Alexander 1973).

Destructive winds are most likely after the spring thaw and during occasional fall storms, when they come mainly from the southwest. Destructive winter winds may blow from the northeast. In any locale, observation of fallen trees suggests the directions from which destructive winds are likely.

Topographic situations where windfall risk is below average, above average, or very high have been summarized by Alexander (1974) as follows:

Below average —

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

Above average —

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

Very high —

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

Trees on shallow or poorly drained soils root shallowly and are windthrown more easily. Trees with root rot are also windthrown more easily, while those with trunk rot break more easily. Trees with long crowns generally are less likely to blow down, and recently exposed trees previously grown in dense even-aged stands tend to be substantially more susceptible than overstory trees grown in open or uneven-aged stands.

Even long-crowned lowerstory trees are very susceptible to windfall if exposed too abruptly. One-step overstory removal may result in heavy blowdown of newly exposed poletimber, including trees with live crowns reaching the ground. Such blowdown can happen even from storms causing little blowdown among the occasional short-crowned overstory culls that are left.

Understory saplings seem much less subject to postlogging blowdown than understory trees 4 inches in diameter or larger.

It seems likely that, other things being equal, species with broad, deep root systems and strong wood are more resistant to blowdown than other species growing on the same site. Other factors tend to obscure the species relationship, however, except that newly exposed aspens are exceptionally susceptible to windthrow.

Blowdown is sometimes heavy along the margins of clearcuttings. While the forester who lays out the boundaries of patches to be clearcut is considering such factors as overstory condition, dwarf mistletoe, esthetics, and advance regeneration, he should also look at topographic and stand characteristics, and locate boundaries to minimize blowdown as much as other considerations permit. Alexander's guidelines for spruce-fir forests (Alexander 1974) seem largely appropriate to mixed conifer forests, and are adapted below in part:

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

SEED DISTRIBUTION

Studies in the southern Rocky Mountains and Southwest (Alexander 1969, Jones 1967b, Ronco 1970b) have demonstrated the importance of wind in the distribution of seed into openings. Much more seed falls on the upwind part of an opening than on the downwind part, and most falls within about 100 ft of the edge. If the upwind part is also upslope, the combined effect can be particularly heavy seedfall over a relatively short distance into the opening.

To receive abundant seed, a clearcut should not be wider than about 200 ft in the direction of the prevailing autumn wind. If conditions are excellent for seedling establishment, however, adequate regeneration may occur over somewhat greater distances. Where environments are unfavorable for regeneration, few seedlings will become established regardless of abundant seed.

OTHER EFFECTS

Winds increase evaporation and transpiration (Meyer et al. 1960) and consequently should increase seedling moisture stress (Jones 1972) and soil drying. Winds reduce the peaks of soil surface temperatures, however, reducing the danger of heat girdling. The frequency and severity of freezing near the ground is also reduced by night winds (Geiger 1957).

Ring shake in large Douglas-fir is often attributed to wind and is commonly called "wind shake", although it is not clear whether wind actually is the cause.

Biotic Factors

COMPETITION

Competition for moisture can seriously delay the regeneration of mixed conifer openings. Heavy grass stands dry the soil severely (Embry 1971), particularly grasses such as Arizona fescue and orchardgrass that make rather vigorous dry-season growth (Schubert et al. 1970). Specific information on soil moisture depletion by sedges and forbs that grow during the dry season is not available. Some may compete as severely as spring grasses.

Bunchgrasses such as Arizona fescue may not appear to fully occupy a site because their aboveground parts form clumps surrounded by bare ground. Commonly, however, their roots fully occupy the soil between the clumps.

Trees and shrubs also deplete soil moisture, but moisture remains available under mixed conifer, spruce-fir, and aspen stands throughout the dry season (Patten 1963, Pearson 1931), even in the upper inch of soil (Pearson 1931).

In mixed conifer and spruce-fir forests, competition for light is important. Understory seedlings grow very slowly, at least partly because of limited light, and growth may be substantially improved when the overstory is thinned or removed (Jones 1971). Release even from the modest shade of aspen canopies substantially increases the growth of understory conifers (Lees 1966, Pearson 1914). The different shade tolerances of mixed conifer species will be discussed later under Some Species Characteristics.

Some plants introduce chemicals into the soil that reduce conifer germination and interfere with normal growth. It is not clear how important this may be under field conditions.

Recent Polish research has demonstrated that at least some grasses also withdraw nutrients from the soil much more aggressively than do competing coniferous seedlings (Fober and Giertych 1971). Competition for nutrients may prove to be a significant factor in seedling survival and development.

In an Arizona study, vigorous ponderosa pine and Engelmann spruce seedlings were planted in a stand of orchardgrass and watered weekly until well into the first rainy season. Others were planted on sites where the grass had been eliminated, and were not watered. After three growing seasons, survival under both conditions was similar — fair for ponderosa pine and excellent for Engelmann spruce — but all the seedlings planted in grass were in poor condition. They had grown very little, and all the spruce were a brassy greenish-yellow color. The most vigorous of the ponderosa pine seedlings added only 6.5 inches of height over three growing seasons. Only one Engelmann spruce grew more than 4.5 inches. On the sites initially without grass, many seedlings added more than 10 inches to their heights during the same period, and a few added more than 20 inches, despite development of variable competition with aspen, raspberries, forbs, bracken, and some grass.

Another effect usually included under competition is the burial of small seedlings by dead herbaceous material or aspen leaves (Canada Forestry Branch 1967, Hughes 1967, Koroleff 1954, Pearson 1914, Pratt 1966). Typical seedlings of Douglas-fir, true firs, and the spruces are less than an inch tall at the end of their first growing season (Jones 1971), and easily buried. Many seedlings, especially

Douglas-fir, covered by dead plant material during the winter, are killed by damping-off fungi (Tappeiner and Helms 1971).

BIRDS

In some regions, birds are major predators on tree seed and newly emerged seedlings (Noble and Shepperd 1973). Juncos have been seen taking seed from seedbeds in the Southwest, and other southwestern birds are known to eat tree seed, but limited experience in seeding suggests that birds are not often serious predators on mixed conifer seed.

White pine seed is large and wingless, yet white pine seedlings can be found well away from a seed source, often in tight clumps and in openings. While rodents may often have buried the seeds, the distances involved frequently suggest birds as the agents.

Birds are important factors in the dynamics of insect populations. Many birds feed on defoliating caterpillars. In some areas woodpeckers have destroyed virtually the entire brood of the spruce beetle (Massey and Wygant 1954).

SMALL MAMMALS

The scope and seriousness of rodent damage to regeneration efforts in southwestern mixed conifers has been abundantly demonstrated. A number of studies have established that seed in unprotected artificial and natural seedings often is almost all taken by rodents (Jones 1967b; Krauch 1936, 1942a, 1942b, 1942c, 1945). Losses are credited largely to deer mice, although ground squirrels, and also shrews (Kangur 1954) are known to eat significant amounts of seed. Newly germinated seedlings too are preyed upon by rodents, and losses on seedspots may approach 100 percent (Jones 1967b, Krauch 1936, Ronco 1967). A planting of Douglas-fir tubelings in Arizona was completely eliminated by rodents within a few nights. Meadow voles are apparently the chief predators on newly emerged seedlings and young tubelings.

Rodent problems are common in coniferous regions, and a considerable literature has developed. Coating seed with endrin has sometimes given effective protection, as has rodent reduction with poisoned baits. Reinfestation from the perimeter of baited areas is quick, however. Deer mice forage widely, with individuals traveling as far as 2 miles (Hooven 1958).

Rodents that eat seeds are much less numerous in the forest than in meadows, burns, or clearcuttings. And rodents do not have an unlimited capacity to find and consume. Where a very large amount of seed falls, even in the open, much of it commonly survives to germinate.

Established seedlings are not immune to rodent damage. Pocket gophers have severely damaged or even eliminated coniferous plantations in some regions (Crouch 1971, Hooven 1971, Ronco 1967). Plantation experience in the Southwest is relatively recent and limited, but here, too, they have damaged plantations both of ponderosa pine and Engelmann spruce. Pocket gopher damage is done mostly in winter and spring when the preferred succulent forbs are unavailable. It is rather easy to identify: the roots may be cut, leaving the drying seedling tilted and easy to pull up. Or the gopher may burrow beneath the seedling and pull it partly or entirely into the ground. Pocket gophers also forage aboveground, especially under the snow, and debark seedlings, leaving rather distinctive tooth marks about 1/16 inch wide. During some winters, well-established seedlings may be debarked and killed by meadow voles, but losses apparently are seldom serious.

At times porcupine damage may be locally severe on saplings, poles, and sawtimber, and occasionally on large seedlings. Rabbits and hares are not known to damage southwestern mixed conifer forests significantly.

Small mammals also have desirable effects. For example, shrews and deer mice eat large numbers of insects, and pocket gophers much prefer competing succulent forbs to tree seedlings. Rodent burrowing can be important in keeping soil highly permeable to water and limiting runoff rates in coniferous forests, where water-repellent layers sometimes develop beneath the litter layer (Meeuwig 1971). But the benefits become academic when rodents reach numbers incompatible with timely reforestation. Fortunately, drastic reduction of rodents by poisoning is very temporary. Strategic timing can give the desired benefits with minimum short-lived side effects.

LIVESTOCK

Where sheep are numerous in mixed conifer areas, they browse all species of regeneration severely (except bristlecone pine). Baker (1925) stated that successful aspen regeneration is not possible where sheep are pastured. Where aspen suckering is abundant and vigorous, however, controlled moderate use of the area by sheep allows satisfactory aspen development, particularly if sheep are excluded the first year (Smith et al. 1972).

Cattle usually graze mixed conifer cutovers. It is often difficult to separate cattle damage from damage by big-game. In the Southwest, cattle sometimes browse ponderosa pine severely. Most damaged seedlings eventually grow out of reach of further browsing, however, and outgrow the distortions of form that developed. The major loss is likely to be the years of growth lost. Historically, grazing pressures were often much heavier than now, and many seedlings were killed.[4] Today, cattle browse seedlings mostly where herbaceous forage is seriously deficient during the period of shoot extension, mainly in June, or where cattle concentrate, as near salt blocks and water tanks. On well-managed ranges, browsing damage by cattle is usually trivial.

Trampling by cattle is more general, and the damage done is generally proportional to intensity of cattle use. In a recent planting study, a salt block was left next to a plot for a few days. Although damage from browsing was minor, trampling damage was considerable. Douglas-fir seedlings planted beneath an aspen stand were severely and repeatedly broken by cattle over a 15-yr period. Although survival was fair, all the trees were low and distorted. None had outgrown the damage.

Abundant slash on an area protects seedlings from both trampling and browsing.

BIG-GAME

Deer have seriously browsed regeneration in some areas. The importance of browsing by elk is less clear, because where elk are present, so are deer. The amount of damage differs by tree species. The approximate order of browsing preference from most to least seems to be: aspen $>$ ponderosa pine $\simeq$ white fir $\simeq$ corkbark fir $\geq$ Douglas-fir $>$ white pine $\simeq$ Engelmann spruce $\simeq$ blue spruce.

Severity of damage is related to the density of game populations near regeneration areas, and the availability of preferred forage species. Another factor is the extent of heavy cuttings or burns in an area: small acreages receive more concentrated game use. On very large areas, such as the Escudilla Mountain burn in eastern Arizona, aspen regenerated successfully even during a period of high game populations. On the 90 acres of clearcuttings at Burro Mountain, 20 miles away, the initially abundant aspen regeneration was completely eliminated by browsing (Jones 1967b).

A Utah study (Smith et al. 1972) and other observations suggest, however, that such elimination happens only with abnormal browsing pressures. Two ponderosa pine plantations at Burro Mountain were essentially eliminated by game browsing during a period of high deer and elk numbers (Jones 1967b). A few years later, deer and elk numbers were considerably lower. Newer clearcuttings on the same forest had developed large patches of aspen saplings, and browsing of study plantations was trivial, even though cattle were present in addition to big-game.

Big-game, especially elk, kill some small seedlings by trampling. In a recent seeding study, 187 of 600 seedspots were disturbed during 2 years by elk, cattle, or deer, in that order of frequency. Many seedlings were stepped on, but most straightened and recovered. Where spots were scuffed, however, seedlings commonly broke or were partly uprooted.

Elk feed on and scar aspen bark rather widely.[5] In some elk wintering areas in Wyoming and Colorado, the damage to aspen stands is heavy. Resulting physiological stress, insect attack, and fungal infection may cause serious mortality which, with associated browsing of suckers, is resulting in gradual conversion to grassland (Krebill 1972). This has so far not been a problem in the Southwest, where elk do not concentrate in aspen areas in winter.

INSECTS

Among the important pests of mixed conifer forests are bark beetles, which depend mainly on overmature or damaged trees to reach outbreak levels. Once outbreak levels have been reached, young vigorous trees may also be killed. Bark beetle outbreaks are most likely to develop during drought years. Outbreaks may develop in heavy blowdown, in trees damaged by forest fire, in concentrations of large logging slash, or in stands badly weakened by defoliating insects.

One of these bark beetles, the spruce beetle, is sometimes very destructive of spruce-fir forests

[4] *Krauch, H., and G. A. Pearson. 1930. Recovery of western yellow pine injured by grazing animals. (Unpublished report in the files of the Rocky Mountain Forest and Range Experiment Station, Flagstaff.) Eight thousand seedlings were studied. A photographic history was compiled of the development of 87 seedlings from 1914 to 1928.*

[5] *Hinds, T.E., and R. G. Krebill. Wounds and canker diseases of western aspen. U.S. Dept. Agric. For. Serv., For. Pest Leafl. (In press.)*

Figure 3.—Engelmann spruce forest wiped out by spruce beetles. The dead trees were cabled down in order to burn the unsalvageable debris. Carson National Forest.

(fig. 3). It is not known to be a threat to mixed conifer stands except where spruces predominate. Its biology and control were described by Massey and Wygant (1954) and more recently by Schmid and Beckwith (1972) and by Schmid (1972). Outbreaks can be stopped by removing infested trees, or by felling followed by spraying or burning infested trunks. Spraying insecticide on the lower trunks of standing infested trees contributes to control. Trap trees, intentionally felled prior to beetle flight, attract beetles and tend to concentrate them. After the beetles have entered the downed trees, the logs may be hauled away for sawing, treated chemically, or removed and burned. Recently, cacodylic acid has been injected in trap trees before felling. The trees are attacked but no brood develops, so the trees need not be disposed of later (Buffam 1971).

Sufficiently cold weather, particularly during early winter, may collapse a spruce beetle outbreak, especially if the snow is not yet deep. Woodpeckers eat large numbers of spruce beetles and their larvae, and may virtually destroy the brood in a locale. Several insect species parasitize or prey on the beetles, their larvae, or pupae.

The Douglas-fir beetle kills many overmature and mature Douglas-firs. Outbreaks, which usually develop following disturbances such as blowdown or defoliation, or in logging slash (Furniss and Orr 1970), sometimes nearly elimnate merchantable Douglas-fir from a stand. The most damaging outbreaks of Douglas-fir beetle in the Southwest have been associated with drought.[6]

Local outbreaks of the fir engraver occasionally damage white fir severely in some locales (Stevens 1971). Outbreaks seem likeliest during or just after drought years.

Several species of bark beetles that damage ponderosa pine forests seem unimportant in mixed conifer forests. These include the mountain pine beetle, the roundheaded pine beetle, and the Arizona five-spined engraver (*Ips*). They may, however, damage mixed conifer stands where ponderosa pine predominates. Lucht et al.[7] reported roundheaded pine beetles killing pines in a south-slope pole stand predominantly of ponderosa pine. Death of the pines was tending to release the Douglas-fir understory and speed succession.

Outbreaks of defoliators may develop in vigorous young forests as well as in overmature stands. The western budworm periodically damages Douglas-fir and white fir in some areas. The insect was recently reviewed by McKnight (1968). Outbreaks may result in extensive dieback but the trees commonly recover. Defoliated trees are also subject to serious attack by bark beetles (Whiteside and Carolin 1961). Growth is reduced in any case, and dead leaders commonly serve as centers of subsequent decay. Sapling stands have been rendered worthless by epidemics of this insect. Since the western budworm is dependent on new foliage for normal development and fecundity, a late freeze may not only kill larvae directly but may cause starvation by killing back the new shoots. During their winter hibernation, however, even the coldest weather does not seem to harm the larvae.

Occasional outbreaks of the Douglas-fir tussock moth result in locally severe mortality and topkill in all age classes. In the Southwest, the known outbreaks have developed with white fir as the primary host (Wickman et al. 1971), but outbreaks probably could develop with Douglas-fir or corkbark fir as primary hosts.[8] During an outbreak, all associated conifers are likely to be defoliated. The insect is attacked by birds, various insects, and a virus

[6] *Personal communication from Frank Yasinski, branch of pest detection and control, Southwestern Region, USDA Forest Service, Albuquerque.*

[7] *Lucht, D. D., R. H. Frye, and J. M. Schmid. Emergence and attack behavior of* Dendroctonus adjunctus *near Cloudcroft, New Mexico. (Manuscript in preparation at Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.)*

[8] *Personal communication from Robert Frye, branch of pest detection and control, Southwestern Region, USDA Forest Service, Albuquerque.*

disease, and outbreaks are usually shortlived (Wickman et al. 1971).

Another defoliator, the New Mexico fir looper, has occasionally damaged and killed considerable Douglas-fir, true firs, and spruce.

The western tent caterpillar[9] periodically defoliates aspen stands in northern New Mexico, southern Colorado, and Arizona's Kaibab Plateau. Stem analyses of old aspens indicate that, in other areas, it does not reach (or at least does not sustain) epidemic proportions. Severe outbreaks may last several years, and are always accompanied by severe reduction in aspen growth. Top dieback may be extensive. Some large stands may be essentially destroyed (fig. 4), with most trees dead and the survivors having severe topkill (Stelzer 1968). Limited observation suggests that such devastated stands generate suckers only weakly.

Figure 4.—Aspen stand in New Mexico 1 yr after collapse of tent caterpillar outbreak. Most trees are dead (Stelzer 1968).

Western tent caterpillar outbreaks usually persist for several years before being ended by predatory or parasitic insects, disease, or starvation. Meanwhile repeated defoliation may damage or destroy stands on many thousands of acres. Theoretically, introduction of an effective natural disease early in an outbreak could collapse the outbreak before serious damage is done. Research on spraying outbreaks with water suspensions of *Bacillus thuringiensis* Berliner and a nuclearpolyhedrosis virus (Stelzer 1967, 1971) have been encouraging.

The southwestern pine tip moth kills the growing tips of ponderosa pine seedlings and saplings, and has caused considerable damage to some pine-zone plantations. Seedlings may be attacked the same spring they are planted. Trees may become forked or crooked, especially when attacked for 2 or more years. It may be that, when plantations and young stands become more widespread in the mixed conifer zone, this insect will be a problem there too.

Insects not now known to be potential problems in Southwestern mixed conifer forests may yet prove troublesome. Recently the white fir needle miner has infested the white fir on about 10,000 acres of the Apache National Forest. Serious topkill or branchkill is not expected but the outbreak is being monitored.

DISEASES

The most important diseases of mixed conifer forests in the Southwest are trunk rots and dwarf mistletoes. Trunk rots and cankers are the major aspen diseases. As management becomes more intensive and research more advanced, diseases not yet appreciated may also prove quite important.

Fungal Diseases. — Trunk rots are widespread in overmature trees. Some species are more affected than others. In old virgin stands, 30 to 40 percent of the volume of white fir and white pine typically is rotten. In some mixed conifer stands the old aspens are almost totally useless as timber because of rot. So are some fire-scarred aspen stands. In contrast, decay usually is not extensive in ponderosa pine and Engelmann spruce.

Much windfall is partly a function of decay that has weakened roots and stems.

In Colorado more than half the decay loss in aspen is due to white trunk rot caused by *Phellinus tremulae* (Bond.) Bond. et Boris (= *Fomes igniarius* var. *populinus*), whose woody hoof-shaped conks are often seen on aspen trunks (Davidson et al. 1959). Aspens with white trunk rot often contain some sound logs, however.

Hinds (1963) has provided a guide to estimating usability of infected aspen in Colorado, based on conk locations. That guide is probably essentially valid for New Mexico and Arizona as well. Hinds and Hawksworth (1966) have also provided a guide to the recognition of decay in standing Engelmann spruce in

[9]*Southwestern populations of the western tent caterpillar were long considered a separate species,* Malacosoma fragile *(Stretch), the Great Basin tent caterpillar. A review of the genus by Stehr and Cook (1968) has placed it within the species* M. californicum *(Packard), the western tent caterpillar.*

Colorado. That guide too is probably valid for the Southwest.

Decay will be much less a factor in future mixed conifer stands because, outside of areas where visual effects are primary, few trees will be allowed to become overmature. Also, much decay in virgin stands resulted from fire scarring, which will be much less common in second-growth forests. In addition, periodic intermediate cuttings will permit salvage of injured trees before they decay extensively, and will maintain the vigor of the healthy trees that remain.

A fungal disease, Hypoxylon canker, is the most important killing disease of aspen in the Lake States (Anderson and Anderson 1969). It is widespread in the West as well (Davidson and Hinds 1956, Riffle and Hinds 1969), though less serious. It may nonetheless prove to be important in the Southwest under some conditions.[10]

Generally, in the West, Cenangium canker seems to be the most serious killing disease of aspen, and Ceratocystis cankers also do widespread damage.[11]

Fralish (1972) described how aspen overstories commonly break up in Wisconsin. Growth is vigorous in immature stands, and canopy gaps formed when trees die are rapidly filled. In mature stands, however, growth does not fill those gaps. The trees are exposed to increased sunlight, wind, and evaporation. As the stand becomes more open, these reach a point which the trees do not tolerate well and their vigor is further reduced. They become more susceptible to disease, insects, and breakage, and deterioration accelerates. Within a few years of the time the process starts accelerating, the stand may be gone.

Hypoxylon canker contributes importantly to the opening of stands in Wisconsin, and increases as the stand opens (Anderson and Anderson 1968). White trunk rot increases with age and contributes to breakage. Sunscald becomes a factor with sufficient stand opening (Hubbard 1972).

In the Rocky Mountains and Southwest, where stands may persist well past age 200, a similar process no doubt operates, albeit slowly. Breakup may well be accelerated by partial cutting.

[10]*Personal communication from Thomas Hinds, Rocky Mountain Forest and Range Experiment Station, USDA Forest Service, Fort Collins.*

[11]*See footnote 5.*

Dwarf Mistletoe. — Dwarf mistletoes are our most difficult disease problem in mixed conifer forests. Their biology has recently been described by Hawksworth and Wiens (1972). These inconspicuous parasitic plants propagate by explosive fruits that propel seeds as much as 50 ft. The average distance is much less, however, because seeds are intercepted by foliage and so forth. Infections typically spread from infection centers at an average rate of 1 or 2 ft a year. Occasional appearances of new infection centers some distance from a source indicate an additional means of seed dispersal; birds have been suggested.

Trees newly infected with dwarf mistletoe show no external symptoms for several years. The first symptom is a swelling at the point of infection, followed quickly by small external dwarf mistletoe shoots. These can easily be overlooked when well above the ground. A few years after shoots appear, witches brooms become noticeable in most cases, and identification of infected trees becomes much easier. By that time the tree has already functioned as a source of further infection.

Dwarf mistletoe has its major impacts on the host tree after infecting the upper half of the crown. Growth then declines rapidly. Other effects include reduced seed production and lower wood quality. When infection becomes intensive enough the tree dies. Infected trees, especially Douglas-fir, become more susceptible to attack by bark beetles. In some cases the resulting brood emergence is low;[12] in other cases serious beetle buildups can result.[13]

Infections after trees have passed their years of maximum growth are less important than infections of young trees. The critical need is to keep mistletoe out of young stands so far as possible. Understories may be heavily infected from dwarf mistletoe fruiting in overstory trees. Heavy infection of an understory can result in a stand composed largely of deformed and stunted trees that are unlikely to live to maturity. This is less a prospect in mixed stands than in pure stands however, because of host specificity. Each dwarf mistletoe species in the southwestern mixed conifers has a principal host species, and normally does not parasitize

[12]*Personal communication from Melvyn Weiss, branch of pest detection and control, Southwestern Region, USDA Forest Service, Albuquerque.*

[13]*Personal communication from Frank Hawksworth, Rocky Mountain Forest and Range Experiment Station, USDA Forest Service, Fort Collins.*

other species to any extent. If, for example, the Douglas-fir in an overstory is seriously parasitized, it will not cause infection among the spruce, pine, and white fir growing under and around it.

The most serious dwarf mistletoe in mixed conifer forests is Douglas-fir dwarf mistletoe. It occurs throughout the range of Douglas-fir in the Southwest and damages trees severely (Graham 1961). Understory Douglas-fir topped by heavily infected Douglas-fir in the overstory normally is heavily infected. Where corkbark fir grows with Douglas-fir, it too is sometimes seriously infected, but infections of other species are trivial. The external shoots of this dwarf mistletoe are often hard to find. They are very small, greenish, and often few, even on heavily infected trees. The conspicuous witches brooms are readily diagnostic, however, once they develop.

Southwestern dwarf mistletoe, sometimes called ponderosa pine dwarf mistletoe, is found almost throughout the range of ponderosa pine in the Southwest. Its biology has been examined in considerable detail by Hawksworth (1961). In mixed conifer forests its hosts are ponderosa pine, and Arizona pine in the few areas where that variety occurs in the mixtures. Trees are seriously damaged. Although witches brooms are commonly conspicuous, some heavily infected trees do not develop brooms.

This dwarf mistletoe is a less serious problem in mixed conifer management than is Douglas-fir dwarf mistletoe. While the disease is indeed very destructive of young pines, in most mixed conifer forests ponderosa pine regeneration is abundant primarily in large openings, into which infections progress slowly.

The dwarf mistletoes of other mixed conifer species are not found regionwide. Western spruce dwarf mistletoe may severely damage both blue and Engelmann spruces almost wherever they occur in Arizona outside the Chiricahua Mountains. In New Mexico, however, it is found only in the Mogollon Mountains. Its small, bristly witches brooms are often numerous on host trees, and easily distinguished from the rather shaggy, yellowish, and often large brooms, really more moplike, induced by spruce broom rust. In the large spruce and mixed conifer forests elsewhere in New Mexico and to the north, the only dwarf mistletoes on spruce are trivial crossovers from other species.

White fir dwarf mistletoe occurs in the Southwest only on the Kaibab Plateau, where it also infects associated subalpine fir. In addition to brooms, dying branches ("flagging") are a conspicuous symptom.

Southwestern white pine has two dwarf mistletoes of limited and nonoverlapping ranges, both known only on white pine. One of them, Apache dwarf mistletoe, is found abundantly and only in east central and southeastern Arizona and in central and southwestern New Mexico. It consistently causes witches brooms. The other species, *Arceuthobium blumeri* (it has no common name) occurs in the United States only in the Huachuca and Santa Rita Mountains of extreme southern Arizona. It is unique among dwarf mistletoes in the Southwest in rarely inducing witches brooms.

Dwarf mistletoes themselves are parasitized by fungal diseases, and their aerial shoots are eaten by insects and larger animals. None of these seem to provide effective natural control, although they may slow the intensification of infestations. Gill and Hawksworth (1961) suggested that damage by Douglas-fir dwarf mistletoe might be much more severe, at least in some areas, were it not for a fungus, *Wallrothiella arceuthobii.*

Forests in some habitat types are more susceptible than others to dwarf mistletoe (Daubenmire 1961). Also, dwarf mistletoe tends to be more serious on some topographic and elevational situations, although reports are not entirely consistent (Hawksworth 1959). In general, severity seems greatest on ridge tops and upper slopes, at least for southwestern dwarf mistletoe in ponderosa pine. In some locales, western spruce dwarf mistletoe occurs largely in canyon bottoms and on lower slopes, but it can be severe on other topographic situations too.

Removal of infected trees from heavily infected ponderosa pine stands will not control the infection (Heidmann 1968, Shea and Lewis 1971). Removal of enough infected overstory trees may result in blowdown of the remaining trees. In heavily infected young stands or understories, many of the trees that appear healthy and would be left are likely to have latent infections. Opening the stand typically stimulates development of shoots from latent infections, which will in turn fruit and intensify the infestation.

In mixed stands with only one species heavily infected, or where infections are moderate, such sanitation cuttings can be effective, generally favoring other species. More than a single treatment is likely to be needed, and followup should not be neglected.

Forest fires and clearcuttings have been effective sanitizers when all or nearly all infected trees were killed or cut. Natural or artificial regeneration then produces a "clean" stand that is only gradually reinvaded by the parasite.

Fire

Burning to dispose of slash is not discussed here; it will be considered later in the section on slash disposal.

More is known about fire is southwestern ponderosa pine forests than in mixed conifer forests. We will look first at the former as a partial basis for discussing the latter.

Some research and considerable historical and modern observation have provided a good picture of the role of fire in ponderosa pine forests prior to white settlement in the Southwest. The results of fire exclusion are also fairly apparent. They include severely overstocked sapling patches, reduced growth, reduced forage, and increased danger of severely destructive wildfires. The evidence has been fairly and thoroughly reviewed by Cooper (1960).

Because of the results of fire exclusion, arguments have been made for prescribed burning in ponderosa pine forests. Fuel conditions now are very different from fuel conditions that existed in the relatively open primeval forests, however. For intentional burning today, planning, skill, and care are needed because the prospects and consequences of stand destruction are substantially greater.

Pioneering tests, notably by the Bureau of Indian Affairs on the Fort Apache Reservation, have taught that "rough and ready" burning is a very crude tool both for thinning and fuel reduction, even in cool autumn weather. Under favorable conditions, when fire will burn without blowing up, it may give crude but more or less acceptable thinning on parts of the treated area. Other parts will not carry fire. On still other parts, regeneration will be largely or totally destroyed, and even some large trees scarred or killed. On parts of the area fuel accumulations will be reduced, on others untouched, and on still others increased by the addition of quantities of fire-killed saplings (Cooper 1960, Davis 1965, Gaines et al. 1958, Lindenmuth 1960).

Such variability within a burn results to a considerable extent from differences in kind and amount of fuel, in topography, and in the size and density of forest stocking. Some of it reflects weather changes while the fire is burning.

Burning as a silvicultural tool can be considerably refined. An area can be divided into subunits according to fuel, stand conditions, and other pertinent considerations. The subunits can then be burned separately when each seems likeliest to give the desired results. Locations, patterns, and rate of torching on a subunit can be adjusted as a continuous reponse to weather, fire behavior, and other on-site conditions. Although that kind of burning is more expensive, administrative studies indicate that costs can still be low — less than one 1970 dollar per acre for some jobs on large acreages (Buck 1971).

On the other hand, mechanical thinning, though expensive in precommercial stands, allows precise control of residual stocking, including selection of the trees to be retained. With present high timber values, such precise stocking control looks increasingly desirable.

The discussion so far has been restricted to ponderosa pine forests. Burning in mixed conifer forests involves some different considerations. The discussion of fire in mixed conifers is of necessity more tentative than for ponderosa pine.

Weaver (1951) dated fire scars in five pine stands. Before white settlement the average interval between fires was about 8 years. Mixed conifer forests are generally cooler and more moist than pine forests, with a litter layer typically less flammable. One would expect them to have burned less frequently than pine forests. That they did in fact burn less often is indicated by the abundance of spruce and corkbark fir of 19th Century origin and older in many mixed conifer stands. Fires in spruce-fir forests seem normally to have been holocausts at intervals of centuries.

Within mixed conifer forests the different species vary in their susceptibility to fire. For trees of pole size and larger, corkbark fir and both species of spruce are easily killed. Ponderosa pine and Douglas-fir are quite resistant. White fir, white pine, and aspen are intermediate. Seedlings of any species are readily killed. Differences in susceptibility may be important among saplings, but species order is not apparent.

Primeval wildfires were important to the composition and structure of mixed conifer forests. Most fires were light, and therefore killed many seedlings and saplings but generally spared larger trees, especially of resistant species. Patches in less flammable situations were often spared. Some patches burned intensely, especially where insects or disease left local concentrations of fuel. In such hot spots even large trees, especially of susceptible species, were scarred or killed.

Partly as a consequence, irregular structures are the rule in mixed conifer stands. Douglas-fir and ponderosa pine commonly predominate in the overstories, even where Engelmann spruce and corkbark fir predominate in the understory. Overstory white fir and white pine often are fire scarred and defective. Groups and patches of even-aged aspen are common, many marking old hot spots.

Occasional intense fires killed almost all the trees on large areas, often leaving only scattered survivors, most commonly Douglas-fir and ponderosa pine. The subsequent succession of vegetation types is discussed in a later section.

Such severe fires do more than destroy forests. Where soils are fairly or highly erodible, severe fire may be followed by appreciable soil movement and stream sedimentation (Rich et al. 1961). Severe fires eliminate dwarf mistletoe from sites where the infected species are wiped out.

Severe fires cause high soil temperatures and can result temporarily in a strongly water-repellent layer in the soil a little below the surface, especially in sandy soils. Soil wetting is seriously inhibited while such a layer persists. Erosion is accelerated and natural regeneration delayed. Light fires burning across soils with a high clay content result in least repellency (DeBano and Rice 1971, 1973).

Prolonged fire exclusion without substitution of cultural equivalents has resulted in frequent well-developed understories of the more shade-tolerant species. Overstocking is much less a problem than in ponderosa pine stands, however, and precommercial thinning seems much less important. Given present and increasing demands, commercial thinning and salvage cutting seem to offer much better means of stocking control and regulation of heavy fuels than does prescribed burning. Prescribed fire in mixed conifer forests and aspen forests seems to have a future mainly (1) as a followup to "commerical clearcutting" where aspen dominance is to be established or perpetuated, (2) as a means of rejuvenating aspen stands for esthetic and wildlife purposes where clearcutting is not feasible, (3) as a sanitation measure following the commercial clearcutting of parts of stands where dwarf mistletoe is especially severe, (4) where an overstory predominance of ponderosa pine or Douglas-fir is to be maintained against aggressive invasion by more shade-tolerant species, (5) as a means of reducing fine fuels in stands resistant to fire under moderate burning conditions, (6) seedbed preparation during development of a cone crop after the seed cutting in the shelterwood system, and (7) as a semi-natural process in wilderness areas.

We need to know more about the effects of atmospheric conditions, fuel, and stand conditions on fire behavior, and the response of different ecosystems to fire of different intensities and duration. Such information would help us understand the potentials and limitations of prescribed burning, and allow better prescriptions.

Experienced field men have developed considerable working knowledge (Buck 1971) that needs to be summarized in print. Existing field expertise seems adequate for expanded field trials.

SOME SPECIES CHARACTERISTICS

Seed Supply

Seed supply at time of germination is a function of more than seed production. How effectively is seed distributed? How much seed is destroyed between seedfall and germination? What proportion of the germinating seedlings will establish themselves?

Based on observations, limited monitoring of cone crops, and limited seed trapping, mostly in the White Mountains of Arizona, the order of seed production by mixed conifer species seems to be approximately: blue spruce $>$ Douglas-fir $>$ Engelmann spruce $>$ corkbark fir $\simeq$ white fir $>$ ponderosa pine $\simeq$ white pine.

Blue spruce bears moderate to heavy cone crops in most years. Substantial Douglas-fir and Engelmann spruce cone crops are also frequent but usually lighter. Corkbark fir and white fir crops are more sporadic. Ponderosa pine crops tend to be lighter at mixed conifer elevations than lower down, and heavy crops are infrequent. In years when few or no ponderosa pine cones are found in some locales, however, significant crops are sometimes found at similar elevations nearby.

Seed production decreases when dwarf mistletoe infects the upper crown (Hawksworth and Wiens 1972).

A species bearing substantial seed crops almost yearly may take better advantage of the infrequent years when conditions for seedling establishment are especially good. On the other hand, species with infrequent good seed years may be less demanding of conditions for seedling establishment, with considerable numbers of seedlings resulting from almost any substantial seed year.

All the conifers other than white pine bear winged seed adapted to distribution by wind. White pine seeds, which are large and have vestigial wings or none at all, are distributed beyond the radius of the crown by rodents which carry seeds away and bury them. Some such caches are not subsequently visited, and the seeds may germinate.

A moderate to heavy cone crop of all conifers in 1964 resulted in very heavy seedfall in Arizona's White Mountains. The fall of sound seed on a 10-acre clearcutting was distributed as shown by the isolines in figure 5. Within the band defined by the 400,000 isoline, seedfall averaged over 500,000 sound seeds per acre, while the area enclosed by the 40,000 isoline averaged only about 10,000 (Jones 1967b). As usual in seedfall studies, the side of the clearcutting from which the prevailing winds blow received much more seed per acre than the downwind side. Upslope sides should also receive more seed than downslope sides, and in this case the upwind and upslope sides were the same side.

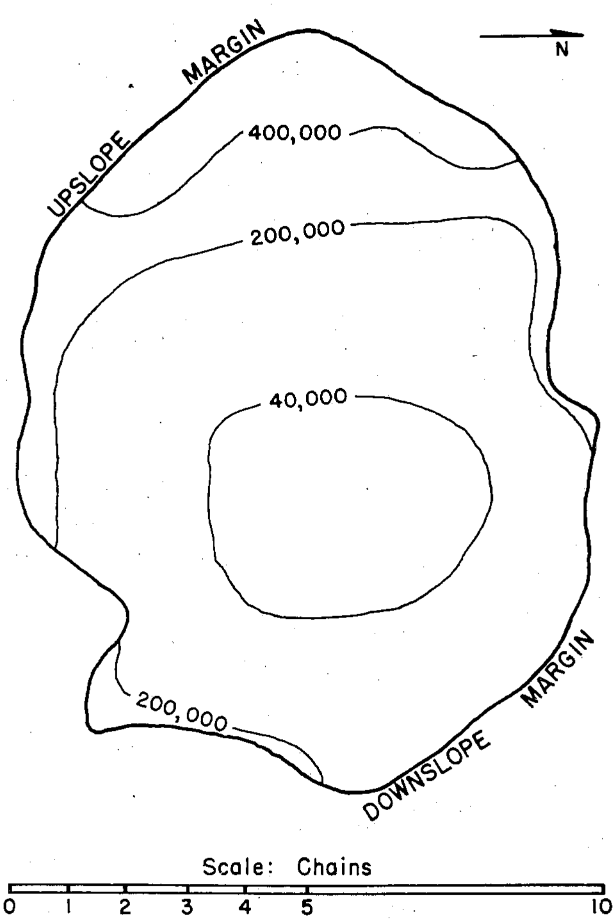

Figure 5.—The fall of sound tree seed on a 10-acre clearcutting in 1964. Very few seedlings became established, however, because of unfavorable conditions. Apache National Forest (Jones 1967b).

Mice prefer seeds of other conifers to those of true firs such as white fir and corkbark fir (Abbott 1962, Krauch 1945, Moore 1940). Some mice reject true fir seed even when extremely hungry (Abbott 1962), which no doubt helps the true firs occupy suitable regeneration sites at the expense of other species. Squirrels, on the other hand, cut and cache cones of all species in large quantities, often far beyond their ability to use them, and may take most of the healthy cones produced in years of light crops.

Aspen seed supply has not been considered because seed production seems to vary widely between pistillate clones, and because aspen regenerates almost entirely from root suckers in this region. Aspen seedlings have been reported for the West in the literature. A number were found in 1970 on the Apache National Forest, but for unknown reasons they were gone by midsummer of 1971. While aspen seedlings undoubtedly do become established under favorable conditions, current aspen regeneration significant to silviculture is by root suckering.

Germination

Germination percentages for mixed conifer species in the Southwest are available only for artificially processed seed collections. Such germination data are important for nursery and seeding practices, but are not relevant to natural regeneration. Germination test results are quite variable for processed white fir and corkbark fir seed, but usually fewer than 50 percent germinate. For the other mixed conifer species in this region, germination is rather consistently above 50 percent (USDA Forest Service 1948).

White fir and corkbark fir seed germinates in the spring on moisture from snowmelt and infrequent spring showers. No summer germination of white or corkbark firs has been observed. Stored seed sown just before or during the summer rains would probably germinate in summer, however. Some white pine seed germinates in spring, with a second period of germination after the summer rains begin. Most seed of ponderosa pine, Douglas-fir, and the spruces germinate during the summer rainy season. If significant showers fall in June, some germination of these species may begin then. June showers are more likely in southern New Mexico than elsewhere in the region.

Ponderosa pine germination on mixed conifer sites may continue well into September, and August germination is common. Late germination results in seedlings with relatively shallow root systems at the end of the first growing season — seedlings which are more susceptible to frost heaving and drought than earlier germinants (Larson 1961). It is not known whether such late germination is as common among the other summer-germinating species. A minor amount of mixed conifer seed that does not germinate the first growing season after seedfall may germinate the second summer.

Aspen Suckering

Aspen stands have a network of interconnected lateral roots (Barnes 1966, DeByle 1964, Gifford 1966). Aspen regenerates by sprouting (suckering) from shallow roots, using food stored in them. Increased root temperature caused by exposure of the soil to sunlight is a cardinal factor in stimulating suckering (Maini and Horton 1966).

When an aspen stand is burned or clearcut, sucker density after the first full growing season is likely to be in the tens of thousands per acre (Baker 1918, 1925; Larson 1959; Smith et al. 1972). Also where aspens were fairly numerous in mixed conifer stands, clearcutting or severe fire has resulted in abundant suckering. In the Lake States, disking has increased initial suckering, but subsequent poor survival and growth have been reported (Perala 1972). Initial sucker density may vary with season of cutting, but the difference decreases with time (Baker 1925, Graham et al. 1963, Sandberg and Schneider 1953) and does not seem important in the Southwest.

In partially cut stands, the remaining overstory aspens shade both the ground and the sucker stand. Also, aspen shows strong apical dominance, at least in young trees (Farmer 1962, Schier 1972). Presumably, then, residual aspens inhibit suckering and sucker growth by shading, by chemical inhibitors, and by priority use of food stored in the parent root system. While initial suckering is sometimes more than adequate following partial cutting, survival and growth are unsatisfactory (Baker 1918, 1925; Farmer 1962; Larson 1959; Pearson 1914; Sandberg and Schneider 1953; Schier 1972; Smith et al. 1972; Stoeckeler and Macon 1956; Zehngraff 1947, 1949).

Early Growth

Studies of juvenile mixed conifer growth rates have been few. A recent Arizona study of limited scope (Jones 1971) gives a picture that agrees in essentials with the limited New Mexico data of Krauch (1956) and Miller.[14] Growth in the shade is slower than in the open. Five-yr-old Engelmann spruce and corkbark fir under a small gap in the crown canopy received little direct sunlight. They averaged only 3 inches tall and showed no sign of accelerating with age. That average is quite in line with findings for those species in other parts of the interior West from Canada southward.

In a larger gap, where seedlings received continuous direct sunlight for 1 to 2 hours daily, 5-yr-old Douglas-fir, Engelmann spruce, and corkbark fir still averaged only about 5 inches tall but their growth had started to speed up.

Although early survival of most species tends to be very poor in the open, those seedlings surviving the sensitive first 2 years or so normally grow much faster than shaded seedlings if competition for moisture is not severe. Six growing seasons after germination on a clearcutting, most ponderosa pines were taller than 25 inches, most Douglas-firs were taller than 20 inches, and Engelmann spruces averaged 15 inches. That species order of growth rates probably would not hold on all mixed conifer clearcuttings. Seedlings of other species were too few for meaningful measurements. Growth was accelerating in all species. Observations suggest these were superior growth rates for mixed conifer clearcuttings, perhaps because of the unusually sparse herbaceous competition. Seedlings were also unusually numerous for a clearcutting.

A large number of Engelmann spruce seedlings suppressed beneath a mixed conifer canopy were partially released by heavy selective cutting in late 1957. They then averaged 7 inches tall. Growing in considerably increased light they reached an average of 77 inches by late 1969 and 92 inches a year later.

Aspen suckers in the open grow much faster than coniferous seedlings. Extensive sampling in Colorado, northern New Mexico, and eastern Arizona showed that most aspen suckers reach breast height within 2 to 5 years. A few reach breast height during their first growing season (Jones 1967a).

Less is known about early root growth than about shoot growth. Our limited information on root growth is from naturally established seedlings growing in silt loams and silty clay loams in Arizona's White Mountains (Jones 1971). The following tabulation gives root

[14]*Miller, F. H. 1923. Growth and yield for the important timber species in northern New Mexico. (Unpublished report in the files of the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona. 61 p.)*

penetration in inches after one and five growing seasons for the four species found in large numbers.

Species	1 yr	5 yr
	(Inches)	
White fir	7½	10
Douglas-fir	3	8
Corkbark fir	3½	6
Engelmann spruce	2½	6

The roots of all species were much more abundantly branched after five growing seasons than after the first (fig. 6). All seedlings were growing in considerable shade. The 1-yr-old white fir were shaded least — about half the day. If 5-yr-olds had been found in clearcuttings they probably would have been found to root more deeply. Rooting might also have been deeper in sandier soil.

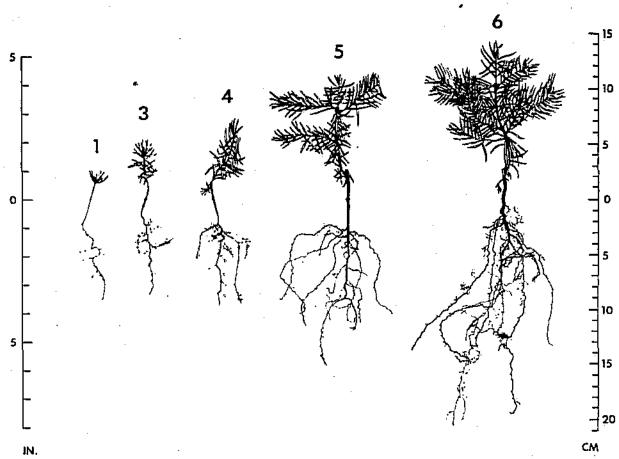

Figure 6.—Representative corkbark fir seedlings after 1 to 6 growing seasons. There is no second-year seedling (Jones 1971).

A few root systems of white pine and ponderosa pine were also examined. Seedlings of both species germinating fairly early in the rainy season seem to penetrate about as deeply the first year as white fir, but white pine roots, at least, penetrate much more deeply than white fir during the subsequent few years.

Later Growth

Our coniferous species grow much faster in the sapling and pole stages than as seedlings. The only pictures we have of growth beyond the seedling stage are given by site index curves.

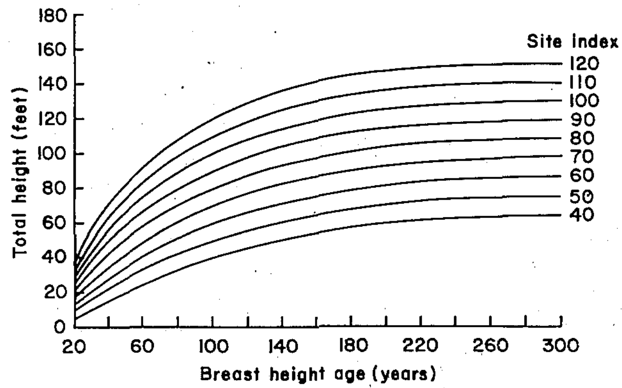

Figure 7.—Site index curves for Engelmann spruce in Colorado and Wyoming. Base age 100 yr after reaching breast height (Alexander 1967a).

Alexander's (1967a) curves for Engelmann spruce in Colorado and Wyoming (fig. 7) seem reasonable representations of Engelmann spruce height growth in New Mexico and Arizona. The ages shown are not total ages, but breast height ages. Thus the curves represent heights at the indicated number of years after the tree reached breast height, which is after the period of very inconsistent and often very slow juvenile growth has ended. Brickell's (1966) site index curves for Engelmann spruce in the northern and central Rocky Mountains should not be used in the Southwest. Their forms do not at all represent growth in this region, and grossly overstate juvenile growth for all Southwestern sites. Therefore they greatly underestimate site index when young stands are used and seriously overestimate it when mature stands are used.

Walter Meyer's ponderosa pine site index curves do not, Meyer wrote, satisfactorily represent the species in the Southwest (Meyer 1938). Minor's (1964) curves, on the other hand, were developed explicitly for ponderosa pine in Arizona (fig. 8), and while based on data from the ponderosa pine zone they probably are reasonably appropriate for ponderosa pine on mixed conifer sites. Like Alexander, Minor used breast height age instead of total age.

Jones (1967a) developed site index curves for aspen (fig. 9), available also as a table (Jones 1966). Again breast height age was used.

There are not site index curves suitable for the other mixed conifer species in the Southwest. Until some have been developed, Alexander's (1967a) curves for Engelmann spruce can be used for Douglas-fir, white fir, corkbark fir, and blue spruce with the understanding that accuracy is very likely poor. Minor's (1964) curves for ponderosa pine can be used for white pine with the same reservation. Brickell's (1968) site index curves for Rocky Mountain Douglas-fir should not be used in the Southwest for the same reasons his Engelmann spruce curves should not: they are grossly inaccurate for this region.

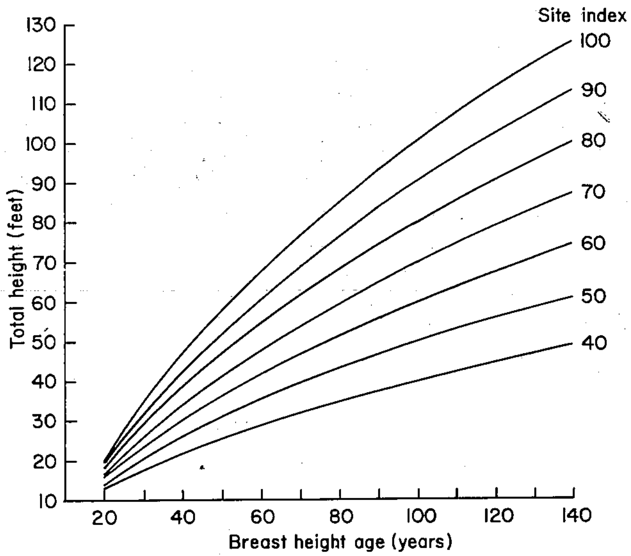

Figure 8.—Site index curves for young-growth ponderosa pine in northern Arizona. Base age 100 yr after reaching breast height (Minor 1964).

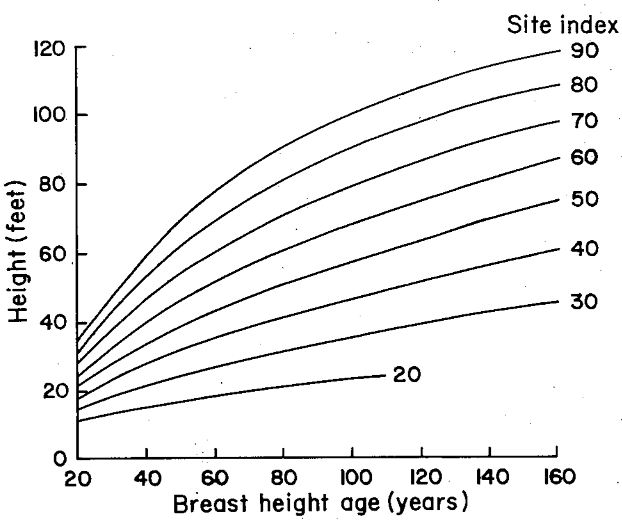

Figure 9.—Site index curves for aspen in the southern Rocky Mountains. Base age 80 yr after reaching breast height (Jones 1967a).

Sample trees from saplings to veterans were measured on 1,800 acres of virgin mixed conifer forest in Arizona's White Mountains (Embry and Gottfried 1971). The largest measurements (below) are not uncommon for the better trees on good Southwestern sites:

Species	Greatest — Height (ft)	Greatest — d.b.h. (in)
Douglas-fir	148	51
Ponderosa pine	145	40
White fir	134	49
White pine	130	44
Engelmann spruce	125	36
Corkbark fir	125	34
Blue spruce	124	26
Aspen	110	26

These are all large trees by Southwestern standards, but none is really exceptional.

An exceptionally fast-growing Engelmann spruce at 9,300 ft in eastern Arizona reached 18 ft 9 inches 24 summers after germinating. It then added 29 ft 10 inches in just 11 yr for a height of 48 ft 7 inches at a total age (not a breast height age) of 35.

Examples of outstanding sizes for the Southwest are an Engelmann spruce 45 inches d.b.h. and 160 ft tall (fig. 10) and a 72-inch d.b.h. Douglas-fir that measured 150 ft to a broken top. Douglas-fir 160 ft tall occasionally are measured.

Figure 10.—An Engelmann spruce 45 inches d.b.h. and 160 ft tall stands in approximate center of photo. San Juan National Forest.

Shade Tolerance

Observation and limited study (Jones 1971) suggests the following species order of shade tolerance in the Southwest: Engelmann spruce $\simeq$ corkbark fir $>$ white fir $>$ Douglas-fir $\geq$ blue spruce $>$ white pine $>$ ponderosa pine $\geq$ aspen. The criteria used were ability of seedlings (or suckers) to continue healthy, if slow, growth in shade; and ability of shade-suppressed seedlings to accelerate growth when light was increased.

Light Tolerance

Light damage to seedlings growing in the open was discussed under the section on light. Limited data on very small outplanted seedlings indicated corkbark fir was extremely susceptible to light damage when unshaded, even though watered. Douglas-fir was highly susceptible. Engelmann spruce and white fir seemed quite susceptible, but apparently less than Douglas-fir. None of those four species seem suited to prompt regeneration of large bare areas from seed unless shade is provided.

Ponderosa pine and white pine are relatively resistant to damage by full sunlight, but benefit from shade in severe situations.

Blue spruce shows a tendency to invade the edges of openings, suggesting good light tolerance, but study results are ambiguous.

SUCCESSIONS AND CLIMAXES

In the absence of severe redisturbance on deforested mixed conifer land, several biotic communities are likely to succeed one another, each modifying the microenvironment in ways that favor its replacement by another community. Prolonged absence of disturbance will result in a climax community that tends to persist on the site until severe disturbance such as fire changes it.

Because the composition of the climax community is a function of various interacting habitat factors, the potential climax community for a site can be used to characterize the habitat (Cajander 1926, Daubenmire and Daubenmire 1968). The sequence of successional communities that follows a major disturbance is partly a function of habitat; partly of the nature, severity, and size of the disturbance; and partly of subsequent events such as the kind, amount, and timing of seedfall.

In forests managed for timber production, frequent light harvests that remove scattered individuals favor development and maintenance of a near-climax community. To maintain the forest in an early successional stage may be difficult, and ordinarily requires the removal of trees in substantial groups to make large gaps in the canopy. To maintain a ponderosa pine forest on a mixed conifer site, for example, may require clearcutting (including understory removal) and planting.

Figure 11 is a diagram of natural forest successions on mixed conifer and spruce-fir sites after complete forest removal. It is partly speculative, and some successions may conceivably have been overlooked. The communities are designated by the predominant plants or life forms.

If a grass-pocket gopher-vole community or oak scrub becomes dominant on a mixed conifer or spruce-fir site, conifers may be largely excluded for decades — in some cases more than a century — unless the site is reforested artificially.

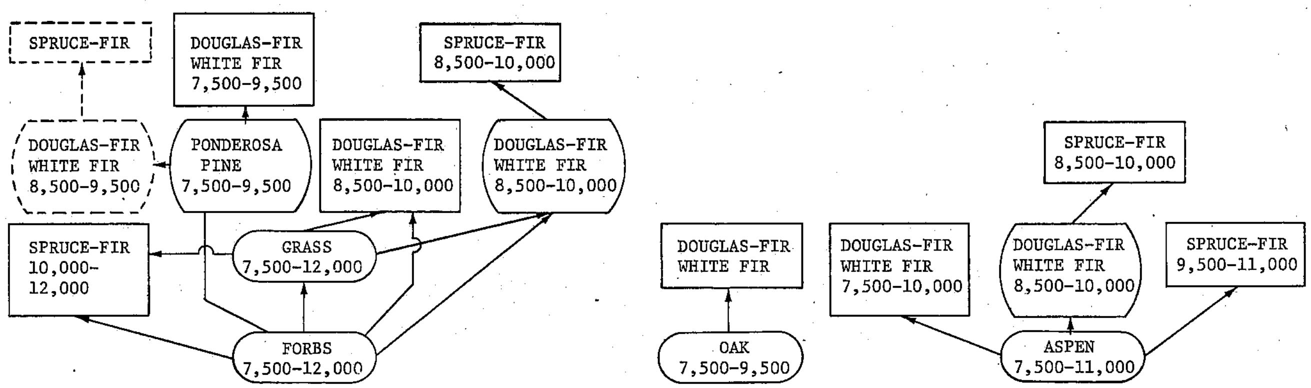

Figure 11.—Mixed conifer and spruce-fir forest successions in the Southwest. Broken lines indicate speculative successions. Numbers are approximate elevations. Community types are labeled according to characteristic dominants.

Successional trends in many spruce-fir stands in the Northern Rocky Mountains indicate strong climax dominance by subalpine fir (Daubenmire and Daubenmire 1968). There is little evidence that this is true of corkbark fir in the Southwest, however. Spruce beetle outbreaks may result in dominance by corkbark fir for a time, but observation indicates that Engelmann spruce regains an important overstory role.

If an aspen stand becomes established following burning or clearcutting of mixed conifers, a coniferous understory is likely to become established within a few decades — sometimes within a single decade — where suitable seed is at hand. Aspen dominance is likely to last for 100 to 200 yr however — until the understory grows through it or the aspen dies.

If adequate coniferous seed is not available for invasion, aspen will maintain dominance, for a time at least, by replacing itself through suckering, even without burning or clearcutting.

In Colorado, Utah, and Wyoming, many aspen stands show no sign of significant coniferous invasion even with a seed source nearby. DeByle has questioned whether aspen can maintain itself on such sites indefinitely without fire or clearcutting, or whether it would eventually be displaced by grass and shrubs.[15] His point is well taken. The somewhat uneven-aged sapling stands that become established during overstory deterioration are certainly much more open and less vigorous than the even-aged stands which follow fire or clearcutting, and may prove unable to replace themselves later.

ECOSYSTEM CLASSIFICATION

Ecosystem classification was recently examined in detail in a Forest Service task force analysis.[16]

It commonly is difficult to generalize the results of experience, observation, and research in mixed conifer silviculture and ecology. A management practice proven successful in a few cases is likely to fail in others. In some cases it may succeed but amount to management overkill — it may be considerably more expensive than necessary for the given set of circumstances. Even the objective of a practice will likely be unrealistic or otherwise inappropriate to some circumstances in which it is applied. These things happen because ecosystems are complex physical-biological systems that differ from place to place and time to time. Inputs differ in different ecosystems, they are processed somewhat differently, and they have different outputs.

The purpose of ecosystem classification in forestry is to define which ecosystems respond similarly to given treatments or other events. The differences and similarities that seem important to how ecosystems behave and respond, or that reflect how they behave and respond, are the basis for ecosystem classification.

Characteristics that differ from one ecosystem to another can be fitted into several categories:

1. The essentially permanent habitat features such as climate, terrain and soil, whose biologically effective interactions are reflected to a considerable degree in the composition of the climax vegetation. For silvicultural purposes, classification of those features is commonly into **habitat** types based on climax vegetation.
2. The existing community of plants and animals, the biological assemblage on the site at a point in time. It may or may not resemble the climax community. It has a composition, a structure, and a condition. It modifies the physical environment provided by the permanent habitat features, and it responds to treatments and other events. The environment on a site is much different if that site is occupied by a dense stand of aspen saplings than if it bore an open meadow. It will be different still when the aspens reach maturity, especially if an understory of conifers has developed. A well-stocked stand of Douglas-fir poles on the site results in another quite different environment. That environment will have changed substantially by the time the stand has aged and the one-time poles have become an open overstory of scattered old veterans, many of them decadent or infected with dwarf mistletoe. Effects and responses of the existing community can be dealt with within the framework of a **stand classification.** In practical stand classification it is probably best to exclude consideration of erratic transient community elements such as outbreak populations of insects.
3. Temporary nonnormal conditions, notably unusual drought, nonnormal seed availability, or exceptional biological pressures such as insect epidemics. It is doubtful that these

[15] *Personal communication from Norbert DeByle, Intermountain Forest and Range Experiment Station, USDA Forest Service, Ogden.*

[16] *ECOCLASS, a method for classifying ecosystems, a task force analysis. Draft submitted to the Chief, USDA Forest Service, on Jan. 18, 1973.*

can be dealt with in ecosystem classification, although they are important considerations in forest management.

Those three categories are fairly inclusive insofar as natural terrestrial ecosystems and their processes are concerned. But some ecosystems are aquatic. And a treatment applied only to a terrestrial ecosystem may nonetheless have important effects on streamflow, sediment load, the kinds and concentrations of solutes in the stream, and so forth, with consequences to fisheries, water supply for wildlife and livestock, and downstream uses.

Also, forests experience nonnatural processes induced by man. A habitat type may sometimes occur on different geological-topographical situations in which the total biological behavior is closely similar, but which may respond differently to traffic, water flow, and other factors. They may require different standards of road construction and maintenance, different logging equipment, different seasons of logging, and may impose different constraints on silvicultural methods.

Thus two more categories of ecosystem characteristics need to be added to the three already discussed. They are:

4. Characteristics of land considered purely as a physical system, not as a physical-biological response system. Those characteristics can be dealt with by what has been called a **land system classification.**
5. The components of an **aquatic system.** A stream or lake integrates responses to elements of all the preceding categories; it responds to all the terrestrial ecosystems of its drainage.

A complete ecosystem classification for forest management would consist of separate classifications defining habitat types, stand types, land systems, and aquatic systems. Four separate classifications do not amount to duplication. Each looks at a different aspect of the total ecosystem, to fill the total management need. Together they can provide a fairly precise framework for relating effects to their causes, or at least to the conditions in which they can be expected. They would enable us to learn much more effectively from our research efforts, our observations, and our management experiences. Predictions and treatment prescriptions would become more reliable and more efficient. Planning would be more effective.

The four constituent classifications can be made independently, although some of the same factors must be considered in all of them. Any one of them can be used alone if the others aren't ready for use. All would be subject to refinement based on use and further research. Development of a fully satisfactory stand classification may well require a habitat type classification as a prerequisite, however, and a fully satisfactory classification of aquatic systems may require that classifications of habitat types, stand, and land systems be available.

The Forest Service established a task force to develop an ecosystem classification for the northwest — Washington, Oregon, Idaho, Montana, and Wyoming. That classification is to serve as a prototype for development of classifications elsewhere in the country. The task force analysis looked primarily at habitat type classification, land system classification, and aquatic system classification. Development and evaluation of habitat type classifications for different parts of that region is well advanced (Daubenmire 1952, 1961; Daubenmire and Daubenmire 1968; Driscoll 1964; Franklin and Dyrness 1973; Pfister et al. 1972; Reed 1969), and seems to have established the practicality of the habitat type approach.

No habitat type classification is yet available for the Southwest. The Southwestern Regional Office of the Forest Service has, however, contracted for a reconnaissance classification of mixed conifer habitats on four southwestern National Forests as a first step. The present "land sensitivity" classification for land use planning in Southwestern National Forests is a partial first-approximation land system classification.

The Soils Branch of the Regional Office has classified and mapped the soils on a considerable portion of the Southwestern National Forests. That work will be useful in developing and refining habitat types, and especially useful in classifying the land system.

A partial first-approximation stand classification for southwestern mixed conifer forests is presented in the next section as a framework for discussing silvicultural treatments.

STAND STRUCTURES

Alexander (1973) classified the stand structures of old-growth spruce-fir forests as single-storied, two-storied, three-storied, and multi-storied. His classification is readily adapted to mixed conifer forests (fig. 12). In the descriptions that follow, advance regeneration less than 4.5 ft tall is not considered to constitute a story.

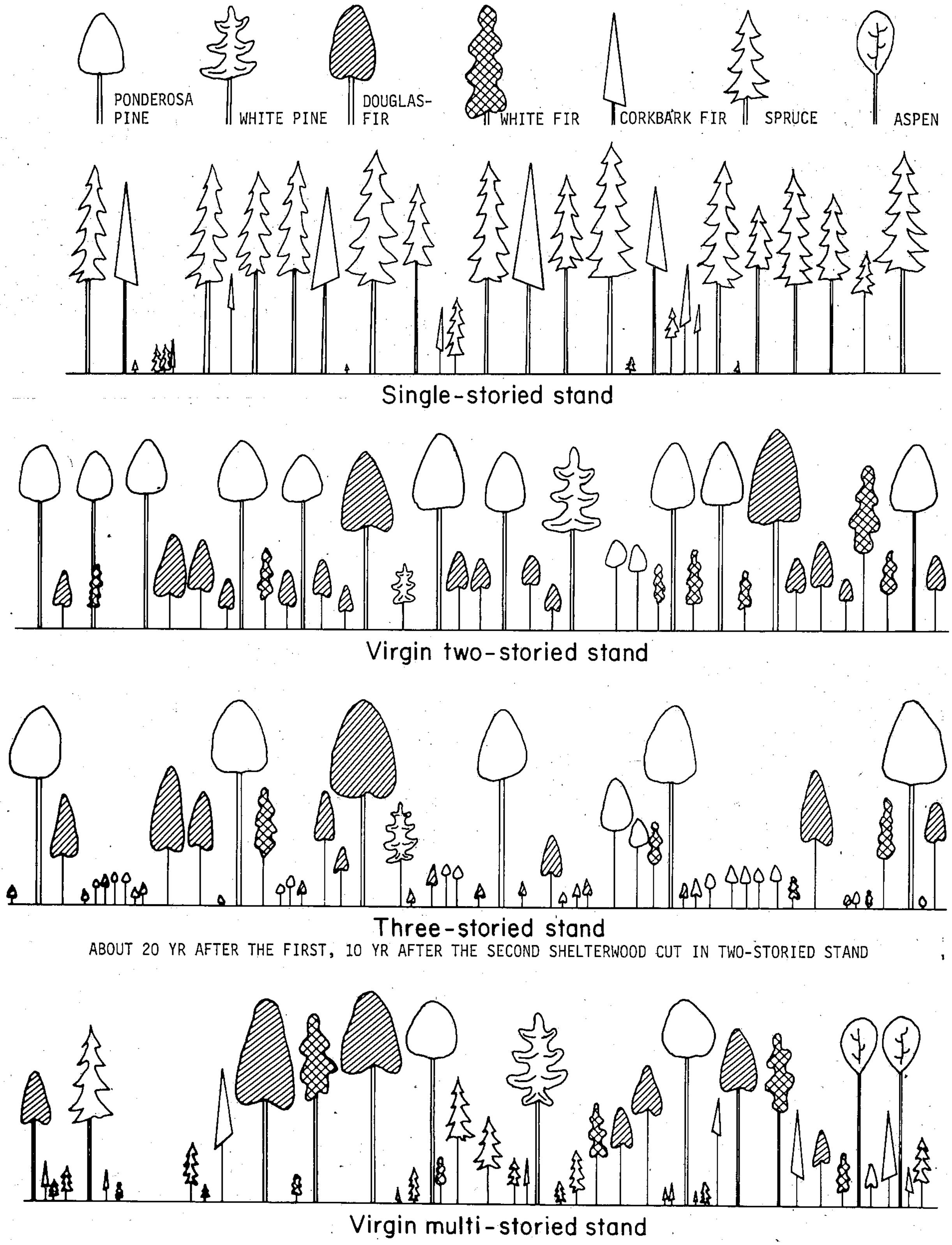

Figure 12.—Transect profiles of stand structures. The species shown represent frequent compositions.

Single-Storied Stands

A single-storied structure is uncommon in mixed conifer forests. It is more frequent in spruce-fir and aspen forests. Single-storied stands have the following characteristics:

1. The stands may appear even-aged but often contain more than one age class. Single-storied aspen stands usually are even-aged.
2. Numerous trees may be 5 to 10 ft taller than the general canopy level, with occasional trees 15 or 20 ft taller. Some trees may be entirely below the canopy, but are too few and too unhealthy to constitute a second story; they are likely to be as old as many canopy trees.
3. A manageable stand of advance regeneration is usually absent.[17] Vigorous advance regeneration is likely to be found mainly beneath scattered canopy gaps where old trees have fallen or died.
4. The canopy is usually rather uniformly stocked.

Two-Storied Stands

Two-storied stands may contain more than two age classes. The overstory is likely to be predominantly ponderosa pine or aspen, with an understory mostly of other species (fig. 13). Aspen stands in the Southwest are often two-storied, with the overstory almost entirely of aspen and the understory of mixed conifers or spruce-fir (usually with few or no ponderosa pine) (fig. 14). The overstory is likely to be rather uniformly stocked.

Three-Storied Stands

Some three-storied mixed conifer stands have resulted from harvesting in two-storied stands. The overstory has been partly removed, and logging has created numerous openings in the second story which have restocked.

Other three-storied stands result from overstory deterioration in two-storied stands. In the latter case the upper story is likely to be rather decadent, and the second story of poles and small sawtimber mostly of shade-tolerant species.

There may be substantial patches with moderate to heavy dwarf mistletoe infection.

[17]*Because even careful harvesting will destroy some advance regeneration, a manageable stand of advance regeneration should consist of at least 600 well-distributed seedlings and saplings per acre with good form and in good condition.*

Figure 13.—A two-storied stand. Overstory is almost entirely ponderosa pine; understory is mostly Douglas-fir, with some white fir, white pine, and ponderosa pine. Apache National Forest.

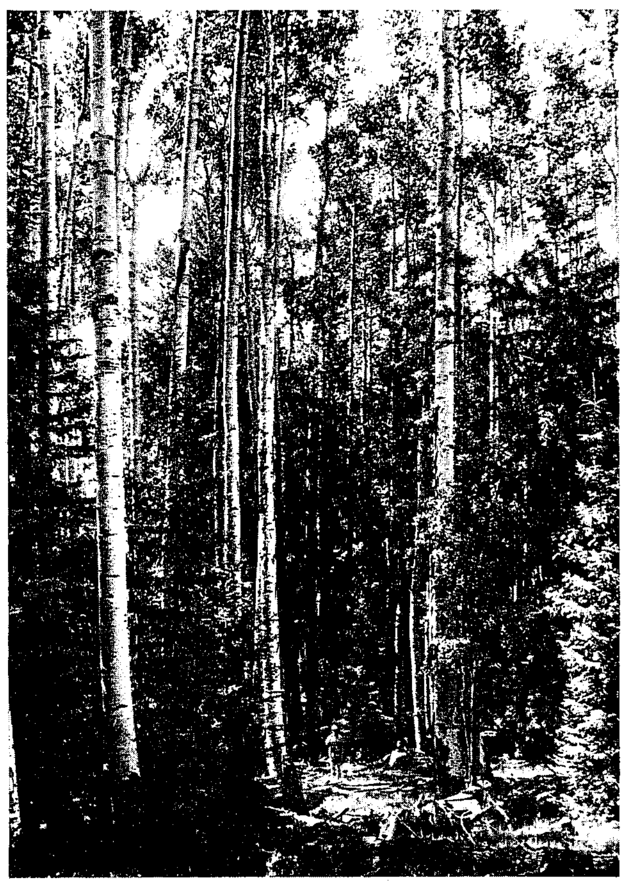

Figure 14.—A two-storied stand. Overstory is 150-yr-old aspen; understory is mostly Douglas-fir and Engelmann spruce. Apache National Forest.

Multi-Storied Stands

Multi-storied stands are common. Their oldest trees are likely to be remnants of what was once, centuries ago, an understory beneath an aspen canopy, or of a single-storied stand that seeded in after a severe fire. The irregular structure of a multi-storied stand is likely to have resulted from the irregular decimation of the older age classes, over time, by lightning, wind, insects, diseases, and more recently by selective cutting. The resulting openings regenerated more or less as they occurred.

Such stands (fig. 15) are likely to consist of a mosaic of groups and patches quite variable in area. Some of the patches may be single-storied, some two- or three-storied, and others multi-storied, but the overall effect is of a multi-storied stand.

Figure 15.—Virgin multi-storied stand. Apache National Forest.

Some other structural characteristics are:

1. Trees are generally of many sizes and ages.
2. In virgin stands the oldest age class is likely to be of very old trees, many occurring in groups. While many may be sound, many others may be seriously decayed or spike-topped, and dwarf mistletoe may be abundant.
3. In stands that have been selectively cut, the oldest age class is likely to be mostly of sound trees without a strong tendency to occur in groups.
4. Ponderosa pine may be numerous among the oldest trees, but is usually much less frequent, or may even be absent, among younger classes.
5. Douglas-fir commonly predominates among the older trees, but among pole and sapling classes often is outnumbered by white fir. In some stands both Douglas-fir and white fir are largely replaced in the sapling class by Engelmann spruce and corkbark fir.

Understocked Stands

Even after a number of years, occasional heavily cut stands have not restocked to the point that "stories" are evident. Occasional virgin stands consist only of individuals and groups in a matrix of grass. Several age classes are likely to be present in these virgin stands, but with no evidence of a strong approach toward full stocking. In the cutover stands much of the stocking is likely to be of mature trees, with regeneration deficient.

SILVICULTURE

Silviculture is an effort to manage forests by influencing ecological processes. The objectives are production of wood, water, forage, and recreational opportunities, and the maintenance of wilderness — singly or in various combinations. At different times and places one or more of these objectives will have limited compatibility with others.

The following discussion is of silvicultural methods primarily for growing timber. While many of the same principles and methods apply to the production of other values, they will sometimes differ to some degree from those discussed here.

Silvicultural methods will be discussed under two headings: reproduction methods and intermediate treatments.

Reproduction Methods

Harvesting is the major reproduction tool. It not only converts trees to useful wood products, it also modifies the environment on the site — may change it strongly if enough trees are removed. The purpose is to provide an environment suited to the establishment and growth of new trees.

In most humid temperate climates, nature will replace a forest without help, but she may take a long time and the result may not be satisfactory from a social or economic point of view. Planting and artificial seeding can often speed reforestation and give better control of the composition and structure of the new stand.

Methods and frequencies of stand treatment should be fitted to the needs of site, stand, and objectives. Discussion of reproduction cutting will be organized largely according to stand structure and composition. Artificial reproduction will be discussed in a separate subsection.

Methods of regenerating spruce-fir forests, as defined on page 1, will not be specifically discussed here, although much that is included here is pertinent to spruce-fir stands. For specific discussions of the silviculture of spruce-fir forests, see Alexander (1973, 1974), and Roe et al. (1970).

SINGLE-STORIED STANDS

Aspen

Much of what is written here is adapted from extensive research and timber management in the Lake States and Canada, modified by observation and research in the West. Convenient major collections of aspen information from northern forests are the proceedings of a recent symposium (USDA Forest Service 1972), and the monograph by Graham et al. (1963). Baker's small monograph (1925) on western aspen is dated but still very useful.

Timber consumption trends suggest that the lumber and fiber potential of western aspen forests will be important in the future. Right now, however, not all locales have a market for aspen logs. The presence or absence of markets strongly conditions what can be done.

Where a market exists for small products such as pulpwood, it may be feasible to harvest almost all the trees. The remainder should be felled during logging or immediately afterward to stimulate abundant vigorous aspen sprouting. Ordinarily that should be all that is necessary for satisfactory regeneration.

If the acreage of aspen cut is small, aspen regeneration may be eliminated by browsing unless protected for the first 2 to 4 years. Cutting fairly large acreages as a single large unit or as several nearby units should reduce browsing pressure.

If a market exists only for saw logs, clearcutting may not be feasible. Residual aspens are very susceptible to windthrow where a mature stand has been opened excessively, and disease may also become severe (Anderson and Anderson 1968). If clearcutting is not feasible, up to 30 percent of the basal area can be marked for removal on an individual tree basis. Group selection may result in sunscald on the north side of the openings (Hubbard 1972). Cutting 20 or 30 percent will not constitute effective regeneration cutting, but the rest of the stand is likely to remain intact for a time and may make good growth (Martin 1965).

An alternative is to cut all merchantable trees, let the unlopped slash cure in place, and broadcast burn during the dormant season. The fire should kill many of the residual trees and stimulate suckering. Burning in autumn, when the cured herbaceous cover is still upright, may work best in the Southwest, where fall is often dry. Concentrating slash around residual trees before burning may give a better kill.

Conifer seedlings grow much more slowly than aspen suckers. There are sites occupied by aspen, however, where conifers will produce more wood per acre per year over the course of time than will aspen. Conversion to conifers may therefore be desirable. Because we are talking about single-storied stands — those without a coniferous understory — planting or seeding shade-tolerant conifers is necessary for conversion.

Shade-tolerant conifers can be planted either before or after the stand is logged. Observation in the Lake States suggests that a heavy stand of suckers constitutes more difficult competition to conifer seedlings than does a mature or overmature aspen stand. Therefore, if planting is to follow cutting, about 60 ft^2 of basal area in aspen canopy trees could be left to suppress suckering (Waldron 1966).

If planting follows partial cutting, the conifers will develop better if the residual aspens are cut or killed when the plantation is about 8 to 10 ft tall (Lees 1966, Steneker 1967). Plantation-release logging of aspen on thousands of acres in Wisconsin has demonstrated repeatedly that, with explicit protective clauses in timber sale contracts, and effective sale administration, plantations can be released by commercial logging without excessive damage to the planted trees. Release by spraying the aspen with chemical herbicides in late summer is economical and effective, but may be controversial.

If the aspen is to be clearcut or nearly clearcut before planting, provision should be made to release the conifers from the resulting suckers two or more times.

Artificial seeding has proved very unreliable for establishing conifers beneath an aspen stand. First-year seedlings in particular suffer heavy losses to burial by aspen leaves and herbaceous growth. Natural establishment of conifers beneath aspen ordinarily results from repeated seedfall over a period of years. If seeding is to be tried, mineral soil seedspots should be made close to the north sides of aspen trunks (Waldron 1961), and plans should be made to repeat the seeding in following years.

Where no aspen market exists, options are limited. If serious deterioration has not begun, the stand can be held untouched for a future market. Ordinarily this maintains the esthetics of aspen but foregoes some other possible benefits.

Decadent stands can be replaced with new sucker stands by a hot burn. In the process, forage for deer, elk, and livestock is greatly increased for several years (Patton and Avant 1970). Water yields should also increase for several years (Johnston et al. 1969). The resulting fire-killed snags might be esthetically undesirable for some areas.

Ordinarily, aspen stands are not very flammable. Burning them requires readiness to act promptly on the occasions when they will, in fact, burn effectively.

Felling the aspen instead of burning provides comparable benefits without creating a stand of snags, but at considerably greater cost. The branchy tops can be lopped after felling to allow game and livestock freer movement, or left unlopped to protect the suckers.

After a few years, water and forage yields on burned or logged aspen areas decrease to pretreatment levels as the sucker stand grows (Johnston et al. 1969, Patton and Avant 1970). Increased water yields can be retained, however, if the aspen type is converted to grassland. An area could likely be converted by burning or by clear-felling and lopping, followed by 3 yr of heavy summerlong use by sheep. The area then could be seeded with grass if necessary.

Conifers

Alexander (1973) discussed and made recommendations for partial cutting in single-storied spruce-fir stands. His ideas (indented below) form the basis of our discussion here. Windfall risks are defined on page 5.

> Single-storied stands are usually the least windfirm because the trees have developed together over a long period of time and mutually protect each other from the wind.
>
> 1. **If the windfall risk is below average, and the trees are uniformly spaced,** the first cut should be light, removing about 30 percent of the basal area of the stand on an individual tree basis. Since all overstory trees are about equally susceptible to windthrow, the general level of the canopy should be maintained by removing some trees from each overstory crown class. Avoid creating openings in the canopy with a diameter larger than one tree height by distributing the cut over the entire area.

The subsequent cut should probably follow after 5 to 10 yr and remove a volume similar to the first cut. A third cut should not be made until the regeneration stand is well established. The third cut might remove all the remaining overstory trees, or part of them might be held for a fourth cut to provide an additional period of protection for the regeneration and to fill gaps in the regeneration caused by the third cut.

> 2. **If the windfall risk is below average and the trees are clumpy,** the first cut should be a modified group selection that removes about 30 percent of the basal area. Harvesting timber in groups will take advantage of the natural arrangement of trees in clumps. Group openings should be kept small — not more than one or at the most two tree heights in diameter — and not more than one-third of the area should be cutover.

Subsequent cuts probably should consist of enlarging the openings after they have regenerated by cutting adjacent clumps. If the clumps amount to patches larger than about 1.5 tree heights in diameter, ignore the clumpiness and mark individual trees as in item 1 above.

> 3. **If the windfall risk is above average,** the first cut should remove about 10 percent of the basal area on an individual tree basis, regardless of the spacing between trees. The objective is to open up the stand just enough to allow the remaining trees to begin to develop windfirmness. This type of cutting resembles a sanitation cut in that the poorest risk trees (and super-dominants) should be removed, but it is important that the general level of the overstory canopy be maintained intact. If the stand is clumpy, try to leave the clumps intact. Provision should be made to salvage windfalls.

Two additional light cuts at 5- to 10-yr intervals should condition the stand for treatments like those described in items 1 and 2 above.

> 4. **If the windfall hazard is very high,** or the stand is breaking up, the choice is usually limited to removing all the trees or leaving the area uncut.

If the stand is clearcut, planting will generally be necessary to regenerate it within an acceptable time, unless an aspen sucker stand develops.

In the Southwest, **dwarf mistletoe must also be considered.** Single-storied stands are likely to be strongly dominated by a single species. If that single species is heavily infected, controlling dwarf mistletoe by harvesting all infected trees in one operation may be too drastic.

Cutting should remove as many recognizably infected trees as possible while still considering windfirmness. If infected trees remain for the final removal cut because the stand had been heavily infected, the final removal should be made no later than 20 yr after the first substantial wave of seedling establishment. The regeneration stand should be sanitized promptly after final removal of infected trees. The regeneration should be reexamined a few years later because a second sanitation is likely to be necessary. A third may be needed after a few years.

Seed production of a heavily infected species may sometimes be so poor that artificial regeneration will be needed if that species is to be retained as an important stand constituent. The ground should be examined for evidence of recent substantial cone crops.

TWO-STORIED STANDS

Ponderosa Pine Overstories

A mixed conifer understory beneath a predominantly ponderosa pine overstory may be rather well stocked and healthy. In that case the reproduction method amounts essentially to the removal cuts of the shelterwood system. Special care (described later) should be used to minimize damage to the understory.

Where the understory is well stocked and primarily of healthy saplings and well-established seedlings, the overstory may be removed in a single carefully planned and controlled cutting. From three to five removal cuts at intervals of 5 to 10 yr can reduce logging damage, however. In that case the first cut should remove no more than 30 percent of the overstory basal area as selected individual trees, to avoid blowdown. If the windfall hazard is greater than average, the initial cut should remove either all the overstory or else not more than 10 to 20 percent of it. The number of log landings for overstory removals is likely to exceed that necessary for intermediate treatments in the new stand. Landings, or parts of landings, to be retained as work openings or wildlife openings should be planted promptly after logging with forage species. Others normally should be planted or seeded to trees. Unless heavy browsing is anticipated, ponderosa pine is an appropriate planting species.

If the understory contains many pole-sized trees or is poorly stocked, the overstory should ordinarily be removed in several installments. Understory trees 4 inches or larger in diameter seem especially susceptible to blowdown if the protection of overstory trees is removed abruptly.

Where the windfall hazard is average, the first cut should remove about 30 percent of the overstory basal area as selected individual trees. A second harvest 5 or 6 yr later would remove about 40 percent of the remainder. The rest of the overstory would be removed in one or two additional cuts over a period of 10 or 15 yr. That should permit the pole-sized trees to develop windfirmness and avoid serious blowdown of overstory pines pending final removal.

In most cases, poorly stocked places should fill in naturally before the final cut. Landings and other disturbed places should be planted promptly after the final removal, with timber or forage species, depending on whether or not the opening is to be retained.

Overstories of Other Conifers

Where the overstory in a two-storied stand consists primarily of conifers other than ponderosa pine, the understory is likely to be somewhat poorly stocked and patchy. Understory trees larger than about 4 inches diameter are likely to be especially susceptible to blowdown if the overstory is cut in one operation.

The shelterwood method is the most appropriate for reproduction where dwarf mistletoe infection is not severe. The first cut should remove about 30 percent of the overstory basal area where the windfall hazard is average. Remove 10 to 20 percent where it seems greater than average. Two to four additional cuts at intervals of 5 yr or more should remove the rest of the overstory. Cuts should be lightest and most numerous where the windfall hazard is greatest. Between the first and last removal cuts, the understory should become windfirm, and poorly stocked places should fill in. Places that are seriously understocked at completion of the final cut should be planted promptly.

Where patches of the understory are heavily infected with dwarf mistletoe, the overstory and understory should both be removed, and the patches regenerated artificially if necessary.

Aspen Overstories

Many aspen stands have mixed conifer or spruce-fir understories. If the understory is primarily of saplings, and conifers are to be favored, the overstory should ordinarily be removed carefully and completely in a single cut. This provides complete release, and vigorous aspen suckers will ordinarily fill the gaps.

Where much of the understory is of seedlings, it is preferable to leave about 60 ft^2 of overstory basal area to suppress the vigor of suckers that might otherwise outgrow and seriously inhibit development of the conifers. Later, when the understory has reached 8 to 12 ft in height, it will benefit by removal of the remaining overstory aspen. Suckers should fill in the stand gaps.

Where the coniferous understory includes numerous trees 4 inches or larger in diameter, the overstory should be removed in three installments over a 10- to 15-yr period, much as a ponderosa pine overstory would be removed, to avoid serious understory blowdown.

If aspen predominance is to be maintained for scenic or other reasons, the aspen should be clearcut in one operation. In that case, maximum destruction of the understory is desirable during logging, as described later in the section on logging. If conditions permit, consider letting the slash cure in place and broadcast burning during the dormant season to stimulate maximum suckering and eliminate culls and surviving conifers.

THREE-STORIED STANDS

In three-storied stands the overstory trees may be fairly windfirm except where they form large groups. The second story, on the other hand, is likely to be quite susceptible to windfall. A one-cut removal of the overstory is likely to result in serious blowdown in the second story. If the merchantable second story trees are removed in the same cut to avoid their loss by blowdown, or if they blow down and are salvaged, the patchy lower story will not approach adequate stocking. Extensive planting will then be necessary unless the area restocks adequately by aspen suckering.

Where dwarf mistletoe is not severe in the middle and lower stories, the overstory can be removed in two or three cuts over a 10- to 20-yr period. Light improvement, salvage, and sanitation cutting may also be appropriate in the lower stories at those times. The resulting stand will be essentially two-storied, and no further reproduction cuttings will ordinarily be appropriate until the new overstory is mature. One or more sanitation cuttings may be needed after a few years, when time and increased sunlight have brought out latent dwarf mistletoe infections.

In other cases, dwarf mistletoe is rather severe in the middle and lower stories. In some such stands the species mixture will permit the above-described treatment. Cutting should discriminate against the infected species. At least two subsequent sanitation treatments commonly will be needed. Parts of some stands may be sufficiently infected that patch clearcutting is desirable, or even clearcutting of the entire stand. Clearcutting should include removal or destruction of infected advance regeneration; it may sometimes be more efficient and effective to remove all regeneration of significantly infected species. If sufficient aspen were present before logging, suckering may restock much of the area. Provision should be made to regenerate promptly and effectively those parts of the area which do not sucker adequately, or where browsing threatens to eliminate the sucker stand.

MULTI-STORIED STANDS

Virgin multi-storied stands, though no longer numerous, will be considered first to establish some principles.

Virgin Stands

In examining a virgin multi-storied stand prior to preparing treatment recommendations, the silviculturist should first consider what would be left if all overmature or defective trees are removed. Commonly, the residual stand would be rather open and susceptible to severe windfall. In some cases the sapling and pole classes would not constitute effective growing stock because of heavy dwarf mistletoe infection. In patches or stands where dwarf mistletoe is serious and host specificity cannot be used to control it, the best choice may be to clearcut and plant.

If dwarf mistletoe is not serious, or if host specificity can be used to control it, then windfall will usually be the primary consideration in the first treatment. Ordinarily not more than 30 percent of the overstory basal area should be removed in the first cut. Where the blowdown hazard seems greater than normal, 10 to 20 percent may be more appropriate. That will usually mean some decadent and otherwise defective trees will be left, but taking them all would likely open the stand excessively. Up to 30 percent of the basal area of subordinate stories may be removed at the same time.

Although, strictly speaking, even the first cut is a reproduction cut, its purpose is to begin the conversion of an old, more or less decadent stand to a healthy, productive stand. Therefore, marking criteria are those of a salvage, sanitation and improvement cut.

The rest of the overmature trees can be removed in two or more additional cuts at 5- to 10-yr intervals.

For substantial patches strongly dominated by overmature trees, methods discussed under single-storied, two-storied, or possibly three-storied stands may be appropriate.

Subsequent prescriptions will depend on what the stand looks like after the overmature trees are gone, and on whether the objective is an even-aged or an uneven-aged stand.

Cutover Stands

In many multi-storied stands, many or all of the overmature trees have already been removed, along with some younger trees. These stands are now likely to be fairly windfirm. Where dwarf mistletoe is not too serious in trees of the pole class and smaller, there are two main management options:

The stand can be managed under the selection system, maintaining its multi-storied character. Cutting should work toward a balanced age-class distribution while discriminating against trees with defects.

The stand can be adapted to even-aged management by restricting cutting largely to older trees, opening the stand as necessary to establish and release regeneration.

Dwarf Mistletoe Infected Stands

Parts of a stand may be unmanageable because of severe dwarf mistletoe infection. Unless there are compelling reasons not to, those patches, or even the entire stand, should be clearcut. Care should be taken to destroy advance regeneration of infected species. This treatment will leave the site essentially unstocked. Provision should be made to plant promptly those parts of the area which do not sucker adequately with aspen, or where browsing threatens to eliminate the sucker stand.

UNDERSTOCKED STANDS

Virgin Stands

Where virgin stands are understocked, a very unfavorable regeneration environment is likely to be responsible. Typically these are on steep southerly slopes. If the mature and overmature trees are short, the environment is also poorly suited to growth. Fairly tall trees, on the other hand, indicate that, once established, trees grow reasonably well.

If established trees grow reasonably well, the forest manager might consider planting to obtain full stocking. Nursery seedlings may survive well on sites not suited to establishment from seed. If the prospects for successful planting seem good, a salvage cut should probably be made first. Where ponderosa pine or white pine is to be planted, the prior removal of all merchantable trees should be considered if the soil does not present a special erosion hazard. If cutting is to be light, ponderosa pine should not be planted except in larger openings.

If the site is poor for growth or unsuited to tree planting, it may be best to leave the stand untreated, especially on readily eroded sites. In stands where the larger openings produce good forage, removing most of the trees and seeding appropriate forage species may be desirable.

Cutover Stands

Stands once well-stocked sometimes remain understocked for a long time if logging is not followed by adequate regeneration. Some such areas have developed substantial grass cover, and site preparation is normally necessary to restock them without considerable additional delay. In such cases planting is more likely to be successful than seeding. Planted seedlings are not affected by germination inhibitors left by the grass, and are better able to compete with returning grass.

SOME LOGGING CONSIDERATIONS

Methods now used to log mixed conifer forests are largely the result of the narrow logging margins dictated by yesterday's low lumber prices. Those methods are sometimes not suited to the intensive forestry needed for good wood production and for the protection of associated values — the kind of forestry made feasible, if not mandatory, by today's forest values.

The economy of long logs is often desirable, but where advance regeneration is important, a 32-ft log length should not be standard. Even large tractors often must jockey around to get a long log out of a bad lay, sometimes approaching from the side to push the log with its blade or with a tread. Valuable seedlings and saplings are broken in the process, and even larger trees may be pushed out of the way. Cutting 16-ft logs would avoid much of this damage.

When the tops of trees are dropped into openings to spare regeneration patches, the logs often are at a poor angle for winching to skid trails. The resulting siwashing can severely damage remaining trees and destroy much regeneration. To avoid this, tops are sometimes felled into regeneration, with the hope that damage done in that way will be less than from siwashing. Another alternative commonly overlooked is to fell the tree into the opening despite the bad angle, and then reduce siwashing by cutting short logs.

An important source of damage to advance regeneration is careless skid trail construction. In most mixed conifer stands, blown-down trees are scattered around the area. The skidder, in making his tractor trail, bulldozes them out of his way, often destroying seedlings and saplings wholesale and damaging or pushing over larger trees. Where advance regeneration is important, it is desirable to pre-clear skid trails. Those segments of blowdowns lying in the skid trail can be cut out with chain saws and pushed into places where damage would be least.

In some situations efforts to spare advance regeneration are undesirable. In parts of stands, or even entire stands, seedlings and saplings may be too few or too unthrifty to be worth saving. Dwarf mistletoe may be so severe in the understory that it is desirable to deliberately destroy the entire understory and start over.

Where aspen stands are to be perpetuated, felling or otherwise eliminating all merchantable and nonmerchantable trees will commonly be desirable. Full-tree logging does the best job of eliminating the young conifers and poor-quality aspen saplings on the site (Zasada 1972, Zasada and Tappeiner 1969a, 1969b). Fellers can deliberately fell trees into young growth, and enroute to the main skid trails, skidders can deliberately drag trees, full length and with tops and branches attached, through young growth.

Trips to the landing should be restricted to main skid trails appropriately spaced, however, because aspen suckering is likely to be inferior on repeatedly or heavily disturbed soil. Trees are then topped and limbed at a topping site adjacent to the landing. The manager should be prepared to plant the topping and landing sites if he does not want to retain them as forest openings.

Skidding the merchantable bole in one piece, after limbing and topping at the felling site, gives somewhat the same benefits as full-tree logging, but the area is less thoroughly disturbed. In either case, the area should be as fully cleared as economically as feasible if full vigorous aspen stocking is wanted.

Sale administration. — Poor silviculture may result from a poor silvicultural prescription, poor marking, or a contract that is weak in some important respect. It may also grow out of poor timber sale administration. As reflected in a recent task force report,[18] not every sale administrator does a good job of supervising logging. Some resist new standards or methods. Some are poorly trained. A few consider the job primarily as one of getting the logs out simply and cheaply. A few too often accept the logger's statement as to what is reasonable or feasible, either through lack of confidence or because they want to be liked. Even a highly qualified and motivated sale administrator may not do a satisfactory job if his time is spread over too many sales.

SLASH TREATMENT

The amount of logging slash produced is being reduced by advancing technology and increasing product demands; much material once left on the ground as unusable is now taken out for manufacture. Also, areas once harvested are likely to contain fewer decayed logs at subsequent cuttings.

Slash has several undesirable characteristics:

1. Wildfires are more severe and difficult to fight in areas with abundant slash.
2. Slash, particularly in large amounts, is esthetically unpleasant in many situations.
3. Some kinds of slash under some circumstances can cause dangerous bark beetle buildups.
4. Where a stand is clearcut or otherwise heavily opened, slash concentrations may contribute to troublesome rodent buildups.
5. Abundant slash makes planting difficult and expensive.

Disposing of slash also has undesirable characteristics:

1. It costs money.

[18]*USDA Forest Service, Southwestern Region. 1972. Timber, the resource and its harvest; an evaluation of quality in timber management. 145 p. (Unpublished task force report on file at Regional office, Albuquerque.)*

2. Where the ground would otherwise be exposed to intense sunlight, slash provides shade favorable to seedling establishment.
3. Some kinds of slash disposal can destroy much advance regeneration, and can also damage remaining larger trees.

In some situations it is best not to treat slash at all. Other situations virtually demand treatment by a specific method. On a single mixed conifer timber sale it will often be desirable to designate areas or conditions for no slash treatment, and other areas or conditions for treatment by one or a combination of methods:

1. Slash can be broadcast burned. Most of the considerations for broadcast burning were discussed in the section on fire. Broadcast burning is cheap but requires skill and care in many situations to avoid unacceptable damage. It reduces the hazards of wildfire and rodent damage. On heavily cut areas, charred trunk sections commonly provide fairly well distributed shade afterward that would have been lost if the slash had been piled before burning. Most unconsumed slash is not suitable to bark beetles. Also, it lays low on the ground and becomes inconspicuous among invading plants. Aspen suckering usually is stimulated if the area is open. On the other hand, areas with valuable seedlings and small saplings cannot usually be broadcast burned safely.
2. Slash can be machine-piled and burned. This cleans up the area as thoroughly as wanted and eliminates beetle hazard, but is much more expensive. There are several ways to machine-pile:
   a. Slash can be bulldozed into piles or windrows. This is very destructive to advance regeneration.
   b. Slash can be pulled lengthwise, branches and all, to burning sites. This greatly reduces tractor movement and the sideways movement of the slash, and reduces destruction of advance regeneration.
   c. The branches can be lopped off and the trunk pieces pulled out, reducing still further the damage to advance regeneration. This is more expensive, may make the slash harder to burn, and leaves branches on the ground; however, smaller burning sites are needed.
3. Slash can be hand-piled and burned. Damage to advance regeneration is relatively light but labor costs are high. Large, heavy trunk pieces remain, some of which may be suitable for bark beetle broods.
4. Smaller pieces can be fed into a chipper and the chips sprayed onto the ground. Effects on the chemistry and biota of the surface soil are not clear. The method is very expensive, and leaves large trunk pieces that may be suitable for bark beetle broods.
5. The branches can simply be lopped off, lowering the slash profile and reducing the wildfire hazard. Lopping is relatively cheap, although more expensive than broadcast burning. It does relatively little damage to advance regeneration and gives least benefits. Both benefits and costs are increased if branches on the underside of trunk pieces, as well as on the upper sides, are cut off, lowering the profile more and considerably speeding decay.

ARTIFICIAL REGENERATION

The discussion here in part summarizes and in part extends three previous papers (Ronco 1972, Schubert et al. 1969, Schubert et al. 1970).

In some situations, opening the canopy is all that is necessary to start a new stand. In others considerably more is needed. That "more" is the subject of this section. It includes not only planting and seeding, but site preparation, including the preparation of seedbeds for natural seedfall.

Just where artificial regeneration is needed must at present be judged entirely by the forester's ecological "feel", based largely on observation and experience. When classifications of habitat types and stand types are available, and observations and research findings have been related to them, such judgments should be easier and more satisfactory.

Site Preparation

Site preparation for planting is primarily intended to remove competing vegetation temporarily, giving the planted tree a good chance to establish itself and begin vigorous growth. Regeneration from seed requires the same help plus a suitable seedbed. In some cases the existing ground surface may be a suitable seedbed; in others a seedbed must be created if the area is to reforest from seed in an acceptable time.

Site preparation is often expensive. The same benefits are often present without expense, however, partly as a temporary holdover from the repressive effects of past shade and partly as incidental side effects of logging or slash disposal. If planting or seeding follows promptly after logging or slash disposal, the costs of site preparation can often be avoided. Such timing requires foresight and planning. Suitable planting stock or seed must be on hand at the right time. Planting or seeding contracts must be prepared and awarded ahead of time, or a crew and equipment otherwise arranged for. Where a stand has been destroyed by wildfire, salvage logging must be prompt or the site may be lost.

If planting or seeding is delayed, or if the site is initially not suitable, then site preparation is necessary for successful regeneration. Delaying planting on a new burn, or seeding grass on it, can result in a need for site preparation on thousands of acres, at a cost of tens or even hundreds of thousands of dollars.

A supervisor may examine a site at winter's end and decide there is too little grass to require site preparation. He should keep in mind that occupation by grass always looks lighter at that season, especially if grazed the previous summer. Also, a moderate stand of grass on a dry site may compete as seriously as heavy grass on a moist site.

Complete site preparation. — Complete site preparation removes all or nearly all the competing vegetation. It is needed mainly on "lost" sites, where grass or shrubs have taken over after past fires or cutting. Complete site preparation provides the best survival and juvenile growth. If done mechanically it is very expensive, especially in the Gambel oak scrub type. Ordinarily, if the expense of complete mechanical site preparation is needed, it should be followed by planting instead of the more uncertain seeding.

Complete site preparation with herbicides can be very effective. If the chemicals and procedures used avoid environmental damage, it is also much less costly than using heavy equipment. While these are sites already lost, and haste is seldom needed, foresight and planning remain important. Preparation and approval of the necessary environmental impact statements take time. Also, vegetation ordinarily must be chemically treated the summer before planting.

Dalapon with, or followed by, atrazine can give good control of herbaceous vegetation. Dalapon will kill existing grass and some forbs. Atrazine prevents quick establishment of new competition from seed; it is suitable only for sites to be planted, not sites to be seeded.

Response to dalapon may vary somewhat between species and sites. In general, however, 5 lb active ingredient per acre should be applied the summer before planting. Much heavier dosages may give inferior kill of grass roots, although the forb kill may be higher. The plants must be green and growing at the time of treatment; when they are setting seed may be too late. The spray must be recently mixed; it deteriorates in storage.

Five lb active ingredient per acre is also about right for atrazine. It too should be applied the summer before planting.

Oak brush can be controlled by aerial spraying with a mixture of 2,4,5-TP and tordon (Marquiss 1973), but the dead stand remains a serious impediment to planting.

Complete site preparation does not, of course, rule out leaving patches of meadow or oak brush within the area to provide diversity of scenery and wildlife habitat.

Partial site preparation. — Scalping with mattocks has been a common means of site preparation. For more than a small, extremely temporary effect, the scalp should be at least 18 by 18 inches. The soil beneath smaller scalps is too quickly reoccupied by grass roots. Larger scalps are safer. Scalping with hand tools can be effective if done properly, but good hand scalping is expensive because of the labor and supervision required. To be useful, scalping must grub out the root crowns of the grass and weeds. Such labor is slow, strenuous, and unpopular. Not infrequently what is actually done is hand **scraping,** which is much faster and cheaper but essentially worthless. The dead tops of the vegetation are scraped off the ground surface, leaving what looks, superficially, like a scalp. The worker may really think he has done a good job, but a close look reveals the root crowns still in place. New tops will grow as soon as the weather is favorable. Money, labor, and usually a seedling have been wasted, and the spot remains unstocked.

A conscientious but poorly trained planter may plant in a small patch of bare ground between grass clumps, where no scalp seems needed. All too often the surface is bare but the soil beneath it is occupied by grass roots from adjacent clumps, and what seems to be planting amounts to premature burial.

In training and supervising scalpers, therefore, emphasis must be put on:

1. Making large enough scalps,
2. Leaving no root crowns,
3. Not planting in bare ground occupied by roots of adjacent grass clumps.

The scalper selects the place where the seedling will be planted. Additional training and supervision are therefore important to assure the selection of suitable microsites, especially for species such as Engelmann spruce that are initially intolerant of full sunlight.

Partial site preparation can also be done with powered hand tools and by tractor equipment. Light bulldozers have been used to scalp patches or continuous strips. A strip scalper with a subsoiler suitable for rough stony ground is being developed. The initial model was designed by George Cullum of the Sitgreaves National Forest. It puts topsoil into the subsoil rip, and helps tree roots penetrate more rapidly below the zone of intense root competition from reinvading grass. An ordinary plow furrow is not an adequate strip scalp.

Strips bulldozed in brushfields have been tried in almost every region of the country where there are brushfields to rehabilitate. California has been a notable example (Schubert and Adams 1971). In general, results have been unsatisfactory, mainly due to brush encroachment and animal damage. Deer, elk, and cattle tend to use the strips as main travel routes, and seedlings are browsed or trampled.

Water-repellent soils. — Wildfires cause major reforestation needs. Because suitable planting stock is seldom available to reforest large burns before serious vegetative competition develops, managers must often resort to seeding. Prompt aerial seeding of such areas has sometimes been very successful in the Southwest. Where fire has made the soil water-repellent, however, failure can be expected unless salvage logging or other disturbance has broken up the thin repellent layer. Parts of burns undisturbed by salvage logging should be examined, and where significant areas are water repellent, seedbed preparation should precede broadcast seeding (DeBano and Rice 1973).

Sometimes undisturbed forest floors also have a thin water-repellent layer, just below the litter layer. This layer may account for some regeneration failures. Strong water repellency can occasionally be found even in severely disturbed soil in skid trails, but apparently it is spotty. We need to know more about the extent of water repellency in the absence of fire and what to do about it.

Site preparation in partially cut stands. — So far we have considered site preparation on largely deforested land. Where advance regeneration is inadequate, seedbed preparation may also be desirable within the shelterwood and selection systems. Logging disturbance and slash disposal sometimes provide too few good seedbeds. Seeding skid trails and other disturbed ground with grass has sometimes seriously delayed regeneration.

A thick organic surface layer often inhibits seedling establishment. Prescribed burning may prove a valuable method of improving such seedbeds following the seed cut in the shelterwood system. The burn would have to reduce the thickness of litter and humus layers appreciably without significantly damaging the shelterwood itself. Such light fires will probably seldom make the soil water-repellent.

Prescribed fire seems to hold less promise for site preparation in the selection system because the areas to be treated would be very small, scattered, and interspersed with areas of sensitive seedlings and saplings. In the selection system, seedbed needs should be considered when prescribing methods of logging and slash disposal.

It should be much easier to diagnose and prescribe for seedbed needs when habitat type and stand type classifications become available.

Seeding

Research in artificially seeding Southwestern conifers has been exploratory.

Without human intercession, nature often takes many years of seeding and reseeding to regenerate an area. In artificial seeding we want to restock the area with a single sowing. This means providing conditions favorable to germination, survival, and early growth.

In Southwestern mixed conifer forests the two most important factors limiting the success of seeding seem to be rodents and frost heaving. In some situations, success is limited or prevented by soil drying or by organic decomposition products that inhibit germination and growth. On southerly slopes it is likely that heat girdling sometimes causes critical losses.

In selecting the species to be sown, rate of root penetration, especially first-year penetration, is a primary consideration. Deep-rooting species are less susceptible to frost heaving and soil drying.

Spot seeding cannot be recommended unless the spots can be protected from rodents. In the absence of rodent control, broadcast seeding may succeed, however, if enough seed is sown to feed the mice and still provide a seedling stand.

On fairly large areas, experience suggests that 100,000 to 200,000 seeds per acre are enough, particularly if substantial natural seedfall in the surrounding area prevents or reduces the movement of additional mice into the seeded area. On small areas, rodents may concentrate so heavily that 200,000 seeds per acre are not enough, even on a good seedbed. If the seed germinates promptly after sowing, rodents have less opportunity to eat it, although they can eat a lot of seed in a single night. Therefore, seeding commonly is best done when the first summer rain storm has been forecast. This has been called "seeding under a cloud."

The seed must be suited to the site. Species suitability has been touched on and will be considered further in the section on planting. Within a species, seed origin has repeatedly been proved important. Schubert and Pitcher's seed zones (1973) provide a basis for selecting seed sources. In addition, the source elevation should not differ by more than 500 ft from that of the area sown. Within a zone and elevation, habitat type too is probably of some importance (Silen 1964).

Planting

Reliable procedures for handling and planting coniferous seedlings have been demonstrated in the Intermountain Region and on the National Forests of Arizona, Colorado, and New Mexico. Because they have been covered in planting schools on most National Forests in the Southwest and are largely described by Ronco (1972) and Schubert et al. (1970), they will not be reviewed here except to comment on auger planting.

The advantages of auger planting have become increasingly appreciated in the Southwest during the last year or two. With an auger, it is much easier to make a hole deep enough for long-rooted planting stock, and correct planting is easier. Acceptance of augers has been slowed, however, by the common belief that augers cannot be used in stony soils. Actually, experience has demonstrated that few areas are too stony for auger planting (fig. 16). Augers can be used in ground too stony to dig adequate holes with a mattock. Only on the most extreme stony sites must one resort to a planting bar.

Figure 16.—A clearcutting later planted successfully using augers. Occasional patches were skipped by the auger men and planted with bars. Apache National Forest.

The primary consideration dealt with in the rest of this section is matching the species to the planting site. On mixed conifer forest land, selection of the species to plant can make an important difference in plantation survival and growth.

Because neither white fir nor corkbark fir has been tested as a plantation species in the Southwest, no large-scale planting of them can be recommended at this time. Small-scale trials are desirable to evaluate problems and potentials.

Where heavy use of an area by deer, elk, or cattle is expected, many planted ponderosa pines or Douglas-firs may be killed, and the less palatable Engelmann spruce, blue spruce, and white pine should be considered. Sheep sometimes browse them heavily too. Chemical repellents are available for treating planted trees, but their success has been erratic.

Where serious trampling or browsing by livestock would be expected, consider keeping livestock out of the plantation for several years.

On sites where planted trees will be shaded, as where numerous aspen overstory trees remain, shade-tolerant species should be used. This choice is even more important where abundant aspen suckering is expected. Engelmann spruce is definitely more shade-tolerant than Douglas-fir or blue spruce. Therefore Engelmann spruce should be seriously considered for shaded northerly slopes above about 8,500 ft and for southerly slopes above about 9,000 ft. On warmer sites, Douglas-fir or blue spruce should be favored.

In general, Douglas-fir seems suited to moderate shade both on southerly slopes between 8,000 and 10,000 ft and northerly slopes between 7,500 and 9,500 ft.

On sites exposed to full sunlight, ponderosa pine seems generally the most satisfactory species for planting below 9,500 ft on southerly slopes and below 9,000 ft on northerly slopes, unless there is a prospect of serious browsing damage. White pine seems well suited to the same sites and is not very attractive to game or cattle. Its tendencies to grow coarse branches and crooked stems, however, make it less desirable than other species for timber. White pine should be planted at a spacing no greater than 6 by 6 ft to improve form and reduce branch size. White pine seed should be from the best-formed trees available.

There is no native species whose suitability has been adequately demonstrated for planting in fully exposed situations above 9,500 ft in the Southwest. Where exposed high-elevation sites require planting, Engelmann spruce can be successfully established, however, if seedlings are carefully planted in the shade of logs, stumps, and so forth (Ronco 1972). Trees planted a foot away from a log on its north side are too far from the log to get any shade in spring and summer. They must be planted as close to the log as possible. This also reduces trampling damage. Where dead shade is not available, an upright shingle or similar object may be firmly planted in or very close to the planting hole on the south side of the seedling (Ronco 1967). If planted firmly, the shingles are not likely to be pushed over onto the seedlings by snow, except perhaps on those steep slopes where shade would have to be provided from the uphill side of the seedlings.

Aspen and lodgepole pine are possible future alternatives to Engelmann spruce for planting on open high-elevation sites. The nursery production of aspen planting stock from seed has been described (Benson and Einspahr 1962, Einspahr 1959), as have techniques for growing aspen directly or indirectly from root cuttings (Benson and Schwalbach 1970, Farmer 1963, Starr 1971, Zufa 1971). Genetic differences between aspen clones may provide real opportunities for the selection of genotypes with superior autumn coloration, growth, or disease resistance characteristics (Egeberg 1963, Graham et al. 1963, Rudolf and Patton 1966, Wall 1971).

Lodgepole pine seedlings survive much better in full sunlight than do Engelmann spruce (Ronco 1967). Lodgepole pine is not native to the Southwest, but was introduced in 1911 on the Columbine Ranger District of the San Juan National Forest, where its development has been quite satisfactory for 60 years. The species has subsequently been planted extensively on the San Juan National Forest. Survival has been generally good, even at elevations that seem high for lodgepole pine, but juvenile growth is said to have been disappointing in some cases. It has not been tested farther south in the region, but probably would prove suitable at conservative elevations — between about 8,500 and 10,500 ft.

Both aspen and lodgepole pine modify the harsh radiation environments of exposed high-elevation sites, making them much more suitable for invasion by the native climax occupants, Engelmann spruce and corkbark fir.

Intermediate Treatments

Intermediate treatments, such as thinning, are not intended to replace an old stand with a new one, or old trees in a selection forest with seedlings, although they may result incidentally in reproduction. Rather, they are made to maintain or improve the growth and condition of existing stands.

No research has been done on intermediate treatments for Southwestern mixed conifer forests. The following discussions and tentative recommendations are based on ecological behavior and general observations, and on research done in other regions.

THINNING

Thinnings are made to give the remaining trees more resources for growth.

Conifers

In mixed conifer forests, overstocking does not often seem to interfere with normal height growth. Only occasionally are young stands or patches seen in which poor height growth appears to result from extreme overstocking (Jones 1971).

On the other hand, diameter growth in many sapling and pole thickets could be improved by thinning. No work has been done toward recommending optimum stocking levels. A relatively inexpensive thinning practice — "crop tree" thinning — does not require stocking level recommendations, however. A form of crown thinning, it favors only trees with good potential as high-quality crop trees. The criteria for selecting trees to favor include more than current quality: trees selected should also seem likely to remain free of dwarf mistletoe, and they should have one or more crown competitors whose removal would help their development substantially. It is best to mark the competitors to be removed. An alternative is to mark the trees to be favored; the cutters are then given a rule of thumb for deciding what competitors to cut. One such rule used in other regions has been to remove all crown competitors growing within a distance, in feet, equal to the crop tree d.b.h. in inches, plus 4. Thus a 6-inch-diameter crop tree would be left with no crown competitors growing within 10 ft.

Aspen

In aspen thinning experiments in the Lake States and Canada, diameter growth was accelerated on most trees, although the larger trees on unthinned plots grew about as well as those on thinned plots. The primary benefits were shortened rotations or an increase in the average size of material produced in a given rotation (Anderson and Anderson 1968, Sorensen 1968, Steneker and Jarvis 1966, Zehngraff 1947). An economic evaluation by Noreen[19] suggests, however, that even with multiproduct markets, precommercial thinning is uneconomical for aspen timber production. Thinnings delayed until profitable material can be removed may not shorten the rotation or provide larger material (Hubbard 1972, Schlaegel and Ringold 1971), although the operation may salvage material that would otherwise die and be lost (Hubbard 1972, Schlaegel 1972).

Hypoxylon canker has been reported as more severe on thinned plots than on unthinned, despite discrimination against infected trees during thinning. It was also speculated that the larger branch stubs in thinned stands might eventually result in more trunk rot (Anderson and Anderson 1968).

On the San Juan National Forest it has been observed that cattle make little use of the abundant herbaceous forage in dense aspen sapling stands. Apparently they find it difficult to move around in them. It may sometimes be worthwhile to thin aspen sapling stands for the combined benefits of better cattle grazing and shorter rotations. Several studies (Sorensen 1968, Steneker and Jarvis 1966, Zehngraff 1947) suggest that sapling spacings of approximately 8 by 8 or 10 by 10 ft are appropriate.

SALVAGE CUTTINGS

Salvage cuttings are solely or primarily for salvaging dead, diseased, insect-damaged, or blown-down trees. Salvage is also accomplished during thinnings and improvement and reproduction cuttings, if merchantable trees are removed which would be lost before the stand is next treated.

[19]*Noreen, P. A. 1968. Economic evaluation of precommercial thinning in good-site aspen. M. S. report, Coll. For., Univ. Minn. 19 p. (Cited by Hughes and Brodie 1972).*

When a stand is being examined for possible salvage cutting, the forester should ask if the value of salvageable material is worth the costs of logging, protection of regeneration, and possible slash treatment connected with the operation.

In preparing a salvage cut, considerations discussed under reproduction methods often apply. Marking a stand heavily for full salvage may well open it to the extent that severe windfall will result.

SANITATION

Sanitation is the treatment of diseased or insect-infested trees that menace the health of nearby trees. It is often part of reproduction or salvage cutting, but it may also be a separate operation. Individual infected trees may be removed to avoid the spread of dwarf mistletoe, for example, or a stand may be clearcut where a serious insect epidemic threatens to spread to other stands. Since such clearcutting is likely to necessitate an expensive reforestation job, and may have important esthetic and recreational impacts, it should not be decided upon lightly.

CLEANING AND IMPROVEMENT CUTTINGS

Cleaning is the removal of saplings of inferior form or less desirable species that are competing with better saplings. Thinnings in sapling stands often constitute cleanings as well.

Cleanings can also have a sanitation aspect. For example, cleaning should remove saplings with visible dwarf mistletoe infection. Cleanings may also remove saplings that have been exposed to dwarf mistletoe infection, even though they show no signs of infection, if they compete with good saplings of uninfected species.

Improvement cuttings have the same general purpose as cleanings, but are made in stands or stories beyond the sapling stage and often remove merchantable material. As in cleaning, trees of inferior form or condition or of species less desirable in the stand are removed if they compete with better trees.

In managed stands on the rotations of the future, and in a world of increasing consumer pressures, there are unlikely to be any low-value species. But on a given site one or more species may have inferior growth potential or be less desirable for other reasons.

WHAT WE NEED TO KNOW

Ecosystem classification deserves the highest research priority, as much research observation, and experience, becomes considerably more meaningful and useful when related to habitat and stand types.

Growth prediction tools are also needed. These include tables or equations for predicting yields of mixed and uneven-aged stands as well as for pure even-aged stands. It is likely that most mixed conifer land in the region will continue to be occupied by mixed stands regenerated under a forest canopy. Classification of habitat and stand types should provide a useful foundation for development of yield predictors.

Most research on the silvics and silviculture of Southwestern mixed conifers has been oriented toward regenerating clearcuttings and other deforested land. While we do not yet know all we need to about that important subject, today we need to give much more attention to the potentials and problems of the shelterwood and selection systems.

In addition, serious work is needed on economic and ecological models as aids in multiple use planning and decisionmaking. As spinoffs, modeling also helps define key research needs that might otherwise go too long unrecognized, and points up relationships that may otherwise be overlooked.

Aspen occupies more than 6 million acres in the interior West. We need to know much more about its ecology and management.

Those are general areas. The following is a partial list of more specific problems. We need to know more about:

1. Recognizing good growing stock in understories.
2. Response of understories to different degrees of release.
3. Spread and intensification of dwarf mistletoe in different habitat and stand types.
4. Evaluation of forest floors as seedbeds in shelterwood and selection forests.
5. Potentials and considerations in prescribed burning.
6. Water repellency in burned-over and unburned soils.
7. Factors affecting survival and growth of seedlings in shelterwood and selection forests.
8. Prescriptions for intermediate treatments.
9. Development of nursery and planting practices for aspen.
10. Tests of exotic conifers for reforesting exposed high-elevation sites.

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COMMON AND SCIENTIFIC NAMES OF PLANTS, VERTEBRATES, INSECTS, AND DISEASES MENTIONED

Nonparasitic Plants

Aspen (quaking)	*Populus tremuloides* Michx.
Bracken	*Pteridium aquilinum* (L.) Kuhn
Douglas-fir (Rocky Mountain)	*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco
Fescue, Arizona	*Festuca arizonica* Vasey
Fir, corkbark	*Abies lasiocarpa* var. *arizonica* (Merriam) Lemm.
Fir, subalpine	*A. lasiocarpa* var. *lasiocarpa* (Hook.) Nutt.
Fir, true	*A.* spp.
Fir, white	*A. concolor* (Gord. & Glend.) Lindl.
Juniper	*Juniperus* spp.
Oak, Gambel	*Quercus gambellii* Nutt.
Orchardgrass	*Dactylis glomerata* L.
Pine, Apache	*Pinus engelmannii* Carr.
Pine, Arizona	*P. ponderosa* var. *arizonica* (Engelm.) Shaw
Pine, bristlecone	*P. aristata* Engelm.
Pine, Chihuahua	*P. leiophylla* var. *chihuahuana* (Engelm.) Shaw
Pine, ponderosa	*P. ponderosa* Laws.
Pine, southwestern white	*P. strobiformis* Engelm.
Pinyon	*P. edulis* Engelm.
Raspberry	*Rubus* spp.
Spruce, blue	*Picea pungens* Engelm.
Spruce, Engelmann	*P. engelmannii* Parry

Vertebrates

Deer (Coues)	*Odocoileus virginianus couesi* (Coues & Yarrow)
Deer (mule)	*O. hemionus hemionus* (Rafinesque)
Deer mouse	*Peromyscus maniculatus* (Wagner)
Elk	*Cervus canadensis nelsoni* Bailey
Ground squirrel	*Citellus lateralis* (Say)
Ground squirrel	*Eutamias spp.*
Hare	*Lepus americanus* (Erxleben)
Junco	*Junco* spp.
Meadow vole	*Microtus* spp.
Pocket gopher	*Thomomys* spp.
Porcupine	*Erethizon dorsatum* Linnaeus
Rabbit	*Sylvilagus* spp.
Shrews	*Sorex* spp.
Squirrel (red)	*Tamiasciurus hudsonicus* (Erxleben)

Diseases

Cenangium canker	*Cenangium singulare* Davidson & Cash
Ceratocystis canker	*Ceratocystis* spp.
Dwarf mistletoe	*Arceuthobium* spp.
Dwarf mistletoe, Apache	*A. apachecum* Hawksworth & Wiens
Dwarf mistletoe, Douglas-fir	*A. douglasii* Engelm.
Dwarf mistletoe, (no common name)	*A. blumeri* A. Nelson
Dwarf mistletoe, southwestern	*A. vaginatum* subsp. *cryptopodum* (Engelm.) Hawksworth & Wiens
Dwarf mistletoe, western spruce	*A. microcarpum* (Engelm.) Hawksworth & Wiens
Dwarf mistletoe, white fir	*A. abietinum* Engelm. ex Munz f. sp. *concoloris* Hawksworth & Wiens
Hypoxylon canker	*Hypoxylon mammatum* (Wahl.) Mill.
(no common name)	*Bacillus thuringiensis* Berliner
(no common name)	*Wallrothiella arceuthobii* (Pk.) Sacc.
Spruce broom rust	*Peridermium coloradense* (Diet.) Arth. & Kern
White trunk rot	*Phellinus tremulae* (Bond.) Bond. et Boris (=*Fomes igniarius* var. *populinus)*

Insects

Arizona five-spined engraver	*Ips lecontei* Swaine
Douglas-fir beetle	*Dendroctonus pseudotsugae* (Hopkins)
Douglas-fir tussock moth	*Hemerocampa pseudotsugata* McDunnough
Fir engraver	*Scolytus ventralis* Leconte
Mountain pine beetle	*Dendroctonus ponderosae* Hopkins
New Mexico fir looper	*Galenara consimilis* (Heinrich)
Roundheaded pine beetle	*Dendroctonus adjunctus* Blandford
Southwestern pine tip moth	*Rhyacionia neomexicana* (Dyar)
Spruce beetle	*Dendroctonus rufipennis* (Kirby)
Western budworm	*Choristoneura occidentalis* Freeman
Western tent caterpillar	*Malacosoma californicum* (Packard)
White fir needle miner	*Epinotia meritana* Heinrich

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Jones, John R.
1974. Silviculture of southwestern mixed conifers and aspen: the status of our knowledge. USDA For. Serv. Res. Pap. RM-122, 44p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521

Describes the status of our knowledge about mixed conifer silviculture in the interior Southwest. Ecological background is reviewed first, followed by description of silvicultural methods. Relevant literature is discussed, along with observations, experience, and results of unpublished research. Contains unpublished input by subject-matter specialists and southwestern forest managers, largely as feedback from their reviews of a working draft. Research needs are also considered. Aspen forests are included; in the Southwest they are usually succeeded by mixed conifers.

Oxford: 614. **Keywords:** Silviculture, forest regeneration, *Abies concolor, A. lasiocarpa* var. *arizonica; Picea engelmannii, P. pungens; Pinus ponderosa, P. strobiformis; Populus tremuloides; Pseudotsuga menziesii* var. *glauca.*

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