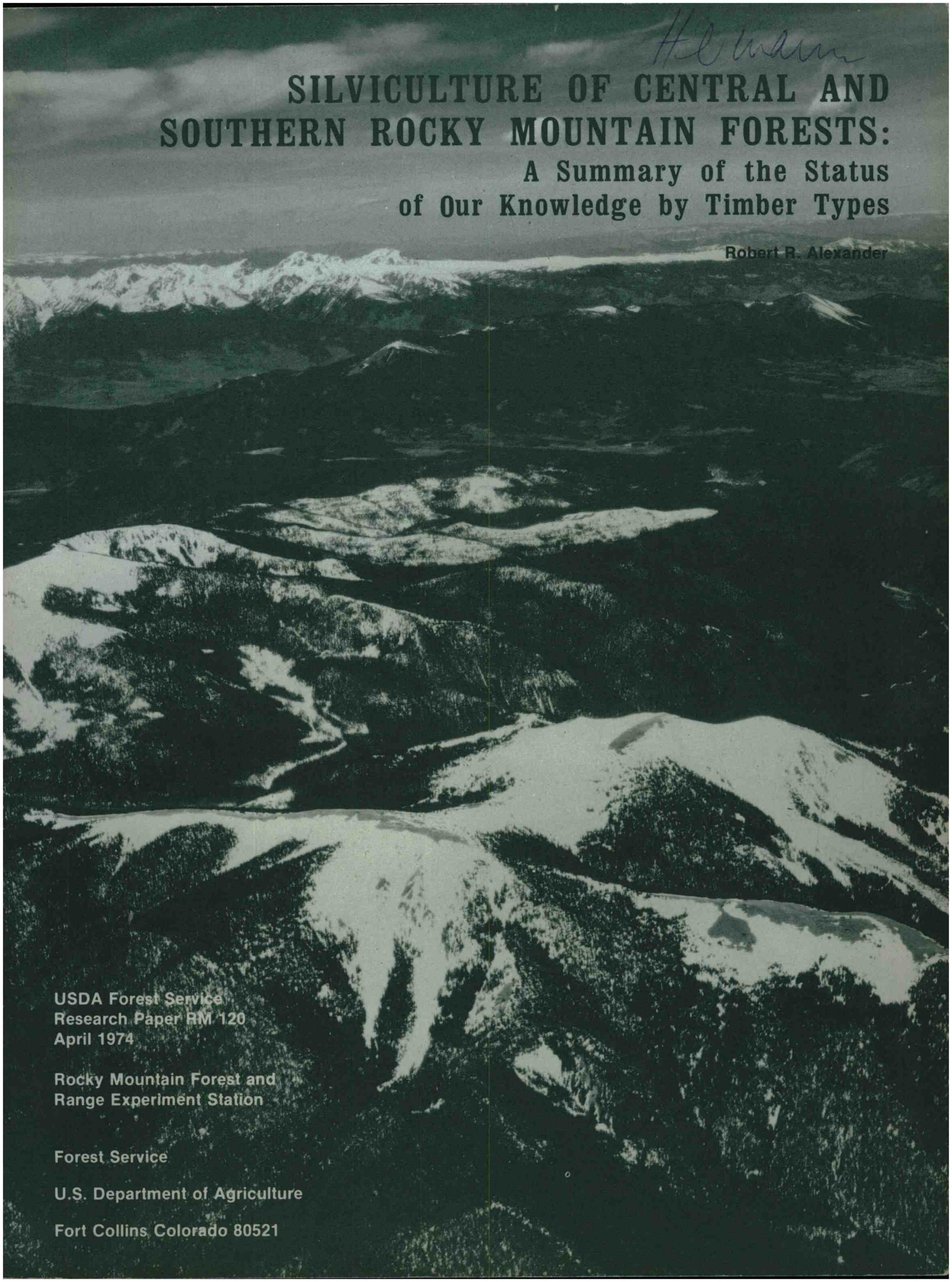
SILVICULTURE OF CENTRAL AND SOUTHERN ROCKY MOUNTAIN FORESTS:

A Summary of the Status of Our Knowledge by Timber Types

Robert R. Alexander



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ABSTRACT

Summarizes a series of comprehensive reports on the silviculture of lodgepole pine, ponderosa pine, mixed conifer, and spruce-fir timber types. Includes what is known, what can be recommended, and what additional information is needed for each timber type.

Oxford: 614. **Keywords:** Silviculture; forest regeneration; growth-yield; *Abies lasiocarpa, A. lasiocarpa* var. *arizonica, A. concolor; Picea engelmannii, P. pungens; Pinus contorta, P. ponderosa, P. strobiformis; Populus tremuloides.*

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PREFACE

Comprehensive reports of the status of our knowledge in timber management, applicable to the important central and southern Rocky Mountain forest types, have been prepared as Research Papers by the Rocky Mountain Forest and Range Experiment Station. These include:

"Silviculture of Subalpine Forests in the Central and Southern Rocky Mountains," by Robert R. Alexander, (RM-121),
"Silviculture of Southwestern Mixed Conifers and Aspen," by John R. Jones, (RM-122),
"Silviculture of Southwestern Ponderosa Pine," by Gilbert H. Schubert, (RM-123), and
"Silviculture of Ponderosa Pine in the Black Hills," by Charles E. Boldt and James L. Van Deusen (RM-124).

These papers have been condensed in this report to provide a general summary of the current status of our knowledge for all forest types in the central and southern Rocky Mountains. Acknowledgments and literature cited are included in the full-length papers.

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INTRODUCTION

Management goals for timber production and other forest uses are met through manipulation of forest cover. The degree of success depends on how well management decisions conform to the inherent characteristics of a particular species, existing stand conditions, and the environment, all of which affect the ability of a tree species to reproduce, survive, and grow. Since inherent characteristics are relatively unchangeable limitations, the resource manager must be certain that existing stand conditions and environmental factors are not altered by cultural practices to the extent that inherent species limitations are exceeded.

Although not all limiting factors and optimum conditions have been identified for tree species in the central and southern Rocky Mountains, Timber Management Research has been gathering data and providing forest managers with ecological and silvicultural information important to the management of commercial forest tree species for the past 60 or more years. A few summary publications on regeneration, silvics, silviculture, and management have been prepared for individual species, but most research results and observations have been presented as individual articles, papers, and notes in a variety of publications. Furthermore, some of what has been learned incidental to studies or from observations has never been fully documented. It is desirable therefore, for the research silviculturist to periodically pull together and organize all information which is scattered in various publications, as well as unpublished information, and make this knowledge available to the forest manager in one source.

The detailed status of knowledge summaries prepared for each forest type are intended to guide professional foresters and land managers responsible for supervising the application of silvicultural treatments by providing information on (1) what is known about the principal tree species, and (2) how this knowledge can be applied in the field to meet management objectives. Spinoff benefits include intensive literature reviews and the identification of knowledge gaps where additional research is needed.

The purpose of this document is to provide a general overview and evaluation of the more detailed reports. The forests of the central and southern Rocky Mountains are too extensive and complex, and the status of current knowledge and management practices too varied, to be handled as a homogeneous unit. Therefore, this Paper has been subdivided into five main sections: The Spruce-Fir Type, The Lodgepole Pine Type, Southwestern Mixed Conifer Forests—Including Aspen, The Southwestern Ponderosa Pine Type, and Black Hills Ponderosa Pine Forests. A discussion of timber resource priority problems is also included. Literature reviewed is not cited in this summary Paper, but is included in each of the four detailed reports as listed in the Preface (spruce-fir and lodgepole pine are combined in one report on subalpine forests).

THE SPRUCE-FIR TYPE

Engelmann spruce-subalpine fir forests occupy the highest forest environment in Wyoming, Colorado, and northern New Mexico (fig. 1). Spruce and fir are the principal species above 9,000 feet elevation on north-facing slopes, and above 10,000 feet on all other aspects. These forests are the largest and most valuable timber resource in Colorado and Wyoming (table 1). They are less important in terms of total forest resources in New Mexico. One of the features of spruce-fir forests is the large proportion of area in sawtimber-sized stands (table 2).

WHAT DO WE KNOW ABOUT SPRUCE-FIR FORESTS

Habitat Conditions

The climate of the spruce-fir zone is characterized by extremes that limit growth and reproduction. It is cool and humid, with long cold winters and short cool summers. Mean annual temperature is below 35° F, and frost can occur any month of the year. Precipitation, largely snowfall, is usually greater than 25 inches annually. Winds are predominantly from the west, and may be highly destructive.

Soils in the spruce-fir zone are young and complex. Soil parent materials vary according to the character of the bedrock from which they originated. Crystalline granitic rocks predom-

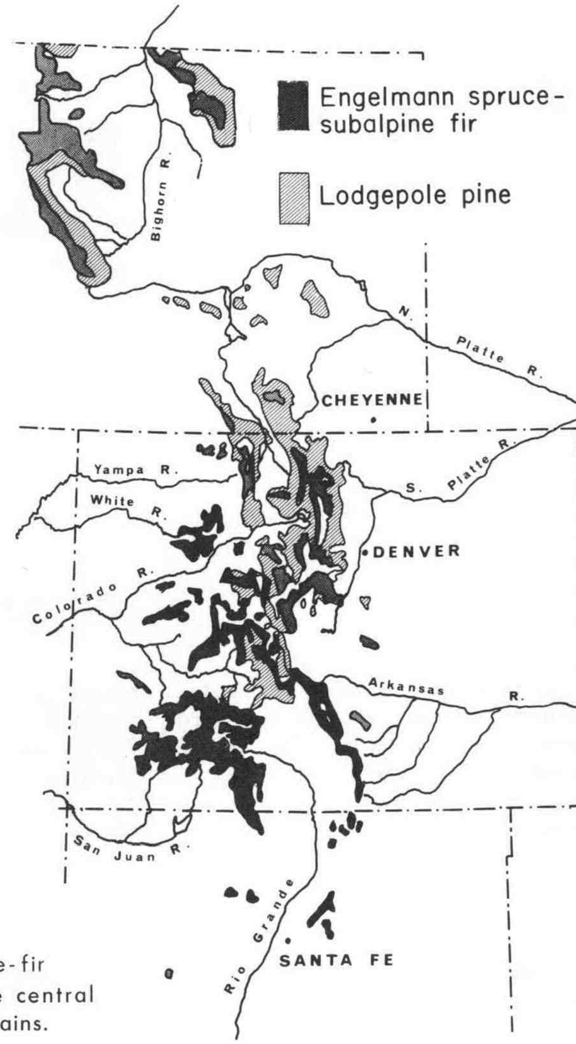

Figure 1.—Distribution of spruce-fir and lodgepole pine in the central and southern Rocky Mountains.

Table 1.--Acreage and volume (International 1/4-inch log scale) of sawtimber on commercial forests in the central and southern Rocky Mountains, by species and States

Species	Colorado		Wyoming		New Mexico		Arizona		South Dakota	
	M acres	*MM bm*	*M acres*	*MM bm*	*M acres*	*MM bm*	*M acres*	*MM bm*	*M acres*	*MM bm*
Engelmann spruce and true firs	3,393	33,260	847	9,541	525	5,257	110	2,147	0	0
Ponderosa pine	2.347	3,783	992	2,072	4,334	16,188	3,658	22,883	1,330	3,268
Douglas-fir	1,451	5,411	701	3,566	1,000	5,025	130	1,476	0	0
Lodgepole pine	2.068	6,024	1,802	5,798	0	0	0	0	--	--
White pines	139	472	166	1,256	43	640	--	186	--	--
White spruce	0	0	--	13	0	0	0	0	23	201
Aspen	2,794	3,482	320	159	367	1,233	79	259	0	0
Total	12,275	52,731	4,853	22,632	6,269	28,343	3,977	26,951	1,534	3,716

Table 2.--Percentage of commercial forest land area in the central and southern Rocky Mountains, by species, stocking classes, and States

Species and stocking class	Colorado	Wyoming	New Mexico	Arizona	South Dakota
Engelmann spruce and true firs:					
Sawtimber	81	82	85	100	0
Poletimber	14	14	5	--	0
Seedlings and saplings	1	1.5	7.5	--	0
Nonstocked	4	2.5	2.5	--	0
Ponderosa pine:					
Sawtimber	64	73	90	95	53
Poletimber	23	20	3.5	2.5	41.5
Seedlings and saplings	1	3	2	1	4.5
Nonstocked	12	4	4.5	1.5	1
Douglas-fir:					
Sawtimber	72	72	90	100	0
Poletimber	27	22	8.5	--	0
Seedlings and saplings	0.5	3	--	--	0
Nonstocked	0.5	3	1.5	--	0
Lodgepole pine:					
Sawtimber	34	47	0	0	0
Poletimber	60	45	0	0	0
Seedlings and saplings	5	6.5	0	0	0
Nonstocked	1	1.5	0	0	0
White pines:					
Sawtimber	45	46	100	0	0
Poletimber	52	44	--	0	0
Seedlings and saplings	2	6	--	0	0
Nonstocked	1	4	--	0	0
White spruce:					
Sawtimber	--	100	0	0	100
Poletimber	--	--	0	0	--
Seedlings and saplings	--	--	0	0	--
Nonstocked	--	--	0	0	--
Aspen:					
Sawtimber	7	18	49	44.5	0
Poletimber	80	57	43.5	49.5	0
Seedlings and saplings	13	16	7.5	6	0
Nonstocked	--	--	--	--	0

inate, but sedimentary, and basaltic and acidic volcanic rocks commonly occur. Most valleys have been glaciated and glacial deposits are common.

Climax and Succession

Spruce-fir forests are considered the climax forests where they grow in the central and southern Rocky Mountains. Climax forests are not easily displaced by other vegetation, but complete removal of a spruce-fir stand by fire or logging results in such a drastic environmental change that spruce and fir are usually replaced by lodgepole pine, aspen, or shrub and grass communities. The kind of vegetation initially occupying the site usually determines the length of time required to return to spruce-fir forests (fig. 2).

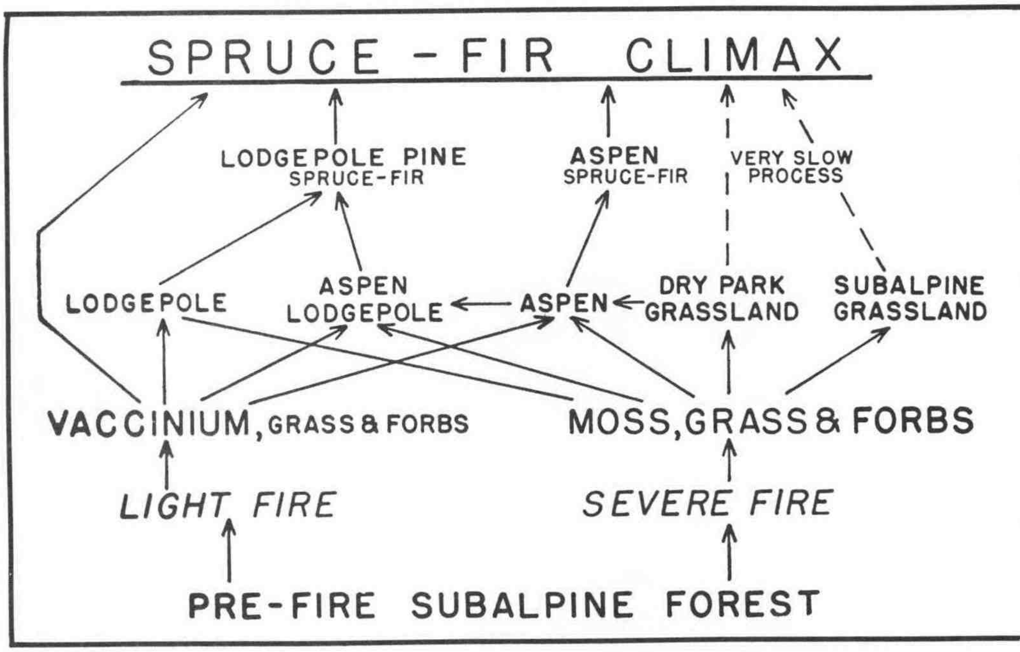

Figure 2.—Succession in subalpine forests after fire.

Stand Conditions

Old-growth spruce-fir forests grow on a wide range of sites with a great diversity of stand conditions and characteristics. This diversity complicates the development of silvicultural systems needed to convert old-growth to managed stands for a variety of uses. Some stands are single-storied, indicating that spruce-fir can be grown under even-aged management. Others are two-, three-,and multi-storied stands. These latter stands frequently have a manageable stand of advanced growth. Associated understory plant communities are also diverse. The distinctive overstory-understory combinations or habitat types each have a distinctive ecology and management potential.

The composition of spruce-fir forests varies considerably with elevation. At high elevations, spruce may form nearly pure stands while at mid elevations spruce usually predominates in the overstory and fir in the understory. At lower elevations where the sites are drier, the ratio of spruce to fir may be low and lodgepole pine may replace spruce in the overstory. Aspen is also a common associate at mid to lower elevations.

Damaging Agents

Windfall, a common cause of mortality in old-growth spruce-fir stands, limits the way stands can be handled (fig. 3). Partial cutting

Figure 3.—Spruce-fir blowdown in an uncut stand. San Juan National Forest, Colorado.

increases the risk of windfall because the entire stand is opened up. Less damage is usually associated with clearcutting because only the boundaries between cut and leave areas are vulnerable. Susceptibility to windthrow is also related to topographic exposure, soil depth and drainage, and age, soundness, size, and stand density.

The spruce beetle is the most serious insect pest of spruce-fir forests, and it limits the options open to the manager. Overmature spruces are attacked first, but if the infestation persists, beetles will attack smaller trees after the larger trees are killed. Epidemic attacks usually have been associated with extensive windthrow where down trees have provided an ample food supply needed for a rapid buildup of beetle populations. Cull material left after logging also has started outbreaks. Felling and salvaging attacked or the larger susceptible, overmature trees, and disposing of green cull material, are the most effective silvicultural controls, especially in stands with a good stocking of trees in the smaller diameter classes.

The most common diseases in spruce-fir stands are caused by wood-rotting fungi and broom rusts. They result in loss of volume and reduced growth, and predispose trees to windthrow and windbreak.

Natural Reproduction and Early Survival

Engelmann spruce reproduces almost entirely from seed. It is only a moderate seed producer, and crops vary from year to year. Infrequent seed crops mean that natural reproduction cannot be expected every year. Spruce seed is light and is dispersed by wind and gravity. Seedfall diminishes rapidly as distance from source increases, with about half of the seed falling within five to six times tree height. This rapid decrease limits the size of opening that will restock to natural reproduction.

Seed sources available for natural reproduction include (1) trees left around the perimeter of cleared openings, (2) residual trees left on the cut area, and (3) seed produced by trees cut on the area. One of the significant considerations in leaving a seed source is the capability of the trees in the residual stand to produce seed. Another consideration is resistance to windthrow.

Viable seeds that survive overwinter normally germinate in early summer following snowmelt. In the undisturbed forest, spruce germinates and becomes established on a variety of seedbeds. Removal of part or all of the overstory produces new microenvironments, some of which are unfavorable to germination and initial survival. Seedbed preparation is one way to modify limiting factors sufficiently to enable seedlings to become established.

Spruce germination and initial survival are usually better on exposed mineral soil and mineral soil with incorporated organic matter than other seedbed types. The natural forest floor, duff, litter and undecomposed humus, decayed wood, and burned areas are generally poor seedbeds even when moist, because either seeds cannot absorb sufficient water to germinate or the rate of seedling root growth is too slow to keep up with the rate of drying.

Engelmann spruce is restricted to high elevations because of low tolerance to high temperatures, but light intensity and total solar radiation are high where spruce grows. Light is essential to seedling survival, but spruce does not establish readily in the open at high elevations. High light intensity is one of the factors contributing to mortality. Solar radiation at high elevations also heats exposed soil surfaces and increases water losses from both seedlings and soil, especially during periods of clear weather in years when precipitation during the growing season is low or irregular. Few seeds can imbibe sufficient water to germinate, and most newly germinated seedlings are killed by drought or heat girdle. Shade reduces mortality from high light intensity, drought and heat girdling, and increases germination by reducing temperatures, thereby conserving moisture. However, low temperatures on shaded seedbeds in the spring following snowmelt may also delay germination so that, by the time seedbeds are warm enough, they are too dry.

Frost can occur any month where spruce grows. It is most likely to occur in depressions and cleared openings because of cold air drainage and radiation cooling (fig. 4). Newly germinated seedlings are especially susceptible to damage from early fall frosts. Older seedlings are most susceptible to frost early in the growing season when tissues are succulent. In the early fall, alternate freezing and thawing and saturated soils unprotected by snow cover are conducive to frost heaving. Shade reduces mortality by reducing loss of radiant energy from soil and seedlings.

Spruce regeneration success is also limited by biotic factors. Cone and seed insects and small mammals reduce available seed supply. Newly germinated seedlings are killed by damping-off fungi on all seedbed types if they remain damp for long periods of time. Snowmold fungi may damage or kill both natural and planted seedlings if they remain under the snow too long. Birds clip the seedcoats of newly

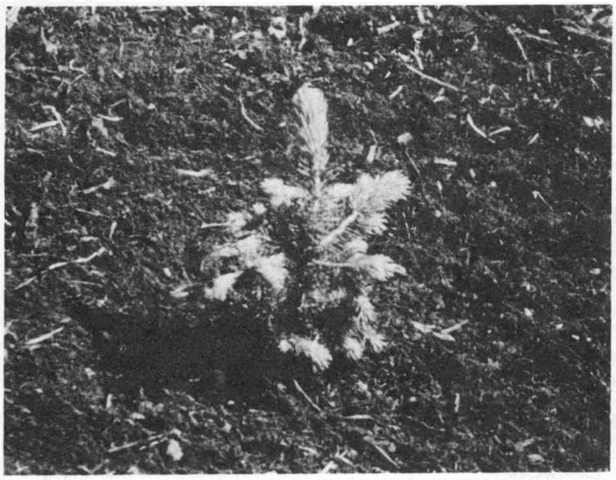

Figure 4.—Frost damage to an open-grown, planted Engelmann spruce seedling.

germinated seedlings, and voles and pocket gophers debark and kill established seedlings. Young seedlings are also vulnerable to trampling.

Spruce seedlings become established more readily on sites protected by such understory plants as willows, shrubby cinquefoil, fireweed, and dwarf whortleberry than in the open. These plants shade seedlings without seriously depleting soil moisture. In contrast, seedlings do not survive near clumps or scattered individual plants of grasses or sedges or herbaceous plants such as bluebells. Death is due to root competition for moisture, and smothering by cured vegetation compacted under dense snow cover.

Site Quality

Site index is the conventional method for estimating potential productivity. Such estimates are essential to the land manager as a means of identifying and intensifying management practices where timber production has the greatest potential. Curves of the height-age relationship of dominant spruce have been prepared that are suitable for estimating site index at base age 100 years in spruce-fir stands (fig. 5).

Frequently the conventional height-age method cannot be used to estimate site index because there are no trees present, or they are either too young or unsuitable for measurement. Site index for granitic soils in northern Colorado and southern Wyoming can be estimated using the depth of soil to the top of the C horizon and elevation in feet (fig. 6). This method is not suitable for other areas in the central and southern Rocky Mountains, however.

Growth and Yield

With the high proportion of spruce-fir still in old-growth stands, the forest manager must largely accept what nature has provided during the period of conversion to managed stands. Growth estimates based on Forest Survey inventories indicate that average annual growth over all sites in old-growth spruce-fir forests is only about 80 to 100 board feet (fbm) per acre.

As areas of old-growth spruce-fir are converted into new stands, they must be managed from the regeneration period to final harvest. The only growth prediction tool now available for spruce-fir stands in the central Rocky Mountains was developed 30 years ago for selectively cut stands, for sawtimber only, and for stand structures that are no longer management goals. Field data are now being collected in the central Rocky Mountains that will use established computer simulation procedures to develop yield tables for managed spruce-fir stands. The program produces a series of yield tables which show how projected growth will vary in response to changes in cultural treatments and/or variations in original stand and site conditions.

WHAT PRACTICES CAN WE NOW RECOMMEND

Regeneration Silviculture

The recognized harvest cutting methods applicable to spruce-fir forests include clearcutting, and shelterwood and selection cutting and their modifications. The choice of cutting method depends basically on management objectives and environmental considerations, but stand conditions, associated vegetation, and windfall and spruce beetle susceptibility — which vary from place to place on any area — impose limitations on how stands can be handled. For example, partial cutting should not be used in high wind risk situations or in stands where spruce beetle infestations are building up. Cutting to bring old-growth under management on many areas is likely to involve a combination of several partial cutting treatments, clearcutting, and sanitation salvage cutting. To restock these cutovers, managers should first consider the cultivation of existing **acceptable** advanced reproduction, and secondly, inducing subsequent restocking by natural or artificial means.

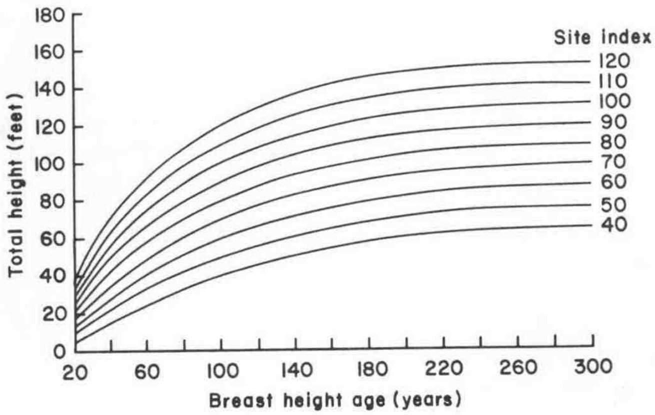

Figure 5.—Site index curves for Engelmann spruce in the central Rocky Mountains.
Base age: 100 years, breast height.

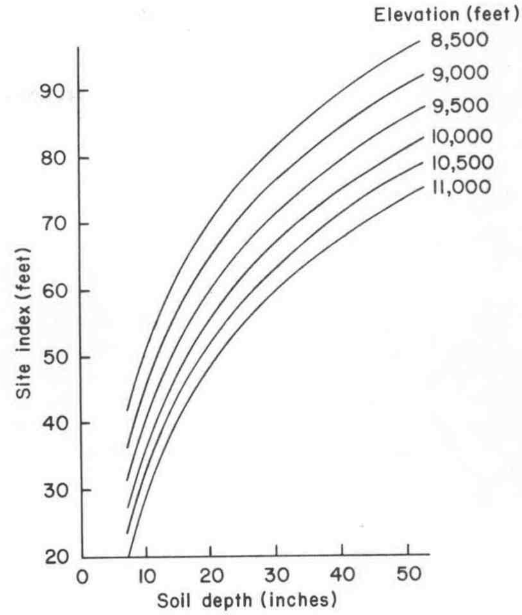

Figure 6.—Site index for Engelmann spruce on granitic soils in southern Wyoming and northern Colorado, determined from soil depth to the top of the C horizon and elevation.

Management With Advanced Reproduction

Many spruce-fir forests have an understory of advanced growth. However, because of variations in age, composition, quality, and quantity of advanced reproduction, its potential for future management must be carefully evaluated before harvesting begins. One course of action is followed if advanced reproduction is to be managed, another if it is not. Furthermore, the manager must reevaluate the stand after the final harvest and slash disposal to determine the need for supplemental stocking.

The size, shape, and arrangement of clearcut openings is not critical from a regeneration standpoint, but to be compatible with other key uses, openings should not be greater than about five to eight times tree height, irregular in shape, and blend into the landscape. The overstory will generally be removed in one step.

On partially cut areas, shelterwood cutting should be used where trees are uniformly spaced, and group selection where they are clumpy in single-, two-, and three-storied stands. The overstory will be removed in more than one step. An overwood removal in one or two steps is usually appropriate in multi-storied stands, while individual tree selection is appropriate in multiple-use areas where management objectives include maintenance of high forests. The amount of basal area that can be removed at each entry, the number of entries, and the size of group openings is determined by stand characteristics and windfall risk.

Protection of the residual stand — merchantable trees left after partial cutting, and advanced reproduction in both clearcutting and partial cutting — from logging damage at each cut is of primary concern (fig. 7). Protection begins with a well-designed logging plan at the time of the first cut. To minimize damage, skid roads must be laid out and marked on the ground, travel of skidding and other logging equipment restricted to the skid roads, and trees felled into openings as much as possible in a herringbone pattern that will permit logs to be pulled onto the skid roads with a minimum of disturbance.

Slash treatment after each cut should be confined to areas of heavy concentrations as required for protection from fire and insects or preservation of esthetic values. Slash must be treated carefully to avoid unnecessary damage to advanced reproduction and residual trees — if they are destroyed during slash disposal, care taken in logging is wasted.

Management With Reproduction After Cutting

On clearcut units, layout, logging plans, and slash disposal and seedbed treatment should be designed to facilitate seed dispersal, and to create favorable conditions for germination and seedling establishment. Clearcutting can be by patches, blocks, or strips. Requirements for seed

Figure 7.—Advanced spruce and fir reproduction after clearcutting and slash disposal. Fraser Experimental Forest, Colorado.

dispersal, site preparation, and aspect will influence the size of opening that will restock to natural regeneration. The cutting unit must be designed so that seed from the surrounding timber margin reaches all parts of the openings. Furthermore, cutting unit boundaries must be located where they will be most windfirm.

In general, clearcutting for natural regeneration is most likely to succeed on north and east aspects, providing the right combination of mineral soil and shade has been created, and openings are no larger than about five to six times tree height. If larger openings are cut, the area beyond effective seeding distance will have to be planted. Clearcutting on south and west aspects is not likely to result in an acceptable stand of new reproduction in a reasonable period of time without fill-in planting.

Slash disposal and seedbed preparation will be needed after clearcutting. If slash is concentrated for burning, the piles or windrows should be kept small or narrow, and cover a minimum proportion of the area. Mineral soil can be exposed by mechanically scarifying the ground surface, sometimes in connection with slash disposal or by broadcast burning. Careful mechanical scarification or broadcast burning will prepare a satisfactory seedbed if it exposes bare mineral soil and destroys some of the competing vegetation, but leaves shade protection. To provide adequate shade, it may be necessary to rearrange some of the residual slash and the true-fir cull material over 8 inches in diameter.

On partially cut areas to be regenerated by new reproduction, an overstory canopy or trees standing around the margins of small openings provide a seed source within effective seeding distance and an environment compatible with germination, initial survival, and seedling establishment. The manager must make sure, however, that a suitable seedbed is provided after the seed cut where shelterwood cutting is used, and after each cut where group selection is used. Some slash disposal will probably be needed after each cut, but it should be confined to concentrations and that needed to reduce visual impact because most equipment now available for slash disposal is not readily adaptable to working in shelterwood cuttings. Furthermore, burning of slash will cause additional damage to the residual stand. As much of the down sound dead and green cull material as possible should be skidded out for disposal at the landings or at the mill. Some hand piling or scattering may be needed where slash disposal equipment cannot be used. In group selection cutting, slash can be concentrated for burning in the openings.

Primary concerns on partially cut areas are protection of the residual stand at each cut, and protection of the new reproduction when the final harvest is made. The same criteria used in management with advanced reproduction applies here.

Management With Artificial Reproduction

On clearcut areas, good sites should be planted immediately after logging where (1) there is not a manageable stand of advanced reproduction, and (2) experience has shown that natural reproduction takes a long time. Areas prepared for natural reproduction that fail to restock in a reasonable period of time should be planted. On partially cut areas, planting should supplement natural reproduction where stocking is inadequate after the final harvest. A minimum goal should be 300 well-established spruce seedlings.

Hand scalping will probably be adequate to prepare the site on most spruce plantations. In areas with a heavy cover of herbaceous vegetation or dense sod, machine methods will have to be used. Broadcast burning can be used where there is no advanced reproduction or residual stand.

Plant only stock meeting Forest Service Regional standards. Spruce planting stock requires exacting care; it should be lifted when dormant and treated as dormant plants during transport to and storage at the planting site. Plant in the spring using the hole method. New plantings should be protected from livestock and rodents.

Until reliable techniques have been developed for the central and southern Rocky Mountains, direct seeding of spruce is not recommended as an operational practice.

Multiple-Use Silviculture

In addition to being the most productive timber type in the central Rocky Mountains, spruce-fir forests are also the highest water yielding, and are valuable wildlife, recreation, and scenic areas. Because of increasing demands on limited forest lands from a rapidly expanding population, management must consider all key land uses. The kinds of stands that appear desirable for increased water yields, preservation of the forest landscape, maintenance of scenic values, and improvement of wildlife habitat have been suggested in a general way by both research and observation.

For water production, about one-third of a drainage or Working Circle should be in cleared openings five to six times tree height. These openings would be maintained by recutting the trees when they reached about one-half their original height. The remaining two-thirds of the area should be retained as continuous high forest where trees would be periodically harvested on an individual tree basis. Big-game use of spruce-fir forests is also improved by the combination of cleared openings and high forests. However, since natural succession is likely to replace the more palatable forage species that initially come in the openings, one way to integrate timber, water, and wildlife production is to periodically cut new openings about four to five times tree height while allowing older openings to regenerate.

Permanent forest cover at least in part is preferred in recreation areas, travel influence zones, and scenic view areas. With some form of partial cutting, forest cover can be retained while at the same time replacing the old with a new stand. However, the visual impact of logging must be minimized. To reduce the sudden and severe visual impact on the landscape viewer, openings cut in stands should be a repetition of natural shapes.

WHAT DO WE NEED TO KNOW

Silvicultural practices are needed that will establish and maintain stands with the form, structure, and arrangement needed to integrate all land uses. For the timber resource these include: (1) classifying spruce-fir forests into categories of similar stand characteristics as the basis for identifying management potentials in existing stands; and (2) testing silvicultural systems and cultural practices in stands of different characteristics.

Classification of vegetation in the spruce-fir zone is needed to guide the manipulation of forests for multiple use. For the timber resource this includes: (1) what species grow together and how to recognize the plant associations; (2) how these species reproduce, grow, and interact in a variety of situations; (3) the response in terms of successional trends and the stability of various plant associations to different management prescriptions; and (4) the extent to which research results can be extrapolated.

Prediction of growth and yield of spruce-fir is needed to provide the basis for decisions on (1) site quality classes that will repay the cost of thinning and other cultural treatments; (2) levels of growing stock — including frequency of thinnings and intermediate cuttings — to meet different management objectives; (3) length of rotation cutting cycles, and allowable cut for different cutting methods, management goals, and utilization standards, and (4) the place of timber management in multiple-use management. Better decisions can be made regarding key uses when the timber potential can be forecast.

Methods of obtaining natural and artificial regeneration have been fairly well developed for Engelmann spruce. What is needed now is information on (1) seed production in relation to source to work out relationships between the source and the amount and periodicity of seed productions; and (2) germination and survival under different environmental conditions to identify limiting factors and provide estimates of the probability of seedling establishment. These data, together with existing information on seed dispersal distances, will permit simulation of the regeneration phase of spruce for different environmental conditions.

THE LODGEPOLE PINE TYPE

Lodgepole pine forests cover extensive areas between 7,500 and 10,500 feet elevation in Colorado and Wyoming, but reach maximum development in the upper montane and lower subalpine zones on south and west slopes between 9,000 and 10,000 feet elevation (see fig. 1). These forests are the second largest timber resource in Colorado and Wyoming (see table 1). The imbalance in age-class distribution is not as serious as in spruce-fir forests, but many of the pole-sized timber stands are either overmature, overly dense, or growing on sites not likely to produce a tree of saw-log size (see table 2).

WHAT DO WE KNOW ABOUT LODGEPOLE PINE FORESTS

Habitat Conditions

The climate where lodgepole pine grows in the central Rocky Mountains is warmer and drier than the higher spruce-fir zone, but is still characterized by extremes. Most precipitation is received as snowfall, and precipitation is likely to be deficient for short periods during the growing season. Best development occurs where annual precipitation is more than 21 inches.

Soils where lodgepole pine grows are young, and the profile is poorly developed. Soil parent materials are varied and mixed. Glacial deposits, alluvial fan sediments, stream alluvium, and materials weathered in place predominate. Crystalline rocks such as granite, gneiss, schist, granodiorite, and rhyolite are the principal bedrocks.

Climax and Succession

Lodgepole pine is an aggressive pioneer and invader, whose occurrence is due largely to fire. Lodgepole pine is considered to be seral in stands that have either a mixed overstory composition or contain appreciable amounts of advanced reproduction of other species. Where lodgepole pine stands are the result of catastrophic fires that have burned so often and so extensively that large acreages are nearly pure pine, it is considered a subclimax because there is no seed for the normal climax species. It is also considered stable when held on an area by factors other than climatic.

Stand Conditions

Lodgepole pine occurs as an even-aged, single-storied, and sometimes overly dense forest only where favorable fire, seed, and climatic conditions once combined to produce a large number of seedlings. Elsewhere, it grows as two-aged, single- or two-storied stands; three-aged, two- or three-storied stands; and even-aged to broad-aged multi-storied stands.

Stands of pure lodgepole pine occur frequently over much of the area it occupies, especially where stands originated after repeated fires. However, mixed stands of lodgepole pine and other species are not uncommon. In mixed stands the overstory can either be pure pine or pine and the climax species, with the climax species in the understory.

Damaging Agents

Lodgepole pine forests are susceptible to windthrow after cutting. While the tendency to windthrow is usually attributed to a shallow root system, susceptibility is related to the kind and intensity of cutting, soil depth and drainage, defect, stand density, and topographic exposure (fig. 8).

The mountain pine beetle is the most serious insect pest in mature to overmature lodgepole pine stands. Usually, outbreaks reach epidemic proportions only in stands that contain at least some older trees 14 inches in diameter and larger. After the larger trees are killed, beetles attack the smaller trees until the outbreak subsides. The only practical silvicultural control in heavily infested stands where the trees are 10 inches in diameter and larger is to harvest the infested trees, burn the unmerchantable material, and regenerate a new stand. In infested stands with a good stocking of smaller diameter classes, removal of the older and larger trees effectively regulates the mountain pine beetle.

Dwarf mistletoe, the most serious disease affecting lodgepole pine, reduces growth and increases mortality. It is most damaging in stands partially opened up by cutting, mountain pine beetles, or windfall, and is of least consequence on regenerated burns. Separation of the old and new stands by clearcutting and felling unmerchantable trees is the best way to control dwarf mistletoe. Partial cutting should be avoided unless the infection is rated class 2 or less (fig. 9).

Figure 8.—Severe blowdown in a lodgepole pine stand after a heavy shelterwood cut that removed 60 percent of the basal area. Fraser Experimental Forest, Colorado.

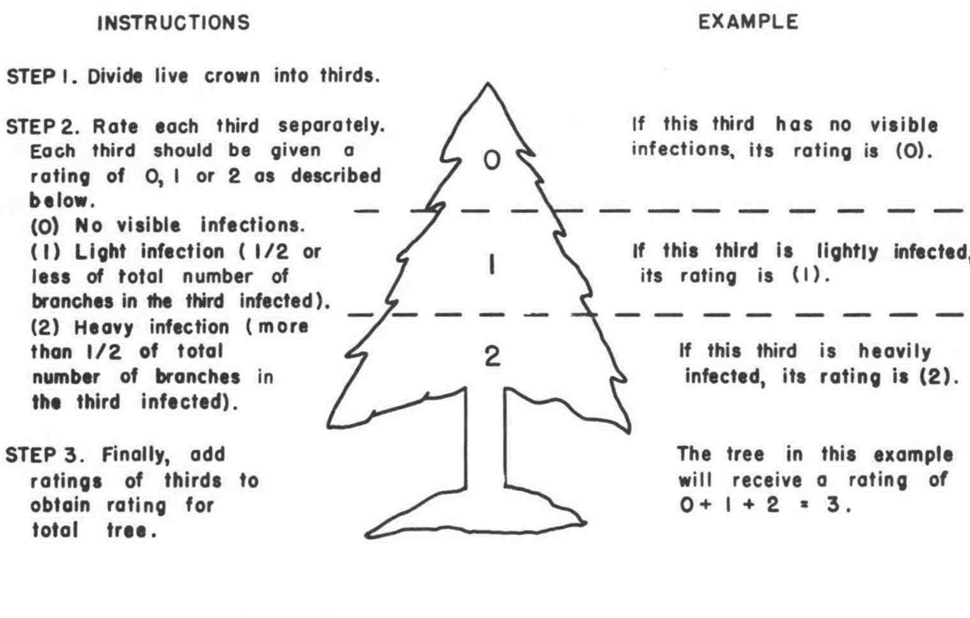

Figure 9.—The 6-class mistletoe rating system.

Comandra blister rust is a common canker disease in the cental Rocky Mountains, but damage has been most extensive in northern Wyoming. Sanitation salvage cutting is about the only practical way of controlling the disease in forest stands.

Natural Reproduction and Early Survival

Lodgepole pine reproduces from seed. It is a prolific seed producer with good crops borne at 1- to 3-year intervals. Throughout much of the central Rocky Mountains, lodgepole pines bear an abundance of serotinous cones that remain unopened on standing trees. However, in some areas, the cone habit is known to be largely nonserotinous. Because the variability in cone habit greatly affects regeneration, each stand must be examined before cutting to determine cone serotiny.

In stands with serotinous cones, seed released from cones attached to the slash and cones scattered on the forest floor is the most important dispersal. Maximum release from this source takes place the first year after cutting. The amount of seed stored in closed cones is usually adequate for regeneration, providing that logging slash bearing cones is carefully handled.

In stands with nonserotinous cones, seed is dispersed from standing trees, largely by the wind. The maximum size of opening that will restock in a reasonable amount of time is probably no greater than about four to five times tree height, because seedfall drops off rapidly as distance from source increases, with most seeds falling within about 200 feet.

The several sources of seed available for natural reproduction include: (1) serotinous cones in the logging slash (a one-shot opportunity), (2) nonserotinous cones on trees either standing around the perimeter of cutover areas or on the area cut, and (3) nonserotinous cones on new reproduction 5 to 10 years old. One of the significant considerations in the kind of seed source to leave in stands with nonserotinous cones is its resistance to windthrow.

Viable seeds of lodgepole pine that survive overwinter normally germinate in the early summer following snowmelt. Lodgepole pine is noted for its ability to establish on burned surfaces after wildfire, but germination and initial survival have usually been better on exposed mineral soil, and disturbed duff and mineral soil than on other seedbed types because of more stable moisture conditions. Germination and early seedling development are usually considered best in full sunlight, but on some sites radiation intensities under full exposure can create temperature and moisture conditions critical to seedling establishment, especially when precipitation during the growing season is low or irregular. For example, on clear days in early summer, exposed soil surfaces are rapidly dried out and heated to high temperatures. Few seeds can imbibe sufficient water to germinate, and many newly germinated seedlings are killed by stem girdle or drought. Shade either from light slash or a residual overstory reduces excessive heating and drying of the soil surface.

Newly germinated seedlings are especially susceptible to damage from early fall frosts, but older seedlings are seldom damaged by frosts during the growing season. The combination of warm daytime temperatures, nighttime temperatures below freezing, and saturated soils unprotected by snow cover in the early fall are conducive to frost heaving. Shade reduces mortality from frost damage by reducing loss of radiant energy from soil and seedlings. Disease, animals, and vegetative competition also limit regeneration success. Newly germinated seedlings are killed by damping-off fungi early in the growing season when seedbeds are damp. Snowmold fungi occasionally cause damage and death to both natural and planted lodgepole pine seedlings if they remain under the snow too long. Young lodgepole pine seedlings are vulnerable to trampling damage. Birds clip the seedcoats from newly germinated seedlings, and mountain voles and pocket gophers destroy established seedlings. Understory vegetation is usually a major constraint to successful seedling establishment.

Site Quality

The conventional measure of site index is the average height of dominant trees in relation to age. The height growth of lodgepole pine, however, is influenced by stand density probably more than any other North American conifer. The height-age relationship of lodgepole pine is thus a valid estimate of site index only when height growth is adjusted for any reduction due to density. Curves of the height, age, and density (measured as Crown Competition Factor, CCF) relationships of dominant lodgepole pine have been prepared that are suitable for estimating site index (fig. 10).

Conventional methods of site determination cannot be used on lands that are nonforested, or that contain trees either too young or unsuitable for site determination. Site index of lodgepole pine in north-central Colorado and

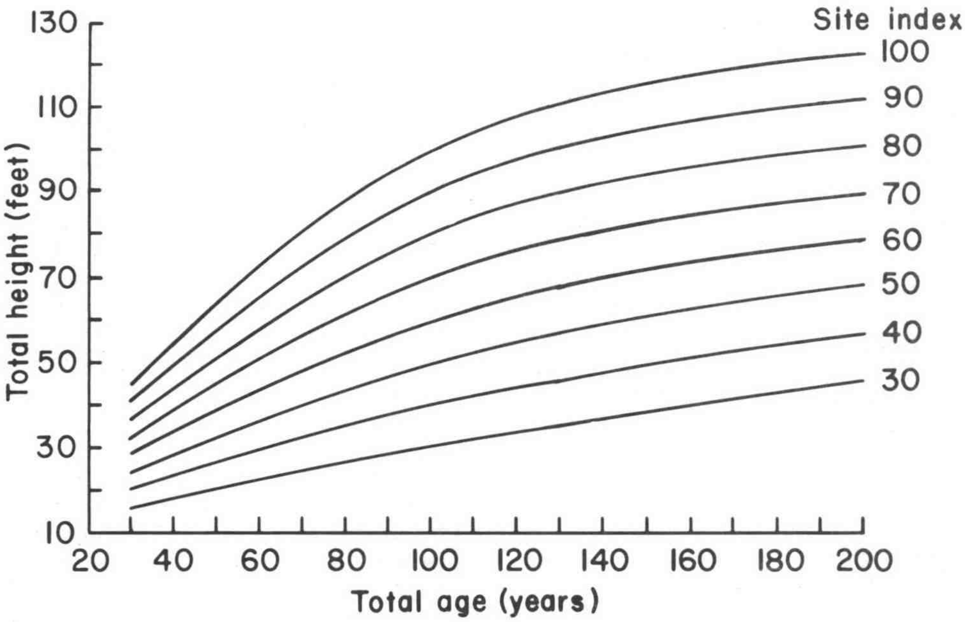

Figure 10.—Site index curves for lodgepole pine at Crown Competition Factor (CCF) levels of 125 or less. Base age: 100 years, total age.

south-central Wyoming can be estimated from environmental factors, but such site indexes have not been developed for other areas in the central Rocky Mountains.

Growth and Yield

Lodgepole pine often reproduces so abundantly following fire or clearcutting that competition for growing space does not permit good development without artificial thinning (fig. 11). Evidence of stand density control on growth in young stands is well documented: (1) diameter growth is greatest at the lowest density and slowest at the highest; (2) height growth is reduced by high stand densities, but the response of height growth to thinning has been variable; (3) basal area increment decreases when basal area per acre exceeds about 80 ft^2 ; (4) cubic foot volume increment increases with an increase in stand density, except in stagnated stands.

Growth estimates based on Forest Survey data indicate that average annual growth over all sites in old-growth lodgepole pine is about 25 to 40 fbm per acre. This low productivity is

Figure 11.—Dense 60-year-old stand of second-growth lodgepole pine. Medicine Bow National Forest, Wyoming.

largely due to the great number of small trees. As old-growth lodgepole pine sawtimber and poletimber stands are harvested, they must be managed from the regeneration period to final harvest. Furthermore, there are many stands of young growth that must be brought under management. Some of these stands have been thinned once but are in need of a second thinning.

Yield tables for managed stands are the basis for timber management planning. Field and computer procedures for preparing yield tables for managed stands of lodgepole pine, including those infected with dwarf mistletoe, realistically simulate (1) stand growth, (2) response to thinning, and (3) reproduction cutting by any of the even-aged systems.

WHAT PRACTICES CAN WE NOW RECOMMEND

Regeneration Silviculture

Harvest cutting methods applicable to old-growth lodgepole pine forests include clearcutting, and shelterwood and group selection cuts. Seed tree and individual tree selection cutting are usually not applicable in lodgepole pine stands. The choice of cutting method depends upon management goals, but stand conditions, windfall, disease and insect susceptibility, and the risk of potential fire damage — all of which may vary from place to place on any area — limit the options available for individual stands. For example, partial cutting should not be used in high wind-risk situations, in stands where mountain pine beetle infestations are building up, or where the severity of dwarf mistletoe infection exceeds class 2.

Management With Clearcutting

In pure lodgepole pine stands there is seldom a manageable stand of advanced regeneration. If regeneration is present, it usually has been suppressed for so long that it has no future management potential. In mixed stands, where the associated species are spruce and fir, there is frequently a manageable stand of advanced reproduction. Procedures developed for the management of advanced reproduction in spruce-fir stands should be followed.

Most lodgepole pine clearcut areas will be regenerated with either natural or artificial reproduction after logging. Cutting unit layout, logging plans, and slash disposal and seedbed treatment should be designed to facilitate seed dispersal, promote seedling survival and establishment, and create favorable growing conditions.

Clearcutting can be by patches, blocks, or strips. The size of opening likely to restock is influenced by the seedbed and whether the seed is dispersed from open or closed cones. Stands with serotinous cones have maximum flexibility in the size and shape of openings cut that will restock, but natural regeneration is normally a one-shot opportunity. However, there is no advantage to cutting openings larger than 30 to 40 acres even for dwarf mistletoe control and smaller openings — 10 to 20 acres — would provide a supplemental seed source in trees standing around the perimeter.

In stands with nonserotinous or intermediate cone habit, the cutting unit must either be designed so that seed from the surrounding timber margin reaches all parts of the opening, or the cut made in a good seed year after cones are mature and seed is shed. Otherwise, plan on artificial regeneration. The maximum size of opening likely to restock to natural reproduction is about four to five times tree height. On south slopes, openings should be smaller — about two to three times tree height. If larger openings are cut, the area beyond effective seeding distance must be planted.

Slash disposal and seedbed preparation will be needed after clearcutting. In stands with serotinous cones, careful handling of slash is required to avoid destruction of seed-bearing cones. If concentrations of slash are piled or windrowed for burning, the piles and windrows must be kept small and well distributed. The lighter areas of slash can be either lopped and scattered or rolled and chopped. Slash can be handled the same way in stands with nonserotinous or intermediate cone habit, except that it can be treated when green. Slash also can be broadcast burned.

Lodgepole pine sites scheduled for planting should be reforested immediately after logging and slash disposal. Areas prepared for natural reproduction that fail to restock in 3 years should be planted; otherwise additional seedbed preparation is likely to be needed. A minimum goal should be 1,200 well-established seedlings per acre where timber production is a primary objective, otherwise a minimum of 600 seedlings per acre is sufficient. Methods of handling planting stock, seedbed preparation, and planting techniques developed for Engelmann spruce also apply here.

Techniques for direct seeding have not been worked out for the central Rocky Mountains, but direct seeding on prepared seedspots has been successful elsewhere.

Management With Partial Cutting

Shelterwood cutting should be used in single-, two-, and three-storied stands, and overwood removal in multi-storied stands. Group-selection cutting is usually appropriate only in stands where natural openings occur or small openings are required to meet management objectives. Group selection is not recommended where disease and insect problems impose limitations on how stands can be handled. The overstory will usually be removed in more than one step. The amount of basal area removed at each entry and the number of entries is determined by stand characteristics, windfall risk, and insect and disease problems. Partial cutting requires careful marking of individual trees or groups of trees to be removed, and close supervision of logging.

In **mixed stands** and to a lesser extent in pure stands, the manager must determine whether he has an acceptable stand of advanced reproduction and decide if he is going to manage it before any cutting begins. Furthermore, he must reevaluate the advanced reproduction after the final harvest and slash disposal to determine the need for supplemental stocking. The same criteria used to evaluate advanced reproduction in spruce-fir stands apply here.

Preventing logging damage to the residual merchantable trees and advanced reproduction — where an acceptable stand is to be managed — at each cut, and new reproduction at the time of final harvest, is of primary concern. To minimize damage, skid roads must be laid out and marked on the ground so that they can be used to move logs out of the woods at each cut. Trees should be felled into openings as much as possible in a herringbone pattern that will permit logs to be pulled onto the skid roads with a minimum of disturbance. Furthermore, as much down dead and cull material as possible should be skidded out to minimize slash treatment.

Some treatment of logging slash and unmerchantable material will probably be needed after each cut, however. Treatment should be limited to lopping and scattering, chipping along the roadway, and hand piling and burning to minimize damage. Machine piling will damage the residual, and broadcast burning slash will not only damage the residual stand, but may destroy the seed supply in stands with serotinous cones. In nonserotinous stands or stands with intermediate cone habit to be regenerated largely by new reproduction, a partial overstory canopy or trees standing around the margins of small openings provide a seed source within effective seeding distance and an environment compatible with germination and seedling establishment. In stands with serotinous cones, the seed supply is largely in the cones attached to the slash or scattered on the ground. The manager must make sure that a suitable seedbed is provided after the seed cut with shelterwood cutting, and after each cut with group selection.

Multiple-Use Silviculture

Timber production is only one of the key uses of lodgepole pine forests in the central Rocky Mountains. They occupy areas that also are important for water yield, wildlife habitat, recreation, and scenic beauty. Forest managers must consider how these areas are to be handled to meet the increasing demands of the public. The kinds of stands that appear desirable for increased water yields, preservation of the forest landscape, maintenance of scenic values, and improvement of wildlife habitat are similar to those suggested for spruce-fir forests.

WHAT DO WE NEED TO KNOW

Current silvicultural practices need to be modified to incorporate the maintenance of scenic values and the integration of other multiple-use values. For the timber resource, methods of establishing and maintaining high forests and grouping existing lodgepole pine stands of like characteristics will provide the forest manager with the basis for such decisions as: (1) the kind of stands that can be converted directly to partial cutting systems, and those that must be started new; (2) the amount of overstory that can be maintained in stands with different characteristics; and (3) the cultural practices needed to meet specific objectives.

The classification of vegetation needed to guide the manipulation of spruce-fir forests is also needed for those areas occupied by lodgepole pine.

The field and computer simulation techniques now available for the management of even-aged stands must be expanded to include uneven-aged stands and irregular stand structures needed for multiple use.

Methods of obtaining regeneration have been largely developed for lodgepole pine stands with serotinous cones. What is needed now are natural and artificial reproduction procedures for stands with nonserotinous cones, especially on south slopes and in tension zones.

SOUTHWESTERN MIXED CONIFER FORESTS—INCLUDING ASPEN

Mixed conifer forests of the Southwest include mixed stands of commercial species in Arizona, New Mexico, and southwestern Colorado that occupy sites more moist than usually occupied by pure stands of ponderosa pine (fig. 12). The most common overstory species, more or less in order of abundance, are Douglas-fir, ponderosa pine, white fir, Engelmann spruce, aspen, southwestern white pine, blue spruce, and corkbark fir. Mixed conifer forests may occur in a variety of mixtures of the above species. At one extreme the overstory may be nearly pure ponderosa pine with other species abundant in the understory, while at the other extreme the overstory may be predominantly Engelmann spruce. Stands of Engelmann spruce and corkbark fir without other species are not considered mixed conifer forests, but where they integrate with other conifers, they are part of the mixed conifers. Aspen management in the Southwest is tied closely to mixed conifer forests.

The principal mixed conifer forest areas (fig. 13) can be found below 6,000 feet elevation in canyon bottoms and on protected north slopes in the pure ponderosa pine type, but most grow at elevations above 8,000 feet. Mixed conifers are largely replaced by spruce-fir above 10,000 feet elevation. Mixed conifer forests, which occupy about 2.5 million acres of highlands in the Southwest, are of less importance in terms of total commercial forest land and sawtimber volume than spruce-fir in southwestern Colorado or ponderosa pine in Arizona and New Mexico (see table 1). As is usually the case with relatively unexploited forests, the largest proportion of Douglas-fir and other components are in old-growth sawtimber-sized stands (see table 2). Aspen, however, is about equally divided between saw-log and pole-sized stands.

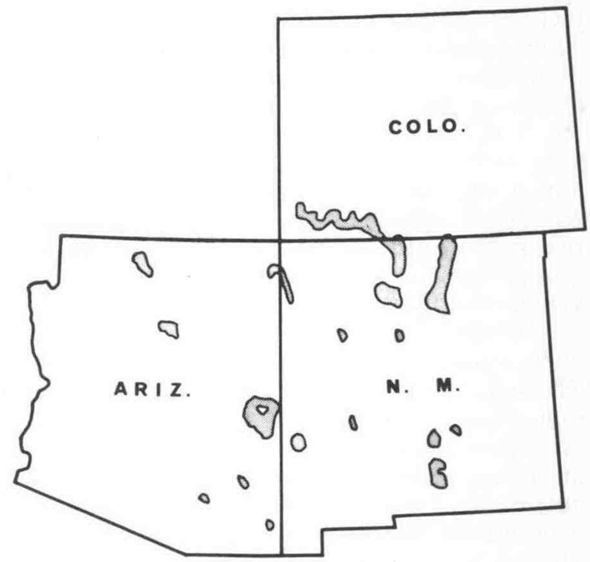

Figure 13.—Mixed conifer areas in the Southwest.

WHAT DO WE KNOW ABOUT MIXED CONIFER FORESTS

Habitat Conditions

The climate, soils, and landforms where mixed conifers grow are similar to spruce-fir

Figure 12.—A virgin mixed conifer stand in the Southwest.

forests at the higher elevations and ponderosa pine forests at lower elevations, but mixed conifer forests are wetter than ponderosa pine and warmer than spruce-fir. Snowfall is heavy, and there is considerable summer precipitation. Spring and early summer comprise the dry season, and moisture may be deficient for short periods of time. Windfall is most likely shortly after snowmelt or during severe autumn storms, when the soil is saturated. Destructive winds blow mainly from the southwest.

Climax and Succession

In mixed conifer forests, Douglas-fir and white fir are considered the predominant climax species below 8,500 feet on north slopes and 10,000 feet on south slopes. Natural forest succession — as well as it is now understood — on mixed conifer and spruce-fir sites after complete forest removal is shown in figure 14. Most mixed conifer forests seem to have followed wildfires. Initial stages are usually forbs, grass, aspen, or oak scrub. Ponderosa pine sometimes restocks these burns. If grass becomes established, coniferous invasion is usually slow. If a seed source is available, Douglas-fir and white fir invade pioneer pine stands. In the absence of a coniferous seed supply, aspen will persist for decades, but in the presence of a seed supply, aspen is quickly invaded by tolerant conifers. Oak scrub may also persist a long time.

Stand Conditions

There is considerable variability in stand conditions and characteristics in mixed conifer forests that complicates the development of silvicultural systems needed to bring these forests under management. Some stands are single-storied, others are two-, three- and multistoried. Single-storied stands are uncommon in mixed conifer forests, but occur more frequently in spruce-fir and aspen forests. Two-storied stands are likely to be predominantly ponderosa pine or aspen in the overstory, with an understory mostly of other species. Some three-storied stands are the result of partial harvesting of single- or two-storied stands. Multi-storied stands are most common in mixed conifer forests. Multi-storied stands have usually resulted from the irregular deterioration of older age classes with time. Douglas-fir frequently predominates among older trees, but is often outnumbered by white fir in the younger age classes. In some stands, these species are largely replaced in the younger age classes by Engelmann spruce and corkbark fir.

Damaging Agents

Although variable, windfall is always a threat to trees growing in mountainous terrain. Susceptibility to windfall in mixed conifer forests is related to the kind and intensity of cutting, topographic exposure, soil depth and drainage, and such inherent species characteristics as age, size, and soundness.

Fire has frequently occurred in mixed conifer forests. These fires have often been light, killing many seedlings and saplings but generally sparing larger trees. Because mature Douglas-fir and ponderosa pine are the most resistant to fire damage, there are often more of them in many mixed conifer forests. These light fires have also contributed to the irregular structure commonly seen in virgin stands, to the presence of aspen groves, and to decay.

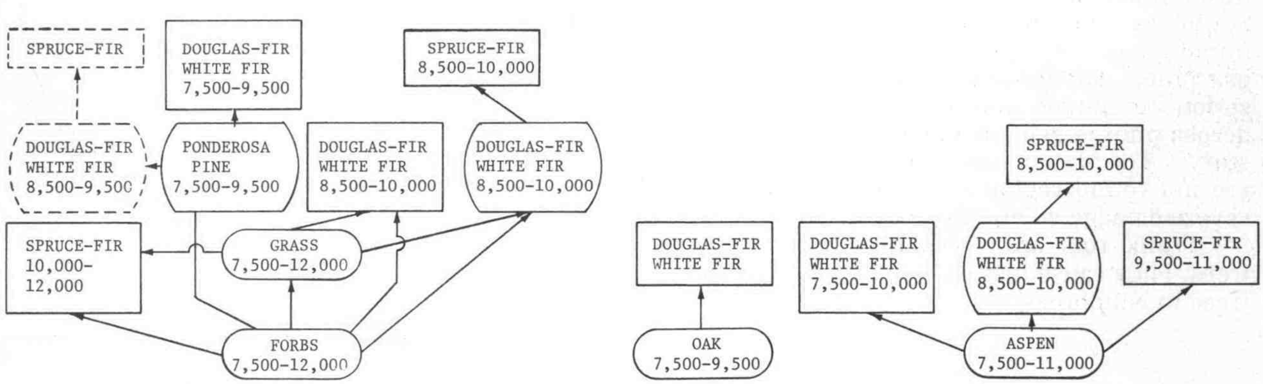

Figure 14.—Forest succession following clearcutting or severe burning of mixed conifer and spruce-fir forests in the Southwest.

Some fires have been intense, killing most trees on areas burned, but leaving a few large trees —usually Douglas-fir or ponderosa pine—as survivors. Forest succession is set back temporarily to the bare-ground stage.

The most important insect pests in mixed conifers are bark beetles and defoliators. The spruce beetle and Douglas-fir beetle attack mature to overmature trees in stands where spruce and Douglas-fir predominate. Outbreaks may develop in heavy blowdown, in trees damaged by forest fires, in concentrations of large logging slash, or in stands weakened by defoliating insects. Once outbreak levels have been reached, young vigorous trees may also be killed or damaged. Spruce beetle outbreaks are best controlled by removing poor vigor and infested trees, followed by the spraying or burning of cull material and infested trunks.

Outbreaks of western budworm periodically damage Douglas-fir and white fir. Infestations develop in young as well as overmature forests. Outbreaks result in dieback, and the dead leaders serve as centers for decay. Growth is reduced but trees commonly recover. The western tent caterpillar periodically defoliates aspen stands. Severe outbreaks may last several years and are always accompanied by a severe reduction in growth. Some stands may be essentially destroyed. In others, the outbreak may persist for several years and then collapse from natural causes.

Dwarf mistletoes reduce growth and seed production and increase mortality in southwestern mixed conifers. Infections are most important in young trees. Heavy infection of understories is less of a prospect in mixed conifer stands than in ponderosa pine stands because each mistletoe species in southwestern mixed conifers has a principal host. Douglas-fir dwarf mistletoe is the most serious, and occurs throughout the range of Douglas-fir in the Southwest. Southwestern dwarf mistletoe is found almost throughout the range of ponderosa pine. Though very damaging, it is less serious in mixed conifer stands because ponderosa pine is seldom numerous in the understory. The dwarf mistletoes on other species are not found regionwide, but they may cause severe damage where they occur.

Trunk rots are widespread in overmature trees. They cause loss of volume and predispose trees to windbreak.

Natural Reproduction and Early Survival

All mixed conifers reproduce from seed, while aspen reproduces by suckering. Blue spruce bears moderate to heavy cone crops in most years. Substantial cone crops of Douglas-fir and Engelmann spruce are frequent, while corkbark fir and white fir cone crops are more sporadic. Ponderosa pine cone crops tend to be lighter at mixed conifer elevations than lower down. The seeds of all conifers except white pine are dispersed by the wind. Seedfall into cleared openings diminishes rapidly as distance from source increased, with most seeds falling within 300 feet of the upwind timber edge (fig. 15). White pine seed is large and wingless, and dispersal beyond the immediate perimeter of the crown is mostly by rodents.

The seeds of white and corkbark firs and some white pine seeds germinate in the spring following snowmelt. The other mixed conifers germinate mainly during the summer rainy season, with ponderosa pine germination continuing into late summer. Germination and initial survival of mixed conifers are best on seedbeds with a constant supply of available

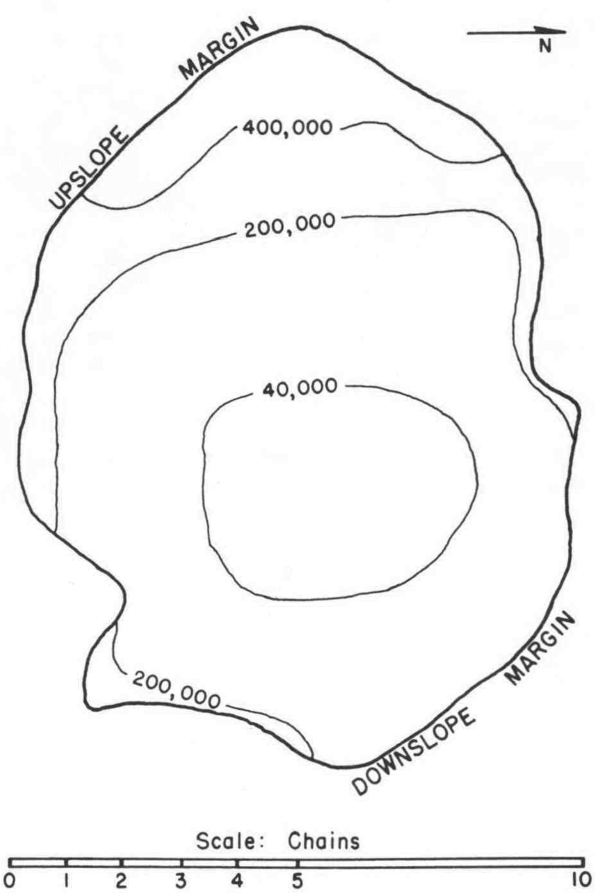

Figure 15.—Number of sound seeds dispersed into a mixed conifer clearcut during a good seed year. Apache National Forest, Arizona.

soil moisture. For example, mineral soil with a thin layer of needle litter that acts as a mulch is usually a good seedbed, whereas duff is a poor seedbed because it dries out rapidly.

Light is essential to seedling survival and growth, but Engelmann spruce, the true firs, and Douglas-fir do not establish readily in the open. Much mortality in the absence of shade is due to drying, but light injury may be a contributing factor. On the other hand, the pines, aspen, and apparently blue spruce are well adapted to establishment in the open. The initial growth of aspen is unsatisfactory in shade, and the growth of all conifers that survive the first 2 or 3 years is better in the open than in shade.

The growth of all seedlings is restricted by low nighttime temperatures early in the growing season. Severe frosts, particularly where cold air collects, may also kill new growth. Newly germinated seedlings are especially susceptible to early fall frosts, while older seedlings are more often damaged in the spring. Sequences of freezing and thawing temperatures when the soil is wet and bare of protective snow cover results in frost heaving. The shallow-rooted species — the spruces, corkbark fir, and Douglas-fir — are most susceptible. Shade prolongs snow cover and reduces the daily thawing of bare ground and the incidence of ground freezing in late spring and early fall. During the spring-early summer dry period, soil moisture deficits may develop that are critical to initial seedling survival, but usually do not kill established seedlings except on severe sites. Fall soil moisture deficits are less limiting to seedling establishment.

Biotic factors also limit mixed conifer regeneration success. Squirrels and other small mammals consume significant amounts of seed, and voles and pocket gophers kill established seedlings. Small seedlings also die from depletion of soil moisture by dense grass stands, and smothering by cured herbaceous material and aspen leaves. Sheep and big-game animals, especially deer, severely browse aspen and all species of conifer reproduction. Young seedlings are also vulnerable to trampling damage by both livestock and big-game.

Site Quality

Site index is the conventional method of estimating potential productivity in forest stands. Curves of the height-age relationship suitable for estimating site index have been prepared for Engelmann spruce (see fig. 5), southwestern ponderosa pine (fig. 16), and aspen (fig. 17), but not for other species of mixed conifers in the Southwest.

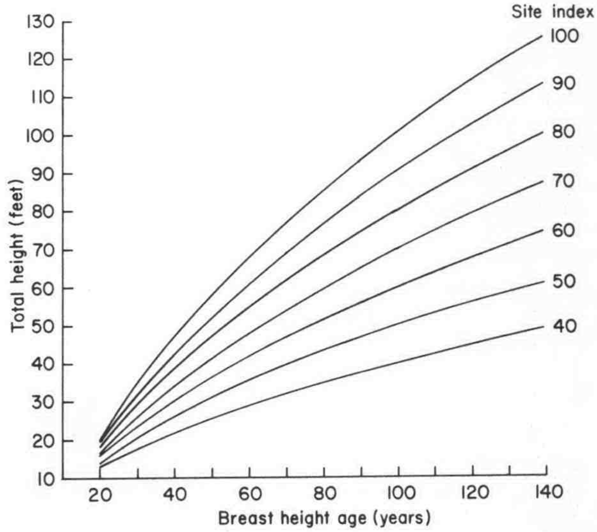

Figure 16.—Site index curves for young growth ponderosa pine in northern Arizona. Base age: 100 years, breast height.

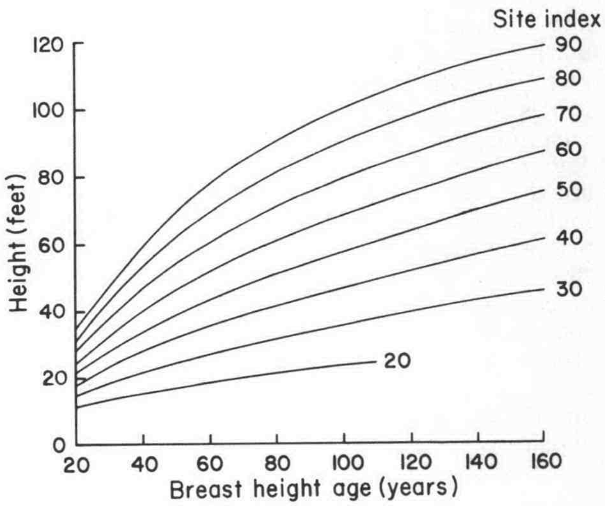

Figure 17.—Site index curves for aspen in southern Rocky Mountains. Base age: 80 years, breast height.

Growth and Yield

A high proportion of mixed conifer forests are in mature to overmature stands. Growth estimates from inventory data indicate that growth is much below what can be expected in managed stands. As old-growth mixed conifer stands are converted to new stands, they will be managed from the reproduction period to the final harvest. The only growth prediction tool available for mixed conifer species is for southwestern ponderosa pine. Data are now being collected to develop a similar yield prediction procedure for Engelmann spruce.

WHAT PRACTICES CAN WE NOW RECOMMEND

Regeneration Silviculture

The recognized harvest cutting methods applicable to mixed conifers include clearcutting, and shelterwood and selection cutting and their modifications. The choice of cutting methods depends on management goals, but stand structure and composition, and wind, insect, and disease problems impose limitations on how stands can be handled.

Aspen Management

Aspen stands commonly occur either as single- or two-storied stands. Single-storied stands should be clearcut—preferably in fairly large acreages to reduce browsing damage—if a market exists for small round products. Unmerchantable trees should be felled and all debris and logging slash cleaned up by broadcast burning or machine piling and burning. This should be all that is necessary to regenerate the area. If there is a market only for saw logs, a three-cut shelterwood is usually appropriate because the unmerchantable portion of these stands is susceptible to windthrow and disease problems if the stands are opened up too much. It may be desirable to convert single-storied stands to conifer forests by planting the areas with shade-tolerant conifers. Provision should be made to release the conifers from aspen suckers.

Two-storied aspen stands usually have a mixed conifer or spruce-fir understory (fig. 18). If this understory is sapling size, the overstory should be removed in a single cut to release the conifers. Aspen suckers will fill in the gaps. If the understory is composed of seedlings or trees larger than sapling size, the overstory should be removed in two or three steps.

Figure 18.—An aspen overstory with a mixed conifer understory in the Southwest.

On partially cut areas and where there is a manageable understory of reproduction, protection of the residual stand during logging is of primary concern. The logging plan should include skid roads laid out and marked on the ground so that they can be used to remove logs at each cut. Trees should be felled into openings as much as possible, and at an angle that will permit logs to be pulled onto the skid roads with a minimum of disturbance. If it is necessary to fell trees at a poor angle for winching onto skid roads, logs should be bucked into short lengths. Some slash treatment will probably be needed after each cut, but it should be confined to concentrations. Where slash disposal equipment cannot operate, slash should be hand piled for burning in small piles or scattered.

Conifer Management

Mixed conifers occur in a wide variety of stand structures and species composition (fig. 19). Single-storied stands are likely to be strongly dominated by a single species. If stands are not widely infected with dwarf mistletoe they can be partially cut. Shelterwood should be used if the stands are even-aged and uniformly spaced, and group selection if they are uneven-aged, clumpy, and irregular. The amount of basal area to be removed at each entry, the number of entries, and the size of group openings depends largely on the windfall risk situation.

In some stands, even-aged, well-stocked overstories of ponderosa pine dominate an understory of mixed conifers. If the understory is seedlings and saplings, an overwood removal in one step can be used in these two-storied stands to release the conifers. If the understory is pole sized, a two- or three-step shelterwood should be used. To maintain ponderosa pine dominance, clearcutting in small patches and planting pine is recommended. Where the overstory in two-storied stands consists of species other than pine, the understory is likely to be understocked. If not badly infected with mistletoe, a shelterwood that removes the overstory in a series of partial cuts is recommended.

In three-storied stands and multi-storied virgin stands where dwarf mistletoe is not severe, the overstory can be removed in a two- or three-cut shelterwood or by group selection. Cutover multi-storied stands are sometimes poorly stocked. They can be managed as uneven-aged stands under a selection system or converted to even-aged management by cutting the older trees. Understocked openings should be planted or otherwise treated to stimulate prompt regeneration.

On all partially cut areas and those clearcut with a manageable stand of advanced reproduction, protection of the residual stand is important. The same care in logging and slash disposal recommended for aspen stands with a conifer understory apply here.

Single-storied stands badly infected with dwarf mistletoe can be regenerated by the shelterwood method if the infected residuals are removed as soon as regeneration permits. The regeneration will require one or more sanitation cuttings after the overstory has been removed. Seriously infected stands with more complex structures may also be manageable by shelterwood or selection methods because of host specificity. Other severely infected stands or parts of stands should be clearcut. Since clearcut mixed conifer areas do not regenerate well naturally, they should be planted.

Planting is also needed on nonstocked areas and to fill in gaps after partial cutting. In areas where big-game and livestock use is heavy, species like the spruces and white pine should be favored over Douglas-fir and ponderosa pine. Tolerant conifers should be planted under aspen. On exposed sites below about 9,000 feet, ponderosa pine is most likely to survive. Above 9,000

Figure 19.—A virgin multi-storied mixed conifer stand in the Southwest.

feet on exposed sites, Engelmann spruce will have to be used, but it must be provided with dead shade. Planting procedures developed for spruce-fir forests apply here.

Multiple-Use Silviculture

Silvicultural prescriptions in mixed conifer stands must consider uses other than timber production. Esthetic and recreational considerations may require the maintenance of a continuous high forest cover. On the other hand, a combination of cleared openings and high forests increases water yields, favors livestock use, and benefits certain kinds of wildlife. Openings cut in stands should be a repetition of natural shapes that will complement the landscape.

Aspen has outstanding multiple use potentials. It is highly regarded for its scenic beauty, especially where other types of vegetation cover extensive areas. Aspen stands without coniferous understories provide considerable forage for big-game and livestock. Aspen is best perpetuated by burning or clearcutting.

WHAT DO WE NEED TO KNOW

Silvicultural prescriptions and cultural practices must be developed in mixed conifer stands of differing structures and species composition that will establish and maintain high forests. Such forests can be used alone or in combination with cleared openings to meet the needs of a variety of uses including timber production. For the timber resource the needs include: (1) classifying southwestern mixed conifer habitats into ecologically similar units; (2) classifying mixed conifer stands into different stand types considering both composition and structure; (3) identifying potentials and problems of different stand types on different habitat types; and (4) testing silvicultural systems and cultural practices in stand types on different habitat types.

Beyond the classification of habitats and stands, we need to know: (1) how to recognize habitat types in areas which have been altered by past activities; (2) how the various mixed conifer species reproduce, grow, and interact in the different habitat and stand types; and (3) the physical responses and successional trends following management prescriptions.

Growth prediction tools for southwestern mixed conifers are or soon will be available for only two species—ponderosa pine and Engelmann spruce. It will be necessary to either develop (1) composite yield tables based on these two species, or (2) growth prediction tools for each mixed conifer species. In any event, volume tables and methods of estimating site index must be prepared for each species before yields can be forecast.

Methods of obtaining natural and artificial regeneration must be explored more fully. Information is needed on (1) regeneration requirements of individual species by habitat types, (2) physiological response of seedlings and planted stock to environmental factors by habitat types, (3) environmental and biotic factors limiting regeneration success for different habitat and stand types, (4) cultural practices and protective measures to modify limiting factors for different habitat and stand types, (5) methods of evaluating and managing advanced growth, and (6) what species to favor for specific management goals.

THE SOUTHWESTERN PONDEROSA PINE TYPE

Southwestern ponderosa pine covers extensive areas in the Southwest (Arizona, New Mexico), Colorado, and Utah (fig. 20). In the Southwest, ponderosa pine grows between 5,500 and 9,500 feet elevation, but reaches maximum development at 7,000 to 8,000 feet. In Colorado, it is found between 5,000 and 9,000 feet elevation. Ponderosa pine is the largest and most valuable timber resource in Arizona and New Mexico, but is less important in Colorado (see table 1). Most of the ponderosa pine forests are in sawtimber-sized stands, but there are more poletimber stands in Colorado than in the Southwest (see table 2). Stocking in all three States is generally low.

Figure 20.—Occurrence of ponderosa pine in the Southwest.

WHAT DO WE KNOW ABOUT SOUTHWESTERN PONDEROSA PINE FORESTS

Habitat Conditions

The climate where ponderosa pine grows can be described as moisture deficient. Average annual precipitation ranges from 18 to 21 inches, but the distribution varies over the area. In the Southwest, April through June are the driest months and July through September the wettest. In Colorado, precipitation is more uniformly distributed from April through September. Considerable snow falls in most winters, but it is less important in terms of total precipitation than for forest types at higher elevations. In years of low snowfall, deep soil freezing occurs. The growing season is fairly long (average 135 days), and monthly mean temperatures vary from about 29° F in January to 68° F in July.

Soil parent materials vary according to the bedrock from which they originate. In the Southwest, soils derived from basalt occur on about half the area, while most of the remaining area has soils derived from granite, sandstone, and limestone. In Colorado, crystalline granitic, sedimentary, and volcanic rocks predominate. Soils vary widely in texture and physical and chemical properties.

Climax and Succession

Southwestern ponderosa pine occurs as a climax type between 7,000 and 8,000 feet elevation, but disturbances by fire or heavy logging have partially or completely converted many climax ponderosa pine stands to other plant communities (fig. 21). The kind of vegetation initially occupying the site usually determines the length of time it will take to return to a ponderosa pine forest. At higher and lower elevations, where ponderosa pine integrates into mixed conifer and pinyon-juniper forests, it loses its climax characteristics unless special effort is made to retain it in the stand.

Figure 21.—A clearcut ponderosa pine area which failed to regenerate because of a lack of seed source. Site is now occupied by Arizona fescue and mountain muhly grasses.

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Stand Conditions

In the Southwest, ponderosa pine forests are usually open-grown, poorly stocked, and interspersed with occasional meadows and parks. These forests occur mainly as irregular, uneven-aged stands consisting of small even-aged groups, varying in size from a few trees to several acres (fig. 22). Past cutting practices involving a variety of selection methods have tended to preserve the uneven-aged structure. However, occasional stands are even-aged where fires, open areas, and early clearcuttings have regenerated.

Pure ponderosa pine stands normally occur where the species is climax. Mixed stands, however, are not uncommon. Both pure and mixed stands may have an understory of younger trees.

Figure 22.—Uneven-aged ponderosa pine stand in northern Arizona.

Damaging Agents

Wind is a primary cause of damage to mature and overmature ponderosa pine, especially when windstorms in the fall and spring are accompanied by heavy precipitation. Lightning also damages old-growth ponderosa pine, but it is not always fatal.

Damage from wildfire occurs mainly in young age classes, but hot fires will destroy all trees in the burned area. Where large trees are not killed, fire scars reduce the value of the butt log and provide entry points for wood-rotting fungi.

Dwarf mistletoe is the most widespread and damaging disease affecting southwestern ponderosa pine (fig. 23). It infects trees of all age classes, and may kill small trees in a few years. Older and larger trees die more slowly. Heavily infected stands should be clearcut and the area replanted. In low density stands with a manageable understory, dwarf mistletoe may be treated by an overstory removal followed by a thinning and pruning of understory trees.

Figure 23.—Dwarf mistletoe damage on southwestern ponderosa pine.

Western red rot is the most important heart rot of ponderosa pine. It causes loss of volume and predisposes trees to windbreak. Sanitation-salvage cutting is the most effective silvicultural control of red rot.

The mountain pine beetle is the most aggressive insect pest of southwestern ponderosa pine. It normally attacks and kills old and weakened trees, but will attack and kill vigorous, young trees when insect populations reach epidemic proportions. The roundheaded pine beetle periodically infests ponderosa pine over many areas. Infestations develop from endemic population levels in dense stands on poor sites or where trees have been attacked by other beetles. Populations may then build up and attack trees on better sites. The western pine beetle attacks trees larger than 6 inches d.b.h. that are of poor vigor.

Animals can damage ponderosa pine other than regeneration stands. For example, porcupines deform, and debark or girdle and kill pole-sized trees and young sawtimber. Twig cutting by tree squirrels normally reduces growth and causes forked trees, but it may be so severe that trees are killed or become susceptible to attack by bark beetles.

Natural Reproduction and Early Survival

Natural reproduction success depends on an ample seed supply and adequate moisture for germination and early survival — conditions that seldom coincide. Ponderosa pine produces good seed crops only at intervals of 3 to 4 years, with lighter crops in some of the intervening years. Seed is dispersed by the wind, but is not effectively disseminated over extensive areas.

Trees vary considerably in their ability to produce cone crops. The best seed producers are vigorous dominants, 24 to 28 inches in diameter, that are free from disease or damage and show evidence of having produced good cone crops (fig. 24).

Viable seeds that survive overwinter do not germinate in the spring because, by the time seedbeds are warm enough in late May or early June, they are too dry for seeds to imbibe sufficient water. Germination usually begins with the summer rains in July, but if the rains are too light to keep the seedbeds moist or are late in coming, germination is delayed until late summer. Late-germinating seedlings are then especially susceptible to frost heaving or fall drought.

The best seedbed is loose enough so that a light layer of mineral soil covers the seeds, and has sufficient dead needle litter to prevent excessive drying. Germination may be good in heavy litter in years of high rainfall, but seedlings do not survive because of rapid drying when the rains stop. Shade from dead material benefits germination because it conserves soil moisture, but ponderosa pine seedlings that start in dense shade do not survive long unless the shade is removed. Live shade is not detrimental to germination, but grasses, shrubs, and other small trees limit seedling establishment because of intense competition for limited soil moisture. On the other hand, although ponderosa pine seedlings are not damaged by exposure to full solar radiation, side or light overstory shade improves survival and early growth by lowering temperatures, thereby reducing water losses from both seedlings and soil.

Low temperatures normally cause only minor damage in the ponderosa pine zone, but young seedlings are susceptible to freezing injury. Newly germinating seedlings, especially those germinating late in the season, are most likely to be damaged by fall frosts. Older seedlings are most susceptible to damage by early spring frosts when tissues are still succulent. Seedlings have been winterkilled, but freezing temperatures are involved only indirectly by their effects on soil moisture. Frost heaving, however, from alternate freezing and thawing of saturated soils unprotected by snow cover, is a serious cause of ponderosa pine seedling mortality. Shade reduces mortality from frost damage by reducing the loss of radiant energy from both soil and seedlings.

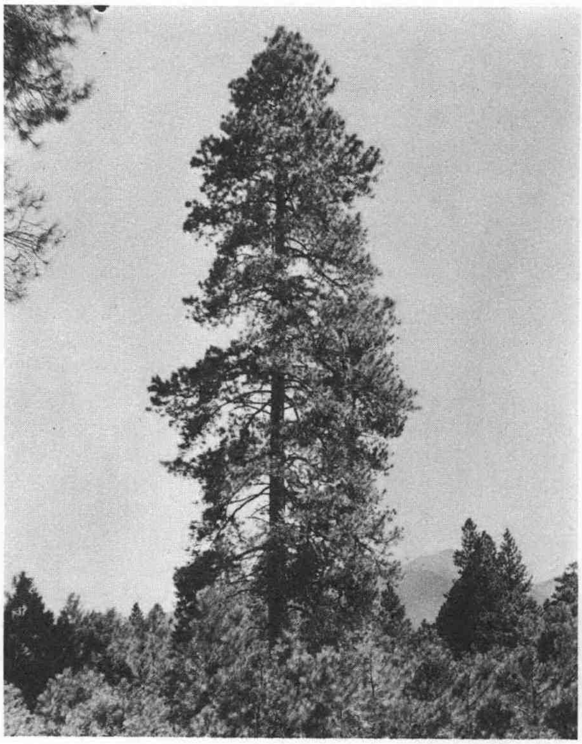

Figure 24.—Excellent ponderosa pine seed tree. Fort Valley Experimental Forest, Arizona.

Diseases, insects, and animals also limit ponderosa pine regeneration success. Newly germinated seedlings are killed by damping-off fungi. Cone and seed insects destroy seed before it is dispersed. White grubs, cutworms, and tip moths damage both new and older seedlings. Small mammals cut and cache cones, eat shed seed, and kill or injure young seedlings. Birds clip the seedcoats from newly germinated seedlings, and big-game animals and livestock browse and trample small seedlings (fig. 25).

Site Quality

Site quality indicates relative productive capacity, and determination of productivity is basic to yield prediction, optimum levels of

Figure 25.—Cattle damage to ponderosa pine. Fort Valley Experimental Forest, Arizona.

growing stock, and the intensity of management. Site index, determined by the height-age relationship, is the conventional method of estimating site quality in southwestern ponderosa pine. In Arizona, southern Colorado, and New Mexico, site index is determined from curves of the height of dominant trees at breast height age (see fig. 16). Curves of the average height of dominant trees at total age are available for estimating site index on the east slope of the Front Range in northern Colorado (fig. 26). Elsewhere in Colorado, regional curves are based on the height of dominant and codominant trees of average diameter at total age. Ponderosa pine forests in the Southwest can also be grouped into three broad site classes for land suitability planning.

Growth and Yield

The effect of stand density on the growth of southwestern ponderosa pine is well documented. For example: (1) diameter growth at all ages is inversely related to residual stand density, and diameter growth decreases rapidly if stand density is not reduced at periodic intervals; (2) basal area increment increases with an increase in basal area stocking until basal area per acre exceeds about 80 ft^2 per acre; (3) height growth is unrelated to stand density, except in very dense stands; and (4) volume growth per acre increases with an increase in basal area stocking, except at very high densities.

Natural stands of ponderosa pine in the Southwest are generally poorly stocked, and low stocking is reflected by the low volumes per acre. For example, in Arizona, ponderosa pine stands average only about 6,200 fbm per acre. Average per-acre volumes are even less in New Mexico and Colorado. Fully stocked stands on good sites are capable of yields of 25,000 to 35,000 fbm per acre.

Forest management in the Southwest is in a transition to more intensive management. As old-growth stands are converted to new stands, they must be managed from the regeneration period to final harvest. Furthermore, many young stands, some of which have been thinned once, must also be brought under management. Yield tables for managed stands are the basis for timber management planning. Field and computer procedures for preparing yield tables for managed stands of southwestern ponderosa pine, including those infected with dwarf mistletoe, realistically simulate stand growth, response to growing stock levels, and reproduction cutting by any of the even-aged systems. The Southwest phase of the Westwide Growing Stock Level study plots will provide periodic checks on the simulation procedures.

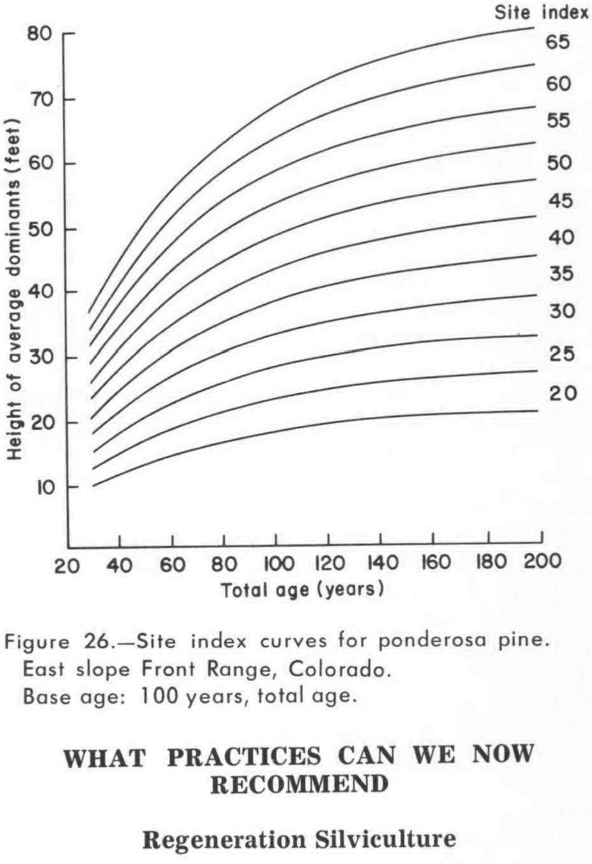

Figure 26.—Site index curves for ponderosa pine. East slope Front Range, Colorado. Base age: 100 years, total age.

WHAT PRACTICES CAN WE NOW RECOMMEND

Regeneration Silviculture

The most appropriate silvicultural systems for southwestern ponderosa pine are shelterwood and group selection cutting, but individual tree selection and clearcutting can be used under certain conditions. Many southwestern ponderosa pine stands can be managed as either even- or uneven-aged, or converted from one management system to another. The choice of cutting method depends largely on management goals and silvicultural stand condition class, but dwarf mistletoe infection, and wind and fire risk may limit the way stands can be cut.

Even-Aged Management With Natural Reproduction

Shelterwood cutting should be used in most stand condition classes where it is desirable to manage stands as even-aged. The three-step shelterwood or a series of partial cuts is most appropriate for unmanaged stands, and a two-step shelterwood should be used for managed stands or those susceptible to windthrow. Care in logging at each cut is essential to protect the residual stand and advanced reproduction where a manageable stand exists. Precommercial thinning of sapling stands before final harvest will reduce logging damage. Other criteria developed for protection of residual stands in spruce-fir forests also apply here. If the stands are to be regenerated to new reproduction, a thorough job of site preparation is needed to eliminate competition and possible loss of the site to grass and brush. The final harvest should be made promptly after seedlings are established to release new reproduction, but protection of the reproduction from logging damage is of primary concern.

Some slash disposal will probably be needed after each cut, but it should be limited to treatment of concentrations and that needed to reduce environmental impacts. Slash should be lopped and scattered where possible. If it must be burned, piles should be kept small and scattered.

Shelterwood cutting also can be used to convert irregular, uneven-aged stands to an even-aged structure. Where there is not a manageable stand of advanced reproduction or the overstory has a heavy volume, a two-step shelterwood should be used. If the overstory is light, with a heavy understory of advanced growth, an overwood removal is appropriate.

Areas heavily infected with dwarf mistletoe should be clearcut in patches or blocks no larger than about 20 acres. If local experience indicates that these areas are not likely to restock naturally, they should be planted.

Uneven-Aged Management With Natural Reproduction

Selection cutting is appropriate in the irregular, uneven-aged stands that occur over much of the Southwest where it is desirable to maintain the uneven-aged structure. Trees may be cut as individuals scattered over the area or in groups, but group selection is the preferred method where the stand condition class and management goals permit its use (fig. 27). Under group selection, the naturally occurring groups, which average from about 1/2 to 2 acres in size, are treated according to their needs. For example, old decadent groups should be cut and the area promptly regenerated by natural or artificial seeding or planting. Immature and mature groups should be given a sanitation cut to improve vigor and growing conditions. Ponderosa pine forests overstocked in the smaller and larger diameter classes, and understocked in the intermediate classes, can be converted to group selection by heavy cutting in the overstocked diameter classes. Slash should be disposed after selection cutting by lopping and scattering or burning in small piles.

Figure 27.—Group selection cutting in southwestern ponderosa pine. Trees at the right are in the group being cut. Young trees in the background came in after an earlier group selection cut.

Management With Artificial Regeneration

One of the objectives of the silvicultural systems described above is to obtain natural reproduction. Areas which do not restock or need supplemental stocking must be either planted or direct seeded.

Complete site preparation to conserve soil moisture is a must if planting or seeding is to succeed. Mechanical scarification that removes or reduces vegetative competition and prepares a good seedbed is preferred to other methods.

Planting is the most effective way to artificially regenerate ponderosa pine. Plant only stock from local seed sources that meets Forest Service Regional standards. Ponderosa pine planting stock must be carefully handled. It should be lifted when dormant and treated as live dormant plant material during transport to and storage at the planting site. Planting may be done by hand using the hole method or by machines. The most favorable sites should be planted first, taking advantage of dead shade. Success is better with spring than fall planting. A minimum goal is 680 trees per acre.

Direct seeding is more economical and flexible than planting, but it is less reliable. Freshly burned and logged areas are the most promising sites for direct seeding. Spot seeding is the most effective method; it requires the least seed and the seed can be placed in the best locations. Broadcast seeding is faster and more flexible, but less effective and requires more seed. The best time to seed is during the last part of June so that the seed is exposed to damaging agents for a shorter period of time before the summer rains begin. Only local seed sources should be used.

Successful seeding or planting is only the first step in reforestation. New plantations must receive care and be protected from damage or loss from fire, insects, rodents, vegetative competition, and browsing and trampling animals.

Intermediate Stand Management

Intermediate cuts are (1) thinnings, and (2) release, improvement, and salvage cuttings. These are made from the time a stand is established until the time to establish the replacement stand. These cuts cover the major portion of the rotation period, and are normally made at periodic intervals to increase growth and quality, and to salvage material that would otherwise be lost.

Multiple-Use Silviculture

Timber management activities in southwestern ponderosa pine have a great impact on all forest uses for wood, forage, recreation, water, and wildlife. Standard silvicultural systems and practices will provide multiple use benefits and sustained yield with only minor adjustments in some instances. For example, by maintaining less basal area and overstory density, and using a longer cutting interval than is optimum for timber production under shelterwood cutting, both the amount and quality of forage can be increased for both wildlife and livestock. Forage production can also be increased by group selection cutting.

In travel and water influence zones, recreation sites, and scenic view areas, individual tree selection cutting can be used to improve natural beauty. Cutting should be light and the number of trees removed varied throughout the stand to develop stands in these special use areas that will contain trees from seedlings to yellow pines.

WHAT DO WE NEED TO KNOW

Silvicultural practices developed for timber production in southwestern ponderosa pine must be modified to establish and maintain stands with the form, structure, and arrangement needed to integrate all key land uses. For the timber resource, these modifications include: (1) grouping pine forests into ecological land units of similar stand characteristics as a basis for identifying management potentials for existing stands, and (2) testing cutting and other cultural practices to attain management goals in stands of different characteristics.

Classification of vegetation in the southwestern ponderosa pine zone is needed as a basis for improved forest descriptions and preparation of management prescriptions needed to guide the manipulation of forests for multiple use. For the timber resource this includes: (1) what ecological land units are present and how to recognize them in areas that have been altered by past activities; (2) how ponderosa pines reproduce, grow, and interact with abiotic and biotic agents in a variety of situations; and (3) how stands respond in terms of succession and the stability of various habitat types to different management prescriptions.

Field and computer simulation procedures developed for the prediction of growth and yield of even-aged ponderosa pine in the Southwest must be expanded to include uneven-aged stands and those with irregular stand structures that can be used for timber production and other key land uses. For both even- and uneven-aged management, the biotic potential and response criteria must be identified for different habitat types to aid the manager in making sound decisions for multiple use management.

Methods of obtaining artificial regeneration have been largely developed for southwestern ponderosa pine, but prompt and adequate natural reproduction has not been attained after cutting in many areas. Natural reproduction requirements are known, but the factors limiting regeneration success and the methods needed to reduce losses must be identified for different habitat types. The most critical needs, however, are to determine the stand densities and cultural practices under shelterwood cutting in different stand condition classes, and the size of opening cut under group selection cutting, required to obtain natural regeneration.

BLACK HILLS PONDEROSA PINE FORESTS

Ponderosa pine forests cover about 1 million acres in the Black Hills of South Dakota and Wyoming, and the Bear Lodge Mountains of Wyoming (fig. 28). These forests form a unique, isolated segment of the interior ponderosa pine type, but management is simplified in the Black Hills because these forests reproduce readily and prolifically, and are free of dwarf mistletoe. Ponderosa pine is the principal timber resource, and it usually occurs in pure stands (see table 1). The original forests have been largely converted to second growth, and the distribution of age classes is better than for central and southern Rocky Mountain timber species. However, the largest proportion of the area still supports the remnants of old-growth sawtimber stands, mostly with regeneration below, and the smallest proportion is in seedling and sapling stands without overstory (see table 2).

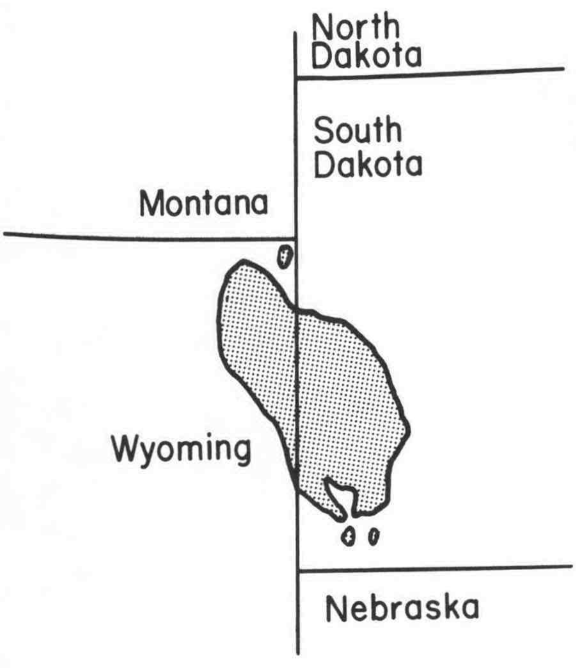

Figure 28.—Occurrence of ponderosa pine in the Black Hills and Bear Lodge Mountains.

WHAT DO WE KNOW ABOUT BLACK HILLS PONDEROSA PINE FORESTS

Habitat Conditions

The climate of the Black Hills is characterized by an orographic rain belt where precipitation is increased and temperatures reduced from the surrounding plains by the mountains themselves. Average annual precipitation varies from 17 inches in the south to 28 inches in the north, 60 percent or more of which falls as rain from April to September. January and February are usually the driest months, and May and June the wettest. The growing season averages about 100 days, and monthly mean temperatures vary from 22° F in December to 68° F in July.

The Black Hills and Bear Lodge Mountains have four visible and distinctive gross geomorphologic features: (1) a "hogback ridge" of mesozoic sedimentary rocks encircling the area, (2) a "red valley" of less resistant sedimentary rock, (3) a limestone plateau, and (4) a central core of crystalline rock (fig. 29). The main timber-producing areas are the crystalline core area, which is characterized by rough to rounded hills and divides generally ranging from 4,300 to 6,000 feet elevation, and the limestone plateau. In the east the plateau forms a narrow ridge that occasionally flattens out to narrow uplands with elevations of 3,600 to 4,400 feet; in the west it forms wide, rather level divides separated by narrow, steep valleys that range in elevation from 4,500 to 7,000 feet.

Soils in the Black Hills have not been surveyed, but their general profile characteristics approximate a loam to silty clay loam of the Grey Wooded Soils Group.

Climax and Succession

Ponderosa pine occurs as a climax type that essentially dominates most forest areas in the Black Hills. A variety of other native tree species are only minor components. For example, white spruce frequently grows in pure stands along streams, lower slopes, and upper north-facing slopes in the northern Hills, but it occupies only about 2 percent of the total commercial forest land. Occasionally ponderosa pine is temporarily replaced by other plant communities after fire or other disturbance, but it usually reoccupies most sites rapidly.

Stand Conditions

In the Black Hills, transitional two-aged stands composed of a light overstory of residual old-growth trees above dense second growth occur on more acres than any other stand condition. Dense, uniform, even-aged stands free of overstory and mostly immature occupy most of

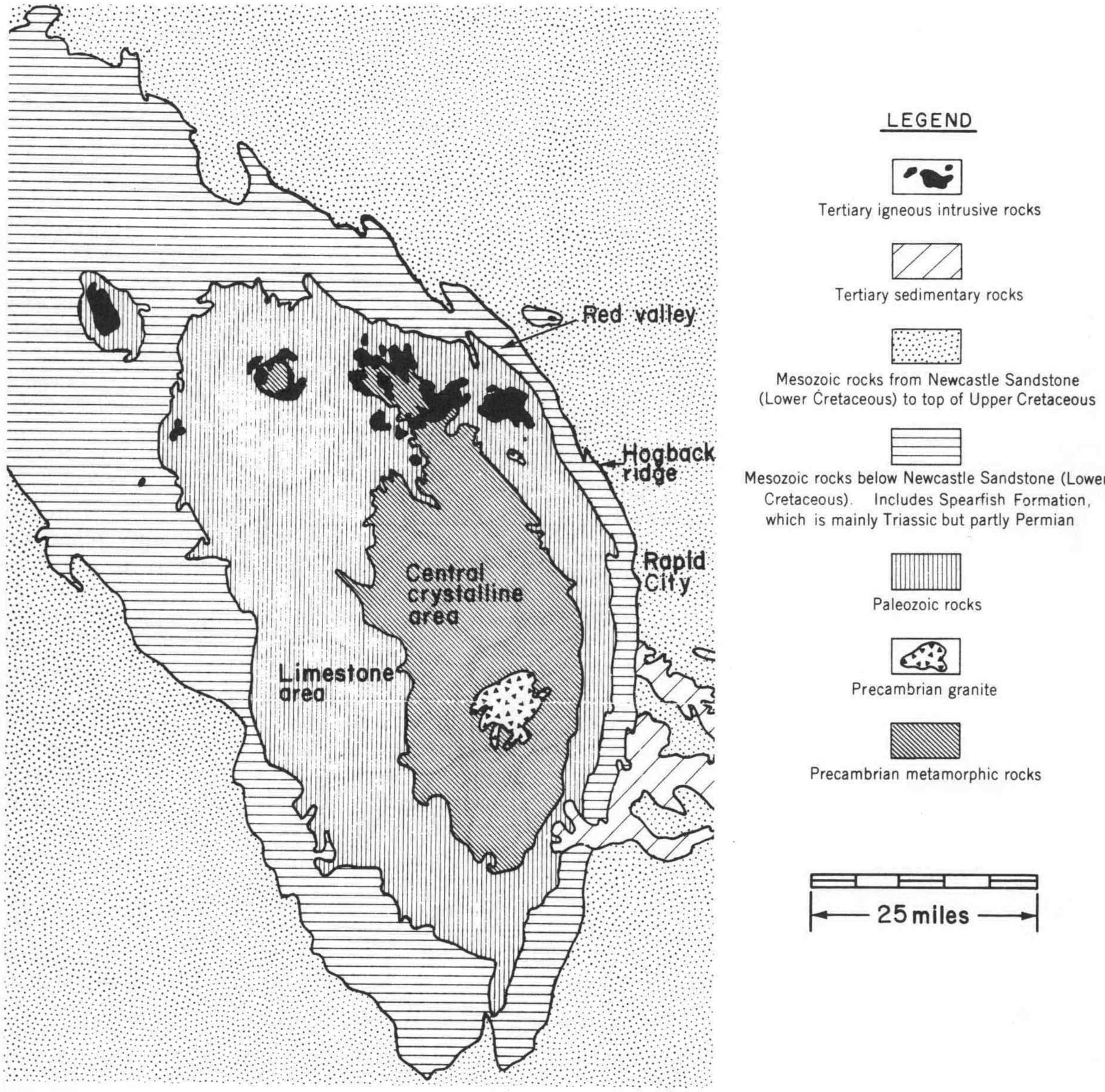

Figure 29.—Geomorphologic features of the Black Hills.

the remaining forest area. Uneven-aged stands can be found occasionally where pine has invaded grassy upland parks or old burns, and there has been prolonged protection from wildfires. Ponderosa pine stands are typically pure in the Black Hills.

Damaging Agents

Ponderosa pine trees that grow in dense stands have diameters too small for their heights, poorly developed root systems, and asymmetrical crowns. Abrupt reduction in stand density by a single thinning usually results in death or deformity from bending, breaking, or uprooting caused by wind and snow.

In much of the Black Hills, wildfires can burn any month, but midsummer through fall is the maximum hazard period. Mature stands of well-spaced trees are less susceptible to damage from crown fires than dense stands, but hot fires will destroy all trees on an area. Large trees that survive ground fires may be scarred so that the value is reduced and the trunks are susceptible to decay.

The most aggressive and damaging insect pest of Black Hills ponderosa pine is the mountain pine beetle. It normally attacks and kills older trees and those weakened by overstocking, but will attack and kill vigorous younger trees when insect populations reach epidemic proportions. Periodic epidemics that require direct control are likely to diminish in the Black Hills as overstocked stands are converted to thrifty stands. The red turpentine beetle is also found in the Black Hills, but it is usually a secondary cause of mortality, attacking trees weakened by other factors.

Western red rot and associated decay fungi cause large volume losses in old-growth timber. The impact of these diseases is reduced in young, thrifty, managed stands.

Of all animals that damage ponderosa pine beyond the seedling stage, porcupines are the most serious and persistent threat to tree growth and yield. The most desirable trees are usually attacked, and debarking and stem girdling will either kill or deform the affected trees.

Natural Reproduction and Early Survival

Ponderosa pine in the Black Hills is a dependable seed producer. Good to excellent crops, by local standards, normally occur about every 2 to 5 years, with light crops or complete failures in the intervening years. Seed is disseminated by the wind; effective dispersal distance from ponderosa pine trees is only about three to four times the crown radius, however. The combination of ample seed and favorable spring and summer precipitation usually makes natural reproduction abundantly available—a unique characteristic in ponderosa pine forests.

Viable seeds that survive overwinter normally germinate in the spring when seedbeds are moist and warm enough for seedlings to emerge. The best seedbeds are mineral soil, or a combination of mineral soil and unincorporporated organic matter which is loose enough so that a light layer of soil covers the seeds. With a constant supply of moisture available during the growing season, however, Black Hills ponderosa pine will germinate and become established on a wide variety of seedbeds.

Germination and early seedling development are usually considered best in full sunlight, but light shade from overstory trees or slash is also beneficial to early seedling survival. The limited competition that favors the development of pine seedlings also favors the development of competitive vegetation, however, and the site may be lost to grass, forbs, or shrubs unless regeneration is promptly established. Ponderosa pines that start in deep shade do not survive or develop unless the shade is removed.

Drought infrequently limits regeneration success in the Black Hills, and low temperatures normally are not a problem, although newly germinated seedlings are susceptible to freezing injury from fall frost.

Diseases, insects, and animals also influence regeneration success. Damping-off fungi kill newly germinated seedlings, especially where seedbeds are kept damp. Mice and voles eat shed seed, and voles, rabbits, and porcupines kill or injure young seedlings. Big-game animals and livestock browse and trample small seedlings.

Site Quality

Evaluation of site quality is the key to focusing effort where timber production has the greatest potential. Site index is the best method of determining site quality in the Black Hills. Curves of the height-age relationship have been prepared that are suitable for Black Hills ponderosa pine stands where the age of index trees is at least 70 years old, and past crowding has not materially restricted height growth (fig. 30).

Very often in the Black Hills, the conventional method of site index cannot be used because either there are no trees present or they are unsuitable for measurement. Site index for either the crystalline or limestone areas can be estimated from equations based on soil and topographic parameters.

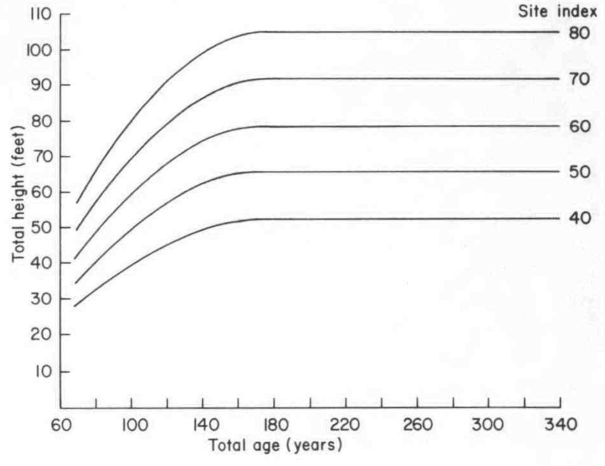

Figure 30.—Site index curves for ponderosa pine in the Black Hills. Base age: 100 years, total age.

Growth and Yield

Extremely high stand densities — often more than one tree per square foot — are common to naturally regenerated stands of Black Hills ponderosa pine (fig. 31). Since these dense stands do not thin themselves well naturally, artificial thinning is needed to reduce competition for growing space. Thinning effectively reduces mortality, stimulates diameter growth in proportion to the reduction in stand density, increases height growth, alters stem form, and concentrates increment on the best growing stock. Basal area increment in thinned stands increases as basal area per acre increases to about 80 ft^2 per acre, although the rate of increase tends to gradually diminish with each successive addition of growing stock. Cubic volume increment increases in a similar manner.

The operable and unreserved original old-growth ponderosa pine stands in the Black Hills have been largely converted to well-stocked and manageable second-growth. In addition, there are many stands of young growth that originated after fires or early cutting, some of which have been thinned at least once, others are overstocked. All of these stands need to be brought under more intensive management for a variety of uses. Yield tables for managed stands are the basis for timber management planning. Field and computer procedures for preparing yield tables for Black Hills ponderosa pine produce simulations of (1) stand growth, (2) response to thinning, and (3) reproduction cutting by any of the even-aged systems. The manager can use the computer simulation program to produce a series of yield tables for different combinations of site quality, growing stock levels, cutting cycles, and rotation ages that will show projected outcomes in response to different cultural treatments, and select the one that best meets his management goals. The Black Hill Westwide Growing Stock Level study plots provide periodic checks on simulation procedures.

Figure 31.—Stagnated stand of Black Hills ponderosa pine saplings, 63 years old with 5,800 stems per acre.

WHAT PRACTICES CAN WE NOW RECOMMEND

Regeneration Silviculture

Regeneration silviculture in the Black Hills has been learned by experience during nearly a century of harvesting that has included all silvicultural systems, and led to the replacement of the original old-growth by well-stocked, manageable second-growth stands. The most obvious lesson from this varied experience is that any regeneration system can be applied to Black Hills ponderosa pine, but even-aged management is the most compatible with the strong natural tendencies of the species, silvicultural condition classes, and regulation of cut for timber production, and best meets other management objectives.

Even-Aged Management With Natural Reproduction

The shelterwood system is the best harvesting method for most ponderosa pine condition classes in the Black Hills because it takes advantage of the species' natural habit of forming even-aged stands. Furthermore, shelterwood cutting combines the advantages of continuous vegetative protection of the site, assurance of an adequate, well-distributed seed source, fair control over development of competitive ground cover, and good control over logging residue. A uniform two-cut shelterwood is the most effective and desirable, but a three-cut shelterwood may be used in very heavily stocked, mature stands where residue buildup, risk of windfall, and logging damage to reproduction pose unusual problems.

Site preparation will be needed on areas to be regenerated to new reproduction if the original stand was open enough to permit a stand of grasses, forbs, or shrubs to establish in sufficient numbers to take over the site before the new reproduction can get started. Along roads or in other high-use areas, slash should be piled and burned or chipped after each cut to reduce fire hazard and create an esthetically acceptable appearance. Elsewhere the slash can be lopped and scattered. The overwood should be removed promptly and carefully after reproduction is established to release new reproduction with a minimum of damage (fig. 32).

Figure 32.—Established 10-year-old Black Hills ponderosa pine reproduction under a shelterwood ready for the overwood removal.

Other even-aged methods have been successfully used to harvest and regenerate ponderosa pine stands in the Black Hills, and they have some advantages and disadvantages relative to shelterwood. For example, the advantages of leaving a few widely spaced trees in seed-tree cutting include less competition to the development of the new stand, less damage to new reproduction during final harvest, and less likelihood of excessive reproduction because of limited seed production potential. On the other hand, the heavy first cut leaves more logging residue that must be treated, the risk of loss of seed trees is high, and the limited overstory competition favors the development of other vegetation as well as tree seedlings.

Clearcutting is the least desirable even-aged system in the Black Hills, especially on areas without advanced reproduction. If stands are to be clearcut and regenerated naturally, either the cut should be made during or shortly after a good seedfall, or the cutover area should be no wider than about 200 to 250 feet to permit adequate seed dispersal from the surrounding uncut stand. Clearcut units can be blocks, patches, or strips with irregular boundaries for improved appearance. Clearcutting entails little risk of loss of seed source and allows the replacement stand to develop free of overhead shade and logging damage, but it generates the maximum amount of logging residue and affords little control over competitive ground cover.

Management With Artificial Regeneration

Planting or direct seeding of pine stands is largely confined to areas recently devastated by fires, tornadoes, or other catastrophies, with site indexesof 50 or more. Experience has shown that whenever a ground cover of grass, forbs, or shrubs has become established on potential planting or seeding sites, mechanical scarification to prepare a seedbed and reduce competition is essential.

Planting has been more successful than seeding in the Black Hills. Stock should be grown from seed collected as near the planting site as possible. In years of favorable moisture, 2-0 root-pruned stock provides the best combination of ease of planting, economy, and performance. Planting stock must be treated as a dormant plant from the time of lifting to the time of planting in the spring. Many sites can be satisfactorily planted by machines; those too rough or steep for machines will have to be planted by hand using the hole method. A minimum goal should be about 540 trees per acre.

Direct seeding, if it is successful, is cheaper than planting, but it is less reliable. A system that places one seed per unit distance in a furrow or one seed per prepared spot is most satisfactory because climatic factors favor the germination and survival of all seeds, while natural competition does not "thin out" multi-seed spots. Seeds should be covered lightly with soil.

New plantations, originating from either seeding or planting, must be protected from damage from domestic and wild animals until trees reach sapling size.

Individual Tree Selection

The selection system as a regeneration method is out of place in the naturally even-aged forests of the Black Hills—at least in regulated stands managed for timber production—but individual tree selection can be used for other purposes. For example, individual tree selection is appropriate for improvement cuts in mature stands to maintain the health and appearance and capture the volume and value of a few high-risk trees when these stands cannot be harvested on schedule.

Selection cutting can be used as a multiple-use silvicultural system in stands where it is desirable to maintain scenic beauty, preserve the forested appearance in recreation areas, and improve wildlife habitat.

WHAT DO WE NEED TO KNOW

Ponderosa pine in the Black Hills has been under management for timber production a longer time than other Rocky Mountain timber type, and at a more intensive level. Consequently, considerable knowledge has been accumulated on the timber resource. For example, cutting practices have been developed for timber production that are sufficiently flexible that they can be readily adapted to provide the kinds of stands needed for a wide variety of uses; yield prediction tools including stand growth and response to thinning are available for managed stands under any of the even-aged regeneration systems; and both natural and artificial regeneration practices have been developed that insure success. Furthermore, current knowledge will provide much of the information necessary to predict the response of the timber resource to a wide variety of treatments, needed as input to multi-resource prediction models.

Refinements needed in silvicultural techniques to determine such things as what overstory densities under shelterwood cutting will result in the desired amount of natural reproduction, can be handled by administrative studies. These should be made in cooperation with research at the planning stage. However, as management is intensified and silvicultural techniques improved, they must be tested by research. The Black Hills are an ideal outdoor laboratory for a wide variety of "on-the-ground" pilot studies.

The intensive use of forests in the Black Hills requires that timber management research become an integral part of multifunctional research directed toward: (1) identifying the response of plant communities to a wide variety of integrated and interacting uses, and (2) developing procedures that will provide an array of management alternatives needed to satisfy the objectives of different uses and users of Black Hills forest land.

TIMBER RESOURCE PRIORITY PROBLEMS

The summaries of existing knowledge for each forest type have described systems of management currently available, and identified where additional information is needed to develop adequate management systems for each type. Solutions to the problems listed below will require: (1) development of quantitative and descriptive models to provide a better basis for making land management decisions currently with information available, and (2) additional research and the development of procedures to fill deficiencies in existing knowledge.

Problem	Priority	Forest Type
1. Silvicultural prescriptions and cultural practices in stands of different structures, composition, and other characteristics that will establish and maintain the kinds of stands needed for a variety of uses including timber production. Descriptive models are now available for most forest types, but the suitability of available quantitative information for current resource and prediction response simulation models must be determined before deficiencies in knowledge can be fully identified.	1 2 3	Mixed conifers, spruce-fir Southwestern ponderosa pine, lodgepole pine Black Hills ponderosa pine
2. Classification of vegetation into units of like biological potential with wide applicability as a basis for understanding the ecology of the forest types, and determining the response of plant associations to different cultural treatments. Procedures for developing vegetation classifications have been standardized, and descriptive models are available for portions of most forest types. The suitability of existing quantitative information for use in current prediction models, and the identification of deficiencies in response data, cannot be determined until the classification of all forest lands is completed.	1	All forest types except Black Hills ponderosa pine
3. Prediction of growth and yield is the basis for management decisions including the place of timber production in multiple-use management. Computer simulation procedures are available to develop yield tables for managed stands from quantitative data. Single-resource response models	1 3	Spruce-fir, mixed conifers All pine types

for yield prediction have been developed for the pine types that must be refined for stand structures other than even-aged. The quantitative data for yield prediction in the other types is not available from existing information. Single-resource response models will provide the growth and yield data needed as part of the timber input into multi-resource response models.		
4. Methods of obtaining natural and artificial regeneration. Prompt and adequate regeneration can be obtained in some types, while in others the factors limiting regeneration success have not been identified. Descriptive models of various degrees of refinement, however, are available from existing knowledge for most forest types. Current resource response and prediction models for the regeneration phase are also available, but either the quantitative data for Rocky Mountain timber types are not available from existing information, or the suitability of existing quantitative data for these models has not been determined so that deficiencies in present knowledge can be identified. Single-resource response models will provide the regeneration input into multi-resource models.	1 2 3	Mixed conifers, spruce-fir Lodgepole pine, southwestern ponderosa pine Black Hills ponderosa pine

Alexander, Robert R.
1974. Silviculture of central and southern Rocky Mountain forests: A summary of the status of our knowledge by timber types. USDA For. Serv. Res. Pap. RM-120, 36 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521.

Summarizes a series of comprehensive reports on the silviculture of lodgepole pine, ponderosa pine, mixed conifer, and spruce-fir timber types. Includes what is known, what can be recommended, and what additional information is needed for each timber type.

Oxford: 614. **Keywords:** Silviculture; forest regeneration; growth-yield; *Abies lasiocarpa, A. lasiocarpa* var. *arizonica, A. concolor; Picea engelmannii, P. pungens; Pinus contorta, P. ponderosa, P. strobiformis; Populus tremuloides.*

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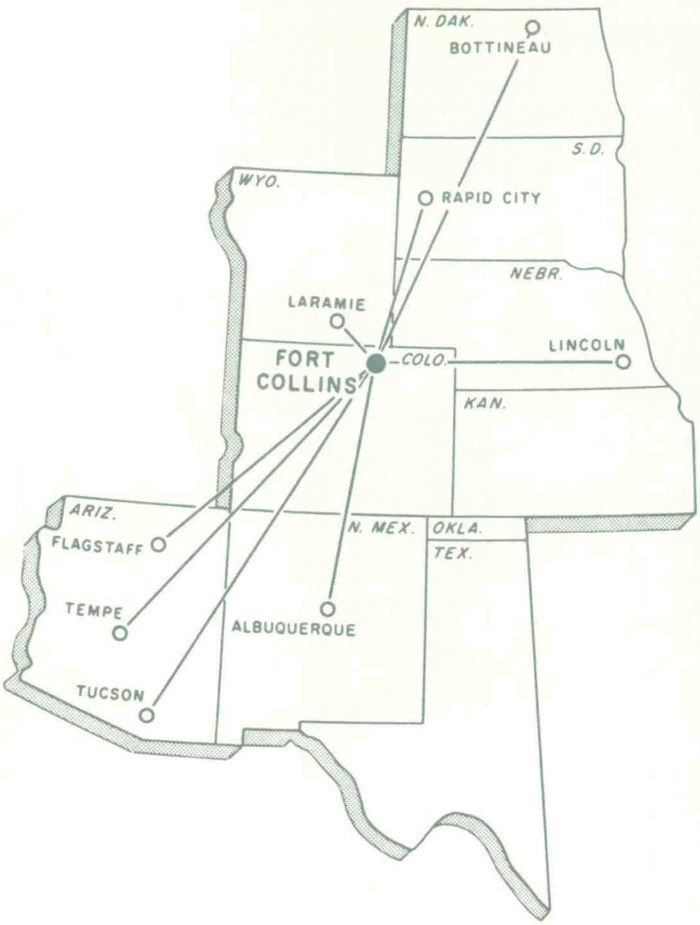
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