MANAGEMENT OF PONDEROSA PINE IN THE SOUTHWEST

As Developed by Research and Experimental Practice

By

G. A. PEARSON, *Silviculturist*

Southwestern Forest and Range Experiment Station

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PREFACE

Ponderosa pine, from the very beginning of the conservation movement, has figured as a leading timber species. In 1908 G. A. Pearson, a year out of forest school, was sent to Arizona to study natural regeneration of this tree, then called western yellow pine. Commercial logging was in full swing on both private and public lands. In the national forests, despite measures that seemed adequate for natural reforestation, seedlings started sparingly after cutting. To provide information on natural regeneration as well as on other phases of ponderosa pine management, the Forest Service established the Fort Valley Forest Experiment Station in 1909. The research field covered Arizona and New Mexico, but work was concentrated largely in what is now the Fort Valley Experimental Forest, a branch of the Southwestern Forest and Range Experiment Station.

A long-range attack on such problems as natural restocking, growth, mortality, and methods of cutting took concrete form in the creation of a series of so-called permanent sample plots. These are essentially experimental management areas on which all trees were numbered and measured periodically. The findings presented are derived not only from academic studies and small plot records, but also from experimental practice and record on areas sufficiently large to permit commercial operations. They cover the five broad phases of ponderosa pine silviculture: (1) Removal of mature, declining, or inferior members; (2) improving growth and quality of less mature stems; (3) training pole and sapling classes with an eye toward future form; (4) regeneration; and (5) protection of all age classes. While these five phases deal with the forest from seedling to sawlog, the sequence here is in a different order, because management usually begins with logging followed by treatment of younger age classes already in the stand; actual regeneration often is deferred until several decades after the first cutting. In a well-managed ponderosa pine forest, all five of these measures must go on simultaneously. Neglect of any one will adversely affect the program as a whole.

Although this work presents findings over a period of 40 years, it aims to leave conclusions open to modification in the light of further experience. Tree records, many of which are now over 30 years old, should be continued. Each remeasurement brings new phases into view and each cutting virtually institutes a new set of records. Intensive management has barely begun. Not until individual areas have gone through the entire rotation from seedling to sawlog under management and record can such an experiment be regarded as finished. Several large areas in the Fort Valley Experimental Forest are unique in that they have undergone almost complete restocking since the first cutting, and the young stands are now approaching the pole stage.

When the western national forests were first created, millions of acres of wild forest were placed under the jurisdiction of a handful of foresters. Forest-management application was necessarily crude and was focused on the protection of forests from fire, and the removal of mature and declining trees through commercial timber sales. Basic silvicultural information was lacking and desirable forest practices were often subordinated to economic demands.

Now, after 40 years, the stage is set for a new era in western forestry. Studies such as those at Fort Valley have made available a large array of timber-growing information. Improved transportation facilities have removed many of the economic barriers to the practice of good silviculture, and trained personnel is available to do the job. Western foresters can now look forward to a period of more scientific and more intensive forest management.

Perpetuation of the lumber industry demands large volumes of usable raw wood material in strategic places. The national economy further demands that long before the dwindling old reserves are exhausted, cut-over forests be placed in a highly productive condition. We must depend upon the ponderosa pine forests of western United States in large part to maintain softwood timber supplies in the immediate future. They contain large bodies of virgin timber and of conservatively logged stands which can be put under management with reasonable effort. Under makeshift management their yields will be low and quality lower; but under scientific management the yield in both volume and quality can be increased several fold.

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The Place of Ponderosa Pine in American Forestry

AREA AND GEOGRAPHIC RANGE

Ponderosa pine *(Pinus ponderosa)* is the most widely distributed conifer in North America, and one of the most valuable. Commercial stands of the species are found in all of the 15 States which lie wholly or in part west of the 102d meridian, and in all but one it ranks among the most important lumber producers (fig. 1). In the Southwest, ponderosa pine is of particular importance since this one species makes up 88 percent of the standing saw-timber volume in the two States of Arizona and New Mexico.

In this treatise, distinction is made between the "interior" ponderosa pine type and the "mixed" type where ponderosa pine is associated with other species. The latter type occurs in zones of high precipitation, mainly near the Pacific coast where ponderosa pine is associated with sugar pine, incense cedar, hemlock, and fir. Smaller areas of the mixed type are found throughout the Rocky Mountain region in the transition zone where ponderosa pine merges with the Douglas-fir-white fir type at higher elevations. In both cases increased soil moisture and lower temperature favor species which by virtue of lower demands on light and heat are able to reproduce under ponderosa pine and thus gain dominance in the next generation. Under these circumstances, even though the present stand may carry a heavy volume of ponderosa pine, the permanence of this species is not assured.

The interior ponderosa pine type, characterized by pure or nearly pure stands of ponderosa pine, occupies middle elevations in a belt about 800 miles wide beginning 150-200 miles inland from the Pacific coast, reaching eastward into the Dakotas, northern Nebraska, and western Texas, and extending clear across the United States from north to south. Commercial stands also occur in Canada and Mexico. The interior type generally receives an annual precipitation of less than 25 inches and in some localities less than 20 inches.

This work deals exclusively with the interior or pure ponderosa pine type and is concerned primarily with the interior type as it occurs in the Southwest.

The total area occupied by the interior ponderosa pine type in the United States is estimated at 37 million acres.[1] Distribu-

[1] Because of the intermingling with other types and the many ownerships involved, exact figures are not available.

FIGURE 1.—Geographic range of ponderosa pine in western United States. (After Sudworth.)

tion is approximately as follows: Northwest, including eastern Oregon, eastern Washington, Idaho, and Montana, 18 million acres; California, east of the Sierras, 4 million acres; the central Rocky Mountains, including Colorado, Wyoming, South Dakota, Utah, and Nevada, 7 million acres; and Arizona and New Mexico, 8 million acres. Of the 8 million acres of interior ponderosa pine in the Southwest, roughly one-third is at present commercially inaccessible or withdrawn from timber growing use. About one-half of the accessible land has now been logged.

BOTANICAL VARIETIES OF PONDEROSA PINE

The United States Forest Service *(89)* [2] recognizes, in addition to the type species *Pinus ponderosa* Laws., two varieties: *scopulorum* Engelm. and *arizonica* (Engelm.) Shaw.

Pinus ponderosa Laws. ranges from near the Pacific coast eastward through California, Oregon, Washington, Idaho, and into western Montana. The variety *scopulorum*, commonly called the Rocky Mountain form, extends clear through the Rocky Mountain region eastward to the Black Hills and south into central Arizona and New Mexico. The other variety, *arizonica*, whose real home is Mexico, occurs on isolated mountains in southern Arizona and southern New Mexico. All three forms are found in the interior ponderosa pine type.

Differences which have given rise to distinctions in nomenclature are both morphological and physiological. The "true" *ponderosa* is a larger tree than *scopulorum*. In the interior region this appears to be due to greater longevity rather than faster growth. Longer needles, larger seeds, and slower germination characterize *ponderosa* as compared with *scopulorum*. Korstian *(34)* has pointed out that the Black Hills pine beetle *(Dendroctonus ponderosae* Hopk.) confines its activity to *scopulorum*, giving way to the species *D. brevicomis* within the range of *ponderosa*. It should be noted, however, that although the Black Hills beetle has attained epidemic proportions on the north side of the Grand Canyon of Arizona it is not known to have occurred in the great pine belt extending from the south rim clear across the State and well into New Mexico. Korstian also calls attention to differences in leaf structure and chemical composition of the oleoresin *(33)*. Weidman *(97)* has made an exhaustive study of leaf characteristics and growth habits of various geographic races.

Scopulorum is by no means a tree of fixed characteristics. According to the textbooks it has two or three needles in a bundle, but in Arizona the number is uniformly three. In the Black Hills, Colorado, and northern New Mexico there are either two or three needles. The Black Hills tree is generally smaller than its Arizona kin; it also has shorter needles, of a yellowish green color in contrast to the bluish green in Arizona, and noticeably smaller seeds. Seedlings grown from Black Hills and Arizona seed in the nursery at Fort Valley have exhibited the same difference in length and color of needles; the Black Hills seedlings were also smaller and had more compact crowns than those grown from local seed. Another characteristic of the Black Hills seedlings was their habit of forming definite terminal buds in their third year, whereas the progeny of Arizona seed do not form terminal buds until several years older. Seedlings propagated from Colorado and Utah seed were intermediate between Black Hills and Arizona types, though more like the former.

The variety *arizonica* differs from the Arizona form of *scopulorum* mainly in having five needles in a bundle instead of three.

[2] Italic numbers in parentheses refer to Literature Cited, pages 213 to 218.

The needles are more slender than those of *scopulorum* and they fall in their third year, whereas those of *scopulorum* persist until their fourth or fifth year.

TIMBER AND OTHER RESOURCES OF THE PONDEROSA PINE FOREST

As compared with forests in humid regions, interior ponderosa pine yields are light, ranging generally from 5,000 to 15,000 board feet per acre though occasionally exceeding 20,000 feet. Less significance is attached to the volume of timber than to its distribution and location. Ponderosa pine may be thought of as the near-desert timber tree of the United States. It is not, strictly speaking, a desert tree but it grows on elevated plateaus rising out of the vast semiarid region known as the Great American Desert. In mountain regions it inhabits the lowest of the zones in which trees attain a stature suitable for lumber. Although too cold for most field crops, the area characterized by the ponderosa pine type does support some agriculture and a large amount of summer grazing. Because of relatively high accessibility, ponderosa pine forests are the main source of lumber and fuel for local consumption within a million square miles of territory. Lumber manufacture is an important industry in hundreds of communities. The pine forests, correctly managed, provide an excellent cover for millions of acres of watershed. They provide summer recreational grounds which rank among the finest in the country.

The low yields of ponderosa pine are in a measure compensated by other features. The tree produces a wood which ranks among the best for all-round use, and it is able to grow on sites generally too dry to support other saw-timber species. One of the distinct advantages of interior ponderosa pine, as compared with some other forests, is that the key species succeeds itself from generation to generation. Another advantage is that fires are more controllable because the crown canopy is more open than that of the heavier stands, so that the forest is less subject to crown fires. According to present standards, much of the interior ponderosa pine type is likely, because of low production or inaccessibility, to remain under an extensive form of management, or multiple use. On the other hand, intensive management can improve this situation by growing heavier stands of superior quality. It is estimated that half of the total acreage would justify intensive management with timber as the major crop.

PROPERTIES OF PONDEROSA PINE

Botanically, *Pinus ponderosa* belongs to the yellow pine group, but the wood resembles more closely the white pines. The heartwood is reddish brown, and the sapwood pale yellow or almost white. In trees under 200 years old, the wood is nearly all sapwood, and if such trees have been well grown the product is a beautiful soft white material comparable to white pine. Old

trees contain a larger proportion of the darker heartwood, which is usually heavier, harder, and stronger than the sapwood. Since the heartwood occupies the central core of the bole, produced while the tree was young, it usually has wider annual rings and contains more knots and resin than are found in the sapwood produced later in life. In slow-growing trees, such as generally occur in dense stands or on dry sites, the sapwood is of very fine and even grain, in contrast to the coarse or variable grain of the fast-growing trees in open stands or on moist sites.

According to Betts *(8)* ponderosa pine ranks moderately high in paintability, being rated above Douglas-fir and the southern pines, but below the commercial white pines. It does not split easily in nailing, but neither does it hold nails as well as some other woods. In contact with the soil, it is said to decay more readily than the white pines; this, however, may not be true of the heartwood which is much more resistant than the sapwood. Both heartwood and sapwood take preservative treatment readily. Compared with Douglas-fir and longleaf pine, ponderosa pine is lighter in weight, weaker, softer, and more easily worked.

A fact which should always be borne in mind in dealing with ponderosa pine is that the wood is extremely variable, according to the conditions under which it has grown. The qualities which place ponderosa pine lumber in the high-value class, namely regular grain and a relatively soft, even textured, and readily workable wood, are attained only by trees grown under conditions which produce clear boles and maintain a uniform rate of growth. Open-grown trees are always limby, and while the boles may become smooth after attaining great size the interior is always knotty. Small, firm knots, produced by small limbs which die and shed quickly, are far less objectionable than the large, loose knots formed when limbs are allowed to grow to large diameter. As will be explained later, both natural clearing of boles and width of annual rings can be controlled by regulating the density of stands. And, fortunately, the measures which induce the development of high quality also make for high yields.

PRODUCTS OF PONDEROSA PINE

Ponderosa pine is adapted to a variety of uses but at present the most important markets are for lumber and railroad ties. In some regions, notably the Black Hills, large quantities of ponderosa pine go into mine props and stulls; the mines promise to take increasing quantities in other regions. Naval stores are a possibility which has been explored in Arizona with results which are not wholly unfavorable *(7)*. Ponderosa pine fuel finds extensive local use throughout the region.

Lumber

Ponderosa pine lumber ranks high among western conifers, commanding prices exceeded in general markets only by California sugar pine and western white pine. In the two States of

Arizona and New Mexico, annual production of ponderosa pine lumber has, since 1925, varied from a high of 345 million board feet in 1946 to a low of 118 million in 1932. Southwestern forests furnish about 10 percent of the national production of ponderosa pine lumber.

Large quantities are absorbed by the building trades which employ intermediate grades for framework, sheathing, and subflooring, the better grades for siding, and the highest grades for window sash, doors, and interior finish. In recent years, knotty pine has become popular for interior paneling. The knots in this class of material must be firm and not excessively large, thus again calling for timber which has grown in close stands. Ponderosa pine is too soft for good flooring.

In addition to that used by the building trades, the fruit and vegetable industry is now absorbing immense quantities of lumber which is remanufactured into boxes and crates. According to statistics by the U. S. Forest Service *(88)*, the volume of ponderosa pine used for "boxes, baskets, and crating" in 1940 was 29,593,000 board feet in Arizona and 7,580,000 board feet in New Mexico.[3] During the same year California and Oregon each used over 300 million board feet and Washington 126 million. In all of the Rocky Mountain and Pacific Coast States except Idaho, ponderosa pine exceeded by a wide margin the total of all other woods used for these purposes.

An acute lumber shortage during the war brought many suggestions for replacement of wooden boxes with fiber cartons. Proposed substitutions encountered many limitations, notably in the transportation of heavy materials, such as ammunition, and produce which tends to exude moisture, such as fruits and vegetables.

Railroad Ties

Next to lumber, the greatest industrial use of ponderosa pine throughout the West is for railroad ties. Ponderosa pine makes a good tie because, along with other desirable qualities, it responds well to preservative treatment. Railroad ties are cut from trees of about the same minimum diameter and quality that is required for good lumber. They must be free of large knots in the section where the spikes are driven, while loose knots and rot are prohibited generally. Ties are of two broad classes: sawn and hewn.

Sawn ties.—Sawn ties are made from medium grades of sawlogs with a minimum diameter of 11 inches inside the bark at the small end. Operations combining production of sawn ties with lumber result in less waste than if ties alone are sawn. One objection to such a combination, however, is that standard ties are now 9 feet long while standard logs are 16 feet, thus yielding one tie plus 7 feet, which is an odd length in lumber. This should not prove to be an unsurmountable difficulty if production of lumber and ties in the same operation is otherwise practicable.

Hewn ties.—Tie hewing is a hand operation whose main justification is that it furnishes employment to low-income groups in remote rural communities. In sections of northern New Mexico, Spanish-American farmers formerly depended on tie cutting as a supplemental source of income. A standard 7- x 9-inch tie requires a minimum diameter at breast height (d. b. h.) outside bark of about 12 inches, and in order to avoid excessive waste of labor and wood, the diameter should not be much over 14 inches. The waste in tops is usually greater than in a sawlog operation. Unless prolific regeneration is the rule, a straight hewn-tie rotation is silviculturally impractical. If, as in most regions, relatively large trees are required as a seed source, and if regeneration is difficult, the only logical course for hewn-tie management is in combination with sawlogs, employing hewn-tie operations for purposes of stand improvement. In recent years hewn ties have been replaced almost entirely by the sawn product.

[3] In southern Arizona, the cost of box shook used in packing the crop from a single acre of grapefruit in full bearing amounted to from $60 to $80 in normal times, and twice those figures since the war.

Mine Timbers

Mine props and stulls[4] offer silvicultural opportunities in connection with saw-timber management because they afford a commercial outlet for material unsuitable as either railroad ties or sawlogs. In the Southwest props may be as small as 5 inches inside bark at the top, and stulls as large as 18 inches, the length in feet equaling the top diameter in inches. Live knots and moderate crook are not objectionable, and therefore these products can utilize stems which will not qualify as sawlogs or ties. At present, the market is inadequate to absorb more than a small fraction of the supply of prop and stull material that should be removed in the near future. In Arizona this is partly because of a preference on the part of copper miners for Douglas-fir in heavy timbers requiring great strength. With a large number of producing mines in the interior ponderosa pine region, cultivation of this market affords an opportunity which should not be overlooked.

Converter poles.—Another commodity which imposes low restrictions as to form or size is converter poles used in copper smelters. Already several small sales have been made in the Southwest to supply this market.

Utility Poles

Having good form and receptiveness to preservatives, ponderosa pine stems are well adapted for use as treated poles. This species is now admitted for use as utility poles under the specifications of the American Standards Association. Since 1946, the numbers of ponderosa pine poles treated in the Northern Rocky Mountain

[4] Props go to coal mines, stulls to metal mines. Some metal mines take round ponderosa pine lagging.

and Pacific Coast States have steadily increased. This development has been retarded in the Southwest because the region lacks wood preservation plants or facilities. Since pole material brings prices equal to or exceeding that of sawlogs, this type of utilization offers distinct possibilities for future development.

Fuel Wood

Fuel wood, though not rated high commercially, is nevertheless of great local importance throughout the 12 States which embrace the main ponderosa pine region. Ponderosa pine makes an excellent fuel where quick, hot fires are required. Cull logs, limb wood, and mill blocks are used in quantity both in rural communities and in the larger towns and cities.

RELATION TO THE NATIONAL TIMBER SUPPLY

At the present time ponderosa pine supplies a substantial portion of the lumber used in all of the States west of the Mississippi River. Large quantities of the better grades are shipped farther east for use by millwork concerns. In saw-timber volume, it ranks second in the United States, exceeded only by Douglas-fir *(79)*. How long ponderosa pine will be able to hold this position depends upon how rapidly intensive management is applied, because the present large volume is accounted for mainly by virgin stands. Growth in the extensive interior type will always be slow. Without intensive management, yields and quality will fall to such a level that, notwithstanding the vast acreage of this type, its contribution to the total timber supply of the country will be insignificant. Even if the object is only to supply local consumption in the western States in which ponderosa pine is the predominant species, management must be placed on a much higher plane than has been attained heretofore on any considerable areas.

A favorable aspect of the timber situation in the Southwest is the fact that approximately four-fifths of the acreage and nine-tenths of the volume in the ponderosa pine type is in some form of public ownership, mainly Federal. Several million acres still remain untouched by the saw and some 2 million acres have been logged under some system of partial cutting. There are in the region probably 4 to 5 million acres of commercially accessible ponderosa pine that could within 50 years, if placed under intensive management, be made to yield an annual increment of 100 to 200 board feet per acre.

Ponderosa Pine Research in the Southwest

EXPERIMENTAL MANAGEMENT

Ponderosa pine research in the Southwest began at Fort Valley near Flagstaff, Ariz., in 1908. Early investigations were made in the national forests of Arizona and New Mexico wherever suitable conditions were found. Cut-over areas came in for major attention. As early as 1909, selected areas designated as "sample plots" were withdrawn from such administrative use as might interfere with permanent records of natural reproduction and tree growth. Other areas were set aside for experiments in artificial reforestation. Research on these areas was directed from the Fort Valley Experiment Station, now a branch of the Southwestern Forest and Range Experiment Station.

In 1931, the Fort Valley Experimental Forest was created by linking together the large sample plots and planting plots nearest the Fort Valley headquarters. Also included were several thousand acres of timberland used since then for new cutting experiments, timber stand improvement, and mistletoe control experiments. Later, several more distant sample plots were added. Figure 2 shows the location of the five units now constituting the Fort Valley Experimental Forest, and figure 3 the headquarters as seen in 1916 and 1942.

Other experimental areas, mainly in New Mexico, though not a part of the Fort Valley Experimental Forest, have supplied data used in this monograph.

Sample Plots

Records of growth, mortality, periodic and average annual increment, progress of reproduction, and numbers of trees per acre by diameter, age, and crown classes are furnished by a series of sample plots, the oldest of which date back to 1909. All trees are numbered with metal tags, on some plots down through the 4-inch diameter class, on others through the 8-inch class. Diameters, and in some cases heights, are measured at 5-year intervals. In total, long-time records on 2,000 acres of sample plots, containing 75,000 tagged trees, are available for study.

Sample plots are of two broad classes—large or "extensive" and small or "intensive." Extensive plots range in size from 72 to 480 acres, intensive ones from 3 to 14 acres. In many cases, the intensive plots are merely subdivisions of extensive ones, selected for detailed record. Originally, the trees on extensive

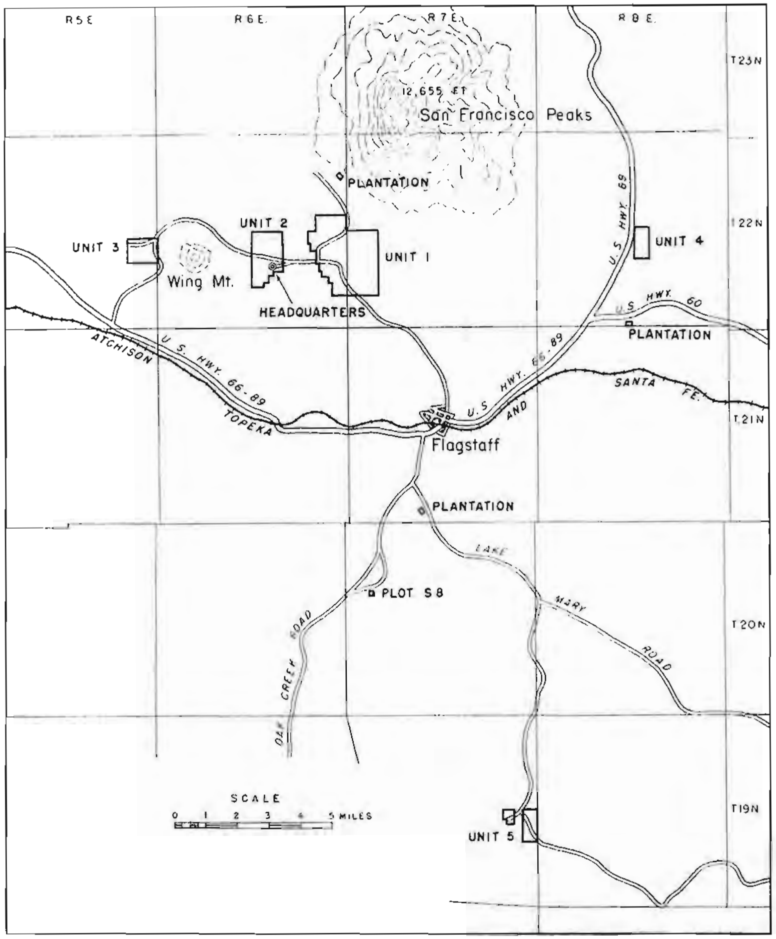

FIGURE 2.—Location of Fort Valley Experimental Forest and nearby experimental areas.

plots were not tagged and diameters were merely tallied; beginning in 1924 (1913 on the S5 series and 1915 on S6), all trees down to 3.6 inches were tagged; since 1939, the minimum limit for tagging and measuring has been 7.6 inches. Intensive plots were all tagged at the beginning; heights as well as diameters were measured; notes have been made on the crown class and condition of each tree; and seedling records have been kept on supplementary small plots. Most of the intensive plots have been mapped on a scale of 1 inch to the chain, showing the location of individual trees, stumps, down trees, and groups of reproduction. This type of map is illustrated in earlier publications *(54, 59)*.

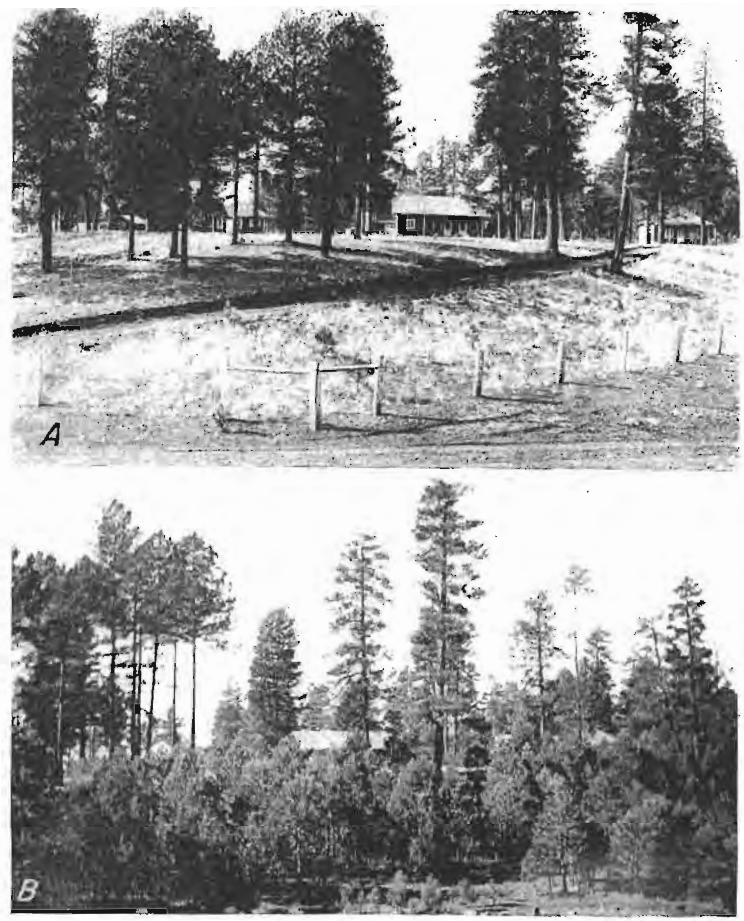

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FIGURE 3.—Headquarters of the Fort Valley Experimental Forest, near Flagstaff, Ariz. Upper view in 1916, lower view from near the same point in 1942. The young trees are of natural regeneration.

Arizona Plots

All but one of the Arizona plots are within what is now the Fort Valley Experimental Forest. Their location by unit numbers and smaller subdivisions is shown in table 1 and figure 2. As may be seen, they are not in one continuous tract, but are widely separated over an area approximately 18 miles square. All are pure ponderosa pine stands except one (S4) which, lying near the lower border of the type, contains a few specimens of pinyon and juniper.

TABLE 1.—*Ponderosa pine sample plots in Arizona and New Mexico*

National forest and State	Designation	Year established	Area, acres	Location and local name
Arizona: Coconino	S1-A	1909	8	Fort Valley Experimental Forest Unit 2.
	S1-B	1909	8	
	S2-A	1909	8	Fort Valley Experimental Forest Unit 1.
	S2-B	1909	8	
	S3 [1]	1909	480	Fort Valley Experimental Forest Unit 3, Wing Mt.
	S4 [1]	1909	320	Fort Valley Experimental Forest Unit 4, Cinder area.
	S5-1 [1]	1913	160	Fort Valley Experimental Forest Unit 5, Coulter Ranch.
	S5-2	1913	169	
	S5-3	1913	127	
	S6 [2]	1925	160	Fort Valley Experimental Forest Unit 2.
	S6-A	1940	80	Do.
	S6-B	1940	72	Do.
	S7	1925	160	Do.
	S8	1926	8	4 mi. south of Flagstaff.
	S9	1941	85	Fort Valley Experimental Forest Unit 2.
	S10	1942	76	Fort Valley Experimental Forest Unit 1, Corey Pasture.
New Mexico: Carson	Amole	1914	3	Amole Canyon.
	Cienega	1915	4	Near former Cienega R.S.
Cibola	S1-A	1910	6	Point-o'-Rocks Canyon.
	S1-B	1910	6	Point-o'-Rocks Canyon.
	S2-A	1910	14	Ranch Supply Canyon.
Gila	S2-A	1912	6	Pinos Altos.
Santa Fe: Jemez Division	S1-A	1911	6	Los Alamos.
	S2-A	1911	6	Buey Canyon.
	S3-A	1911	6	Water Canyon.
Pecos Division	S1-A	1911	6	Tecalote Canyon.
	S2-A	1911	6	Tecalote Canyon.

[1] S3, S4, and S5 include intensive plots.
[2] S6 was divided in 1940 into S6-A and S6-B.

The extensive plots in Arizona are really management areas. All but one (S6) are cut-over; two (S3 and S7) have been logged twice, and others are scheduled for second cutting within the next few years.

New Mexico Plots

These plots are all of the intensive class. They are small because at the time they were established national forest cuttings in New Mexico were all small-mill operations. Besides being widely dispersed geographically, these plots embrace a climatic range extending from the lower to the upper transition zones of the ponderosa pine type. Several of the stands contain a considerable representation of Douglas-fir, white fir, and limber pine. The New Mexico plots are regarded as too small and not sufficiently typical of extensive stands and cutting practice to carry much weight individually; but collectively and in coordination with the more adequate Arizona plots they constitute a valuable source of data.

New Mexico ponderosa pine stands differ from typical Arizona stands in several details. As a rule the volume per acre is less in New Mexico; the New Mexico stands characteristically contain more and smaller trees and the pole and sapling stages are better represented than in Arizona. These differences are associated with and probably caused by differences in seasonal distribution of precipitation.

APPLICATION OF SOUTHWESTERN FINDINGS

Foresters are constantly reminded that since conditions change from one place to another, management cannot be uniform. This is literally true. It is true not only of widely separated regions, but also of localities within the same region, of sites within the same locality, and of subdivisions within a management unit. Forestry "by the acre" must eventually be further refined into forestry by the group or by the tree. Fine distinctions have their place in silviculture, as is recognized by the practice of marking individual trees for cutting.

Granted that local conditions influence silvicultural practice, they are transcended by certain basic relationships. Without the perspective which comes with a recognition of these broader relationships, it is easy to misinterpret and overemphasize local factors. The behavior of ponderosa pine in response to environment is remarkably consistent throughout the Southwest. From seed to sawlog its growth, form, and existence are governed by heat, light, and moisture. Silviculture becomes essentially uniform when based on an understanding of these factors, their interdependence, and the modifying effects of competition; it may vary in detail but only in the sense that different adjustments may be necessary to bring about proper coordination.

Competition for the limited moisture supply dominates the whole ecological picture. In the reproduction stage it is competition imposed upon seedlings by grass or brush, later it is competition between trees. Response to release from competition is as universal as competition itself and recognition of this principle is the key to effective silviculture in southwestern ponderosa pine.

Temporary or artificially imposed conditions may influence cutting practice to the extent that it will vary within a region and with the passing of years. For many years the transportation problem handicapped silviculture by demanding a heavy cut. Overmaturity or mistletoe may dictate heavier cutting than would otherwise be desirable. Markets determine the size and class of material desired, and thus the type of cutting, rotation, and cutting cycle.

Ponderosa pine management in the Southwest is governed by many circumstances. But, assuming a policy which looks toward growing maximum timber crops on lands most valuable for that purpose, management must recognize basic silvicultural principles. This monograph deals primarily with silviculture, because of its permanence and fundamental character; but economic aspects are not ignored, because silviculture cannot function without commercial outlets for its product.

Insofar as practice is outlined, this monograph is intended primarily for application in the Southwest and more specifically for the Coconino Plateau area in northern Arizona. Local conditions will call for adjustment even within this restricted area. Some of the basic concepts, however, may find application in the management of interior ponderosa pine in many portions of the West.

Silvicultural Foundations

CLIMATIC CHARACTERISTICS

The geographic range of interior ponderosa pine in the Southwest is associated with certain climatic characteristics which vary little from one locality to another. In general terms, the climate may be described as cold and dry, mean annual temperature varying from 42° to 48° F. and growing-season temperatures (June through September) from 58° to 65°. Maximum temperatures seldom exceed 95° and frost may occur in any month of the year. Precipitation ranges generally between 18 and 22 inches, though occasionally it may be higher or even lower.

Temperature and Moisture Limiting Factors

Temperature as well as moisture may be a limiting factor in the distribution of ponderosa pine. There is much evidence that in most of its interior range the tree grows in climates too cold or with a growing season too short for optimum development *(4, 57)*. The reason for this anomaly is physiographic. The lowlands and plains of this generally mountainous region are semiarid. It is only by ascending to the higher slopes and tablelands that sufficient moisture is obtained; but this ascent is also accompanied by a drop in temperature, and as moisture approaches the optimum the heat deficit becomes prohibitive. In the San Francisco Mountains of Arizona, sites above 8,500 feet receive as much as 30 inches of precipitation, but here ponderosa pine disappears except on the southerly aspects. Ponderosa pine makes extraordinary growth when planted and watered in the warm valleys below its natural range.

As may be expected, the altitudinal limits of the type are nicely adjusted to latitude, aspect, and other conditions which affect temperature. In the Pacific Northwest region pure ponderosa pine forests occur generally at altitudes between 3,000 and 5,000 feet, but in Arizona and New Mexico the pine zone is pushed up to altitudes above 6,500 feet. The species must go approximately 3,000 feet higher in Arizona than in Oregon in order to find the same moisture conditions. This circumstance greatly restricts the acreage suitable for ponderosa pine in its southern range. If pine forests could maintain themselves at altitudes of 3,000 to 6,000 feet in the Southwest, as they do farther north, there would be available for their use some 40 million acres now occupied by grass, scrub, or "woodland," the latter consisting of pinyon, juniper, scrub oaks, and mesquite.

Temperature and Precipitation in the Southwest

The records in tables 2 and 3 and figure 4 are from the Fort Valley station located within a body of uncut ponderosa pine near the middle altitudinal range of the type. Temperature may be slightly below and precipitation slightly above the average for the type as encountered throughout the Southwest. Marked features of the precipitation record are a sustained high from December 1 to March 31, an extreme low in June, and another high in July and August.

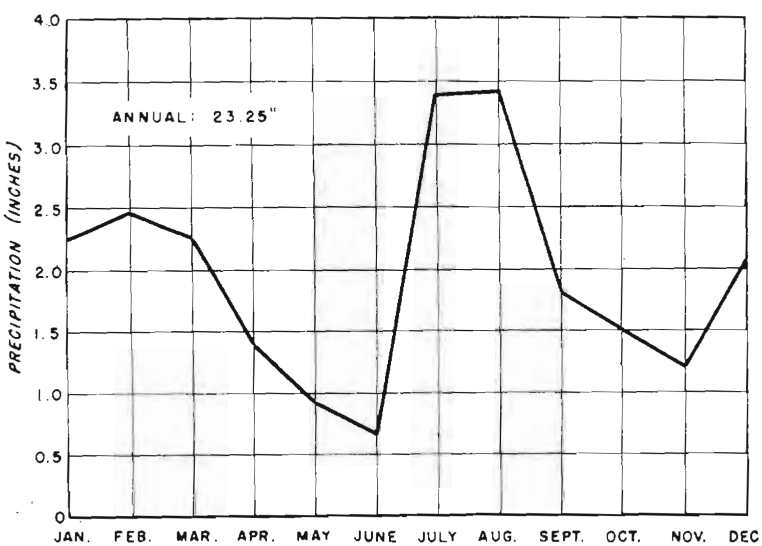

FIGURE 4.—Thirty-year average monthly precipitation at the Fort Valley forest station, 1909-38. Ponderosa pine type.

Summer rains of Arizona and New Mexico are erratic, often barely sufficing to moisten the soil as much as 1 foot in depth. This July-August precipitation is important mainly in relation to germination and survival of seedlings. It is the winter precipitation, always penetrating many feet (as do also the roots of ponderosa pine), which makes sustained tree growth possible.

The climatic records most commonly used in forestry are monthly and yearly averages for 10 years or more. Such figures give a general picture which is sufficient for most purposes. For the student of silvicultural problems, however, averages are not enough: he must also know about the variations. This is particularly true of such problems as natural regeneration, planting, seeding, and fire suppression. To the casual observer, the average precipitation of 3.11 inches in July and 3.31 inches in August (table 2) appears to provide excellent conditions for germination of pine seeds and establishment of seedlings in the Southwest.

TABLE 2.—*Summary of temperature and precipitation within a virgin stand of ponderosa pine in the Fort Valley Experimental Forest, 1909-42*

Month	Temperature			Mean precipitation
	Mean maximum	Mean minimum	Mean	
	° F.	*° F.*	*° F.*	*Inches*
January	39.5	11.1	25.3	2.24
February	41.3	14.0	27.6	2.48
March	47.1	19.0	33.0	2.18
April	54.8	25.1	39.9	1.51
May	64.4	30.4	47.4	.83
June	75.4	38.2	56.8	.65
July	78.2	47.0	62.6	3.11
August	76.1	46.0	61.0	3.31
September	70.6	38.9	54.7	1.97
October	60.6	28.0	44.3	1.64
November	50.7	19.8	35.2	1.19
December	41.8	13.8	27.8	2.12
Annual	58.4	27.6	43.0	23.23

But examination of table 3 shows that in many years one or both months fall far below the average. Moreover, daily records show that in some years of average July precipitation, effective rains did not begin until the latter part of July. Again, heavy rains early in July may be followed by a temporary drought of several weeks between the middle of July and the middle of August, sufficient to arrest germination or kill seedlings of recent germination. Similarly, the fire problem is affected more by current than average precipitation. As a rule, the fire danger in the Southwest is practically over by July 15, but some disastrous fires have occurred after that date.

Temperature is also subject to considerable fluctuation in comparing the same month in different years. Temperature, however, is less critical than moisture. Heat, like moisture, is generally deficient; but whereas a long drought may be fatal to seedlings or even old trees, periodic low temperature only retards growth temporarily. Moreover, the seasonal graph of temperature follows more closely the normal pattern than does the precipitation graph. A peculiarity of temperature is that a marked departure from normal in one part of the year is usually compensated by a swing in the opposite direction several months later. Departures from the annual normal seldom amount to more than 3 or 4 degrees F., but any one month may register a departure of as much as 10 degrees. A complete record of temperature calls for both maxima and minima, and an average of the two, called the daily or monthly mean. But it is low maxima rather than low minima that retard the growth of ponderosa pine throughout the semiarid interior region of its range *(57)*.

TABLE 3.—*Monthly and annual precipitation (inches) in the Fort Valley Experimental Forest,*[1] *by years, 1909-45*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1909	2.88	3.19	2.68	0.50	0.28	0.71	2.50	5.74	1.80	0	1.50	3.10	24.88
1910	2.79	.39	3.22	.50	0	.50	1.88	3.40	.41	.59	.88	.97	15.53
1911	2.76	2.72	2.64	.22	T	.22	5.71	2.76	3.47	2.68	.22	.69	24.09
1912	.12	.14	5.43	1.48	.55	.67	3.70	.81	.06	4.43	.25	.88	18.52
1913	.95	3.56	1.28	.09	T	.16	2.16	4.44	1.87	1.26	1.88	1.47	19.12
1914	2.29	.86	.48	.75	.84	1.22	3.76	2.66	.89	1.84	T	2.23	17.82
1915	3.19	2.95	.95	4.35	2.15	.35	2.92	.67	.54	.29	1.35	4.45	24.16
1916	8.57	.82	2.69	.03	.35	0	3.54	3.97	2.01	3.82	0	1.15	26.95
1917	2.98	1.43	.58	4.40	1.13	.02	5.10	.92	1.62	T	T	T	18.18
1918	2.01	2.13	5.19	T	T	1.76	3.67	3.25	1.01	.73	1.58	2.61	23.94
1919	T	2.75	1.68	.68	3.54	T	8.39	2.32	3.22	3.71	4.56	.98	31.83
1920	1.85	6.44	3.09	1.10	1.13	.08	2.00	2.38	.91	2.94	.97	1.02	23.91
1921	2.70	.47	1.49	1.47	2.37	.83	4.93	4.92	.16	3.04	.65	4.52	27.55
1922	4.45	1.85	3.11	1.54	1.23	1.31	1.16	2.53	1.40	1.63	2.64	1.87	24.72
1923	2.59	2.30	2.35	.93	.33	0	4.03	2.70	4.49	.32	2.66	4.39	27.09
1924	T	.09	2.92	2.27	.09	.21	3.34	.20	3.15	1.52	.73	4.48	19.00
1925	.13	1.00	1.77	2.07	0	1.18	1.73	3.72	3.37	2.38	1.53	.11	18.99
1926	.14	1.58	2.58	4.09	1.93	.60	2.12	1.12	1.14	.59	1.02	3.36	20.27
1927	1.22	6.22	1.66	1.38	.90	1.87	2.01	3.75	4.71	1.27	.67	2.15	27.81
1928	1.07	1.94	.80	.58	1.12	.10	1.95	5.78	.44	3.07	2.28	2.02	21.15
1929	3.24	2.50	2.14	.97	.84	T	4.88	7.24	1.88	.40	.03	.01	24.13
1930	4.18	1.87	2.27	1.26	1.08	.55	7.32	2.22	1.64	.28	2.84	.05	25.56
1931	.46	2.76	.28	1.57	1.07	1.63	2.48	4.64	2.67	1.05	3.07	3.22	24.90
1932	1.42	6.19	1.13	1.50	.65	.56	2.04	3.79	1.47	1.60	0	2.65	23.00
1933	3.17	.59	.06	1.60	1.08	.14	2.84	4.05	1.25	2.97	1.26	1.09	20.10
1934	.77	1.28	.49	2.90	1.55	.40	1.88	5.92	.30	.08	1.15	1.38	18.10
1935	4.70	2.75	2.90	1.10	.91	.12	2.14	4.78	2.83	.09	.85	1.26	24.43
1936	.31	4.52	2.71	.41	.20	1.66	5.42	5.82	1.89	1.79	.58	3.13	28.44
1937	4.63	4.50	3.92	.25	1.63	1.62	4.40	2.19	1.87	0	.25	2.98	28.24
1938	1.48	3.94	5.63	.76	.16	1.27	1.34	4.26	1.16	.95	.72	3.38	25.05
1939	2.08	2.09	1.34	1.05	.06	.04	.63	3.97	3.66	.55	1.47	.14	17.08
1940	2.90	3.37	.41	2.98	.30	1.37	.13	2.30	5.47	3.67	1.59	4.35	28.84
1941	2.56	2.74	3.09	4.48	.64	.98	1.87	1.87	3.30	4.93	1.08	3.72	31.26
1942	1.67	2.48	1.19	2.19	T	0	1.89	1.29	.88	1.14	.29	2.25	15.27
1943	4.38	1.84	2.61	1.18	.25	.38	1.45	5.34	1.52	1.96	.27	2.23	23.41
1944	1.96	3.88	2.26	2.62	1.33	T	1.22	1.90	1.17	.97	2.48	1.99	21.78
1945	2.59	.75	5.06	1.07	.04	.06	2.18	3.42	.34	1.12	.16	3.57	20.36

[1] In virgin stand of ponderosa pine, altitude 7,400 feet.

Growth Periods of Ponderosa Pine

It is of interest that the height growth of ponderosa pine beyond the seedling stage takes place almost entirely during the driest season of the year, namely in June and early July. Buds begin to elongate in May or even in April, but subsequent cold spells usually check this early growth so that it seldom gets well under way until the middle of June. During the early part of the season, shoot growth is a more sensitive indicator of temperature than of moisture because trees whose roots are down 2 feet or more in the soil are largely independent of current rainfall, but available heat energy at this season is so near the minimum that a slight drop halts growth. The foregoing applies mainly to the middle and upper zones; growth dates are earlier and less subject to fluctuation in the lower and warmer portions of the type. Later in the season, after temperature ceases to be critical, soil moisture appears to be the controlling factor.

In years of more than average April-May precipitation, pine shoots grow unusually long *(53)*. Maximum height growth takes place during June and early July; it tapers off rapidly after about July 10 and approaches zero at the end of the month. Regardless of summer rains, height growth slows and stems harden during July. Fowells *(22)* working in the Sierras of California, where summer rains are normally light, reported practically the same dates for height growth.

Current diameter growth is less readily observable than is current height growth. Dendograph records by the author *(55)* in Arizona, by Fowells *(22)* in California, and by Daubenmire *(20)* in Idaho indicate trends generally similar to those of height growth, though with a tendency toward greater prolongation of diameter growth in Arizona. More pronounced radial growth in Arizona than in California and Idaho during the months of July and August appears to be associated with Arizona's summer rains.

Needle growth begins later and terminates later than shoot growth. By the time pine shoots in Arizona have made half their seasonal growth, the needles have barely emerged from the papery scales which enclose them; and by the time the shoots have attained full length late in July the needles are only 2 to 3 inches long. The needles continue to grow well into autumn, attaining a length of 6 to 8 inches by October 1.

Low temperature in early spring when surface moisture is generally abundant accounts for the fact that pine germination in Arizona is almost invariably delayed until midsummer. Germination requires an average daily soil temperature of about 55° F., which is not usually attained until the middle of May. A few degrees more of heat in April would enable pine seeds to germinate, but by the time temperatures have risen enough to stimulate germination the topsoil has become dry. Only once during 35 years—namely, in 1919 when 3.5 inches of rain fell during the month of May—has appreciable germination taken place in the vicinity of Fort Valley prior to July. New Mexico, in contrast, may have copious rains in May and June, with the result that germination during these months is not uncommon.

LIGHT AND MOISTURE REQUIREMENTS

The relative importance of light and moisture in relation to forest tree growth has been a subject of controversy for many years. Differences arise largely from the fact that in nature light and moisture, or their opposites shade and drought, are so closely related that the influence of one cannot always be separated from that of the other. When a tree is shaded by other trees it is also subject to their root competition, although the converse is not necessarily true. Moreover, the energy called light also includes other properties, and therefore it is more properly called solar radiation or simply sunlight.

Trees are most subject to the influence of sunlight or its absence during the seedling stage. In that stage they may be completely shaded by older trees, by shrubs, or even by grass. It is also in the seedling stage that intense radiation may injure plant tissues directly by high temperature or indirectly by drying out the soil, while at the same time inducing high transpiration; thus the injurious effect of sunlight becomes a heat-drought effect.

Photosynthesis, or the elaboration of carbohydrates, is the function most generally ascribed to sunlight, but there are others. Sunlight is the direct source of heat which warms air and soil and the plant itself. In most plants more or less direct sunlight is necessary for the development of normal stem form.

Utilization of light and heat energy in photosynthesis is restricted by the availability of water. A growing plant may be likened, in its use of heat and water, to a steam engine. In the engine. heat furnishes the energy which converts water into steam; but if water is not supplied as fast as it is used the engine cannot operate at full capacity. No matter how much fuel is available, its use is then limited by the water supply. Correctly interpreted, the situation in the Southwest is this: a relatively small leaf surface is sufficient to handle all the photosynthetic activity that the limited water supply can support; and a large crown is like a large power plant which because of inadequate water supply might be compelled to operate only part time.

A more or less obscure but nonetheless important function of sunlight is the regulation of plant form *(98)*. Plants kept in shade tend to become pale and slender. Potato sprouts in a dimly lighted cellar are an extreme example. Also, if the main source of light is on one side, the plant bends in that direction, exhibiting the familiar phenomenon of heliotropism. The usual reaction of trees fully exposed to strong sunlight is abnormal lateral development expressed in broad crowns, coarse branches, and thick, sharply tapering boles. Shade retards lateral growth more than height growth, with the result that the crowns become narrow and the boles slender with little taper. The ultimate form depends much on the duration of shade and whether or not the top is shaded. In general, side shade is beneficial but overhead shade is detrimental.

Extensive observations supplemented by experimental tests indicate that, biologically, ponderosa pine thrives best in practically full sunlight, but that controlled shade is essential to produce the form required in good saw timber. Seedlings grown in half shade created by lath screens, free from outside root competition, survive well. and to the inexperienced eye may appear more vigorous than seedlings in full sunlight; but after about 5 years the shaded seedlings will have become extremely slender and inclined to bend over. In 25 percent shade, development is more nearly normal; both the axis and the branches are less coarse than in open-grown trees, but the stems are sturdy enough to support themselves and on the whole the form is superior to that of open-grown trees. If the shade is increased to 85 percent, development is subnormal from the start and within 2 years mortality is almost total (fig. 5).

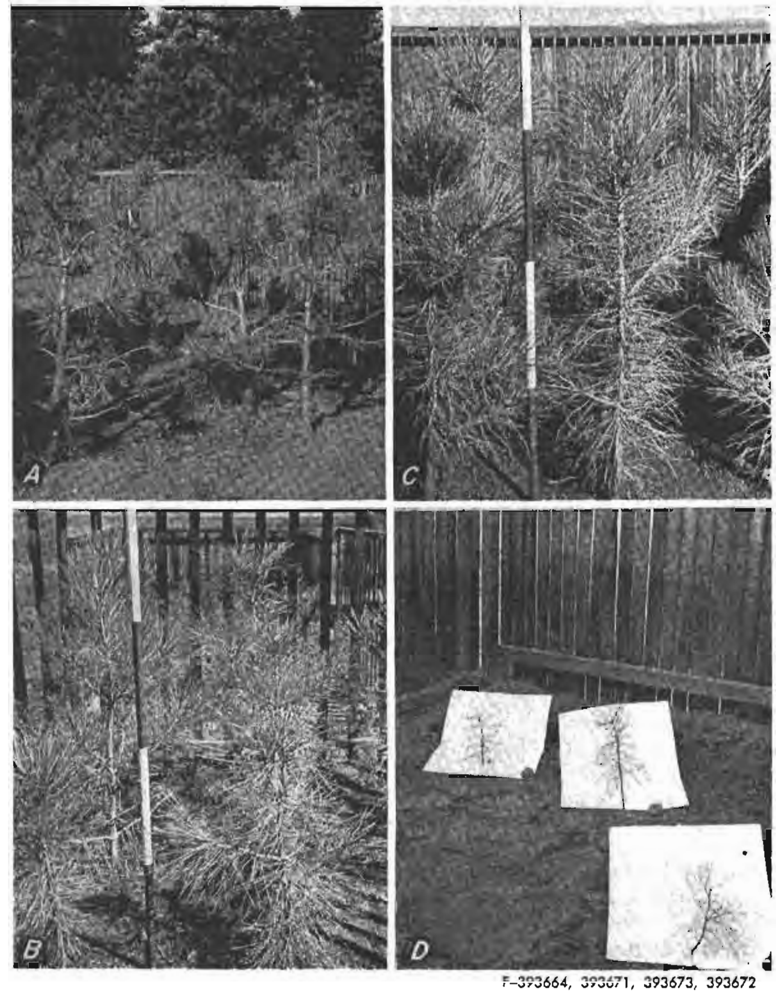

FIGURE 5.—Shade effects in ponderosa pine 9 years after planting. *A*, Full sunlight; *B*, one-third shade, open above; *C*, 85 percent shade, open above; *D*, 85 percent shade above as well as on sides.

Experiments in Light Requirement

The foregoing relationships with respect to seedlings were brought out by experiments in the Fort Valley nursery over a period of 12 years *(61, 69)*. Direct insolation was regulated by means of lath screens to give several intensities of shade while soil moisture was constantly held near the optimum through artificial watering. All the tests were replicated, with slight modifications, at least once. Tables 4 and 5 and figure 5 summarize the more significant results.

TABLE 4.—*Development of ponderosa pine grown in different degrees of shade (dimensions, in inches, recorded in 1939)*

Year planted and kind of stock	No shade		50 percent shade		67 percent shade		85 percent shade	
	Basal diameter	Height	Basal diameter	Height	Basal diameter	Height	Basal diameter	Height
1929:								
Transplants	3.13	88	[1]2.02	74				
Seedlings	2.07	79	.75	44				
1932:								
Transplants	1.96	53	.80	40	0.44	30	0.36	18

[1] Top shades were removed in 1936 to make room for height growth.

Previous to these light requirement experiments, light measurements in the forest had been taken over many years with a photometer, using sensitized paper *(54)*. A comparison of readings among seedlings that were exposed to different light conditions and observed to be in different states of vigor, led to the conclusion that they do not develop normally where they receive less than 0.4 of full sunlight.

The foregoing results differ materially from forest and greenhouse tests which have been reported by various investigators *(5, 24, 35, 86)*. The difference is probably due to the fact that the latter tests have been largely confined to measurement of height growth alone, without regard for diameter growth, and have been of too short duration to permit full expression of the effects of shade.

The removal of overhead screens as indicated in table 5, permitting direct sunlight to enter from above, was suggested by observations in the forest where seedlings start in openings surrounded by tall trees. In the nursery test, excellent development was obtained under dense side shade but with access to full sunlight from above during 4 to 6 hours each day through the summer. The same relation holds in the forest but with the difference that seedlings subjected to side shade are also subjected to root competition from larger trees, to say nothing of herbaceous vegetation. Nevertheless, the form of saplings and poles which have grown up in small openings is so superior that side shade is regarded as an indispensable instrument in silviculture (fig. 6).

As trees emerge from the pole stage they become less subject to overhead shade and thenceforth the light question resolves itself almost entirely into a matter of overhead insolation and side shade. This fact assumes many different aspects, all of which are important. In dense, even-aged stands mutual shading reduces the size of crowns by restricting lateral development and by causing

TABLE 5.—*Development of ponderosa pine planted in 1935 under overhead shade as compared with side shade on ponderosa pine planted in 1935 (dimensions, in inches, recorded in 1939)*

Kind of stock	33 percent shade				50 percent shade				85 percent shade			
	Covered [1]		Open above		Covered		Open above		Covered		Open above	
	Basal diameter	Height	Basal diameter	Height	Basal diameter	Height	Basal diameter	Height	Basal diameter	Height	Basal diameter	Height
Transplants	1.16	32	1.04	31	0.62	22	1.04	32	0.20	7	0.99	37
Seedlings		14		16		6		16		[2]		10

[1] Covered plots shaded above as well as on sides. Open plots shaded only on sides.
[2] Died first year.

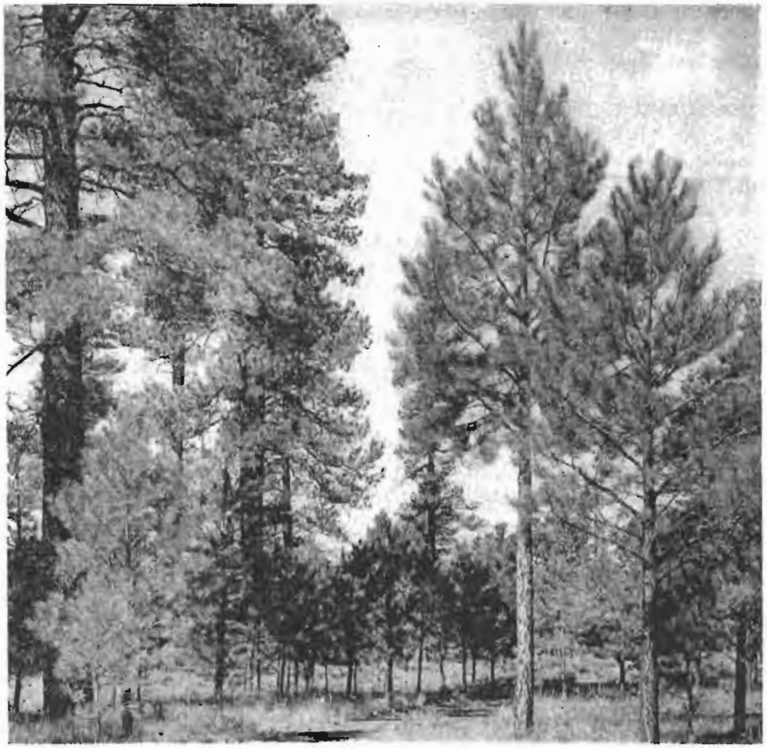

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FIGURE 6.—In the forest, saplings in open spaces surrounded by tall trees develop slender stems and fine branches like those induced by artificial side shade in the nursery, as shown in figure 5, *B* and *C*.

the base of the living crown to recede upward in consequence of the progressive dying of lower branches. Root competition for moisture may be a contributing factor in this movement. Within limits, the loss of side branches is beneficial in clearing the bole. Dominants which gain a lead of as much as 10 feet during the early pole stage evade to a large extent the influence of side shade and tend to become too limby for good saw timber.

Interrelation of Shade and Root Competition

Small groups display the characteristics of both dense stands and open-grown trees. Interior members of tree groups tend to become subordinate in size and general development because their root zone and moisture supply are restricted, rather than because their crowns become narrow and short under the influence of side shade. As illustrated by figure 7, outside members of the group develop one-sided crowns, the branches dying on the inside but attaining abnormal development on the outside. Such trees usually

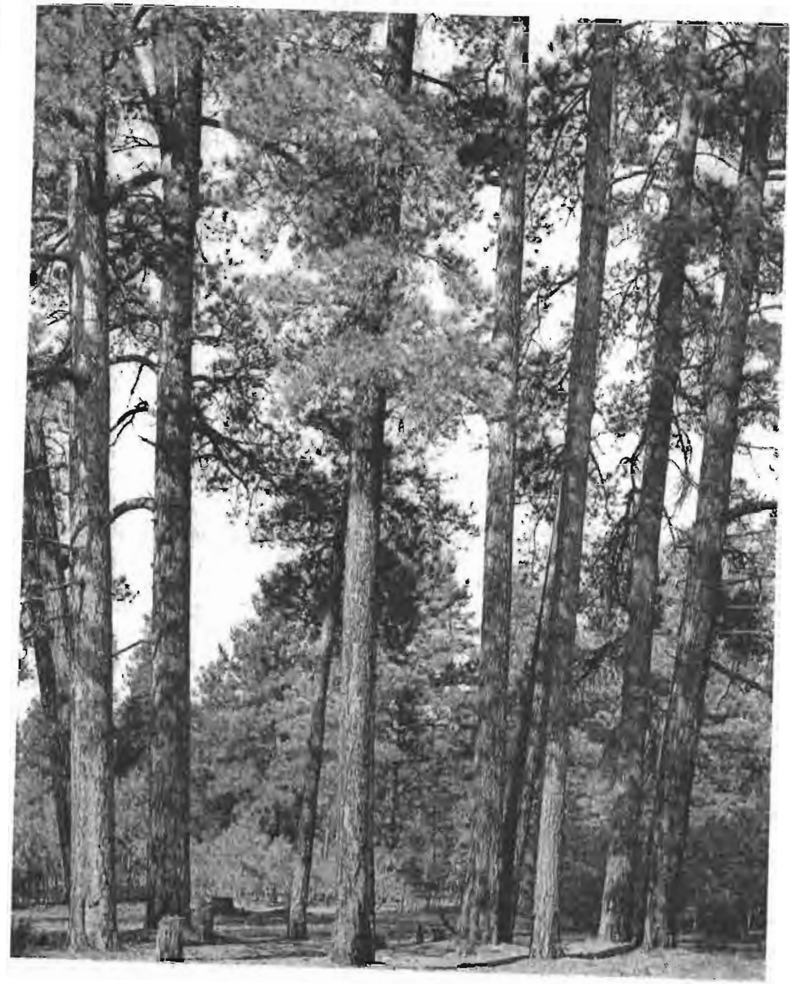

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FIGURE 7.—A 200-year-old ponderosa pine group. The outside members are largest; the boles are limby on the outside but clear on the side facing the interior of the group. Interior trees are generally clear on all sides, but of relatively small diameter.

lean away from the group. The form characteristic of outside trees is most conspicuous in pairs which grow up at some distance from other trees, their leaning boles forming a distinct "V"; the butt logs may be almost clear on the inside but bearing large branches on the outside.

Outside members of a group grow rapidly in diameter even though their crowns may be one-sided, because their roots are usually free to extend away from the group into fields of low root competition. Interior dominants, even though they may have good crowns, grow slowly because their roots encounter too much competition.

In the Southwest, sunlight, unlike soil moisture, is always present in virtually inexhaustible quantities which can be made available to any tree by the simple expedient of removing obstructing trees. Small trees, in the seedling, sapling, and pole stages, may be more or less completely screened by larger trees and suffer from light deficiency. In trees that have passed the juvenile stage, the problem is more often one of restricting than promoting the access of sunlight. With tops free, sunlight is much less likely to become limiting than is soil moisture.

Although cutting acts most directly in the introduction of sunlight, it is nevertheless an effective means of relieving or avoiding stagnation due to deficient soil moisture. According to measurements at Fort Valley *(51)*, opening up the crown canopy in dense groups may increase the proportion of the total precipitation that reaches the ground by as much as 40 percent. The greatest benefit, however, comes from reducing the number of trees which are sustained by a fixed water supply within a definite soil area. If, for example, 100 blackjacks are occupying an acre of land and 50 average specimens are cut, those remaining, if well distributed, will have available the total water supply, meaning that the allotment to each tree has been doubled.

Ponderosa pine exhibits a remarkable capacity for appropriating soil areas which have been vacated by felled trees. The roots of a medium-sized tree commonly radiate 50 feet or more, as shown by many years of experience in soil sampling, ditching, and digging post holes. Because they interlace with the roots of neighboring trees, response to the removal of competing neighbors usually takes place within 2 or 3 years, and often the first year. That the characteristic acceleration of diameter growth under these conditions is due primarily to moisture rather than light is evident from the fact that large-crowned dominants respond in much the same way as do small-crowned subordinates.

SOIL REQUIREMENTS

Ponderosa pine is not exacting in regard to soil *(57)*. In Arizona and New Mexico, it occurs on soils derived from igneous formations—basalt, granite, and cinders—as well as on soils of sedimentary origin—limestone and sandstone. Soils in the ponderosa pine type are usually low in organic matter and about neutral in reaction.

Soil variations affecting distribution of ponderosa pine are more likely to be physical rather than chemical. Variations in depth, physical composition, and organic content exert an important influence on the amount of moisture available for tree growth. In general, sandy or gravelly soils are more favorable to the establishment of ponderosa pine reproduction, but growth on the heavier clay soils is usually good once trees have passed the seedling stage.

STOCKING

Few subjects in forestry present so many complicated aspects as stocking. Assuming uniform distribution, it may be possible to ascertain what basal area in a given age class will give the maximum cubic increment per acre, but that is not the answer if the desired product is sawlogs. Even if the increment be expressed in board feet, there remain the questions of form, quality, desired sizes, and economic cutting cycles. In other words, degree of stocking cannot be satisfactorily reduced to a rule expressed in number of trees, basal area, cubic feet, or board feet per acre.

Notwithstanding many variations, however, certain fundamentals must be recognized: (1) Stocking should be such as to obtain effective utilization of the soil. (2) It should be such as to produce efficiently the dimensions and form suitable for the desired product. (3) If the product is saw timber, stocking should be such as to promote natural pruning and regulate texture or "grain" through width of annual rings.

Expressed in concrete terms applicable to management, stocking resolves itself into spacing. In stand improvement and harvest cuttings, the timber marker is continually asking how much space is required by a given tree for effective growth. The answer obviously depends on the size of the tree and the rate of growth desired. A 24-inch tree requires more space than one of 18 inches, and a diameter growth of 2 inches per decade calls for wider spacing than a growth of 1 inch in the same tree. Maximum diameter growth of individual trees does not necessarily imply maximum increment per acre, and it is usually attained at a sacrifice of quality.

Space Requirement

"Space requirement" is a relative term and is therefore somewhat a misnomer. Strictly speaking, it is the space required to produce a preconceived state of growth and form.

In regions of deficient precipitation, space requirement is primarily an expression of water requirement, although light also plays a part, as previously stated. If spacing is so wide as to prevent full occupation of the soil by the roots, incomplete utilization of the available soil moisture results. If, on the other hand, spacing is too close the moisture supply, though completely absorbed, may not be used to the best advantage. Both conditions, namely localized understocking and localized overstocking, commonly occur on the same area in ponderosa pine stands. It is in the extremes that light becomes a factor. The crowns become too large or too small according to their access to sunlight, as determined mainly by spacing.

A spacing table for trees of different diameters (table 6) has been prepared by Lexen *(40)*. His source of material was a well-stocked, many-aged stand on a better than average site for the Southwest. The values given in table 6 represent conditions as found in a prevailingly mature natural stand; they are not necessarily optimum conditions for either form or rate of growth; rather, they express the adjustments resulting from the struggle for survival. Wider spacing would probably be required for good growth on most sites in the Southwest.

TABLE 6.—*Theoretical spacing and volume in a well-stocked stand of ponderosa pine*[1] *(Lexen)*

Diameter at breast height (inches)	Space occupied	Distance apart[2]	Trees per acre	Volume per acre
	Square feet	*Feet*	*Number*	*Board feet*
2	12	3.5	3,615.4	
4	41	6.4	1,073.7	
6	88	9.4	492.3	
8	156	12.5	279.6	
10	243	15.6	179.6	
12	348	18.7	125.0	4,600
14	474	21.8	91.9	7,500
16	619	24.9	70.4	10,800
18	783	28.0	55.6	14,400
20	967	31.1	45.0	17,500
22	1,170	34.2	37.2	20,400
24	1,393	37.3	31.3	23,000
26	1,634	40.4	26.6	25,300
28	1,896	43.5	23.0	26,900
30	2,193	46.8	19.9	28,500
32	2,476	49.8	17.6	29,600
34	2,796	52.9	15.6	30,700
36	3,135	56.0	13.9	31,000
38	3,493	59.1	12.5	31,500
40	3,870	62.2	11.2	31,600
42	4,268	65.3	10.2	31,600
44	4,684	68.4	9.3	31,700
46	5,120	71.6	8.5	31,200
48	5,575	74.7	7.8	31,000
50	6,050	77.8	7.2	30,900

[1] Based on 100-percent cruise of 640 acres on the Long Valley Experimental Forest.
[2] Assuming a rectangular space. Actually, the space occupied is irregular.

Regulation of Spacing

Application of spacing rules is difficult where trees of different sizes are intermingled, or where the stand is grouped as is the prevailing habit of ponderosa pine. Densely stocked groups manage to carry on by sending their roots 50 or more feet outside the group, provided they do not encounter too much competition from neighboring groups. As a rule, it is the interior members of the group that suffer most from moisture or light deficiency. They can be relieved either by thinning within the group or by cutting some of the outside members, thus allowing the roots to reach out into formerly occupied territory. Dominants are able to grow in dense stands by robbing their smaller neighbors, which eventually become suppressed. Natural thinnings made in this way are costly, especially if the dominant is of inferior timber quality.

Dense stocking is desirable in young stands.—During the pole stage, when the stems are shaping up, diameter growth is secondary to form and natural pruning. Dense stocking should be the rule. Overstocking in this stage is preferable to understocking, because in the former case, dominants usually assert themselves. If, as a last resort, thinning becomes necessary, removal of only enough stems to encourage the development of dominants will break the deadlock. If pole stands are too widely spaced, pruning provides a partial remedy. Progress of natural pruning provides an excellent criterion as to proper density of young stands.

Spacing guides must be flexible.—The guides in table 6 are for application in principle rather than in letter, because the stands must be taken as found and remedies must be sought in modification rather than reconstruction. In overdense sapling or pole groups, the cost of artificial thinning is usually prohibitive, except to the extent of releasing a limited number of selected stems designated as crop trees. As poles approach the 12-inch diameter, thought should be given to utilization. Often the solution may be to wait until occasional stems become large enough to yield a log, a railroad tie, or a mine prop, then cut them, thus automatically releasing the nearest neighbors.

In practice, only part of a young stand will have optimum spacing. Some portions may be too dense and others too open. Under intensive management the answer might be uniform thinning in one instance and planting in the other, but neither of these correctives is now feasible on a large scale. A practical and economical means of opening up thickets is to poison *(63)* dominants of poor form here and there and depend on the resulting breaks in the canopy to encourage desirable stems to gain dominance. In spots of wide spacing, early pruning will insure a clear butt log, and since trees in these situations grow rapidly they can be left to attain large size. This subject is discussed further under Stand Improvement.

Thinning in Seedling and Sapling Stands

Although overdense sapling stands are rather common, thinnings are not considered feasible or necessary in the Southwest. Although correctly timed and executed thinnings might be expected to increase the growth rate, the cost under present conditions would be far out of proportion to the benefits. Moreover, dominants generally make their appearance in the sapling thickets, and once they gain the lead, they hold and increase it. Even the densest stands seldom stagnate as they do in some other regions.

A thinning experiment on the Sitgreaves National Forest illustrates the foregoing observations. Large areas in the Decker Wash district became densely stocked with ponderosa pine in 1914. In 1926, when the seedlings were mostly between 2 and 3 feet tall, five plots of 50 x 125 feet were thinned to different densities, as shown in figure 8 and table 7. Density of stocking before thinning varied within plots from 10,000 to 50,000 per acre. Measurements were made at 5-year intervals on a 5 x 125-foot strip in each plot,

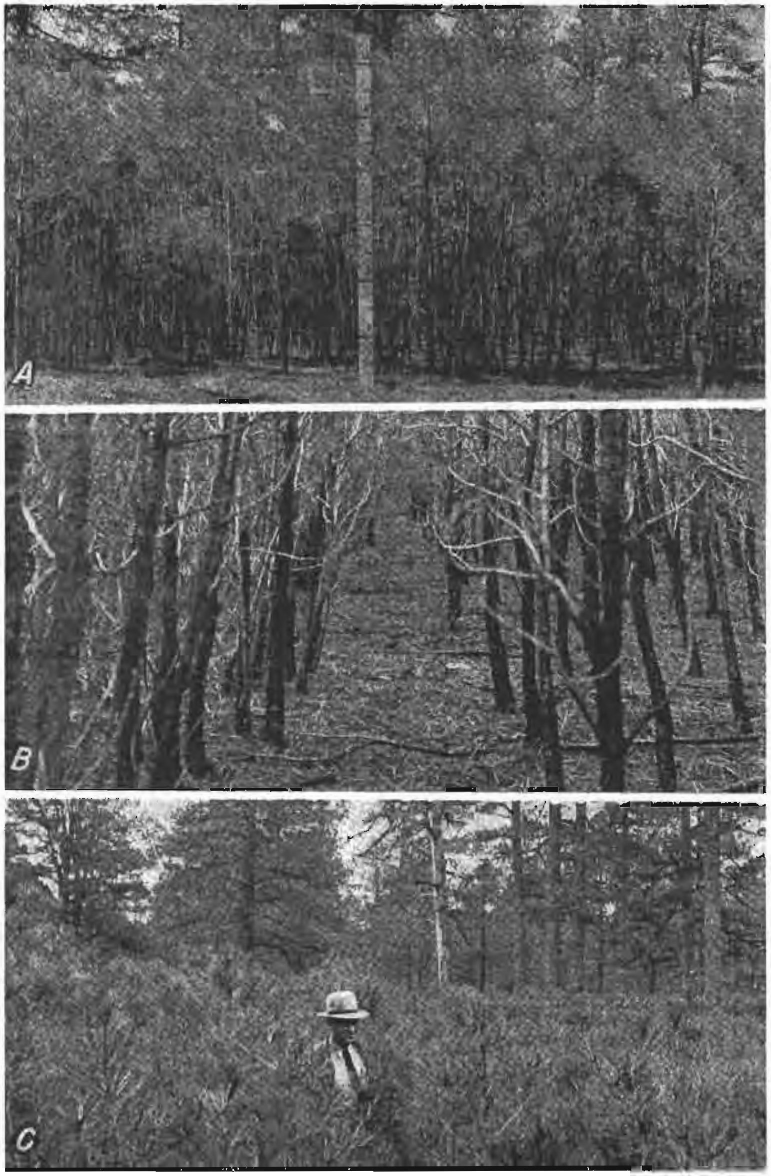

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FIGURE 8.—Thinning plots on the Sitgreaves National Forest in 1936. Reproduction started in 1914, was thinned in 1926. *A*, No thinning; note uneven contour of top line, indicating the development of dominants. *B*, Thinned to 20-24 inches. *C*, 20-24 inch thinning, showing uneven heights, a most desirable feature.

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FIGURE 8 continued.—*D*, 30-36 inch thinning, complete needle cover. *E*, Thinned to 10 x 10 feet, grass cover almost complete.

except that the entire plot in the 10 x 10-foot spacing was measured. Differentiation in height was already noticeable in the first measurement and became more and more striking with succeeding measurements. It soon became apparent that the relative merits of the several degrees of thinning would be determined not by the average height growth but by extremes, in other words the appearance of relatively few exceptionally tall stems capable of dominating the rank and file.

TABLE 7.—*Number of trees by height classes above 6 feet on 5 x 125-foot strips in 1941, on Decker Wash plots, Sitgreaves National Forest, thinned in 1926*

Thinning treatment	Number of trees in each height class (feet)					
	Under 7	7	8	9	10	11
No thinning	137	47	14	1	0	0
20–24 inch spacing	300	34	8	1	0	0
30–36 inch spacing	113	23	20	24	7	0
40–48 inch spacing	152	17	10	7	3	5
10 x 10 foot spacing [1]	51	8	4	1	0	0

[1] Based on entire plot.

According to table 7, the tallest trees are in neither the densest nor the most heavily thinned stands, but in the intermediate thinnings. Nevertheless, the unthinned plot contains as many distinct dominants as are needed to develop the desired irregular crown canopy.

Height growth in all the plots has been greatly retarded by tip moths, which appear to be most active in the heavily thinned stands.

An important factor in future development is the relation between density and ground cover. In the 10 x 10-foot spacing, blue grama grass in 1941 formed a broken turf; in the 40- to 48-inch spacing grasses had been largely replaced by needle litter; in the closer spacings replacement was complete and a uniform mat of needles covered the soil. From the standpoint of tree growth and water infiltration, needle litter is the more desirable cover.

It is too early to draw final conclusions. During the next 10 years the dominants will be entering the pole stage and in 20 years the sapling stand will have been converted into a pole stand. Only then can final judgment be passed. The desirable type of pole stand is one in which the dominants have been crowded by subordinates sufficiently to bring about natural pruning on the lower portion of the bole; but if the dominants should be numerous enough to compete severely with one another, additional thinnings will become necessary.

Arbitrary stocking or spacing tables, whether applied to saplings, poles, or more advanced classes, are impractical in the many-aged and otherwise heterogeneous stands generally encountered in ponderosa pine. An ecological approach is more satisfactory.

Saplings and poles should be dense enough to promote natural pruning without stagnation. The foremost objective in this stage is to build a growing stock. Above 8 inches d. b. h. the increment borer is a good guide. Up to a diameter of about 24 inches the goal should be a diameter growth of 1.5 to 2 inches per decade, and where it is less than the lower figure thinning is in order. As diameters advance beyond the 24-inch class a moderate decline in growth rate must be expected, but it should be kept as near to 1.5 inches per decade as possible and should not be allowed to fall below 1 inch per decade.

FORM

Form may be more important than volume in determining the value of a stand for saw timber. Of the form characteristics which tend to lower the value of stems those most common in the Southwest are: rapid taper, coarse branching, forking, crook, and lean. In many instances two or more of these characteristics are associated.

High Taper

Taper acts directly in reducing board-foot volume, inasmuch as logs are scaled at the small end and the number of logs in a tree is determined by the merchantable length below the point where the diameter of the bole falls to 8 inches, or whatever is the minimum merchantable limit.

Rapid taper is an effect of open spacing and long crowns. It is not uncommon to find open-grown trees 18 inches d. b. h. containing but a single 16-foot log whose upper diameter is only 8 or 10 inches. An 18-inch, 1-log blackjack, according to the Southwestern Region ponderosa pine volume table, contains 100 board feet, but individuals of the wolf type may scale only half that much. An 18-inch blackjack grown in a fairly dense stand usually contains three logs and scales 200 board feet. The lesson taught by these comparisons is that d. b. h. measurements alone may give a misleading estimate of volume increment. Long-crowned trees usually are credited with a much higher rate of increment than they are entitled to on the basis of actual growth in merchantable volume.

Added to the waste and loss of stumpage values in trees of high taper is the cost per M of transporting and handling logs a large part of whose contents goes into the slab. In hewn tie operations, the labor cost is materially increased by sharp taper. Stems of the dimensions usually cut for poles may likewise be rendered valueless by high taper.

Abnormal Branching

Coarse branching is commonly associated with high taper, both characteristics being the result of a common cause—open spacing in youth. The lower branches die eventually, even in open-grown trees, but not until they have grown too large for natural pruning (fig. 9, *A*). It is not uncommon to find trees over 24 inches d. b. h. whose first two logs are studded with dead branches or stubs 3 to 4 inches in diameter. In sawn timber, these dead limbs result in large loose knots in the outer layer of wood deposited since the branches died. They also are the most common entrance point of heart rot *(2, 3, 42)*. Although small pieces of clear wood may be sawed out between knots, the whole picture is one of inefficient production. When the branches are large in diameter they are also, as a rule, numerous and close together. If the distance between branch whorls is 2 feet or more, quality material can be sawed out between knots, but if the whorls are only 1 foot apart or even less, a common arrangement in wolf trees, resaw operations are hopelessly handicapped.

The only way to obtain high-grade sawlogs from open-grown trees in the Southwest is to prune to the height of one or more logs while the trees are relatively small, preferably below 9 inches d. b. h. Since open-grown trees commonly attain a diameter of 30 to 40 inches in 150 years, they offer an excellent opportunity for profitable pruning if the operation is performed in time.

Mistletoe is a contributing cause of coarse branching. Associated with the large branches are pitch flow and distortion of the bole. If, however, the affected tree is in a dense stand, the abnormal branches usually die at an early age, although the mistletoe continues to be active in the bole.

Forked Boles

Forking is the cause of much waste and sometimes the loss of an entire tree. A fork within the first log length results in excessive if not total waste of what is usually the most valuable part of the stem (fig. 9, *B*). Forking above the first log length is less serious, and in large trees it is sometimes possible to utilize all or the major portion of the members of a fork.

The cause of forking may be either hereditary or accidental. Positive proof of hereditary forking is not available in ponderosa pine, although circumstantial evidence is not difficult to find. Strongly suggestive of this are trees which fork and refork, presenting a succession of forks in each of the main divisions of the trunk.

Examples of forking due to injury are abundant and in many instances the chain of evidence is complete. The most familiar example is that of a crotch with a dead, pitchy spike in the middle remaining as mute evidence of how, some 50 years earlier, a porcupine girdled the main stem and two or more side branches grew up around it. Essentially the same effect may be created when the slender terminal stem is cut off or peeled by the Abert squirrel or killed by the pine tip moth. In this case, however, the terminal stem is usually smaller and breaks off and disappears. The general effect of killing the leader is to stimulate the growth of side branches, and thus wolf trees may result from injury rather than heredity or early environment.

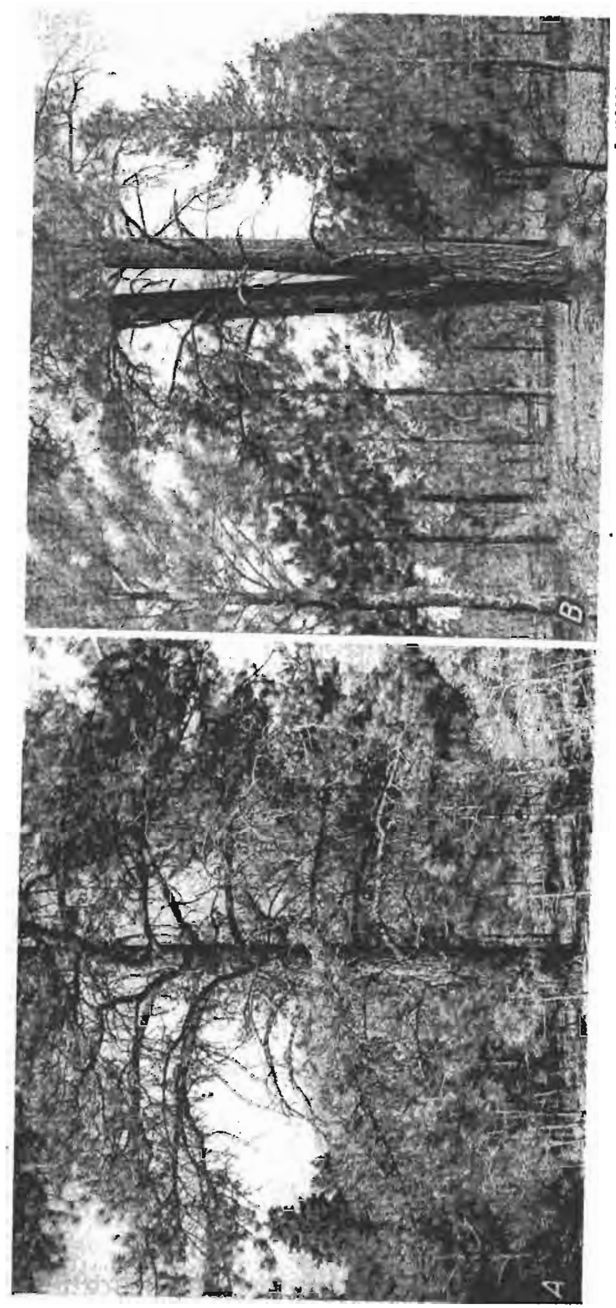

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FIGURE 9.—Abnormal boles. *A*, Coarse branches or dead stubs extend almost to the ground. Although some usable material can be obtained by sawing out pieces between knots, the waste is enormous. *B*, Low forking often results in waste of 6 to 8 feet in the lower part of the bole.

Crooked or Leaning Boles

Crooked and otherwise deformed boles are the result of various forms of injury, including those which cause forking. One of the most common sources of crook is snow pressure. A slender stem is bent to an angle of perhaps 45 degrees from the vertical by a load of snow. When growth resumes, the young leader rises vertically, and although the old stem struggles to regain the upright position, it often remains out of plumb while the new top grows erect. Similar effects are brought about in many ways, notably by windfall or logging in which a large tree or log is thrown against a smaller one.

Lean is in most instances purely a natural phenomenon. When several trees start in a group, those on the edges tend to lean out away from the middle of the group if there is an open space adjoining (fig. 7). The base must remain fixed but the top is pushed outward, so to speak. If these forces act throughout the early life of the tree the stem may remain straight though inclining at an angle from the vertical. If leaning trunks are in a stand, neighboring trees exert a counter influence, but if they border on an opening the tops grow farther and farther apart. The branches on the inside are shaded out while those on the outside are unrestrained. Thus, the unequal distribution of weight exerts an additional force which tends to pull the trunk away from an upright position.

Leaning boles tend to develop a structural peculiarity on the lower side known as compression wood. Compression wood is brash and weak, warps badly, and in other ways is inferior to wood of normal structure.

AGE CLASSES

The oldest ponderosa pine on record in the Southwest bore 650 rings on the stump. Trees over 400 years old are found occasionally, but mature trees in general are not much over 300 years old and most of them are less than 300.

Age in the Southwest is commonly determined by ring counts on the stump without correction for the number of years required to reach stump height. Although technically incorrect, this practice is regarded as legitimate as long as its limitations are understood. The time required to grow from the ground line to stump height is extremely variable because of agencies which retard early height growth. Except as a measure of these retarding influences, the time required to reach stump height is unimportant because in a selection forest, seedlings cannot be said to be occupying space or using water in competition with older trees.

Physiologically, there is no apparent reason why ponderosa pine should not commonly live to an age of 500 years in the Southwest as it does in eastern Oregon and eastern California. Higher precipitation and faster growth in Arizona and New Mexico should favor a longer, rather than a shorter life.

Why do relatively few trees in the Southwest attain really great age? One answer is lightning. As soon as a tree rears its head well above the general crown level, it becomes a lightning rod. Lightning is one of three most common causes of mortality in the Southwest, but it is a minor factor in California and the Northwest. Lightning may not be the sole cause of the earlier death of southwestern trees, but it is undoubtedly a major one.

For purposes of management, trees are commonly divided into six broad age classes: three juvenile classes (seedlings, saplings, and poles); blackjack, under 150 years old; intermediate, 150 to 200 years; and yellow pine, 200 years or over. The three older age classes, readily recognized by the color of the bark and form of the crown, are the basis of important silvicultural distinctions in management.

Juvenile classes.—Below the 12-inch diameter are the seedlings, saplings, and poles, of ages commonly ranging from less than 20 up to 80 years, and occasionally higher. These classes are the source from which must come the replacements as merchantable sizes are cut or lost through mortality.

Blackjack class.—Blackjacks are young trees which possess all the biological advantages of youth. They are characterized by a dark, almost black bark, a relatively short, rapidly tapering bole, a pointed or rounded top, and ascending upper branches. Although sometimes attaining large diameters, blackjacks are characteristically shorter and more tapering than are mature trees of the same diameter. Clear and select lumber grades form a smaller percent of the volume than in yellow pine; but blackjacks also contain less of the extremely low grades due to heart rot and large, loose knots. In blackjack lumber from trees well grown and harvested in the right stage, there may be knots, but these are mostly of the firm and relatively small type permitted in lumber grades No. 1 and No. 2 Common. Defect due to heart rot in blackjacks is generally less than 5 percent of the gross volume.

Intermediate age class.—Intermediate trees have practically all the biological advantages of blackjacks. They represent a transition stage from blackjack to yellow pine. This applies to the color of the bark which may be described as turning from black to yellow or brown. Intermediate trees are often dark on one side of the trunk and light on the other, and the upper portion of the bole is darker than the lower part. The tops are somewhat more rounded than those of blackjacks. The branches generally are more nearly horizontal but the upper ones are distinctly ascending. Boles of a given diameter are longer and less tapering than are those of blackjack though less cylindrical than those of yellow pine.

As in blackjack, the percent of heart rot is relatively low. Diameter growth is almost as vigorous as that of blackjack. Lumber grades, however, are likely to reflect the disadvantages of yellow pine without its advantages. After the lower branches die there is a period during which new wood is deposited around these dead branches or stubs, thus forming loose knots. Unless the bole has been pruned, this period falls predominantly in the advanced blackjack or the intermediate stage. Left to grow to full maturity and to the large diameters common in the yellow pine stage, many of the branches are shed and overgrown by a layer of clear wood. If grown in dense stands or if the bole is pruned while the branches are still alive, intermediate trees will have a central core containing firm knots covered by a clear layer, thus combining relatively high percents of lumber grades from No. 2 Common up through the Select and Clear grades.

Yellow pine class.—Yellow pines commonly range from 200 to 300 years old. As far as years are concerned, trees 300 years old may have all the potential vigor necessary for good growth and 400-year-old trees are often found to be growing vigorously. When vigor is declining the reasons for such decline are associated with but not necessarily a result of old age. Large size, which is a normal product of age, exposes the tree to increased danger from physical agencies such as lightning and wind. If the stand is crowded the large tree encounters increasing difficulties in obtaining enough water. Parasites such as mistletoe and heart rot, having once gained a foothold, exert a cumulative effect with advancing years. All things considered, old trees are a poorer risk than young ones, but age is not in itself a limiting factor. A 300-year-old tree which has escaped the many deteriorating agencies is not a poor risk except as large size may expose it to unusual hazards.

Yellow pines are characterized by a reddish yellow or cinnamon brown bark on all sides of the bole, this color extending quite or almost to the tip, a flat or broadly rounded top, and horizontal or drooping branches. Trees which have grown in close formation have long cylindrical boles comparatively free of branches for one or more log lengths. Surface-clear logs, however, are rare and are confined mainly to trees of large diameter. Boles affected by heart rot suffer a large reduction of net volume and this loss, together with mortality, tends to offset increment in trees over 30 inches d. b. h. Sound, well-formed trees which have cleared their boles are, however, to be considered for their value increment. In natural stands they are almost the sole source of clear lumber. In contrast, yellow pine boles that are studded with dead limbs or stubs are a liability which should usually be eliminated from the growing stock to make room for more valuable trees.

Balanced Gradation of Age Classes

In order to maintain a sustained yield under selective logging on short cutting cycles, it is important that at least five of the age classes—seedlings, saplings, poles, blackjacks, and intermediates—be well represented. What proportion of the total area or number should be allotted to each class has not been determined. Considerable latitude is permissible. As for the yellow pine class, its presence is not essential in a forest fully stocked with younger classes. Actually, most stands under management after conversion from the wild state will contain many gradations within the broad age classes listed. Assuming intervals of 20 years between classes, an extreme range of 200 years would provide ten age classes.

Age-Diameter Relationships

In practice it is not necessary to make fine distinctions in age. Within limits of about 100 years, actual age is less important than diameter. In order to regulate yield it is necessary to observe certain relationships in distribution of diameter classes. Although these relations need not be ironclad, it is at least essential to have many more trees in the lower than in the upper diameters. Examples of actual distribution of diameter classes on areas of 80 acres or more are given in the next chapter. On none of these areas are diameter classes under 18 inches d. b. h. adequately represented.

In typical even-aged blackjack groups of about 140 years, diameters commonly range from below 12 inches to 26 inches or even higher. The 9- to 11-inch trees are usually subordinates in the intermediate crown class; except for greater height, smaller crowns, and cleaner boles, they are equivalent to poles 50 to 60 years old. The largest trees are dominants corresponding in diameter to yellow pines of the 200-year class. In between these extremes are stems ranging mostly from 12 to 20 inches. The group as a whole, though actually even-aged (with a 20-year range), is for management purposes equivalent to a many-aged group with age classes ranging from 60 to 200 years. All trees, barring the suppressed or diseased, have the capacity for growth when given adequate space. Stems over 24 inches d. b. h. are for the most part ready to be cut now, having already passed the stage of most profitable increment. Some of the smaller stems have marked time for 100 years; they may continue in a subordinate role during another cutting cycle and then grow rapidly to merchantable size if released. The fact that such trees may be as much as 300 years old when harvested does not mean that under management they could not have attained merchantable size in a much shorter period.

Average diameter-age tables are interesting and may be of practical value if used with an understanding of their limitations. It must be borne in mind, however, that on the same site individual trees may depart 100 percent or more from the average because of peculiar environmental conditions. An example of the extreme variability is furnished by a summary of records obtained from the Wing Mountain area logged in 1939 (table 8). The ages were determined by ring counts on stumps of trees felled in a second cutting.

TABLE 8.—*Age in relation to diameter for three 30-year age classes on the Wing Mountain area of the Fort Valley Experimental Forest 30 years after first cutting* [1]

Age class		Diameter at breast height			Trees in class
Mean	Range	Mean	Minimum	Maximum	
Years	*Years*	*Inches*	*Inches*	*Inches*	*Number*
130	111–140	20.8	9.7	40.5	979
145	141–170	21.8	10.9	39.8	1,055
246	231–260	31.2	14.8	46.8	251

[1] Data compiled by Wm. L. Chapel *(15)*.

Rotation

At present the rotation period is less important than the cutting cycle; but after the old-growth timber has been removed, the time required for trees to grow from stump height to a specified diameter will assume increasing importance. Under present utilization standards the diameter of the average tree felled in commercial logging in the Southwest is approximately 22 inches, and the average age is estimated at 250 years. According to table 8, trees in the 145-year age class averaged 21.8 inches d. b. h., ranging from 10.9 to 39.8 inches. At 130 years, the average tree was 20.8 and the extremes were 9.7 and 40.5. From what is known about the response of tree growth to increased spacing, it seems likely that with timely improvement cutting 22-inch trees could be grown on this area in 130 years or even less.

SITE QUALITY

The site classification developed by W. H. Meyer *(44)* for selectively cut ponderosa pine forests of the Pacific Northwest has been used in this monograph to rate the relative productive capacity of ponderosa pine forests in Arizona and New Mexico. This classification recognizes six site qualities varying from I (the most productive, where total height of mature dominants averages about 190 feet) to VI (the least productive, where mature dominants average about 63 feet in total height). On this basis, southwestern ponderosa pine forests vary in site quality from III to VI, but the large majority of stands fall in classes IV and V.

It should be recognized that the use of a height-age relationship may underrate the relative productive capacity of southwestern ponderosa pine. The prevalence of lightning tends to reduce the average height of mature dominants since exceptionally tall trees are highly susceptible to damage from this source.

TREE CLASSIFICATIONS IN RELATION TO GROWTH

Classification of tree crowns with respect to size, shape, physical character, and exposure to sunlight dates back to the earliest silvicultural practice. The basic concept is that capacity for growth is determined by the capacity of the food laboratory which is vested in the foliage. A circumstance often overlooked is that the output of the food laboratory is limited not only by its own size and mechanical efficiency but also by the raw material and energy available. The raw materials are mainly water, carbon dioxide, nitrogen, and certain mineral elements; the energy is sunlight or solar radiation. Deficiency in one or more of these essentials may become the limiting factor in growth. Several classifications employ different criteria.

Position in the Crown Canopy

Dominance, or the relative position of individual tree crowns in a stand, was the basis of the oldest classification and is still a sound basis when used understandingly. Four classes, defined in standard textbooks, are: Dominant, codominant, intermediate, and overtopped or suppressed. A fifth class—open grown—has been used with ponderosa pine in the Southwest for isolated trees not competing for crown space. The limiting factor is assumed to be exposure to sunlight. The great abundance of sunlight in the ponderosa pine type, together with the open character of the pine forests, has led many to assume that light is never deficient and therefore to discount the importance of dominance. This assumption overlooks the fact that a small tree may be almost wholly deprived of direct solar radiation through interception by one or more larger trees. It is of common observation that when ponderosa pine needles are continuously subjected to shade they become thin and pale and the twigs eventually die. In dense stands the death of twigs and branches proceeds from the ground upward until the only remaining green foliage may consist of small tufts at the extreme tips of tall, slender poles. In such stands, the individuals which chance to be a few feet taller than their neighbors have a great advantage. This relation was readily observed by early foresters, even though they may not have known much about photosynthesis and metabolism.

Diameter growth in the four classes is generally in descending order from *dominant* to *overtopped*, although the relationship between dominant and codominant classes is not strictly consistent. The reason for this lack of consistency is that the classification does not take ground space into account. Generally a dominant has more ground space than a codominant, but this is not always true. The dominant in a large group may be pressed by many smaller trees which, though unable to interfere seriously with its access to sunlight, may encroach upon its root zone and exert severe root competition. Dominants in such positions sooner or later decline in diameter growth and their crowns may suffer sharp reduction by loss of foliage through shading of lower branches. Codominants generally grow less rapidly than dominants because both crowns and roots, especially the latter, are subjected to more intense competition. With correct spacing, however, it is possible for codominants to grow as rapidly as dominants. Trees in the intermediate and overtopped classes are always of slow growth because their position is the result of crowding. As will be shown later, the slow growth of trees under domination is no criterion of growth capacity when released by management.

Age-and-Vigor Classes

Another system of classification is based on age of trees and the size and physical condition of their crowns. It integrates the relation between the size of the tree and the area of active crown or leaf surface, assuming that in the final analysis area of leaf surface is a measure of growth capacity. The idea was first introduced by Dunning *(21)* in California who separated the trees of cut-over ponderosa pine stands into seven classes. More recently, Keen *(31, 32)*, working in the Northwest, elaborated a similar scheme which, though based on the same general concept, organized the classes on a different plan. Keen used four age classes corresponding roughly to the broad age classes of the Southwest: each class is further divided into four "vigor" classes corresponding roughly to the standard dominance classes, but placing more stress upon size and density of the crown than upon its position in the canopy.

A modified age-and-vigor classification was developed by Thomson *(84)* for use with ponderosa pine in the Southwest. Thomson recognized four age classes and five vigor classes, which may be briefly described as follows:

AGE CLASSES

I. Young blackjacks (mainly below 12 inches d. b. h.).
II. Blackjacks of saw-timber size (usually 12 inches d. b. h. or larger).
III. Intermediates or young yellow pines (mature).
IV. Old yellow pines (overmature).

VIGOR CLASSES

AA. Extremely large crowns, length 70 percent or more of total tree height (wolf-type trees).
A. Full vigor, crown 55 to 70 percent of tree height.
B. Good to fair vigor, crown 35 to 55 percent of tree height.
C. Fair to poor vigor, crown 20 to 35 percent of tree height.
D. Very poor vigor, crown less than 20 percent of tree height.

Thomson's modified classification has been used for describing individual trees on several of the Fort Valley plots and is the basis for the "tree class" designations given in this and later chapters.

Keen designed the age-and-vigor classification primarily for purposes of rating bark-beetle susceptibility, but timber managers have used it widely as a basis for silvicultural practice. The theory is that growth rate decreases with age and increases with size of active crown. That young trees grow more rapidly than old ones cannot be disputed; but under 200 years, age is no serious handicap in southwestern ponderosa pine. As for crown size, growth figures obtained by mass averaging support the theory; but on examination of individual trees, exceptions are so striking as to raise doubts as to the soundness of the principle. Analysis in the light of plant physiology points in the same direction. It is true that the average A tree grows faster than the average C tree, but many individual C trees grow as rapidly as the best A trees. There is a "law of the minimum" which says, in effect, that growth rate is governed by the essential element which is least available.

In a region such as the Southwest, which is characterized by an overabundance of sunshine and a deficiency of precipitation, moisture rather than solar energy is most likely to be the critical factor. And growth is dependent more upon a large root system than upon a large crown. It is possible that leaf surface beyond the requirements of photosynthesis can become a hindrance by inducing excessive transpiration. The enormous volume of limb wood in Class A trees and wolf trees furthermore represents wasted energy, to say nothing of lumber quality.

It follows that crown size, used as an index of growth, is subject to the same limitations as crown dominance: neither a large crown nor free exposure to sunlight avails if the root system is unable to supply the needed water. Class A trees usually maintain a superior growth rate because, in addition to being dominant, they are also usually isolated. In less degree, the same is true of B trees, as compared with those of classes C or D. Not only is crown size associated with position but it is determined by position. A large crown is not the cause of rapid bole growth, but is itself an effect of the same factor that produces rapid bole growth, namely, abundant moisture made possible by a large root system in an area relatively free of competition by other vegetation.

Growth tables based on the age-and-vigor classification have shown a marked decline in growth rate through the series of "vigor" classes from A to D. These tables, however, disregard the fact that class A and class B trees usually occupy much more ground space than do class C and class D trees of the same diameter. Briegleb's *(11)* tables are based on growth in virgin stands where A and B trees are the dominants which have appropriated more than the average share of space. Hornibrook's *(30)* and Thomson's *(84, 85)* figures on growth in cut-over stands evidently have not taken into account the fact that only a small proportion of the C and D trees have been adequately released in past cutting, whereas the A trees and, to a less extent, the B trees remaining after cutting are generally isolated.

Another practice which places the C and D trees at a disadvantage is that of throwing into these classes all trees suffering from any ailment which has reduced the leaf area. Thus a large A or B tree which is declining as a result of lightning, mistletoe, or squirrel injury, automatically falls into the C or D class.

Position on the Ground

Within well-stocked stands it is impossible, without extensive excavation, to outline the root pattern of individual trees and thus determine the degree to which one competes with another. From observations of windfalls, however, it is apparent that trees within groups have more restricted root systems than trees on the edge of the group or entirely outside. Occasionally an interior dominant, usually older than its associates, may send some roots clear beyond them into an open space, or a large tree outside of a group may send roots into the group. With the foregoing clues, the following rough classification is used for rating the relative space available to the individual tree or its position on the ground. The following symbols have been used to designate typical positions:

X. *Isolated.*—At least 30 feet (usually more) from other trees.
O. *Open.*—Detached from a group but nearer than 30 feet.
M. *Marginal.*—In the outside rank of a group or only slightly inside.
I. *Interior.*—Distinctly within the group.

Growth rates of tagged trees have shown a fairly consistent correlation with position on the ground.

Figure 10 illustrates the influence of ground space on diameter growth in three blackjacks, all in age class II and crown class B, but one interior, one marginal, and one open. Despite similarity in age and vigor, the open-grown tree is growing about three times as fast as the interior dominant.

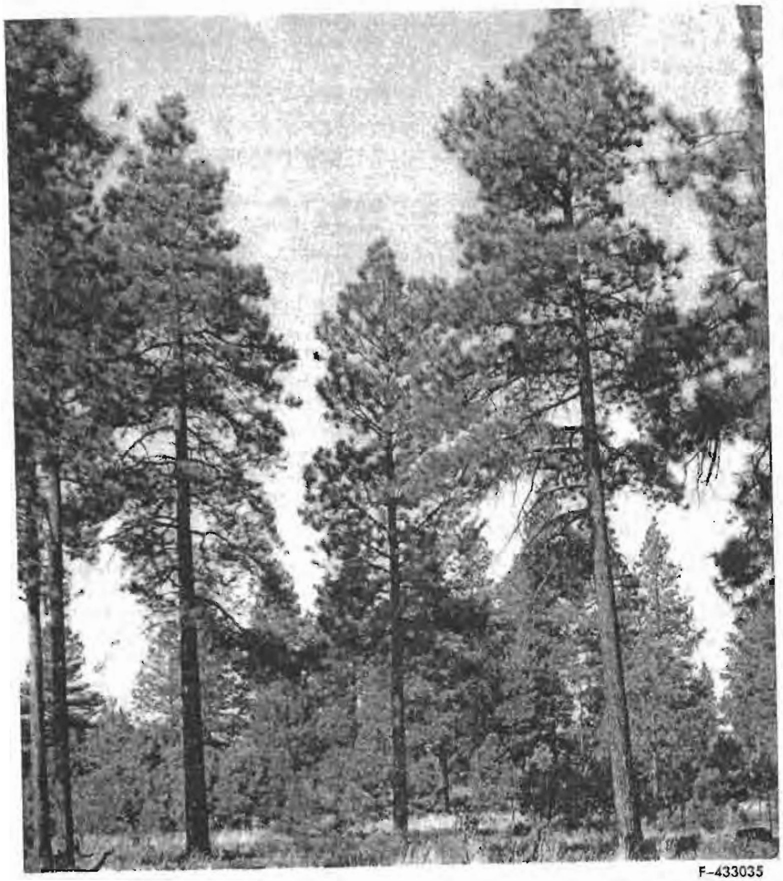

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FIGURE 10.—Three blackjacks, all with class B crowns but in different positions in a large group. Diameter growth during decade 1929-39: tree at left, interior, dominant, growth 0.8 inch; right, marginal, codominant, growth 1.5 inches; rear center, open, dominant, growth 2.5 inches.

A Comparison of Ground Space and Crown Vigor

Growth records from tagged trees on the Wing Mountain experimental area (S3) provide a basis for comparing position on the ground with crown vigor, as a basis for rating growth ca-

pacity. In table 9, 10-year diameter growth of 348 trees classified by both systems is summarized. Trees were classified in 1939 and the diameter growth is for the third decade (1929-39) following the first cutting. All trees are immature (age classes II and III) and they include all stems in 21 selected blackjack groups.

TABLE 9.—*Average 10-year diameter growth of 348 trees in 21 blackjack groups by Keen's vigor class and by ground position class. Wing Mountain Sample Plot (S3), 1929-39*

Vigor [1] class	Ground position class				All position classes	Basis, trees
	X (isolated)	O (open)	M (marginal)	I (interior)		
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Number*
A	2.39	1.74	1.33	----------	1.77	59
B	----------	1.79	1.34	0.84	1.36	84
C	----------	1.74	1.35	.98	1.29	140
D	----------	----------	.90	.52	0.63	65
All vigor classes	2.39	1.76	1.29	.75	1.26	----------
	Number	*Number*	*Number*	*Number*		
Basis, trees	15	60	171	102	----------	348

[1] All trees in age classes II or III. Crown length in percent of total height: A, 55 or more; B, 35-55; C, 20-35; D, under 20.

Average diameter growth by crown-size classes, disregarding ground position, follows the conventional downward trend from A to D. Essentially the same relationship has been reported from all ponderosa pine regions and has been accepted as conclusive evidence that growth capacity is directly related to crown "vigor" as measured by size of active crown.

When the vigor classes are further divided into ground position subclasses, however, the picture changes radically. Corresponding position classes show almost identical diameter growth through vigor classes A, B, and C. X (isolated) trees are represented in only one vigor class—A, whereas I (interior) trees are missing from class A. This mode of occurrence is characteristic and explains the high average diameter growth usually found in class A trees. All the class D trees were in ground positions M or I; they were mostly of subnormal root and crown development because of prolonged subordination.

When a second cutting was made in 1939, about half of the trees in ground position M or I (table 9) were released and retained in the reserve stand. A record of their average 5-year diameter growth following cutting (table 10) shows that all vigor classes respond well to release. Response is ordinarily most pronounced in position classes M or I, because it is here that increased space is most needed. Average diameter growth following release was almost identical in vigor classes A, B, and C. On a percentage basis, class D trees showed the greatest response to release, but actual diameter growth was considerably below that of the other vigor classes.

TABLE 10.—*Average 5-year diameter growth of released trees in ground positions I and M, by vigor classes, before and after cutting*

Vigor class	Trees	Average 5-year diameter growth	
		Before cutting (1934–39)	After cutting (1939–44)
	Number	*Inches*	*Inches*
A	6	0.66	1.00
B	33	.62	1.02
C	63	.61	.96
D	31	.32	.56

Of the two classifications ground space evidently provides the best clue to the growth capacity of the individual tree. Where harvest cutting operations are involved, however, it should be remembered that the space after cutting, not before cutting, will exert the primary influence.

Use and Limitations of Tree Classifications

Young trees grow faster than old ones; but ponderosa pine remains physiologically young until at least 200 years old, and if other conditions are favorable good vigor persists to an age of 400 years or more. Injury, disease, competition, and sheer size, rather than age, are the limiting factors in old trees.

Crown size becomes limiting only in extremes. Rapid growth is found in classes A, B, and C, but class D is below or near the limit of photosynthetic adequacy. There are indications that extremely large crowns are a hindrance to bole growth, and this is certainly true as regards quality.

Crown dominance is important to the extent that it expresses access to direct sunlight. Exposure of the upper portion of the crown equal to one-third the total height of the tree is sufficient.

Ground space as an expression of access to soil moisture ranks with crown dominance. Utilization of soil space, however, is difficult to measure or estimate because the roots are hidden. The terms *isolated, outside, marginal,* and *interior* are only rough approximations of the soil actually utilized. Obviously, ground space does not avail if the root system is subnormal on account of disease, injury, or restricted development.

Tree classifications are useful mainly for purposes of description. Collectively, the three classifications here discussed, when supplemented by an appraisal of bole form and general physiological condition, can serve as a guide to silvicultural cutting; but no one system is adequate when used alone.

Cutting in Virgin Stands

Silvicultural cutting aims at three broad objectives: (1) To harvest the crop of merchantable timber; (2) to leave a growing stock capable of producing satisfactory future crops at required intervals; and (3) to encourage natural regeneration where stocking is deficient. Ideas regarding the best ways of achieving these objects have been modified from time to time. They have found expression in "methods of cutting" applied in both extensive and experimental practice.

METHODS TESTED AT FORT VALLEY

Six methods of cutting have been tested in the Fort Valley Experimental Forest: Group selection, light selection, scattered seed tree, favoring dominants, improvement selection, and salvage. The sample plots representing each method are listed in table 11, along with pertinent information concerning each plot. An undisturbed virgin stand is included in the series for the purpose of comparison. An additional method of cutting, maturity selection, is not included in the Fort Valley series, but it has been widely employed and is discussed later in the chapter. Residual stands, broken down into 3-inch classes above 8 inches d. b. h., are shown for each area in table 12. Cutting practice under each method and special conditions encountered on each area are described in the following pages.

Group Selection

Understanding the philosophy of group selection requires that the governing conditions be taken into account. Large operations before about 1930 usually employed railroad logging. Liquidation of fixed charges required a minimum cut of 4,000 to 6,000 board feet per acre, depending upon location and total volume available to amortize the cost of railroads. Such growth figures as were to be had indicated that from 60 to 100 years must elapse before increment could provide enough volume to justify a second cut. In such a program large yellow pines left for seed were regarded as a liability chargeable against regeneration. Consequently, where advance reproduction was present heavy cutting in the yellow pine class was common. Contracts generally called for reserving one-third of the merchantable volume; but in many instances, particularly where few seed trees were thought necessary, the reserve was considerably lower. Residual volumes varied from 4,000 board feet per acre to as low as 1,500 board feet. In general, blackjack groups were left intact while yellow pine groups were heavily cut.

The effect was dense groups of blackjack separated by spaces 100 to 300 feet in diameter occupied only by occasional large seed trees. Such a cutting is illustrated in figure 11. The map was made

TABLE 11.—*Summary record of large sample plots in the Fort Valley Experimental Forest*

Method of cutting	Plot designation	Year established	Area	Average height mature dominants	Site quality [1]	Original gross volume per acre [2]	Residual stand [3]			Mistletoe
							Trees per acre	Volume per acre	Volume per tree	
			Acres	*Feet*		*Feet board measure*	*Number*	*Feet board measure*	*Feet board measure*	
No cutting	Virgin S6	1925	160	98	V+	11,778	19.5	11,778	604	Medium.
Group selection	Wing Mt. S3	1909	456	98	V+	12,000	11.7	3,520	301	Heavy.
Group selection	Cinder S4	1909	304	83	V−	7,000	9.4	2,328	248	None.
Group selection	Coulter Ranch S5–1	1913	139	79	V−	8,000	12.1	2,846	235	Heavy.
Scattered seed tree	Coulter Ranch S5–2	1913	152	82	V−	9,000	3.9	1,873	480	Heavy.
Light selection	Coulter Ranch S5–3	1913	112	84	V−	9,000	13.7	4,510	329	Heavy.
Favoring dominants	Fort Valley S7	1925	160	93	V+	12,000	13.8	3,385	245	Medium.
Salvage	Fort Valley S6B	1940	72	95	V+	12,000	16.7	8,877	532	Medium.
Impr. selection	Fort Valley S9	1941	85	95	V+	16,892	18.9	8,029	425	Light.
Impr. selection	Corey pasture S10	1942	76	96	V+	12,826	13.1	5,376	410	Medium.

[1] Based on Meyer's classification for the Pacific Northwest.
[2] Estimated for plots established prior to 1940.
[3] Trees over 11.5 inches d. b. h. at the time the plots were established, based on extensive plots only.

TABLE 12.—*Number of trees per acre when first recorded, by diameter class, on sample plot left uncut and nine plots cut by specified methods, Fort Valley Experimental Forest* [1]

D. b. h. class (inches)	Virgin S6	Group selection			Scattered seed tree S5–2	Light selection S5–3	Favoring dominants S7	Salvage S6B	Improvement selection	
		S3	S4	S5–1					S9	S10
9–11	2.33	3.31	2.39	3.92	1.37	4.33	5.93	3.16	2.96	6.27
12–14	2.36	2.81	2.53	3.82	.61	3.97	4.18	2.62	3.41	3.16
15–17	2.83	2.20	2.38	3.06	.51	3.04	3.73	2.11	4.00	2.04
18–20	3.31	2.69	1.91	2.11	.63	2.15	2.61	3.31	3.58	1.89
21–23	3.35	2.00	1.11	1.52	.72	1.70	1.76	3.09	3.11	2.24
24–26	2.83	1.01	.79	.83	.55	1.16	.86	2.57	2.66	1.66
27–29	2.03	.54	.31	.50	.37	.84	.46	1.59	1.61	1.20
30–32	1.46	.29	.23	.15	.32	.46	.16	.81	.41	.64
33+	1.32	.17	.13	.13	.19	.40	.06	.64	.08	.29
Total:										
9″+	21.82	15.02	11.78	16.04	5.27	18.05	19.75	19.90	21.82	19.39
12″+	19.49	11.71	9.39	12.12	3.90	13.72	138.2	16.74	18.86	13.12

[1] Data for S3, S4, S5-1, S5-2, and S5-3 include only "extensive" plots.

directly after cutting; trees which died during the next 20 years were designated later. Three areas now included in the Fort Valley Experimental Forest (S3, S4, and S5-1) were cut under group selection from 1909 to 1913. They are briefly described in the following paragraphs.

Wing Mountain plot S3.—This is the largest and one of the two earliest sample plots. Lying 6 miles west of the Fort Valley head-

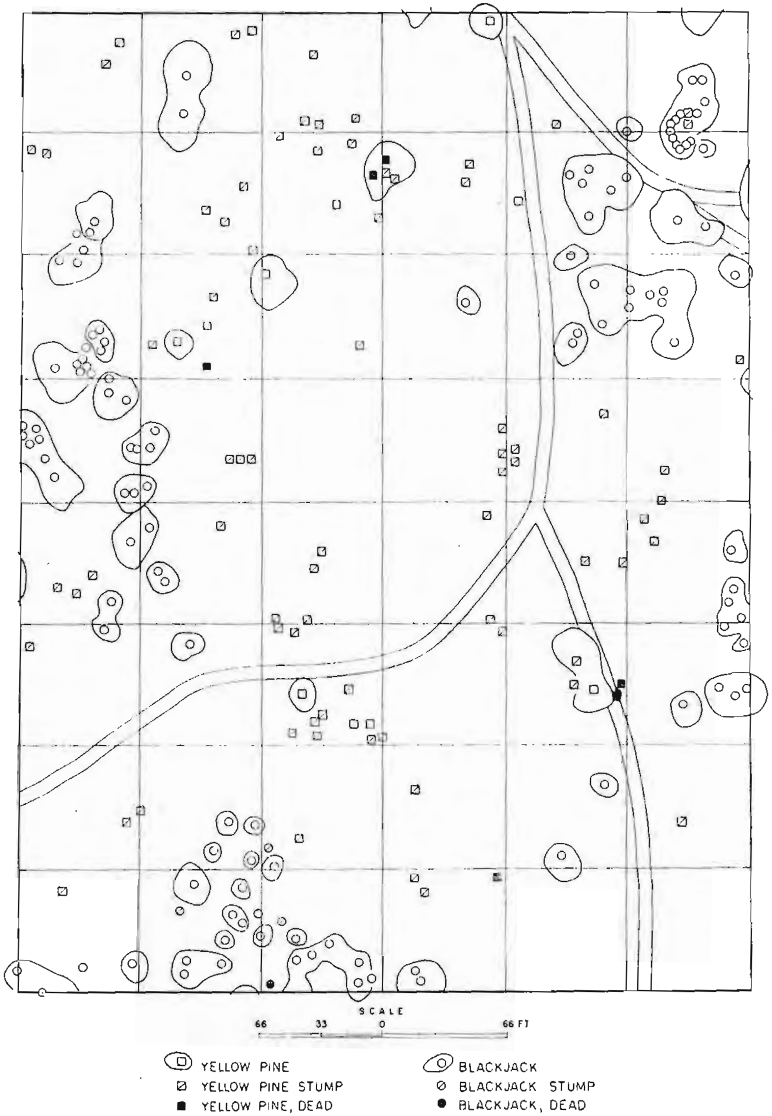

FIGURE 11.—Distribution of trees after group selection cutting.

quarters, its altitude, temperature, and precipitation are similar to those at the headquarters (table 2). Site quality is a high V. The soil is a fairly deep, stony clay loam of volcanic origin, slightly acid in reaction. The original stand consisted mainly of three broad age classes ranging from 100 to 300 years old and from 12 to 40 inches d. b. h. An even-aged group arrangement was very pronounced. Cutting, in 1909, was strongly influenced by the absence of advance reproduction and the presence of mistletoe. Many large yellow pines were left as seed trees. Blackjack groups were generally left intact, but in some places trees with heavy mistletoe infection were cut as a salvage measure.

The original gross volume on this plot was about 12 M board feet per acre. Of a residual stand of 3,520 board feet per acre, 58 percent was in the blackjack or intermediate age classes. Table 12 reveals a great deficiency of diameter classes below 18 inches, and other records show that the deficiency becomes even more outstanding on approaching the 4-inch class. The area occupied by trees just after the cutting is estimated at only one-third of the total. Spots a hundred yards or more in diameter were left unstocked except for occasional seed trees. These open areas became almost completely restocked with seedlings in 1919.

Cinder plot S4.—This area was logged and records begun in the same year as the Wing Mountain plot. In many respects the two plots present strong contrasts. The cinder area lies 13 miles east of Fort Valley at an altitude of 6,700 feet, near the lower border of the ponderosa pine type. The site quality is low V, determined by lower precipitation (about 20 inches) and higher evaporation than on the Wing Mountain plot. As the name implies, the soil is covered with volcanic cinders, black or red, to depths varying from an inch to several feet. Water penetrates the cinders readily, but the upper layers dry out quickly. Age classes and diameter classes were about the same as on the Wing Mountain plot, including absence of advance reproduction.

Although marking here followed the same principles as on the Wing Mountain area, a lighter and more open original stand resulted in leaving a thousand board feet per acre less. The trees are generally shorter and limbier. Unlike Wing Mountain, this area is entirely free of mistletoe. Young seedlings have come in sparingly, with the result that 35 years after cutting, large openings still remain sparsely stocked.

Coulter Ranch plot S5-1.—This group selection cutting belongs in a series of three, logged and established in 1913 for the purpose of comparing group selection with light selection (S5-3), and scattered-seed-tree (S5-2) cuttings (fig. 12). The site quality is V-, determined mainly by a shallow soil. Altitude and precipitation are almost identical with Fort Valley and Wing Mountain. The original stand was considerably lighter than on the Wing Mountain area, and cutting removed about 60 percent, leaving 2,846 board feet per acre. Diameter classes show the characteristic deficiency of stems below 15 inches, although poles and saplings were more abundant than on the Wing Mountain area. Scattered advance reproduction supplemented by partial restocking in 1919

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FIGURE 12.—Three methods of cutting in the Coulter Ranch series of plots logged and photographed in 1913.

A, Scattered-seed-tree method (plot S5-2). Trees left, primarily for seed supply, numbered 3.9 per acre, mainly over 18 inches d. b. h. Blackjack groups were cut severely. The hardwoods are Gambel oak of no commercial value.

B, Group selection. Blackjack group intact, characteristic of both group selection and light selection. Under the scattered-seed-tree method nearly all the blackjacks 12 inches and over would have been cut. Under light selection several of the yellow pines represented by stumps in foreground would have been left.

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FIGURE 12 continued.—*C*, Light selection. Under group selection most of the large trees would have been cut, though leaving a few for seed. Large natural openings as seen in the foreground are common to all methods of cutting.

has given rise to a fair pole class. Mistletoe has infected a large proportion of trees in all age classes. Of the three Coulter-Ranch plots, S5-1 is the poorest site (table 11)—characterized by shallow, very stony, clayey soil and short timber.

Light Selection

The general principles observed in this method were the same as those of group selection, but cutting practice was modified in the hope that more seed trees and a denser crown canopy might favor regeneration, which at that time (1913) was a very serious problem over much of the Coconino Plateau. Groups were treated the same as in group selection, except that in yellow pine groups more trees were left. On the whole, more large seed trees were left in the openings between blackjack groups than after group selection cutting. The thought of leaving a large volume for an early second cut was entirely subordinate to reproduction. Railroad logging demanded relatively heavy cuts at long intervals; in fact, the first cutting in this instance was considered too light to be economic from the operator's viewpoint. The first cut, which removed a net volume of about 3,000 board feet per acre, was not much out of line with present national-forest practice, except for leaving too many old trees over 30 inches d. b. h.

Coulter Ranch plot S5-3.—This light selection cutting left numerous large yellow pines, which account for the relatively heavy residual volume of 4,500 board feet. Wind, lightning, and mistletoe have taken an enormous toll from these large trees; but for the most part they served their purpose in providing an ample seed supply before they were lost. Most of that portion of the area which received protection against grazing restocked well in 1919. Mistletoe is at its worst on this area, having infected all age classes, including large pole groups which but for this pest would contribute much to the future growing stock. This area is the only early example of light cutting under experimental record, and it has provided useful guides in the light-cutting practice developed in recent years.

Scattered Seed Tree Cutting

As the name implies, this method undertook to leave only as much merchantable timber as was considered necessary to provide an adequate seed supply. In the absence of pole stands a second cutting under this practice could not be expected in much less than the full rotation period. Since only full-crowned trees could qualify as seed trees, groups of both blackjack and yellow pine were almost clear cut, the seed trees left being of the open-grown type. As viewed in 1913, advantages of the method were (1) a profitable cut for the operator and (2) assuming reproduction, a young stand free from domination by an older generation. Disadvantages were (1) the uncertainty of regeneration and (2) a long wait for the second cut. From an experimental point of view, the method promised to bring out contrasts with the more conservative group selection and light selection practices.

Coulter Ranch plot S5-2.—This plot has a general northerly aspect whereas the other two Coulter Ranch plots face the south; in no case, however, are the slopes steep. Although accurate records are not available, this stand is thought to have been somewhat heavier than the other two. As shown by table 11, the reserved stand contained only 3.9 trees per acre 12 inches and over d. b. h., less than one-third the number on the companion plots S5-1 and S5-3. A few poles and clumps of Gambel oak helped to relieve the general barren effect following cutting. Advance reproduction below the pole stage was deficient here as on the other two areas, but reproduction after cutting has exceeded all expectations, considering the few seed trees. With respect to reserved volume, this area compares favorably with some group selection cuttings; the difference is that in heavy group selection cuttings the volume is mainly in many small blackjacks, whereas here it is mainly in few relatively large yellow pines.

Favoring Dominants

One of the main tenets of ponderosa pine silviculture has been the belief that large-crowned dominants constitute the best growing stock. During the many years when restocking was a major problem in the Southwest, seed production was a further and in fact the primary incentive to leaving this type of tree. The specifications for seed trees called for healthy, full-crowned, preferably

isolated trees at least 20 inches d. b. h. *(54)*. Studies also indicated the need of at least four such trees per acre; and since the blackjack class seldom afforded enough seed trees in the right places the yellow pine class was called upon to make up the deficit.

Investigations *(37)* had shown that well-released yellow pine seed trees were capable of a high growth rate, even in diameter classes above 30 inches. It was therefore reasoned that a more liberal quota of large yellow pines would add substantially to the increment, provided that too many were not lost before the second

FIGURE 13.—A blackjack group opened by cutting under the method favoring dominants. Small-crowned trees large enough to make a log were generally cut.

cut. Furthermore, it was recognized that the principle of accelerated growth after release cutting applied also to blackjacks. All this reasoning was influenced by the thought that the best response would be obtained from trees of relatively large, well-formed, and well-exposed crowns.

Fort Valley plot S7.—The area selected for this type of cutting consists of 160 acres located within one-fourth mile of the Fort Valley headquarters. It was logged in the fall of 1924 and the sample plot was established in 1925. (Adjoining is the virgin stand, sample plot S6, also comprising 160 acres.) The original stand is estimated to have contained slightly under 12,000 board feet per acre. Cutting left 3,423 board feet. The remaining volume was almost identical with that of the Wing Mountain group selection plot S3. In the yellow pine class, volume and distribution on the two plots were quite similar, and for this reason S7 has been referred to as group selection cutting. But treatment of the blackjack groups was very dissimilar: on S3 they were left almost intact whereas they were opened up on S7. It is in the blackjack and pole groups that cutting to favor dominants found major expression. Subordinate blackjacks were cut where large enough to make logs, in order to give more space to the favored dominants. Figure 13 illustrates a blackjack group after the cutting, and figure 14 shows two common types in the intermediate and yellow pine classes. The rough dominant in figure 14, *A* is not only of poor quality but is also a mistletoe bearer. By contrast, the large, clean-boled yellow pine in figure 14, *B* will contribute value increment as long as it can be kept growing.

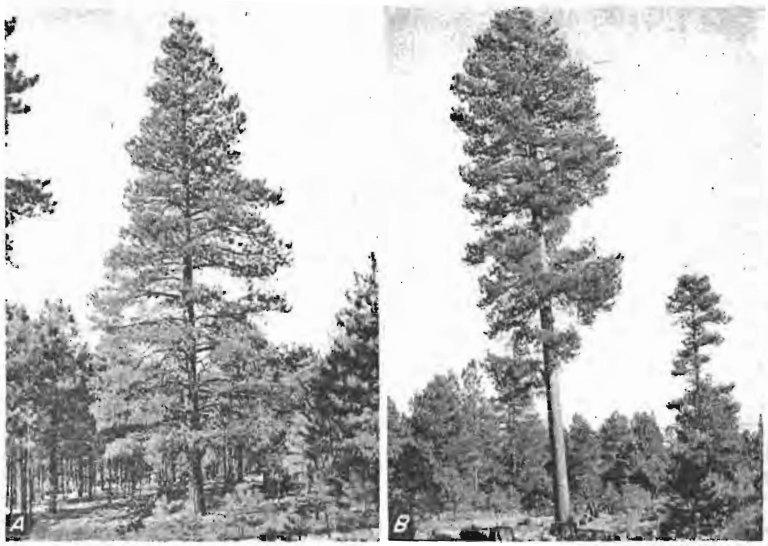

FIGURE 14.—Two types of large trees left in cutting under the favoring-dominants method. Cut in 1924, photographed in 1940.

A, 29-inch blackjack of poor form dominating good poles on all sides. Diameter growth by 5-year periods 1925-45: 0.9, 0.7, 0.8, 0.6 inch.

B, 34-inch yellow pine of good bole in a group of 12 stumps representing trees down to 12 inches d. b. h. Although this is a fine tree it is a high risk, and when gone it will leave a vacant space of about ½ acre. Diameter growth by 5-year periods 1925-45: 1.5, 1.0, 0.7, 0.4 inches.

Salvage Cutting

The salvage method removes only distinctly declining trees, with the object of salvaging usable material which would be lost if left until a regular commercial cutting is made 10 to 20 years later. An advantage of the practice is that the relatively light cut makes it possible to cover large areas in a short period. Since only small mills are usually interested in this type of operation, however, the aggregate area covered is likely to remain small. Many small operations sprang into existence under the stimulus of boom prices during and immediately after World War II. It is reasonable to expect a decrease in this class of activity if the demand for lumber declines toward prewar levels. Since the volume removed in salvage cutting is relatively small, the existence of adequate roads, or a terrain which requires little or no road building, is a prerequisite.

Fort Valley plot S6B.—This salvage cutting area is the east half of a 160-acre virgin stand which had been carried as a sample plot (S6) since 1924. Thus, the cut-over area has individual tree records which began 15 years before the 1940 cutting. Cutting in 1940 removed 4,000 board feet gross from a stand containing 12,000 board feet per acre. Cull and defect amounted to 48 percent. Since a second cut in 10 years was planned, only distinctly declining trees were removed. This left a considerable number that had been struck by lightning but gave promise of persistence. Many trees in early stages of decline were left because appearance indicated that they would live 10 years more.

Maturity Selection

Maturity selection was developed in the Pacific Northwest under conditions in which operators found it unprofitable to handle any trees but those of relatively high quality. The method is an attempt to harmonize silviculture and economics under adverse economic conditions. It makes use of classified growth tables designed to show the net percent of volume increment in each class; it also employs tables showing the marginal value, after deducting cost of logging and manufacture, of trees of different diameter and log grades *(10, 12, 47, 48)*. Assuming that gross earning capacity is proportional to net volume increment, net earnings are expressed by increment percent minus a fixed interest on the investment. If the interest rate is as high as 3 percent the net earning capacity of the larger trees is nearly always a minus quantity and is called a carrying charge or the cost to the owner of holding the tree in question. If the marginal value of the tree is low, the carrying charge becomes correspondingly low, and if the marginal value is negative the carrying charge becomes zero. Only young and fast-growing trees of relatively low diameter are capable of positive earnings—that is, a net annual volume increment exceeding 3 percent.

Selection by Age-and-Vigor Classes

Maturity selection growth tables give the growth in diameter or increment in percent by Keen's age-and-vigor classes.[5] Invariably the growth rate is higher for relatively young trees than for old trees and higher for large-crowned trees than for small-crowned trees. A combination of age and vigor in merchantable diameter

[5] Age-and-vigor classes are defined on p. 41.

classes gives the highest growth rate for II-A trees and the lowest for IV-D trees, with intermediate rates for intermediate grades.

On the basis of carrying charges as indicated by growth capacity and log grades, Bruce *(12)* has developed a marking schedule for the Northwest, and a slight modification of the same table has been used by Munger and Briegleb *(48)*. Key points in the specifications are: (1) The older age classes are marked to a lower diameter than are young age classes, (2) small-crowned trees are marked to lower diameters than are large-crowned trees, and (3) trees of a high log-grade composition are marked to a smaller diameter than are those of a low log-grade composition. In classes IV-C and IV-D, trees of high value are marked to the lowest merchantable diameter, but those of the lower grades are not cut unless the diameter is at least 34 inches. No trees in age class II are cut, and of course this rule applies also to class I, which includes mainly those trees below 12 inches d. b. h.

Modified Practice in the Southwest

For several years prior to 1946 maturity selection was employed in modified form in the Southwestern Region of the Forest Service. Log-grade composition and carrying charges were disregarded; but the Keen tree classification was used as an index of growth capacity. Application of the method has been discussed by Thomson *(84, 85)*.

Maturity selection was not included among the more recent Fort Valley cutting experiments because its major tenets are not in accord with findings on management areas where individual tree records have been carried 20 years or more *(70, 72)*. Following are some of the more important discrepancies:

1. Fort Valley tree records indicate that diameter growth is related more closely to ground space available following cutting than to age and vigor prior to cutting (tables 9 and 10).
2. In a region characterized by drought and low-quality timber, release of desirable trees from root competition by cutting less desirable stems is the key to effective silviculture.
3. Large-crowned trees are often the limby dominants or wolf trees which have grown more or less in the open; small-crowned trees are the codominants or intermediates in crowded stands. Small-crowned trees usually display the clear, cylindrical boles that should be retained to promote value increment.
4. Ponderosa pine stands are characteristically deficient in growing stock of young age (or small diameter) classes. Building up this part of the growing stock by favoring the better type of poles, blackjacks, and small yellow pines is considered a primary object of silviculture in the Southwest.

The nearest approach to maturity selection in the Fort Valley Experimental Forest is the cutting to favor dominants on sample plot S7, logged in 1924. Marking in the mature class followed essentially the pattern of maturity selection, though without use of an age-and-vigor classification. In immature classes it went a step beyond maturity selection by cutting subordinates, if merchantable, where they were competing with the favored dominants.

Improvement Selection

Improvement selection was developed in the Fort Valley Experimental Forest because it was realized that other methods had proved silviculturally deficient. As the name implies, improvement selection is planned and directed toward improvement of the stand *(70, 72)*.

Improvement selection recognizes and undertakes to correct, as far as possible, the common deficiencies of ponderosa pine stands: (1) General understocking accompanied by local overstocking, (2) a preponderance of mature classes at the expense of immature classes, (3) poor spacing and inefficient use of soil moisture, (4) prevalence of low quality due to inadequate natural pruning and dominance of inferior types, and (5) high mortality rate and low productive efficiency of large trees. These factors are closely interrelated; individually or collectively they account in large measure for the low yield of unmanaged ponderosa pine.

Silviculturally and economically the primary aim of improvement selection is to build up an effective growing stock. This takes precedence over immediate timber sale receipts and yield of the near future. Initial increment may be low but it is expected to rise with development of the growing stock, and quality is expected to rise more than volume increment. But ponderosa pine stands are usually so irregular that development of a satisfactory growing stock is a slow process. An adequate growing stock must first of all contain enough well-distributed trees to make reasonably full use of the soil; and the gradation of size classes must provide for a succession of cuts at relatively short intervals.

The first step, in conjunction with harvesting the crop, is to liberate trees which have a silvicultural and economic future. Trees of good bole and potential growth capacity will be found in mature as well as immature classes. In yellow pine groups they are the smaller stems, codominants or intermediates, of short crown and relatively clear bole. In addition to removal of declining and low-quality trees, the stand must be opened up enough to enable remaining trees to grow and bear seed. No rules can be given as to what volume should be left, but generally there should be enough relatively large trees to provide several cuts within the next 50 years.

Blackjack groups offer the greatest opportunity for salvage of potential growing stock. Removal of a single limby dominant usually liberates several smaller trees of good form. The increment borer is a better guide than spacing rules. Diameter growth of less than 1.5 inches per decade generally calls for thinning; but it should be borne in mind that moderate growth on many stems is preferable to maximum growth on a few.

If spaces between yellow pine or blackjack groups have been occupied by poles, saplings, and seedlings, the future of sustained yield is secure. Wolf trees and other undesirable types should be cut if merchantable. A market for stems below sawlog size would open new vistas in silviculture, but at this point commercial cutting merges into stand improvement, which is discussed in a later section.

Better Use of Soil Moisture

It is axiomatic that wherever moisture is the limiting factor in survival and growth, silviculture calls for development of a strong root system, in proportion to the size of the tree. The demand for root space invariably exceeds the demand for crown space. Fastest growing trees may be in vigor class A, B, or C, but they are nearly always in position class X (isolated), O (open), or M (marginal), meaning that the roots can extend freely in at least one direction. Slow growers may be in any vigor class but are invariably in position class I (interior).

Partial cutting, in addition to harvesting the mature crop, effects a redistribution of soil moisture among the remaining trees. Ideally, a harvest cutting under any selection system should leave the soil almost fully occupied. In overmature stands this result is not always attainable but it should still be held up as an objective. In typical blackjack groups, as will be shown later, 30 to 40 percent of the volume can be removed without lowering the volume increment during the ensuing 20 years, and if the trees have been well selected, value increment will increase greatly.

If the stand is stocked to the limit of the moisture supply, increase in size of individual trees must be accompanied by decline in diameter growth unless some of the trees are removed. Under a stocking that makes most efficient use of the soil, stems above the 20-inch class seldom grow in diameter at a rate exceeding 1.5 inches per decade, and as they approach 30 inches the growth will decline to 1 inch or less per decade. Wider spacing can increase these figures, but it should be remembered that the ultimate criterion is not diameter growth of individual trees but volume and quality increment of the stand as a whole.

Placing Increment on the Best Boles

Improvement selection endeavors to place the increment on the best boles in the stand. If a desirable clean-boled tree is crowded, additional space is provided by cutting less desirable neighbors of the rough-boled type; these are usually present in abundance. Occasionally several excellent stems occur in a clump; other things being equal, the largest is cut because two or three small trees have a higher potential earning capacity than a single large one. Stems below 24 inches d. b. h. are preferable as growing stock; but high-quality larger ones up to 26 inches, and even larger, may be left if they are provided with space in proportion to their size.

Limby dominants usually represent the lowest quality and the least efficient soil utilization in a stand. They grow rapidly for a time at the expense of subordinates, but eventually they too must yield to competition. Not only do they suffer from root competition but side shade from surrounding trees causes the lower branches to die. This last process would be desirable but for the fact that it usually begins too late to bring about natural pruning. Figure 15 illustrates a large tree of this class.

In pole stands most of the trees should be crowded into vigor class C and held in that class until about 50 feet tall. As soon as a commercial cutting can be made, groups should then be opened by removing first the limby dominants and others of poor form, then further cutting to improve spacing and finally supplementing with stand improvement. Limby class A trees should not be left unless they are in isolated positions and then they should be pruned while below 12 inches d. b. h. Figure 16 illustrates a large pole group treated in about this manner.

F-421060

FIGURE 15.—A 22-inch class C tree (extreme left) whose rough bole shows that it was formerly in class A but that the crown was reduced by intense side shade. It will grow as a result of release, but the bole will remain rough until it reaches at least 30 inches d. b. h.

Well-released class C trees will tend to build up their crowns, approaching the B class, but under light or moderate release they will remain in class C. Decline of some trees to class D is not serious but overtopping should be avoided. Early crowding forms a good bole and encourages natural pruning while the branches are small; cutting beyond the pole stage checks extreme competition and sustains diameter growth.

Boles are of two broad classes: (1) Those which have been cleared of branches early in life, at least to the extent of forming a surface-clear butt log while below 20 inches d. b. h., and (2) those which still bear coarse limbs either living or dead after reaching the 20-inch diameter class (fig. 15). Only the first class has high potential value. Although mill-scale studies show that the value of rough boles increases with size, it should be understood that substantial improvement in this class of tree comes only as the diameter exceeds 30 inches. Green limbs are preferable to dead ones in large boles.

FIGURE 16.—A pole group after improvement selection cutting and stand improvement in 1941. Several stems were cut for sawlogs; those marked with white cards at breast height were poisoned; all remaining have been pruned to one log length. Several trees will be large enough for sawlogs in 1951.

Application of Improvement Selection

Improvement selection, in contrast to group selection and maturity selection, removes fewer trees from yellow pine groups and more from blackjack groups. It leaves a larger total volume than does group selection, and about the same volume as maturity selection. Improvement selection leaves fewer large yellow pines but more in the middle and lower diameter classes, of a size and type that may be expected to become valuable in 20 to 40 years (fig. 17). In contrast to salvage and maturity selection, it opens up blackjack groups by taking out the largest and limbiest trees (fig. 18). In both yellow pine and blackjack groups it aims to leave the best available stems with respect to potential value increment, so spaced as to encourage growth. On an average, from 40 to 50 percent of the gross volume 12 inches and over d. b. h. is left and

FIGURE 17.—A desirable type of yellow pine stand after the first cutting by improvement selection. The three largest trees, between 24 and 28 inches d. b. h., will furnish volume for a second cut. The remaining five, between 18 and 24 inches d. b. h., can be held over two or three cutting cycles of 20 years each.

this is distributed as uniformly as circumstances permit. The proportion cut or left is subordinated to silvicultural objectives.

Advantages of extending the first cut to blackjack groups instead of confining it to the older age classes are that it makes possible:

1. Relief from stagnation in relatively young groups.
2. Liberation of potentially valuable subordinates while they are still capable of response.
3. In substance, a transfer of the growth which can be sustained by a fixed moisture supply from the poorest to the best stems in the stand.
4. Arresting extreme crown reduction which leaves coarse dead limbs on the upper portion of the bole.
5. Stimulation of root development sufficient to maintain growth and build up resistance to wind and bark beetles before the trees approach maturity.

Analysis of cutting on two areas.—Improvement selection is represented in the Fort Valley Experimental Forest by two areas (S9 and S10) logged in 1941 and 1942. Both plots are site quality V+, but S9, with an original volume of almost 17,000 board feet per acre, had by far the heavier stand. Plot S10, with an original volume of about 13,000 board feet, is more typical of stands as found on the Coconino Plateau. The two areas are compared as to number of trees and volume cut and left in table 13.

A second cutting on both of these areas in 10 years and a third 20 years later is contemplated. Removal of about 3,000 board feet per acre on S9 after a 10-year interval, assuming a net annual increment of 100 board feet in the meantime, will leave a reserve of approximately 6,000 board feet per acre. A cut of 2,000 board feet on S10 will leave about 4,000 board feet per acre. In both instances the second cut would remove: (1) Practically all yellow pines over 30 inches d. b. h.; (2) most yellow pines over 25 inches d. b. h.; (3) diseased, injured, or otherwise inferior trees of all age classes; and (4) additional stems as needed to improve spacing and especially to liberate trees of good form. In stands whose original volume is appreciably less than 9,000 board feet it may be advisable to defer the second cut 20 years.

Advantages of a light second cut in 10 years over taking an equivalent additional volume in the first cut are:

1. Less violent disturbance of yellow pine groups.
2. Increased opportunity for salvage as compared with a second cut deferred 20 years.
3. Additional opportunity for refinement in spacing, release, and selection of a superior growing stock.
4. Less damage to reproduction because nearly all trees in the second cut can be felled either within open tree groups or into spaces where trees were dropped in the first cutting.


F-427512

FIGURE 18.—A blackjack group after the first cutting by improvement selection. The trees are 10 to 18 inches d. b. h. and about 100 years old. Those under 16 inches d. b. h. have been pruned to a height of 17 feet. A few will be removed in 20 years in order to maintain vigorous growth.

TABLE 13.—*Number of trees and gross volume per acre cut and left by improvement selection method on sample plots S9 and S10* [1]

Diameter group (inches)	Blackjack and intermediate				Yellow pine				Volume, all age classes	
	Trees		Volume		Trees		Volume			
	S9	S10	S9	S10	S9	S10	S9	S10	S9	S10
	Number	*Number*	*Feet board measure*	*Feet board measure*	*Number*	*Number*	*Feet board measure*	*Feet board measure*	*Feet board measure*	*Feet board measure*
CUT [2]										
12–20	1.97	1.61	353	271	1.15	0.36	225	104	578	375
21–30	2.86	1.68	1,990	1,024	2.88	1.97	2,507	1,922	4,497	2,946
31+	.35	.22	504	300	1.73	2.02	3,284	3,829	3,788	4,129
Total	5.18	3.51	2,847	1,595	5.76	4.35	6,016	5,855	8,863	7,450
LEFT										
12–20	7.93	6.73	1,106	804	3.05	0.37	741	91	1,847	895
21–30	1.21	4.15	617	2,418	6.37	1.21	5,082	1,056	5,699	3,474
31+	.02	.29	29	376	.28	.37	454	631	483	1,007
Total	9.16	11.17	1,752	3,598	9.70	1.95	6,277	1,778	8,029	5,376

[1] Original gross volume S9, 16,892 board feet; S10, 12,826 board feet.
[2] Percent of gross volume cut S9, 52 percent; S10, 58 percent. Defect and cull, in percent of volume cut:

	Blackjack	*Yellow pine*	*Total*
S9	14	29	24
S10	14	28	24

Growth After Partial Cutting

Timber yields are determined by three elements: Growth, mortality, and replacement. Growth is directly manifested in the diameter and height accretion of individual trees, which is first translated into volume increment of trees and ultimately into volume increment of stands. Mortality works in the contrary direction by eliminating individual trees and thus lowering the aggregate increment. Replacement through regeneration and advance into the merchantable classes tend to counteract mortality.

In virgin stands, growth and mortality are often assumed to be in equilibrium. This is true only under certain conditions. In a fully stocked mature stand mortality is likely to exceed increment but only temporarily, because eventually replacement comes into play. In understocked stands containing a fair representation of immature age classes, increment exceeds mortality until such time as increased stocking and maturity bring about an equilibrium. The majority of virgin ponderosa stands in the Southwest are in the understocked class and they may therefore be expected, under protection, to increase their volume per acre substantially.

Harvest cuttings on a selection basis anticipate mortality, and if frequent enough they convert practically all growth into yield. Well-ordered selection cutting permits neither prolonged decline nor prolonged understocking.

DIAMETER GROWTH

Diameter growth is less closely related to diameter of bole than might be expected. Obviously, a given diameter growth represents a much greater volume increase in a large tree than in a small one. Nevertheless, it is not uncommon in cut-over stands to find that trees up to 24 inches d. b. h. are growing practically as fast in diameter as are 12-inch trees. Assuming a more or less constant relation between volume increment and growing space, the unexpected phenomenon of constant diameter growth through ascending diameter classes can only be explained by a decrease in the number of active stems per unit of area.

In dense young stands the larger stems are the faster growing ones in diameter as well as in volume. They are the dominants, which have been able to appropriate more and more space at the expense of their smaller neighbors. The subordinate stems are at the same time continually losing ground, thus lowering the average growth for their diameter class.

Diameter Growth Affected by Cutting

Comparison of Virgin and Cut-Over Stands

The effect of cutting on diameter growth can best be analyzed by considering also the rate of growth in virgin stands. A direct

comparison is furnished in the Fort Valley Experimental Forest by two adjacent areas of 160 acres each, one a virgin stand (S6) and the other a cut-over area (S7) logged in 1924 (tables 11 and 12). Although the cut-over area appears to have had a better representation of younger age classes, even before cutting, the stands and sites were generally similar. Apart from the expected deficiency in number of large trees on the cut-over area, numbers on both areas are sufficient to give a fair representation of the various diameter classes.

Table 14 shows the number of trees and growth rate by diameter classes on the two areas during the 10-year period, 1925-35. Below the 12-inch class, diameter growth in the virgin stand compares favorably with that in the cut-over stand. Beyond the 11-inch class diameter growth forges ahead in the cut-over stand and this lead is retained throughout the series. In the 18-inch class and upward the effect of cutting is shown in the decreased number of trees as well as the increased average diameter growth.

TABLE 14.—*Diameter growth of ponderosa pine in a virgin stand and in a cut-over stand (sample plots S6 and S7, Fort Valley Experimental Forest)*

D. b. h. class (inches)	Trees in class, 1925		Diameter growth [1] 1925–1935	
	Virgin	Cut-over	Virgin	Cut-over
	Number	*Number*	*Inches*	*Inches*
4–5	605	2,396	1.91	1.74
6–8	635	2,109	1.69	1.78
9–11	367	996	1.66	1.65
12–14	376	681	1.01	1.58
15–17	447	599	.99	1.58
18–20	522	417	.92	1.62
21–23	525	273	.84	1.42
24–26	443	135	.76	1.35
27–29	313	67	.62	1.20
30–32	220	26	.54	1.25
33–35	108	6	.52	1.19
36–38	51	4	.41	1.54
39–41	30	----------	.40	----------
42–44	8	----------	.37	----------
45–47	1	----------	----------	----------
48	1	----------	1.00	----------

[1] Unadjusted values.

Notwithstanding a marked superiority of the cut-over stand, growth in the virgin stand was by no means negligible. Even in diameter classes above 30 inches, growth continued at a rate well above a half inch per decade, which in trees of this size means considerable gross volume increment. The reason for the good growth of large trees in the virgin stand is that most of them were partially isolated. But now that reproduction has come in, young trees will claim an ever increasing share of the limited moisture supply which the veterans were able to monopolize as long as fire and grazing prevented regeneration. It is to be expected that another 20 years will witness a marked decline in the growth of large trees; even the cut-over area is experiencing this change because, although the large trees were well isolated by cutting, saplings have encroached on their root zones.

Diameter Growth Under Three Methods of Cutting

Table 15, compiled by Krauch (38), gives the diameter growth by diameter classes of blackjack and yellow pine on three adjacent areas cut under different methods in 1913. Trees in the scattered seed tree cutting where the heaviest volume was removed have made by far the best diameter growth. Under this method, blackjack groups were drastically opened up and the reserve yellow pines were nearly all isolated. Nevertheless, increment per acre was low because so few trees were retained in the stand.

TABLE 15.—*Average annual diameter growth, 1913-33, under three methods of cutting* [1] *(Coulter Ranch, S5 series of plots.)*

[Inches]

D. b. h. class	Blackjack			Yellow pine		
	Light selection (S5-3)	Group selection (S5-1)	Scattered seed tree (S5-2)	Light selection (S5-3)	Group selection (S5-1)	Scattered seed tree (S5-2)
4-11	0.168	0.177	0.246	0.125	0.128	0.167
12-20	.173	.174	.222	.113	.117	.143
21-30	.165	.149	.200	.107	.097	.113
31 and over						

[1] Based on records of 12,433 trees.

Diameter Growth in Relation to Time After Cutting

Figure 19 illustrates the decline in diameter growth on the Coulter Ranch plots (tables 11 and 12) from the first to the third decade after cutting. Of special significance is the high proportion in the third period which made no growth at all or grew less than 1 inch in diameter, as shown by the record of individual trees. In diameter classes above 20 inches in the light selection cutting (S5-3), 43.4 percent grew over 1.6 inches during the first decade, but during the last decade, the percentage fell to 14.7. During the first decade, 0.2 percent registered no diameter increase, but in the last decade this class rose to 4.3 percent. Practically the same relationships are found on the other two areas. Growth was most rapid in both periods on the heavily cut scattered seed tree area, but even here average growth declined nearly an inch during 20 years after the first decade.

In all three pairs of curves the difference between the first and the third decades widens in a striking manner in diameter classes below 10 inches. The probable explanation is that released small trees account for the high average growth during the first decade.

Later they passed into higher diameter classes, leaving unreleased trees to represent the lower diameters during the third decade. Considerable numbers of small overtopped trees remain within the blackjack groups. They will not accelerate growth until further release cuttings are made.

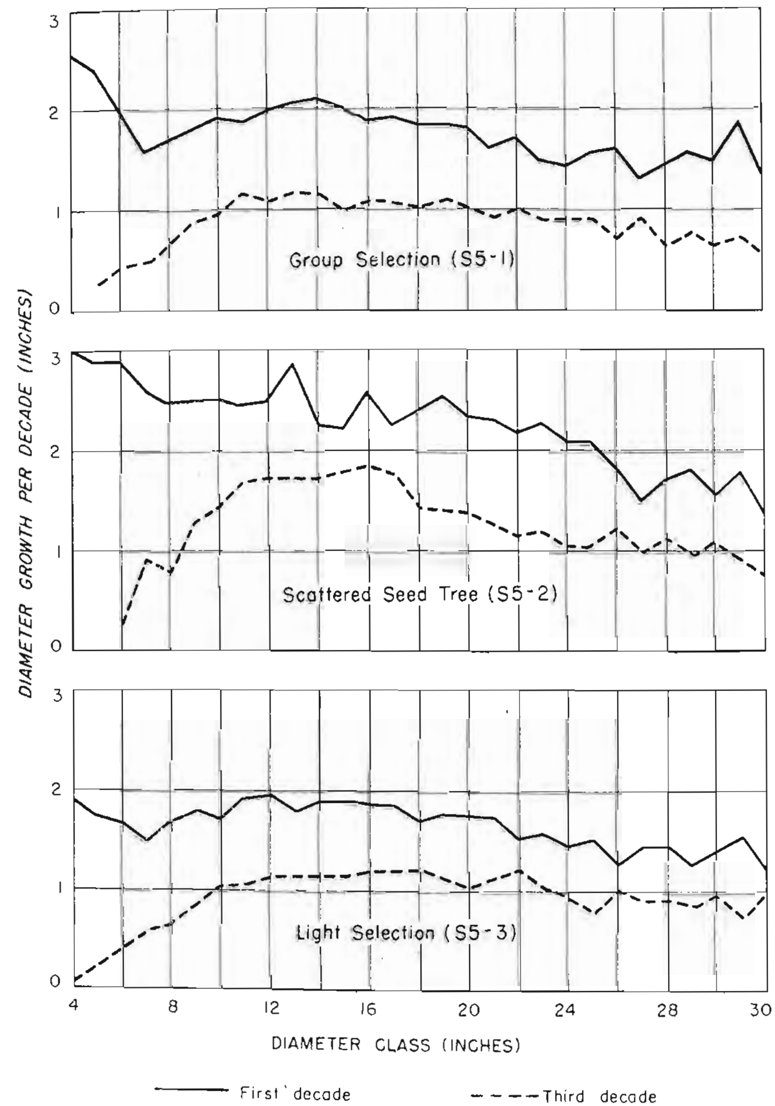

FIGURE 19.—Average diameter growth by diameter classes during the first and third decades after cutting. Coulter Ranch sample plots, 1913-43.

Although the influence of cutting is complex, and variables other than intensity of cutting have not been wholly eliminated in the comparison of different areas, it is fair to conclude that cutting in general tends to increase the diameter growth of the remaining stand. This is true only to the extent that cutting lowers competition for sunlight and soil moisture. Trees which are already in the open cannot be expected to respond greatly; and likewise trees in groups far from felled trees cannot be expected to show much acceleration. On the other hand, it should be borne in mind that large trees as far as 200 feet apart may possibly send their roots into a common zone. The effect of cutting on shade is felt mainly in the understory.

MORTALITY

Table 16 gives the mortality on seven areas over periods of 15 to 30 years. As may be seen, the volume of mortality varies greatly in different stands, localities, and periods. The influence of cutting operates mainly through volume and character of the stand left. Volume losses are greatest in the heaviest reserve stands, but expressed on a percentage basis the relation is often reversed. Losses in number of trees follow closely the pattern of volume losses.

Mortality in Virgin and Cut-Over Stands

As may be expected, mortality in virgin stands is generally much higher than in cut-over stands. This relation is attributed less to the larger volume in virgin stands than to the presence of a greater proportion of highly susceptible trees—decadent, defective, and very large trees—which would be more or less completely removed in any kind of silvicultural cutting. A good comparison of mortality in a virgin stand with that during the same period in a similar stand which has been logged is furnished by sample plots S6 and S7, table 16. Records began on these adjacent areas in 1925, the year following the logging on S7. Site quality, topography, original volume, and general character of the original stands are regarded as sufficiently alike to make cutting the outstanding variable.

Mortality in virgin stands is characterized by sharp rises above the generally high level which normally prevails. During a 15-year record of the virgin stand (S6), average annual losses for consecutive 5-year periods were 45, 44, and 102 board feet. Corresponding figures for the adjacent cut-over stand (S7) were 10, 13, and 14 board feet. Note that the cut-over area registered no appreciable rise corresponding to the high of 102 in the uncut area during the third period, 1935-40.

Mortality in Relation to Time After Cutting

Marked fluctuations in mortality are the rule after cutting as well as before cutting, although losses are much lower in cut-over than in virgin stands. Occasional suggestions of a definite trend up or down are not borne out when as many as four consecutive

TABLE 16.—*Periodic annual mortality in a virgin stand and in stands cut by different methods*

Method of cutting	Year plot established	Area	Reserve volume[1]	Average annual loss per acre, by successive 5-year periods: 1	2	3	4	5	6	Average annual loss per acre: 20 years, Volume	20 years, Percent	30 years, Volume	30 years, Percent
		Acres	*Feet board measure*	*Feet board measure*	*Feet board measure*	*Feet board measure*	*Feet board measure*	*Feet board measure*	*Feet board measure*	*Feet board measure*	*Percent*	*Feet board measure*	*Percent*
Group selection (S3)	1909	456	3,520	11	19	24	27	16	36	20	0.57	22	0.63
Group selection (S4)	1909	304	2,328	6	9	7	11	7	12	8	.34	9	.39
Group selection (S5–1)	1913	139	2,846	26	17	10	19	20	21	18	.63	19	.67
Scattered seed tree (S5–2)	1913	152	1,873	32	16	17	18	21	13	21	1.12	20	1.07
Light selection (S5–3)	1913	112	4,510	27	25	36	39	63	20	32	.71	35	.78
Virgin, no cutting (S6)	1925	160	11,778	45	44	102	------	------	------	------	------	------	------
Favoring dominants (S7)	1925	160	3,335	10	13	14	9	------	------	12	.35	------	------

[1] Volume includes trees 11.6 inches and over d. b. h. in year plot was established (based on extensive plots only).

TABLE 17.—*Mortality of ponderosa pine during 30 years*[1] *after cutting, classified by cause and diameter group of trees*[2]

Diameter group (inches)	Stand per acre when plot established		Percent of reserved volume killed in 30-year period by—					Total annual loss in percent of original stand	
	Trees	Volume	Wind	Lightning	Bark beetles	Mistletoe	Un-classified	Trees	Volume
	Number	*Feet board measure*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
GROUP SELECTION CUTTING, PLOT S3									
12–20	7.97	1,102	1.8	1.0	0.8	6.5	1.3	0.38	0.38
21–30	3.70	1,959	4.5	4.0	.7	5.8	.5	.42	.52
31+	.33	481	14.9	14.8	1.2	11.1	.6	1.39	1.42
Total	12.00	3,542	5.1	4.5	.8	6.7	.8	.42	.60
GROUP SELECTION CUTTING, PLOT S4									
12–20	6.82	833	1.5	0.4	1.1	0	1.9	0.17	0.16
21–30	2.30	1,121	3.2	3.1	1.9	0	1.7	.33	.33
31+	.29	347	2.3	8.3	0	0	4.5	.50	.50
Total	9.41	2,301	2.4	2.9	1.3	0	2.2	.22	.29
GROUP SELECTION CUTTING, PLOT S5-1									
12–20	9.01	970	0.7	0.8	1.1	5.2	0.6	0.32	0.28
21–30	2.94	1,557	4.8	5.4	3.3	2.8	1.4	.54	.59
31+	.22	366	15.7	27.2	2.7	7.2	6.8	1.94	1.99
Total	12.17	2,893	4.8	6.6	2.5	4.2	1.8	.40	.66
SCATTERED SEED TREE CUTTING, PLOT S5-2									
12–20	1.65	210	2.2	1.2	0	3.2	2.9	0.43	0.32
21–30	1.80	1,056	9.0	7.4	3.7	1.4	1.5	.69	.77
31+	.43	656	13.2	23.6	8.7	5.6	1.8	1.53	1.76
Total	3.88	1,922	9.7	12.3	5.0	3.0	1.8	.67	1.06
LIGHT SELECTION CUTTING, PLOT S5-3									
12–20	9.64	1,112	2.7	0.8	2.2	4.9	0.8	0.34	0.38
21–30	4.16	2,599	9.0	4.9	2.3	3.6	.8	.62	.69
31+	.63	1,041	18.9	15.3	8.8	2.0	1.7	1.50	1.56
Total	14.43	4,752	9.7	6.2	3.7	3.6	1.0	.47	.81

[1] Data are for extensive and intensive plots combined. Records for plots S3 and S4 cover years 1909-39; for other plots, years 1913-43.

[2] In each of the three diameter groups, the percentage of loss attributed to each killing agent is based on the board-foot volume in that group at the beginning of the record and the volume of killed trees at time of death.

5-year periods are considered. This may be partly due to temporary disturbances such as wind or insect epidemics, but even in the absence of such disturbances there is a tendency for casualties to come in surges. A period of exceptionally high losses is often followed by one of comparative quiescence, suggesting that for the time being the most susceptible trees have been eliminated.

Some agencies, such as windfall, tend to be most violent during the first few years after cutting; others, such as mistletoe, tend to increase in virulence. On the whole, however, there is a progressive weakening which may not manifest itself so much in outright death as in decline. Some areas logged 20 years ago now present a skyline of spiketops and stagheads suggestive of the uncut forest. In addition to dead trees there are many which are only partially dead from the effects of lightning or parasitic attack. Many of these trees linger for years, and undergo a process of deterioration which for practical purposes writes them off the forest inventory long before death removes them from the tally sheet. Of the five 30-year records in table 16, all but one show a higher volume of loss during the last 15 years than during the first 15, and a higher loss during the entire 30 years than during the first 20. The one exception is the scattered-seed-tree plot (S5-2) where high loss from windfall and lightning occurred during the first 5 years after cutting.

Causes of Mortality

The four main causes of mortality in the Southwest are wind, lightning, mistletoe, and bark beetles, as shown by tables 17 and 18. Their relative magnitude varies with locality and other factors *(65)*. Wind and lightning are the most universal killers; mistletoe and bark beetles may cause as much loss as the other agents, but they are more variable. The high mortality on the Wing Mountain area (S3) and the light selection area (S5-3) in the last decade was due to increasing virulence of mistletoe. In contrast, no mistletoe loss is reported on the cinder area (S4) because mistletoe does not occur here. Bark beetles are generally a minor cause of mortality in cut-over stands, but in the virgin stand (S6) it ranked as a major factor. In tables 17 and 18 mortality which could not be definitely attributed to any one agent is grouped under the general heading "unclassified." Recent information indicates that much of this loss is due to root rot, of which there are two kinds, and a stem rust *Cronartium filamentosum* (Peck) Hedgc. Both of these agents are more fully discussed later under "Control of Damaging Agents."

Fire is another factor that exacts a sizable toll each year; it is not listed as a cause of mortality in tables 17 or 18, however, because no destructive fires have occurred on the experimental areas during the period of record. A 10-year summary for the southern Rocky Mountain region *(90)* indicates, however, that timber killed by fire and not salvaged, averages only 1 to 2 board feet per acre annually.

The agencies causing mortality are generally the same in uncut stands as in those which have been logged, but their relative rank as measured by loss inflicted may change appreciably as a result of cutting. As previously stated, bark-beetle losses, normally low in cut-over stands, were almost as high as lightning and higher than windfall in the virgin stand. During 15 years of simultaneous records bark beetles accounted for only 11.5 percent of the total volume lost in the cut-over stand as compared with 27.3 percent of the total volume killed in the virgin stand (table 18). During this period bark beetles killed 16.5 board feet per acre annually in the virgin stand, as compared with 1.3 board feet in the cut-over stand. During the same period lightning killed an average of 25.9 board feet per acre annually in the virgin stand and 5.8 board feet in the cut-over. An important side light in this record is that in both stands only one-third of the lightning-struck trees died during the 15-year period.

TABLE 18.—*Percent of trees and of board-foot volume killed by different agents in a virgin and a cut-over stand, 1925-40*

Kind of stand and killing agent	Percent of 1925 stand killed, in diameter group (inches)—								Percent of total 5-year mortality	
	12–20		21–30		31 and over		12 and over			
	Trees	Volume	Trees	Volume	Trees	Volume	Trees	Volume	Trees	Volume
Virgin (S6):										
Lightning	0.4	0.4	1.4	1.9	6.3	6.4	1.5	3.3	30.6	42.8
Wind	.5	.6	1.4	1.3	1.8	1.7	1.0	1.4	20.4	18.2
Bark beetles	.8	.8	2.0	2.0	2.7	2.7	1.6	2.1	32.7	27.3
Mistletoe	.3	.3	.1	.1	.4	.3	.3	.2	6.1	2.6
Unclassified	.5	.6	.3	.4	1.4	1.3	.5	.7	10.2	9.1
All agents	2.5	2.7	5.2	5.7	12.6	12.4	4.9	7.7	100.0	100.0
Cut-over (S7):										
Lightning	.5	.8	4.1	4.4	0	0	1.3	2.6	44.8	50.0
Wind	.2	.2	1.3	1.2	7.7	6.6	.5	1.2	17.2	23.2
Bark beetles	.1	.2	.6	.9	0	0	.3	.6	10.4	11.5
Mistletoe	.4	.4	0	0	0	0	.3	.2	10.4	3.8
Unclassified	.5	.4	.6	.8	0	0	.5	.6	17.2	11.5
All agents	1.7	2.0	6.6	7.3	7.7	6.6	2.9	5.2	100.0	100.0

Notwithstanding one severe blow-down in the virgin stand (negligible in the cut-over stand) windfall ranked below bark-beetle losses in this stand. Wind accounted for a loss of 11 board feet per acre annually in the virgin stand and 2.7 board feet in the cut-over stand. Mistletoe was relatively inactive on both of these areas: it is charged with only 2.6 percent of the volume loss in the virgin stand, and 3.8 percent in the cut-over stand. During 30 years mistletoe loss accounted for 37.6 percent of the total volume lost on the Wing Mountain area (S3) 6 miles distant.

Mortality in Relation to Size and Age

Closely associated with causes of mortality is the size of trees, which in turn is broadly related to age. Mortality is much greater in large than in small trees, and this is true whether the percentage is based on number or volume. Most killing agents take a relatively small toll from the 12- to 20-inch diameter class, but mistletoe is an exception. Not only are large trees more susceptible to certain killing agencies, but because of their large size they contribute more to the volume loss. According to figure 20, mortality, based on number of trees on the Wing Mountain sample

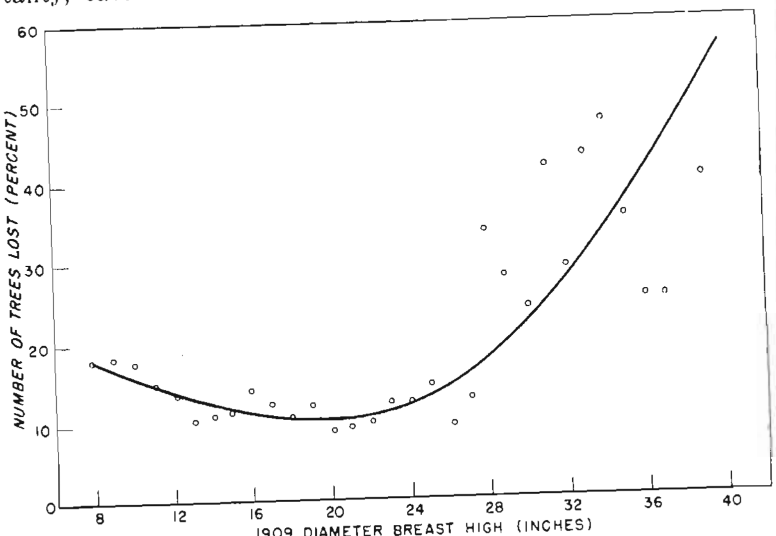

FIGURE 20.—Mortality by diameter classes, sample plot S3 (456 acres), 1909-39.

plot (S3), decreases from the 12-inch class to the 20-inch class, then rises, slowly at first, but rapidly beyond about 26 inches. The main factor in the lower diameter classes is mistletoe and in the higher classes there are two major agents—wind and lightning. Large yellow pines struck by lightning usually die at once or within a few years, whereas blackjacks usually recover.

The following tabulation shows mortality separately for the two broad age classes, blackjack and yellow pine, in a virgin stand and a cut-over stand. The data cover the period 1925-40, percents being based on the stands as measured in 1925.

Kind of Stand and Age Class:	*Proportion of trees lost (percent)*	*Proportion of board-foot volume lost (percent)*
Virgin stand (S6):		
Blackjacks	1.41	1.33
Yellow pines	7.96	9.40
Cut-over stand (S7):		
Blackjacks	2.04	2.68
Yellow pines	9.74	11.77

Losses in the yellow pine class were much greater than in the blackjack class. During the 15-year record the total loss per acre in the virgin stand was: blackjack 33 board feet; yellow pine 874 board feet. In the cut-over stand corresponding figures are: blackjack 66 board feet; yellow pine 109 board feet.

Mortality in Relation to Method of Cutting

Method of cutting affects mortality mainly through size, number, and character of trees left. The only cut-over areas on which results are really comparable are the Coulter Ranch series, S5-1, S5-2, and S5-3 (tables 16 and 17), all of which are on nearly the same site and whose records cover the same years. The light selection plot, with its large reserve volume, suffered the greatest loss per acre, but on a percentage basis the loss was lower than in the scattered-seed-tree plot, which had a far smaller reserve volume. Lowest in both quantitative loss and percentual loss was the group selection area.

The main reason for the high loss on the scattered-seed-tree area is that the stand was made up of relatively few but large trees. The scattered-seed-tree area had a reserve of only 1,922 board feet per acre made up of 3.9 trees averaging 493 board feet, whereas the group selection area had a reserve of 2,893 board feet per acre made up of 12.2 trees averaging only 237 board feet (table 17). On all three areas the higher losses occurred in the larger trees.

The two latest methods of cutting—salvage and improvement selection—are too recent to yield authentic records of mortality. Plots representing these two methods lie almost side by side, being separated by the uncut plot S6A. Annual losses per acre during the first 5 years were: Virgin (S6A) 63 board feet, salvage (S6B) 11 board feet, improvement selection (S9) 13 board feet. It is evident that both cuttings largely eliminated the mortality which would have been experienced if no cutting had taken place. Lightning accounts for nearly all the mortality on the salvage and improvement selection cuttings; trees struck but not killed far outnumber the fatalities.

REPLACEMENT

Advance Reproduction

Prompt replacement of the trees which die or are cut calls for reproduction in advance of logging. Few trees are literally replaced in the sense that a young tree grows beside the stump of the dead one. But in a well-managed selection forest, saplings, poles, or larger trees should always be near enough to send their roots into any space that may be vacated. When poles reach the 12-inch class, they are credited with a board-foot volume and classified as "new" trees or "ingrowth."

In mature forests lacking advance reproduction, mortality and cutting usually leave large spaces unoccupied by trees. This is a common condition on sizable areas of cut-over land. Even if natural reproduction promptly follows cutting, decades must elapse before the young generation begins to contribute to the board-foot volume.

The Wing Mountain plot (S3) is typical of the condition just described. Only about half of the land was occupied by trees before the first cutting, which reduced the occupied area to less than one-third. In 1939, 30 years after cutting, there were only about 10 poles per acre between 6 and 12 inches d. b. h., and few of them were in the spaces formerly occupied by the trees which were cut in 1909. Abundant reproduction which started mainly in 1919 reached the sapling stage about 1939 and in 30 more years many will be entering the 12-inch class. The young generation will more than replace the original stand, but 50 years will have elapsed in the process. If the forest had been placed under adequate protection 40 years before the first cutting, scores of poles on nearly every acre would have stood ready to step into the ranks when logging removed 8,000 board feet gross per acre in 1909 and 3,000 more in 1939. Now that most of the old-growth forests contain a large representation of saplings and poles in what were formerly treeless spaces, these advancing young classes bid fair to become an important source of board-foot increment after logging.

In predicting yields over long periods, allowance must be made for space occupied by young trees below the stage in which their growth is measurable in board feet. In other words, if a stand is fully stocked with trees 12 inches and over d. b. h., then the younger age classes are not adequately represented. These classes require both sunlight and root space. Seedlings less than 3 feet tall may not make great demands upon the soil, but beyond that stage their demands increase rapidly. Generally, sufficient openings will come about automatically through logging and brush burning, but the fact remains that a ponderosa pine stand cannot remain 100 percent stocked with trees in saw-timber sizes while at the same time building up the desired younger age classes.

Redistribution of Diameter Classes Through Growth

Diameter growth over a period of years results in a progressive upward movement of individual trees toward higher diameter classes, which may or may not be compensated by the entrance of new trees into the lower classes. This upward movement is of interest in relation to the availability of merchantable sizes for future cutting.

Figures 21 and 22 *(38)* illustrate the progressive advance of diameter classes and the replacement of dead trees on two group-selection cuttings (S3 and S5-1). In figure 21 replacement from diameter classes below 12 inches has been inadequate because advance reproduction was practically absent at the time of cutting. Figure 22 illustrates a more satisfactory condition in which poles from 8 to 11 inches d. b. h. are advancing toward the 12-inch class, and the number of trees per acre in all diameter classes has increased.

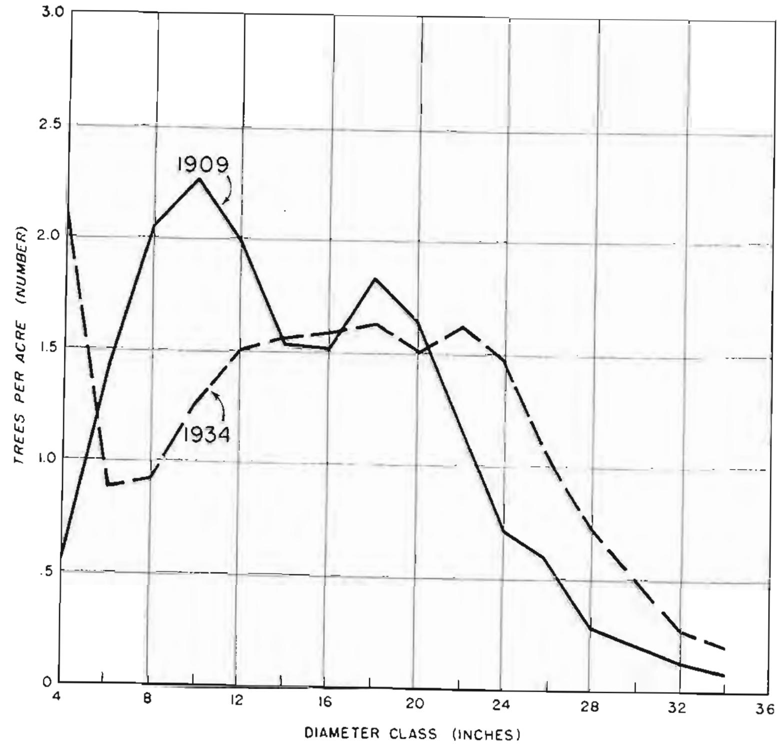

FIGURE 21.—Number of trees of different diameters per acre in 1909 and 1934 on group-selection plot S3.

VOLUME INCREMENT OF STANDS

For purposes of analysis, distinction is made between net increment, gross increment, and ingrowth.

As used in this monograph, the term "net increment" is the total change in board-foot volume of the living trees (11.6 inches d. b. h. or larger) in a stand when the same stand is measured at different times. Net increment is based on the full volume-table values and no deductions have been made for decay or other defect. Net increment includes both the volume increase of the original trees that lived through the remeasurement period and the total volume of the trees that grew into the minimum merchantable size (11.6 inches d. b. h.) during the period. In some of the analyses that follow, net increment has been broken into

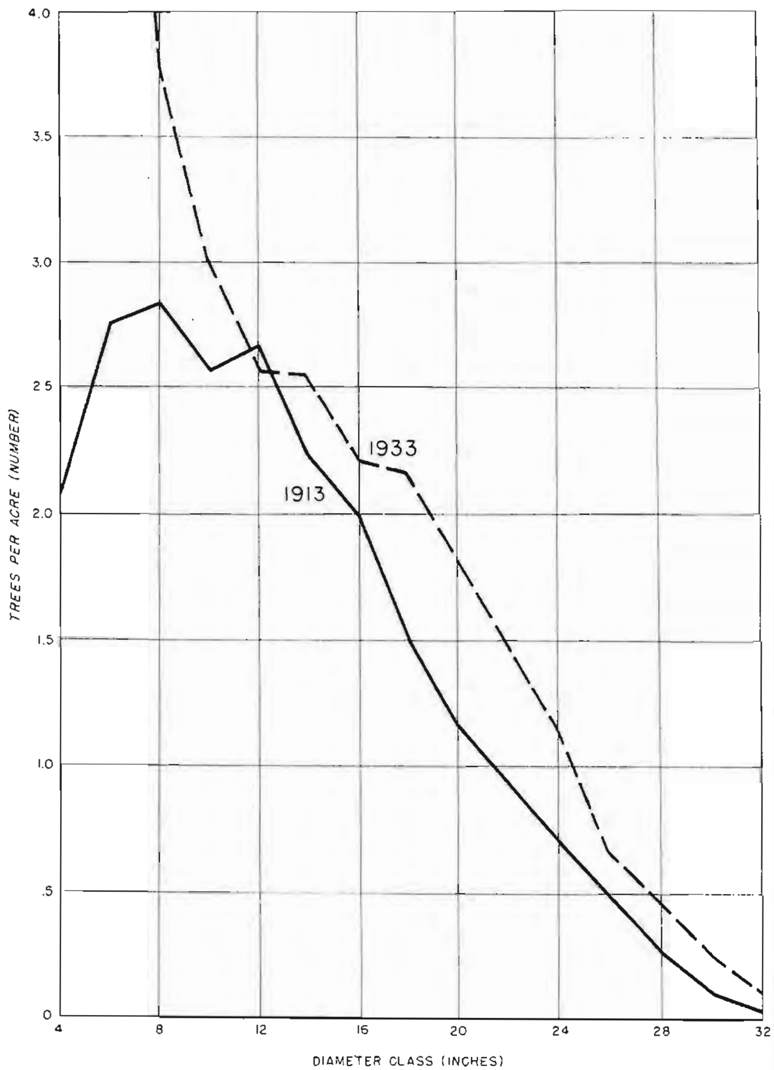

FIGURE 22.—Number of trees of different diameters per acre in 1913 and 1933 on group-selection plot S5-1.

these two components—"original" tree increment and "new" tree increment or ingrowth.

Gross increment is a theoretical value designed to express potential growth if mortality were eliminated. It is obtained by adding to the net increment the volume of the trees that died during the remeasurement period.

Increment in Relation to Volume and Character of Growing Stock

Table 19 by Lexen *(39)* correlates volume growth with average diameter and residual volume on the Coulter Ranch plots S5-1, -2, and -3. Since the table takes into account neither mortality nor ingrowth, it represents the gross increment of original trees only and is chiefly valuable as an indication of growth capacity. The high growth values in the two lower lines of the first three columns suggest possibilities of well-stocked stands made up of young age classes. Average diameter is used as a rough index of diameter distribution; in specific areas it may be fairly uniform or may range from 12 to 40 inches. Extensive stands in which the average diameter is as low as 16 inches are practically nonexistent in partially cut forests; but after 50 years of management such stands should become the rule rather than the exception. The values are probably conservative because the site quality at Coulter Ranch is slightly below average for the region and growth is handicapped by mistletoe.

TABLE 19.—*Average annual growth*[1] *per acre in board feet and cubic feet during 20 years after cutting, sample plot S5*

Reserved volume per acre	Growth when average stand diameter is—					
	12 inches	16 inches	20 inches	24 inches	28 inches	32 inches
Board feet	*Board feet*	*Board feet*	*Board feet*	*Board feet*	*Board feet*	*Board feet*
1,000	74	47	33	25	20	--
2,000	120	76	53	40	31	26
3,000	159	101	71	53	42	34
4,000	194	123	86	65	51	41
5,000	227	144	101	76	59	48
6,000	257	163	114	86	67	54
Cubic feet	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*
200	9.8	7.2	5.6	4.6	4.0	--
400	15.1	11.1	8.8	7.2	6.2	5.4
600	19.6	14.4	11.4	9.4	8.0	6.9
800	23.4	17.2	13.6	11.2	9.6	8.3
1,000	27.0	19.8	15.6	12.9	11.0	9.6
1,200	30.2	22.3	17.6	14.5	12.3	10.7

[1] Gross increment of original trees only. No allowance for ingrowth or mortality.

Reasons for a higher rate of increment in stands made up of small rather than large trees are almost self-evident. Other things being equal, a given volume of growing stock divided among several small trees is more effective than if concentrated in a single large tree on the same plot of land. The several small trees, if well distributed, have better access to soil moisture and their roots are able to permeate the soil of a given area more completely than those radiating from a single large tree.

The foregoing relationships between large and small trees are further illustrated by figure 23. In this instance, gross increment and mortality are coordinated, so that the difference between the two graphs represents net increment. Since values are expressed in percent of the original volume in each diameter class, they indicate the earning capacity of the wood capital, or interest on the investment. The average 16-inch tree earns about 5 percent annually as compared with less than 1 percent for the average 28-inch tree.

The data plotted in figure 23 were compiled from the three sample plots of the S5 series, representing group selection, scattered seed tree, and light selection cutting. Separate graphs for the three areas *(66)* show the same general trend of both growth and mortality as in this case where all three are combined. Since the point for each diameter class represents an average value, the graph cannot be expected to fit every type of tree. Growth values are too high for crowded, overtopped, or mistletoe-infected trees and too low for normal, open-grown trees. The growth rate of blackjack is generally higher and the mortality lower than that of yellow pine of equal diameter.

The graph is not intended for rating the growth capacity of individual trees but rather to show general trends. Its greatest value lies in pointing out the low efficiency of large, mature trees, beginning approximately with the 28-inch class. Here the question of spacing and general vigor does not enter because large yellow pines reserved from cutting have always been well isolated and in at least fair physical condition. What happens to such trees under the impact of lightning, wind, and bark beetles is clearly told by the mortality graph.

Increment on Large Cut-Over Areas

Table 20 gives average increment together with other pertinent data on the large plots in the Fort Valley Experimental Forest. Net increment in table 20 is considerably below the highest values given in table 19. One reason for this is that table 19 does not take mortality into account. In stands of good advance reproduction mortality might be more than offset by new trees, but new trees have thus far been a small item on all but a few of these plots. Another factor is the low volume of growing stock on the old plots in table 20 as compared with the highest in table 19. Of greater importance than volume is the size and number of trees in the growing stock. The "average diameter" class of 12 to 16 inches in table 19 signifies a general absence of large and old trees; that is, the stand is made up of blackjack groups almost entirely. Average diameters in the cut-over plots in table 20 are mostly between 18 and 20 inches; it is known that yellow pines over 30 inches d. b. h. contribute in large measure to this high average diameter.

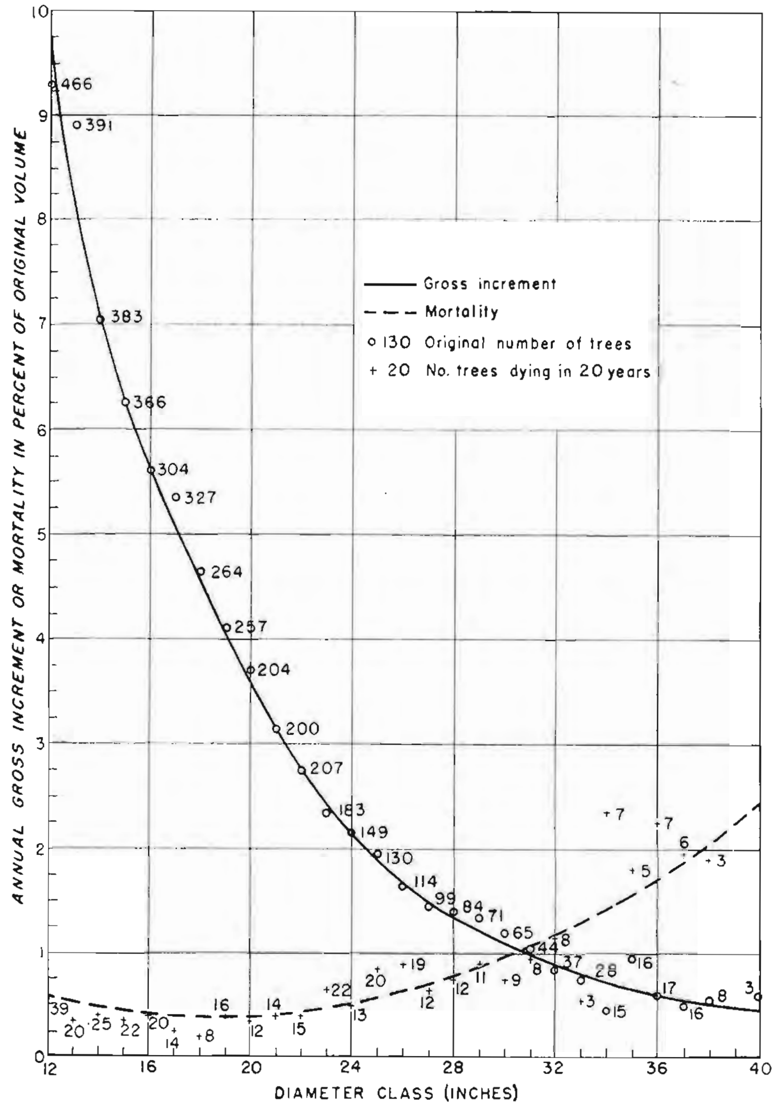

FIGURE 23.—Annual increment and mortality during 20 years after cutting in percent of reserve board-foot volume in each diameter class. Coulter Ranch plots (S5).

TABLE 20.—*Increment on large sample plots of long record in the Fort Valley Experimental Forest*

Method of cutting and plot designation	Period of record	Area of plot	Residual stand [1]			Average annual increment per acre			Average annual increment in percent		
			Trees per acre	Average d. b. h.	Volume per acre	Gross	Mortality	Net	Gross	Mortality	Net
	Year	*Acres*	*No.*	*Inches*	*Ft.b.m.*	*Ft.b.m.*	*Ft.b.m.*	*Ft.b.m.*	*Percent*	*Percent*	*Percent*
No cutting (S6)	15	160	19.5	23.7	11,778	112	64	48	0.95	0.54	0.41
Group selection (S3)	30	456	11.7	19.6	3,520	103	22	81	2.93	.63	2.30
Group selection (S4)	30	304	9.4	19.0	2,328	70	9	61	3.01	.39	2.62
Group selection (S5-1)	30	139	12.1	18.5	2,846	89	19	70	3.13	.67	2.46
Scattered seed tree (S5-2)	30	152	3.9	22.7	1,873	45	20	25	2.40	1.07	1.33
Light selection (S5-3)	30	112	13.7	19.8	4,510	116	35	81	2.57	.78	1.79
Favoring dominants (S7)	20	160	13.8	18.1	3,385	105	12	93	3.10	.35	2.75

[1] Includes only trees over 11.5 inches d. b. h. at the time the plots were established.

Increment on Small, Well-Stocked Plots

Table 21 substantiates in a general way the high yields indicated for heavy stands of low diameter in table 19. It should be noted, however, that wherever heavy mistletoe infection is prevalent, it cuts down the increment, partly through mortality but also by retarding the growth of living trees.

TABLE 21.—*Increment on small plots of ponderosa pine in blackjack and intermediate age classes, Wing Mountain sample plot (S3)*

Subplot No.	Area	Residual stand, 1909 [1]			Average annual increment per acre 1909-34			Mistletoe
		Trees per acre	Average d. b. h.	Volume per acre	Gross	Mortality	Net	
	A.	*No.*	*In.*	*Ft.b.m.*	*Ft.b.m.*	*Ft.b.m.*	*Ft.b.m.*	
1	0.8	16	21.9	6,062	156	0	156	Light
2	1.2	29	18.1	5,918	158	8	150	Moderate
3	.6	27	17.0	4,347	178	0	178	Light
4	.6	32	16.7	4,900	232	0	232	Light
5	1.2	22	16.6	3,298	153	15	138	Moderate
6	2.0	19	18.8	4,404	154	9	145	Moderate
7	1.2	37	18.0	7,482	236	5	231	Moderate
8	2.0	31	18.1	6,337	144	40	104	Heavy
9	1.5	26	17.5	4,753	135	32	103	Heavy
10	4.0	25	18.9	5,907	165	2	163	Moderate

[1] Includes only trees over 11.5 inches d. b. h. at time plots were established.

These plots constitute large groups or an aggregation of small groups in the blackjack or intermediate age classes. Because of uneven distribution of the trees, few if any plots can be regarded as properly stocked, some portions being overstocked and others understocked. In order to allow for root spread, the boundary lines were drawn 20 to 30 feet outside of the crown projection of living trees, including also stumps of large trees felled in 1909 and groups of reproduction.

The 4-acre subplot No. 10 is regarded as an example well within the possibility of attainment under systematic management on large areas. It is by no means an example of a model forest, but contains enough area stocked with saplings and poles to maintain a succession of diameter classes. A salvage cutting in 1939 was too long delayed and did not remove enough of the large dominants in dense groups. In order to maintain a high rate of increment in any stand, cutting must be frequent enough to salvage declining trees and to relieve congestion in dense groups.

Increment in Relation to Time Since Cutting

Table 22 indicates general trends of increment after cutting. All methods of cutting except favoring dominants (S7) show a sharp rise of both gross and net increment in the plots continues through the 30th year. The trends on the group selection cutting (S3) are shown graphically in figure 24, which also includes mortality.

The second-period rise reflects the effect of increased growing space which apparently was not fully appropriated during the first 5 years. That the rise in the second period is not due to climatic effects is suggested by the fact that the second period in the Coulter Ranch series (S5) occurs 4 years later than in

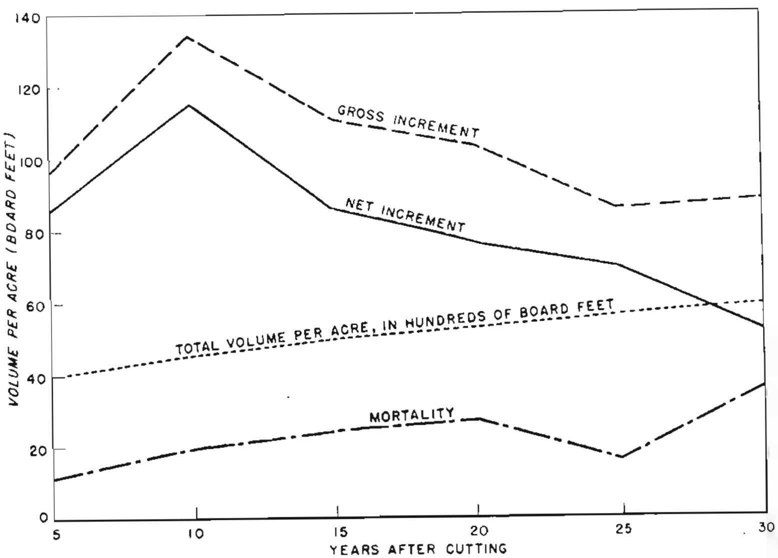

FIGURE 24.—Periodic annual increment and mortality in board feet per acre, 1909-39. Sample plot S3.

group selection cuttings (S3 and S4). In other words, increment reached its peak in one series after it had started to decline in the other.

Plot S7 (favoring dominants) has a different growth pattern, probably because the blackjack groups were opened up in cutting. Net increment was relatively high during the first period and remained almost constant for three periods, then fell sharply in the fourth. Mortality remained relatively low through all four periods; this was due in part to a low incidence of mistletoe.

If it were possible to maintain increment at the high level reached in the second period on such plots as S3 (group selection) and S5-3 (light selection), management of ponderosa pine would be revolutionized. But on both of these cuttings the current net annual increment at the end of 30 years was only about half that attained in the 10th year. Where will it be at the end of 40 or 50 years?

TABLE 22.—*Gross and net periodic annual increment per acre on eight sample plots by 5-year periods*

Method of cutting and plot designation	Record begun	Gross increment in board feet by 5-year periods						Net increment in board feet by 5-year periods					
		1	2	3	4	5	6	1	2	3	4	5	6
No cutting (S6)	1925	121	111	105				76	67	3			
Group selection (S3)	1909	96	134	110	103	85	88	85	115	86	76	69	52
Group selection (S4)	1909	61	94	72	74	65	52	55	85	65	63	58	40
Group selection (S5-1)	1913	84	114	93	99		[1] 73	58	97	83	80		[1] 53
Scattered seed tree (S5-2)	1913	49	62	45	55		[1] 29	17	46	28	37		[1] 12
Light selection (S5-3)	1913	108	143	114	123		[1] 104	81	118	78	84		[1] 63
Favoring dominants (S7)	1925	108	109	110	91			98	96	96	82		

[1] Sixth period in S5-1, S5-2, and S5-3 represents 10 years, 1933-43.

There are strong indications that cut-over stands with a large residual volume tend, after about 20 years, to assume the characteristics of a virgin stand (S6). A large portion of the stand has ceased to be growing stock; it is capable of some growth, but the increment of the old stock is outweighed by mortality. What little net increment accrues is attributable largely to the younger age classes which constitute a small part of the total volume.

Reasons for Decline of Increment

In seeking an explanation of the downward trend of increment, following the initial rise, attention at once falls upon the rising mortality; but gross increment, which excludes the influence of mortality, follows the same general trend. Associated with mortality and contributing directly to it, however, is a growing army of slowly dying trees suffering from old lightning strikes, chronic mistletoe infection, or stagnation resulting from prolonged competition in dense groups. The skyline of a light selection cutting, as viewed 30 years after logging, resembles that of a virgin stand (fig. 25). In addition to the dead trees are still larger numbers which are slowly dying. Figure 26 illustrates a tree which was struck by lightning 20 years ago. It was still classed as living in 1943 but it had ceased to grow and the bole was deteriorating. Trees in advanced stages of mistletoe infection fall in the same class.

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FIGURE 25.—A stand 30 years after cutting by light selection (S5-3). In addition to dead trees, many are in a dying condition. Note mistletoe-infected branches on tree at right.

F-427987

FIGURE 26.—A 28-inch yellow pine struck by lightning between 1923 and 1928 (plot S5-3). Diameter measurements at 5-year intervals beginning 1913 and ending 1943 are: 26.4, 26.9, 27.6, 27.9, 28.0, 28.0, 28.0.

The cumulative effect of mistletoe infection is illustrated by a 30-year record of diameter growth in a group of 10 blackjacks. All 10 trees are mistletoe-infected. Diameter growth averaged 1.2 inches the first decade, 0.8 inch the second, and only 0.5 inch the third decade after cutting. Influences other than mistletoe are at work in this group, some favoring and others retarding growth, but mistletoe is credited with the consistent decline of all trees in the group, irrespective of ground position.

Competition is less conspicuous but may be as effective as lightning and mistletoe in retarding growth. Figure 27 illustrates two blackjack groups, both practically free of mistletoe and both on the best site found on the light selection cutting. The group in figure 27, *A* was little affected by the 1913 cutting; the trees remained closely spaced. A few of the trees made fair growth during the first decade after logging, but in the third decade only two grew as much as an inch and the majority were far below that mark. Group *B* which was opened up grew vigorously from the start, and although the rate had declined by the end of the third period, 7 of the 17 trees were still exceeding 1.5 inches. Table 23 gives the average diameter growth in the two groups during the 30 years since logging.

TABLE 23.—*Average diameter growth in a densely stocked blackjack group and in one opened by cutting (plot S5-3)*

Condition	Trees	Mean periodic diameter growth		
		1st decade	2d decade	3d decade
	Number	*Inches*	*Inches*	*Inches*
Densely stocked (not released by 1913 cutting)	23	0.9	0.7	0.5
Open (border trees removed in 1913 cutting)	17	2.0	1.6	1.4

Original Trees and New Trees

Table 24 throws further light on what is taking place in the cut-over stands. It separates the net increment into that contributed by "original" trees or those in and above the 12-inch class at the beginning of the record, and "new" trees or those which have entered the 12-inch class since the record began 20 or 30 years ago.[6] The latter were small poles or saplings released by the cutting; some were less than 4 inches d. b. h. when the plots were established, and the largest are now 18 inches d. b. h. In the light selection plot (S5-3) the new trees contributed 35 board feet annually to the net increment during the last decade as against 28 board feet for the original trees. It is obvious that without advance reproduction, which was fairly abundant on these areas at the time of cutting, net increment would in another decade approach the vanishing point. Moreover, the growth of small trees, including large numbers of 1919 origin and still below the 12-inch class, is largely dependent upon removal of dominating members of the old stand. Present indications are that the

[6] This distinction cannot be made on the earliest group selection cuttings, S3 and S4, because the trees were not numbered individually until 15 years after the plots were established.

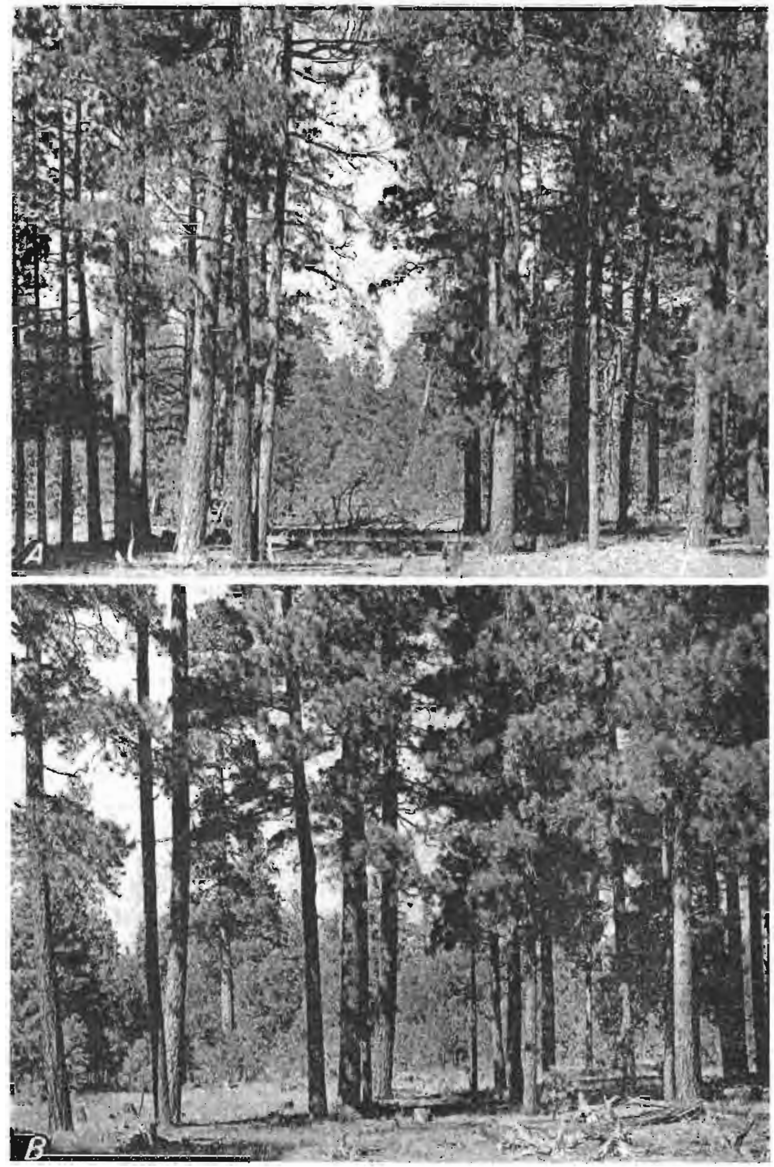

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FIGURE 27.—Two blackjack groups 30 years after logging. *A*, Dense stand; not a tree has grown more than 1 inch in third decade after cutting. *B*, Stand opened up; 12 trees have grown over 1 inch and 6 more than 1.5 inches during third decade. (See table 23.)

yield of original trees will decline even more rapidly henceforth than in the past. New trees, on the other hand, promise to contribute at a rising rate, both through the growth of those now in or above the 12-inch class and through the addition of new members as they advance into the 12-inch class.

TABLE 24.—*Periodic net annual increment, per acre, of original trees,[1] new trees,[2] and all trees on four method-of-cutting plots*

Item	Annual increment per acre in board feet, by 5-year periods—				
	1	2	3	4	5 and 6 [3]
Net increment, all trees:					
Group selection (S5-1)	58	97	83	80	53
Scattered-seed-tree (S5-2)	17	46	28	37	12
Light selection (S5-3)	81	118	78	84	63
Favoring dominants (S7)	98	96	96	82	----------
Net increment, original trees:					
Group selection	50	88	75	72	25
Scattered-seed-tree	13	41	23	30	-14
Light selection	72	108	70	76	28
Favoring dominants	87	81	76	55	----------
Net increment, new trees:					
Group selection	8	9	8	8	28
Scattered-seed-tree	4	5	5	7	26
Light selection	9	10	8	8	35
Favoring dominants	11	15	20	27	----------

[1] All trees 12 inches d. b. h. or larger at beginning of record.
[2] All trees reaching 12-inch diameter class after plot was established.
[3] 10-year period, 1933-43.

Decline of the original stand and the mitigating influence of ingrowth is still more strongly demonstrated on the "Favoring Dominants" plot (S7). Net increment of the stand as a whole held a high and even course through the first three periods, then dropped sharply in the fourth, but decline of the "original" stand began in the second period (table 24). Although net annual increment of the entire stand was 96 board feet per acre in the second period, that of original trees, excluding "ingrowth," was only 81. In the fourth period, original tree increment fell to 55. The saving element was ingrowth, which increased steadily during the four periods.

Ingrowth, indispensable as it is to future production, should not be allowed to blind the manager to the true condition of his forest. Few of the stems that appear as ingrowth during the first 20 years will figure in the log cut within four decades. In all of the cut-over stands listed in table 24, the class of timber that will make up the second and third cuts began declining in growth rate after the tenth year.

Although total mortality on the favoring-dominants cutting has been low, lightning has accounted for half of it and has resulted in damage to twice as many trees as were killed. But in addition to visible deterioration, there has been a slowing of growth disclosed only by successive measurements of individual trees. Opening up the blackjack groups resulted in excellent diameter growth during the first decade, but a noticeable slow-down is evident in the last 5-year period. The greatest decline in growth and physiological condition has occurred in the large, more or less isolated trees of yellow pine age class. In many instances the cause is apparent in lightning damage, squirrel damage, mistletoe, or rust *(Cronartium)*, but in other instances there is no sign of injury or parasitism; in the latter case indications point to root competition either from neighboring trees or from groups of poles and saplings (fig. 28).

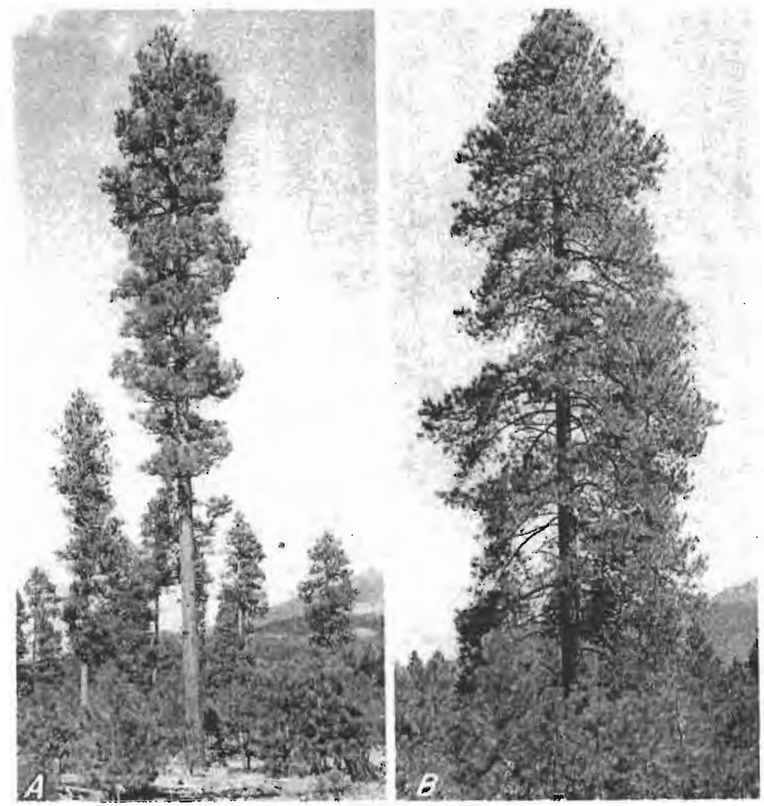

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FIGURE 28.—Large trees are declining in growth 15 years after the 1924 cutting favoring dominants.

A, A 26-inch tree (class III-B), sole remnant of a large group; top injured in 1940, apparently by lightning; saplings encroaching on root area; growth by 5-year periods: 1.8, 1.2, 1.2, 0.4 inch.

B, A 30-inch tree (class III-AA), open grown, no apparent injury but surrounded by dense sapling stand; growth by 5-year periods: 0.4, 0.6, 0.4, 0.2 inch.

Increment of Large Trees

A tabulation of growth records in the 24-inch and larger diameter classes on the plot cut to favor dominants (S7) discloses a noticeably higher diameter growth during the first decade than during the second, and a very pronounced decline during the last 5 years. Of the 243 trees 24 inches and over in 1925, 28 or 11.5

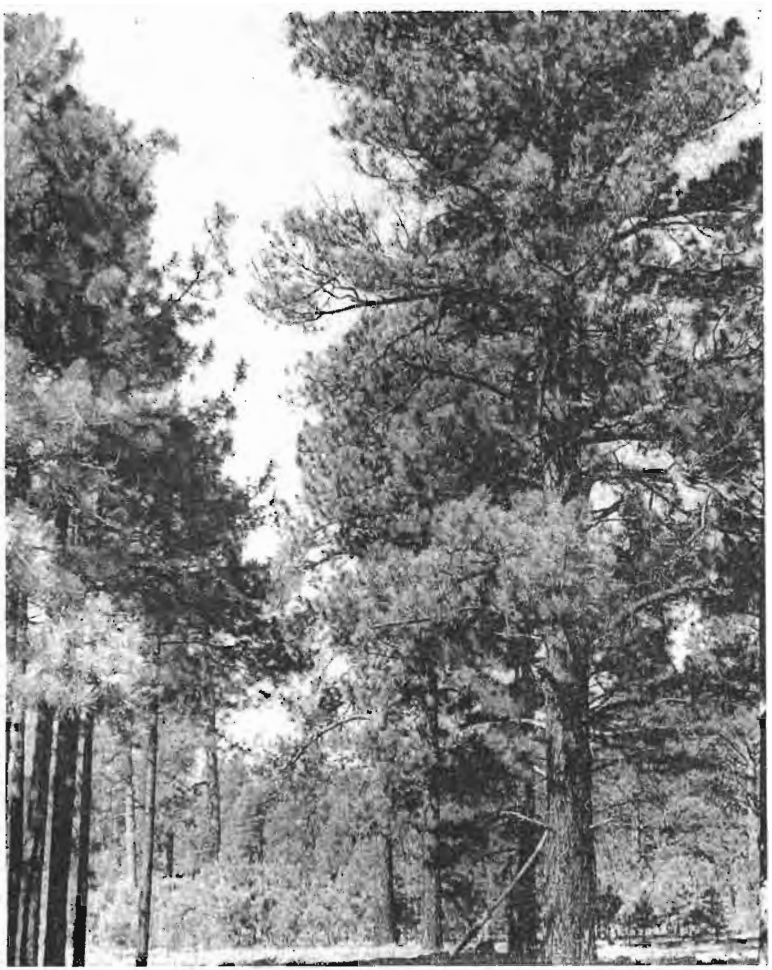

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FIGURE 29.—A nearly worthless blackjack 28 inches d. b. h. which is dominating groups of poles. The dominant itself is declining in growth as a result of root competition.

percent died by 1945. During the 20 years the diameter growth rates of the 215 trees still living in 1945 were as follows:

	First decade (Trees)	*Second decade (Trees)*
Growth per decade:		
2 inches and over	21	0
1.5 to 1.9 inches	53	18
1 inch and over	164	80
0.9 inch or less	51	135

Extremely slow growth, 0.3 inch or less in 5 years, was recorded for 20 trees during the first 5 years, and for 103 trees in the last 5 years of the two decades.

Of no less consequence than the slow growth of large trees on the favoring-dominants cutting (S7), is the fact that many of the still vigorous survivors of the upper diameter classes are of the wolf type. During the 20 years since cutting, crowns have increased their spread and limbs have attained enormous size. Since the subordinates cut were necessarily of merchantable size, the stimulation of remaining dominants was considerable, but the boles in many cases are so rough that value increment has been negligible (fig. 29). In the light of recent findings, a reversal of the favoring-dominants practice—cutting the rough dominants and thus liberating healthy subordinates of good form—would have improved the stand.

Increment on Small Cutting Plots in New Mexico

A series of 11 small plots in New Mexico gives results which stress even more than do the Arizona plots the importance of mortality and new trees (*74*). Pertinent data appear in table 25 and figure 30. In general, the New Mexico stands are made up of smaller trees and more trees per acre than are found in Arizona stands. A much larger pole class in the New Mexico plots adds to the role of new trees.

The New Mexico plots are too small to give the regular periodic trends obtained from larger numbers of trees in the Arizona plots. Individually, they tend to exaggerate particular features. The group as a whole, however, points to consistent trends in agreement with those of the Arizona plots.

Figure 30 brings out emphatically: (1) The high potential yield capacity as reflected in net increments as high as 149 board feet in the first decade; (2) high mortality and declining growth of original trees; and (3) high net increment of new trees.

To Keep the Forest Growing

The foregoing tables show clearly that yield or rate of increment in the heterogeneous, many-aged, and usually understocked stands of ponderosa pine is not a stable quantity which can be determined once and for all by some formula. All the large sample plots and nearly all of the small ones show that when ingrowth is eliminated the current rate of increment undergoes a progressive decline

TABLE 25.—*Periodic annual increment on 11 small New Mexico plots cut by group selection*

National forest	Plot	Year of cutting	Period of record	Area	Reserved stand per acre: Volume	Reserved stand per acre: Trees 8-11"	Reserved stand per acre: Trees 12"+	Net annual increment per acre by 5-year periods—: 1	2	3	4	5	6
			Years	*Acres*	*Ft.b.m.*	*No.*	*No.*	*Ft.b.m.*	*Ft.b.m.*	*Ft.b.m.*	*Ft.b.m.*	*Ft.b.m.*	*Ft.b.m.*
Santa Fe	Jemez:												
	S1A	1911	30	6	5,823	17.5	33.9	122	96	−81	22	54	[1] 35
	S2A	1911	30	6	3,821	9.8	18.8	67	115	28	68	55	19
	S3A	1911	30	6	4,472	13.8	23.8	151	134	99	96	97	12
	Pecos:												
	S1A	1911	30	6	5,912	19.2	46.0	77	114	29	49	−25	−3
	S2A	1911	30	6	6,290	10.7	31.7	79	93	35	12	27	−20
Carson	Amole	1914	20	2.9	1,302	71.7	18.3	....	[2] 131	75	189	....	....
	Cienega	1915	20	4	3,072	23.0	21.3	....	[3] 93	74	97	....	....
Cibola	S1A	1910	30	6	1,954	16.8	16.8	69	60	−93	−13	44	24
	S1B	1910	30	6	2,087	29.5	16.7	77	51	−126	19	42	58
	S2A	1910	30	14.4	2,982	24.2	20.6	152	145	−3	29	125	101
Gila	S2A	1912	25	6.4	2,338	9.9	14.9	71	56	29	51	−3	....

[1] Includes 15 feet cut in trespass.
[2] 10 years.
[3] 9 years.

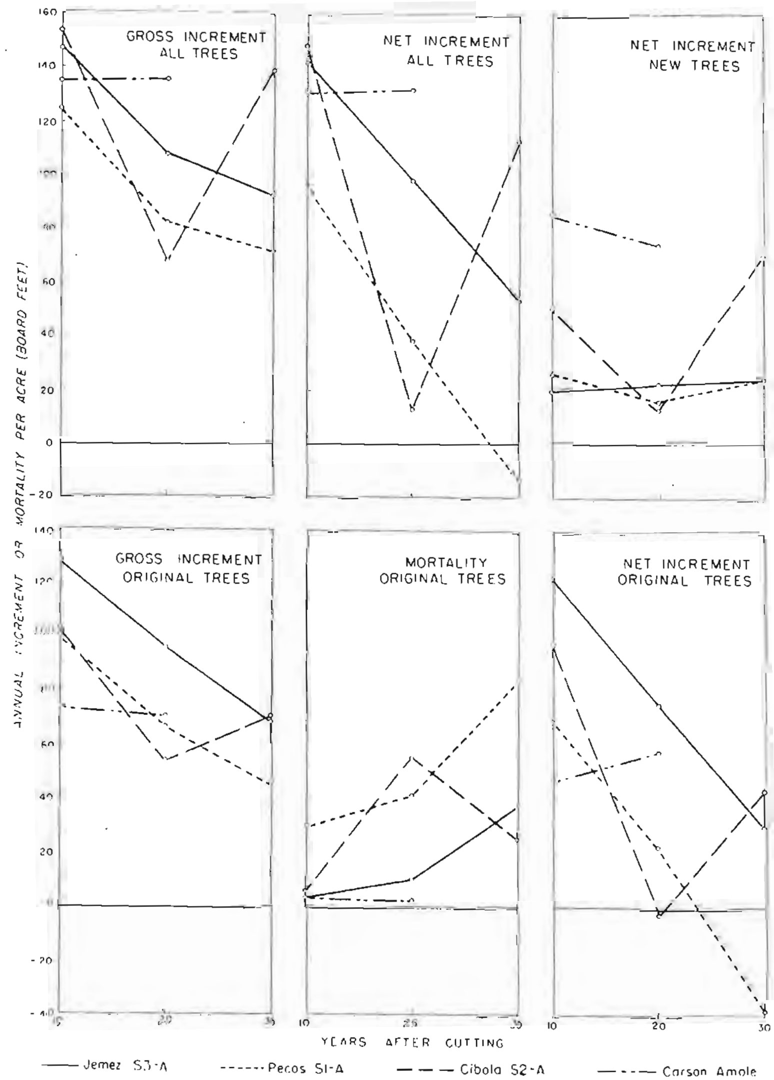

FIGURE 30.—Increment and mortality by 10-year periods during 30 years after a group selection cutting on four ponderosa pine sample plots in New Mexico.

which begins about the tenth year and continues at an accelerating rate. In stands left to take the natural course, this trend can be reversed only through build up of young age classes.

The problem of silviculture is to stop the decline in trees of merchantable size by combating the agencies responsible for death, stagnation, and deterioration. As an emergency measure, decadent and injured trees can be cut before they die; parasitism can be curbed by cutting infected trees, and stagnating stands can be revived by release cutting. In the long look ahead, silviculture must aim to checkmate destroying or retarding agencies by developing stands which are resistant or little affected.

For the time being, we shall consider only emergency measures in which depressing agencies already at work are met in the most direct way—by cutting. Salvaging diseased, injured, and dying trees at least staves off a loss equivalent to mortality. But it accomplishes more by incidental liberation of dominated trees and reproduction. A full measure of liberation, however, requires more than salvage; it requires systematic removal of low-grade or surplus stems in order to improve spacing. Salvage cutting, to be fully effective, should cover the forest annually, but for economic reasons such a program is seldom practical in the ponderosa pine region. The answer, for the present at least, seems to lie in frequent periodic cuttings (*64, 73*). A 10-year interval, with provision for supplementary operations in the event of heavy storm damage or bark-beetle infestations, would salvage most of the lightning-struck trees and windfalls, and practically all of the trees which decline slowly under the influence of mistletoe, rust *(Cronartium)*, and squirrel damage.

A 10-year cutting cycle, or even one of 20 years, is a far cry from the 60-year cycle formerly used under railroad logging. The old rule that a minimum cut of about 5,000 to 6,000 board feet per acre is necessary for economic justification of logging operations no longer blocks effective sustained yield. Many investigators have shown that with truck and tractor logging it is not low volume per acre so much as small and low-quality trees that increase logging costs. Investigations by Hasel (*25*) dealing with ponderosa pine in Blacks Mountain Experimental Forest, Calif., and by Reynolds, Bond, and Kirkland (*78*) dealing with second-growth shortleaf pine at Crossett, Ark., reached almost identical conclusions. In the last-named study, the time required to cut, skid, and load a thousand board feet of logs remained virtually unchanged in cuts ranging from 500 to 5,000 board feet per acre. In the Fort Valley Experimental Forest several second cuttings before, during, and immediately after the war removed only 1,500 to 2,500 board feet per acre, and though no time studies were made, the sales encountered no objections from contractors on grounds of low volume per acre.

Volume of cut per acre affects transportation costs only insofar as road building must be financed by the timber operation. In the case of public lands the cost is variable since most roads are built for a variety of purposes, of which timber transportation may be only one. On the other hand, a private operator who must finance essential roads entirely out of the proceeds of a timber project may find the cost of road construction a formidable item. In this case, the volume per acre, which determines the total number of thousand board feet to pass over the road, may determine the feasibility of the entire project. This explains why some large areas of timberland, even in the virgin state, are regarded as economically inaccessible. Once a road has been built and the initial cut completed, however, only the cost of maintenance is a legitimate charge against future cuttings.

A common obstacle to the short cutting cycle is a heavy initial cut. If the first cut is relatively light, a part of the reserve may be used to bolster up subsequent cuts, and at the same time a fairly high rate of increment may be maintained; but if the first cut takes nearly all the merchantable timber, future cuts are dependent almost entirely upon current growth. If, for example, the first cut leaves only 2,000 board feet per acre, and the net annual increment is only 60 board feet, a second cut in 10 years is probably out of the question, and even at 20 years a logging operation on such land may be a doubtful financial venture. But if the first cut leaves 5,000 board feet per acre, there is a good chance that increment in merchantable sizes will contribute 1,000 board feet in 10 years, which with 1,000 board feet of the reserve would provide a cut of 2,000 board feet without impairing the growing stock.

Absence of advance reproduction is another handicap. Some stands, because of overmaturity, mistletoe, or for other reasons, do not contain as much as 3,000 board feet which is fit to leave for 20 years. Twenty years may still see deficient restocking and then the manager must choose between two evils: leave declining trees for seed in the hope that reproduction will finally occur through a break in the climatic complex; or salvage all that are below par, thus further impairing the chances of regeneration. With good advance reproduction a second cut at the end of 10 or 20 years might take nearly all of the merchantable volume and still leave a growing stock which, though deficient in immediate board-foot increment, would eventually develop into a productive stand.

A review of all the old sample plots in the Fort Valley Experimental Forest—those logged prior to 1930—reveals that at the outset not one of them possessed the characteristics required to maintain continuous high increment. The group selection cuttings removed too much of the smaller yellow pine class and failed to open up dense blackjack groups; the blackjack class was deficient; advance reproduction was almost totally absent; and mistletoe was serious in two of the three plots. The light selection cutting left a fair volume, but poorly distributed, and there were too many large yellow pines; the younger age classes from seedlings to blackjacks were inadequate; mistletoe was a scourge which has persisted and increased since cutting.

A second cut at the end of 20 years should have been made to improve this stand. The scattered-seed-tree cutting removed even more of the growing stock than did group selection cutting; deficient growing stock, deficient advance reproduction, and mistletoe put this plot out of the running at the very outset; reproduction after cutting has, however, preserved the forest stand. The cutting to favor dominants was blessed with good advance reproduction; but too many of the smaller stems were sacrificed in favor of a few relatively large ones which after 10 years began to decline at a rapid rate.

A New Silvicultural Program

Rarely are natural ponderosa pine forests found in such condition that cutting can at once put the stand into a high state of production. A common handicap is predominance of old trees and a corresponding deficiency of young and intermediate age classes. Advance reproduction is of great help but cannot bridge a gap of 100 years in age classes. Mistletoe foreshadows an increment rate 10 to 50 percent below site capacity. Nevertheless, the first cutting can determine whether postponement of full production is a matter of 20 or 100 years. Enemies such as fire, bark beetles, wind, lightning, plant parasites, and rodents present hazards which must be anticipated and met by scientific counterattack. Poor form can be overcome by correct spacing, selection, and training through the juvenile period. Timber growing is not merely correct harvest cutting, or restocking, or protection, but all of these and much more coordinated in a long-range program.

With these thoughts in mind, a new series of plots was begun in 1940. Three areas of approximately 80 acres each were selected almost side-by-side in a fairly uniform stand. The usual disadvantage of too much old timber was partially offset by excellent advance reproduction mostly in the sapling stage but also a fair representation of seedlings and poles. A salvage cutting (S6B) and an adjoining control plot in a virgin stand (S6A) were established in 1940, and an improvement selection plot (S9) in 1941. The board-feet volumes in 1940-41 were, in round numbers, virgin stand 13,000, salvage 9,000, and improvement selection (S9) 8,000. Further details regarding residual stands are given in tables 11, 12, and 13. Methods of cutting have been described earlier under "Cutting in Virgin Stands." The first 5-year record is summarized in table 26.

TABLE 26.—*Annual increment and mortality, in board feet per acre, during 5 years after salvage cutting and improvement selection, compared with nearby virgin stand*

Item	Virgin stand, 80 acres (S6A)		Salvage,[1] 72 acres (S6B)		Improvement selection, 85 acres (S9)
	1930–40	1940–45	1930–40	1940–45	1941–46
Volume at beginning of record	12,639	13,122	12,967	8,877	8,029
Gross annual increment, original trees	106	101	101	98	116
Mortality, annual, original trees	67	55	82	11	13
Net annual increment, original trees	39	46	19	87	103
Net annual increment, new trees	9	11	7	4	5
Net annual increment, all trees	48	57	26	91	108

[1] 1930-40 before cutting; 1940-45 after cutting.

A second improvement selection cutting (S10) is, for reasons explained later, not comparable with the above series.

Salvage Cutting

Salvage cutting as applied at Fort Valley is regarded as a preliminary measure preparatory to a silvicultural cutting to come later. The program calls for a second cutting by improvement selection in 10 years. The merits of a salvage cutting have been questioned on the grounds that it neglects silvicultural opportunities in the younger age classes while placing all the stress on saving declining trees which, in this instance, were 48 percent defective (fig. 31). Nevertheless, it is of interest to consider the effect of the salvage cutting on the remaining stand. In this appraisal, the companion plot in the virgin stand may be used as a yardstick on one side, and the improvement selection plot (S9) on the other. The virgin stand is more directly comparable since records on the two plots cover identical periods; the improvement selection plot records began a year later. Another check on the performance of the salvage plot is furnished by records in this same stand covering the 10-year period before cutting (table 26).

According to the 1940-45 mortality records in virgin and salvage stands (table 26) the salvage cutting accomplished a saving of 44 board feet per acre annually which would otherwise have been lost. Gross annual increment of original trees in 1940-45 was 3 board feet per acre less on the salvage area than on the uncut area; but net annual increment of original trees during the same period was 41 board feet higher on the salvage area. The last figure (disregarding ingrowth) may be assumed to express approximately the net effect of the salvage cutting.

Unfortunately, a large portion of this apparent gain is only on paper. It has been pointed out that much of the volume saved through reduction of mortality was defective. More disturbing is the fact that a large part of the net increment is on inferior boles. Salvage, as usually practiced, makes no conscious effort to remove trees of this type unless they appear to be dying; on the contrary, they are favored because they are usually the limby dominants or open-grown individuals which may be expected to live indefinitely. Often they are dominating smaller trees of better form which would grow if liberated.

Salvage cutting automatically opens up the stand and provides release in many tree groups. However, far too many crowded groups, especially in the blackjack age class, are denied the benefits of release under this method. A gradual decline takes place in dense groups of both blackjack and yellow pine when they are ignored in the salvage operation. This is illustrated by the following record of average 5-year diameter growth in two typical nonreleased groups.

	Trees in group	Average 5-year diameter growth (inch)	
		Before cutting, 1935-40	After cutting, 1940-45
Age class:			
Yellow pine	11	0.40	0.24
Blackjack	21	.42	.34

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FIGURE 31.—Declining trees in a virgin stand. In salvage cutting only the three dying trees, already in advanced stages of deterioration, would be cut. More would be accomplished by cutting the nearer less decrepit tree, which is still worth salvaging.

In both groups, the diameter growth rate was considerably lower after cutting than before, indicating that stagnation had not been relieved.

The yellow pine group (fig. 32, *A*) is relatively young and of better-than-average quality; several of the subordinates have two almost clear logs. The group as a whole would benefit greatly from the removal of two or three of the largest stems before they begin to deteriorate and before their crowding of good subordinates proceeds further. In the blackjack group at least seven rough boles

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FIGURE 32.—Crowded tree groups left in a salvage cutting, 1940. *A*, Yellow pine group. Three large trees (marked x) have passed the stage of profitable growth and should be harvested. The space they occupy could be used to better advantage by smaller and better stems under their domination. Small stumps resulted from a cutting for poles or house logs about 50 years ago. Turpentine faces date back to 1910. *B*, Blackjack group. Proposed removal in the next cutting of seven trees (three marked x illustrate the type) would stimulate growth to the extent that volume increment would exceed that of the entire group before cutting.

should be taken out. Those marked x in figure 32, *B* illustrate the type. In handling trees of this class the important question is not how much they will grow but how much they will damage better trees if allowed to stand. Their removal would leave the group stocked to the full capacity of the soil and would result in a substantial increase in volume increment in the group as a whole, all placed on boles classed as fair to good.

If salvage is followed within 10 years by a silvicultural cutting, the delay in improvement of the stand may not prove serious; if, on the other hand, cutting is postponed as much as 20 years, the loss from decline or death of good subordinates will more than offset the apparent gain through salvage of defective and low-quality trees.

Improvement Selection

Improvement selection undertakes to accomplish in the first cutting what the salvage method would do in two cuttings, assuming that the second cut gives adequate attention to improvement of the stand. As in the salvage method, improvement selection contemplates a second cut in 10 years; but instead of a light first cut and a heavier second cut, improvement selection would reverse the order.

Theoretically, it might be possible in improvement selection to make the first cut heavy enough to give all the release necessary for a 20-year period. Actually, however, this would result in leaving too much soil unused during the first half of the period. The most urgent reason for a short interval between the first two cuts is that it affords an opportunity to salvage large trees which usually begin to decline soon after the first cutting. In the event of heavy windfall, a salvage operation should be made without delay. In order to justify such salvage from the operator's standpoint, it may in some instances be necessary to take a portion of the reserve which may in turn necessitate postponing the scheduled 10-year cut. With a reserve of as much as 5,000 board feet per acre, however, it is not likely that the cutting program need be disrupted.

Originally it was contemplated that both of the improvement selection areas in the Fort Valley Experimental Forest would be put on a 20-year cycle after the second cutting. But the trend throughout the ponderosa pine region is continually toward lighter and more frequent cuts. Silviculturally, a 10-year cycle, or even a shorter one, is highly desirable as a general program. Such a program would accomplish far more than mere salvage. It would make possible the frequent reduction of competition which is necessary to keep stands growing. Wherever advance reproduction is abundant and provision is made for future regeneration, it is only a question of time until short cutting cycles must become the rule. With the disappearance of old trees, salvage will recede farther and farther into the background, and increasing emphasis will be placed on quick growth of many young, clean-boled trees to diameters of 18 to 22 inches.

According to table 26, the improvement selection area, notwithstanding a lower volume of growing stock, produced annually during the first 5 years after logging 17 board feet per acre (net increment) more than the salvage area. The important difference is in quality rather than volume of increment. Before the salvage area can yield the quality of new wood produced under improvement selection it will be necessary to remove about 3,000 board feet per acre of wolf trees, limby dominants, and deformed or defective specimens, regardless of growth rate, which are using water needed by the remaining 6,000 board feet of relatively normal trees.

The photographs in figures 32 and 33 illustrate better than words the difference between salvage and improvement selection cutting. Improvement selection has opened up both yellow pine and blackjack groups, not enough to obtain rapid growth but enough to arrest decline and start an upward trend. Measurements before cutting are not available for the improvement selection area, but records during 5 years after cutting show that in yellow pine groups 29 percent of the trees grew 0.5 inch or more in diameter, while in the salvage cutting only 9 percent of the yellow pines attained this mark. In a similar comparison of blackjack groups improvement selection scored 61 percent against 29 percent for salvage. Not until after the second cut, however, will pronounced acceleration come into play. And it is worth reemphasis that improvement selection stimulates growth of the best boles by removing the poorest.

As previously stated, the improvement selection cutting of 1942 (S10, tables 11, 12, and 13) is not directly comparable with the series of plots in table 26. Because of great irregularities in stocking, however, it is valuable for analysis. The area lies on the east side of a large open area or "park" which is being invaded by pine from all sides. A strip of nearly 20 acres within the cutting area, next to the park, bears a sparse stand of sawlog size but is densely stocked with saplings and poles which originated in 1914 and 1919. Residual volume, number of trees per acre, and average diameter have been computed by 2-acre or 2.5-acre subdivisions. Average volume of the whole 76 acres after cutting was 5,376 board feet per acre; but there are 8 acres on which the volume ranged from 0 to 1,050, and 9.5 additional acres which bore 2,800 to 3,700 board feet per acre. Thus, 17.5 acres or 23 percent of the area had a residual volume of less than 4,000 board feet per acre. The remaining 58.5 acres ran from 4,100 to 9,600 board feet per acre, with only 5 acres above 9,000.

A freak storm sweeping in from the park cut a swath 4 to 6 chains wide diagonally across one end in 1943, blowing down enough timber to account for an average annual loss of 25 board feet per acre on the whole area during the first 5-year period of record. For this reason, only gross increment is considered in computing growth for this period.

Average annual gross increment per acre on the area was 88 board feet. Subplots bearing 4,000 to 9,600 board feet per acre show an increment range from 25 to 147 board feet, and the

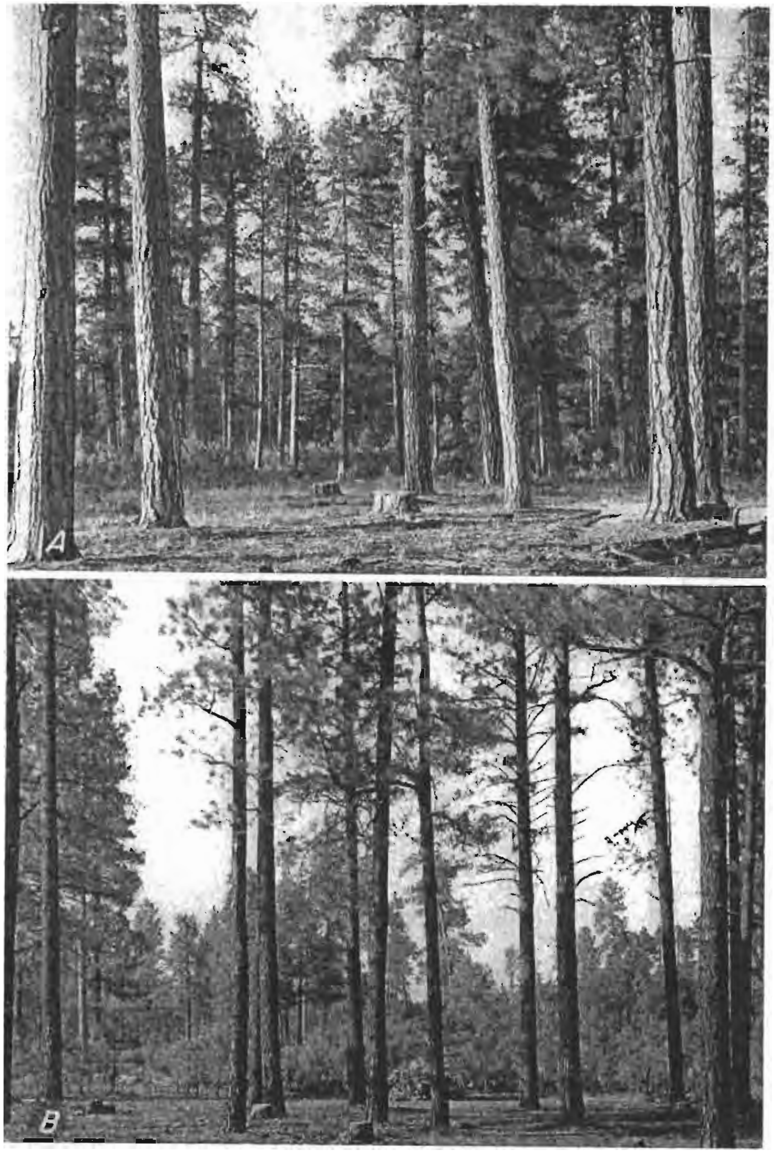

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FIGURE 33.—Groups cut under improvement selection in 1941 which are still too heavily stocked for good growth. The program calls for a second cutting in 1951. *A*, Yellow pine; *B*, blackjack.

correlation between increment and volume is by no means consistent. Highest increment is not on the two highest-volume plots but on one of 6,100 feet. Of the seven 2.5-acre plots which produced 130 board feet per acre or more, two were in the 5 thousand class, two in the 6 thousand class, three in the 8 thousand class, and none in the 9 or 10 thousand class. Evidently a large residual volume is not alone sufficient to insure a high rate of increment: the volume must be made up of many relatively small trees so distributed as to make good use of the soil.

On the improvement selection cutting (S10), as in table 19, average diameter is fully as important as volume. With a given volume per acre, a low average diameter means smaller trees and more of them, usually occupying a greater proportion of the soil. Average diameter does not necessarily express the true situation because a few large trees may raise the average in a stand of prevailingly small trees; but it is the best single figure available. Average diameter on the S10 subplots ranges from 18 to 26 inches; the top ranking subplot, whose annual net increment was 147 board feet per acre, bears 19.6 trees per acre averaging only 18.6 inches d. b. h.

In a stand as a whole each succeeding cut will continue to stress improvement of growing stock. The second cut will remove most yellow pines over 26 inches d. b. h., as well as inferior stems of smaller size in both yellow pine and blackjack classes. The third cut if made as much as 20 years later will leave very few yellow pines over 24 inches d. b. h. Thenceforth, the yellow pine class will be represented mainly by trees which rated as subordinates in the virgin stand—trees which in other methods would have been cut because of a small or unsymmetrical crown (fig. 34). Beyond the fourth cut, the original yellow pines will cease to figure prominently in the growing stock; their wide spacing will provide room for regeneration; the present blackjacks and intermediates, along with an important class recruited from ranks now below 12 inches d. b. h., will then constitute the merchantable stand. Groups approaching maturity will have been opened up to such a degree that remaining trees will have room for development; they will also be relatively wind-firm by virtue of a strong root system. Present pole and sapling stands will then be the blackjacks (fig. 32, *B*). Stand improvement begun after the first cut will have eliminated undesirable types and provided space for unhampered development of the best. In about 50 years the new forest visualized in the first marking will have become a reality.

Prediction of Yield

Normal yield tables, granting that they represent stands which scarcely exist, nevertheless create standards which are useful in setting up goals to strive for. Meyer's yield tables for even-aged, fully stocked ponderosa pine in the Northwest *(45)* give an indication of the yields attainable if stocking and age classes on large areas could be made to conform to the standards on small plots. Lexen's empirical growth table for the Southwest *(39)* provides

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FIGURE 34.—Subordinate trees of vigor class C released by improvement selection cutting in 1941. Diameter growth during 5 years after cutting, left 0.7 inch; right, 1.1 inches. Trees of this class usually have the making of an excellent butt log; they would be cut under group selection or maturity selection.

a reasonably satisfactory basis for predicting gross increment on large, partially cut areas. Additional adjustments for mortality and ingrowth are called for, however, unless the forest technician is willing to assume that mortality is balanced by ingrowth. Lexen's table also serves to bring out a significant contrast between well-stocked young stands and the understocked and overaged stands usually encountered.

For large areas of national-forest cutting in sites IV and V in the Southwest, a mean annual increment of 60 board feet per acre on cutting cycles of 30 years is about as good an average growth estimate as can be offered. Large residual volumes, unevenly distributed, will lower rather than raise the net increment unless the cutting cycle is short. Abundant ingrowth may increase this figure; deficient ingrowth will reduce it. The presence of good advance reproduction should raise the increment, looking ahead 50 years or more; but until cutting practice recognizes development of growing stock as the major objective, yields must remain low in both volume and quality.

On the whole, yield predictions in the present stage of management are of only passing interest. It matters little whether the estimate of 60 board feet is 5 percent or 30 percent in error. What does matter is that lands now yielding only 60 board feet per acre annually can be made to double or triple their yield. For the next 50 years the problem is not so much the exact measurement of current increment as it is the need for aggressive steps toward raising the increment to a level commensurate with the productive capacity of the land.

Regeneration—Natural and Artificial

That a forest cannot be maintained without regeneration is axiomatic. The generally understocked character of virgin ponderosa pine stands in the interior region is due either to faulty regeneration or to the destruction of young trees which normally would fill the gaps caused by mortality. In order to maintain a suitable gradation of age classes in many-aged stands, regeneration must go on more or less continuously. It is not uncommon to find gaps of as much as 100 years between age classes. Although this usually means that intervening classes have been destroyed, probably by fire, it is known that long intervals may elapse between years in which appreciable numbers of seedlings become established. Studies of increment have shown the advantages of an abundant inflow of new trees as expressed by "ingrowth," and by contrast the decline of increment where ingrowth is lacking.

Restocking may be accomplished by either natural or artificial means. As explained later, artificial reforestation on the dry sites usually occupied by ponderosa pine is too difficult and expensive for general application, and for this reason reliance must be placed mainly on the natural process by which seedlings originate from seed scattered by trees on the area.

NATURAL REGENERATION

Prior to the great seedling year of 1919, the Southwest was noted for its poor reproduction. This was not true of the whole region; in fact, a survey might have shown that less than half of Arizona and New Mexico was troubled in this way. But the sore spots were vital because they occurred almost invariably in localities of heavy timber use. Large areas of old cutting both within and outside the national forests had failed to restock. In some instances the reasons were obvious—heavy cutting or fire, often both. But national-forest cuttings were not restocking despite fire protection and safeguards for seed trees.

Years of detailed study in the Fort Valley Experimental Forest and adjacent country have brought to light much information which has been presented in several publications *(54, 56, 59, 61, 69, 71)*. Although the 1919 class of seedlings furnished the first opportunity for a comprehensive study, remnants of earlier classes occurred under conditions which indicated that with adequate protection, natural regeneration could be expected, though at long and irregular intervals. In the light of what has been learned from correlation of conditions surrounding all of these age classes, the factors which call for special consideration are: Seed supply, seedbed, climate, cutting practice, and protection.

Seed Supply

Nature is wasteful in the use of seed. Germination tests of ponderosa pine give from 5 to 97 percent viability, averaging around 59 percent. Under nursery conditions in the Southwest, practically complete germination takes place in 15 to 20 days, but in the forest it continues over a much longer period. The quantity required for adequate regeneration has been variously estimated at from 4 to 10 pounds per acre. Although large trees may occasionally yield 10 pounds of seed in a single crop, they average 2 pounds per tree in "good" years and 3 or 4 pounds per tree in "bumper" years. Good cone crops occur once in 3 or 4 years with lighter crops intervening; cones are practically absent about 1 year out of 4. At irregular intervals, evidently dependent on a number of chance variables, there is an exceptional seed crop such as was recorded on the Coconino and Kaibab National Forests in 1913, 1918, 1927, 1936, 1942, and 1945.

Important factors in decreasing seed yields are the cone beetle (*Conopthorus scopulorum* Hopk.) which destroys the seeds within the growing cone, and the Abert squirrel which cuts off enormous numbers of cone-bearing twigs in winter and feeds on green cones from July until the seeds are shed in October or November. After the seed fall and until July of the next year, seeds on the ground are an important source of food for mice, chipmunks, and mantled ground squirrels. If these rodents are numerous they may consume practically the entire seed crop.

The minimum seed-tree requirement was formerly placed at four trees, 20 inches d. b. h. and over, per acre *(54)*. In "good" seed years, these four trees average 2 pounds each or a total of 8 pounds. Contributions by smaller trees on the same acre might bring the total quantity to 12 pounds. Assuming an average of 10,000 seeds per pound and estimating that under moderately favorable field conditions only 1 seed in 100 produces a seedling that will survive, 10 pounds would yield only 1,000 seedlings. Really effective regeneration on cut-over lands in a single season requires at least 2,000 seedlings per acre, thus calling for 20 pounds of seed.

When allowance is made for the numerous agents of destruction and waste, together with the fact that about 10 percent of the seed trees will die over a period of 20 years, the minimum of four seed trees is barely sufficient unless the area has considerable advance reproduction. Since more than four suitable trees as large as 20 inches d. b. h. are seldom available, it seems necessary to lower the specified minimum diameter to 18 inches. The minimum seed-tree requirement for the Southwest may then be restated as six well-distributed trees 18 inches d. b. h. or larger. Obviously, the trees which make up this quota should be in or adjacent to areas in need of restocking, and the crowns should be freely exposed. Isolated individuals, or trees released by cutting in groups, meet the essential requirements. The old requisite of large crowns may be modified by placing less stress on size and more on vigor of the top, because it is the upper part of the crown that bears most of the cones.

Seedbed

It has been demonstrated repeatedly that pine germination is quicker and surer if the seeds are lightly covered with soil than if lying on the surface of the ground. Seeds which lie over winter tend to become covered by checking and heaving of the soil, but artificial covering is more effective. Unfortunately, artificial seed covering is seldom practical.

Experience in the Southwest has borne out the old observation that germination is better when the seeds are in contact with mineral soil than in deep needle litter. In years of unusually heavy summer rainfall, however, germination in the litter under trees is abundant, but the seedlings invariably die in these situations if the litter is deep and if the ground is shaded more than half of the day.

Effect of Herbaceous Vegetation

Partial shade by grass and weeds favors germination, but later effects are on the whole detrimental to pine seedlings. Survival and growth during the first few years are greatly favored by elimination of all competing vegetation, especially the bunchgrass Arizona fescue. Generally the most adverse effect of herbaceous vegetation is root competition. Tests during drought periods have consistently shown more moisture in the soil at depths of 4 to 9 inches where vegetation has been removed than where it is present. Shade may become equally injurious if herbaceous vegetation is tall and dense, as in the case of Arizona fescue and lupine. Figure 35 shows an ungrazed stand opening that bears a dense

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FIGURE 35.—A dense cover of herbaceous plants hinders ponderosa pine regeneration. A typical ungrazed bunchgrass area in which no pine seedlings have survived since 1909, although it borders an established stand.

cover of arizona fescue. The area has remained unstocked with pine from 1909 to the present. Numerous seedlings started in 1919 but died within a year.

The adverse influence of dense herbaceous cover on pine regeneration is shown not only by extensive observation but by experiments carried on from 1928 to 1944 *(60, 71)*. Part of the area illustrated in figure 35, bearing undisturbed stands of Ari-

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FIGURE 36.—Plots seeded with ponderosa pine and completely protected against rodents. *A*, Portion of plots seeded in 1929, photographed in 1937. Wall of seedlings in background is on plot denuded of grass and weeded. An unclipped control plot and plots with grass clipped to 6-inch and 2-inch heights are in foreground; they contain 5, 4, and 11 seedlings, respectively. *B*, Plot seeded in 1937. Denuded-weeded area in foreground had 35 seedlings when photographed in 1941. Undisturbed grass area in background had 1 seedling, which has since died.

zona fescue, was enclosed with a rodent-proof fence in 1928 for seeding tests. One plot was denuded, one burned, and others were clipped twice annually to heights of 2, 6, and 10 inches; on two control plots the bunchgrass cover was left in natural condition. The denuded plot was kept free of vegetation other than pines. Equal quantities of pine seed were sown and excellent germination resulted on all plots in 1929. By far the best survival and growth occurred where the grass and other vegetation were removed and kept out by weeding; distinctly less survival and slower growth where the grass was clipped (survival increased

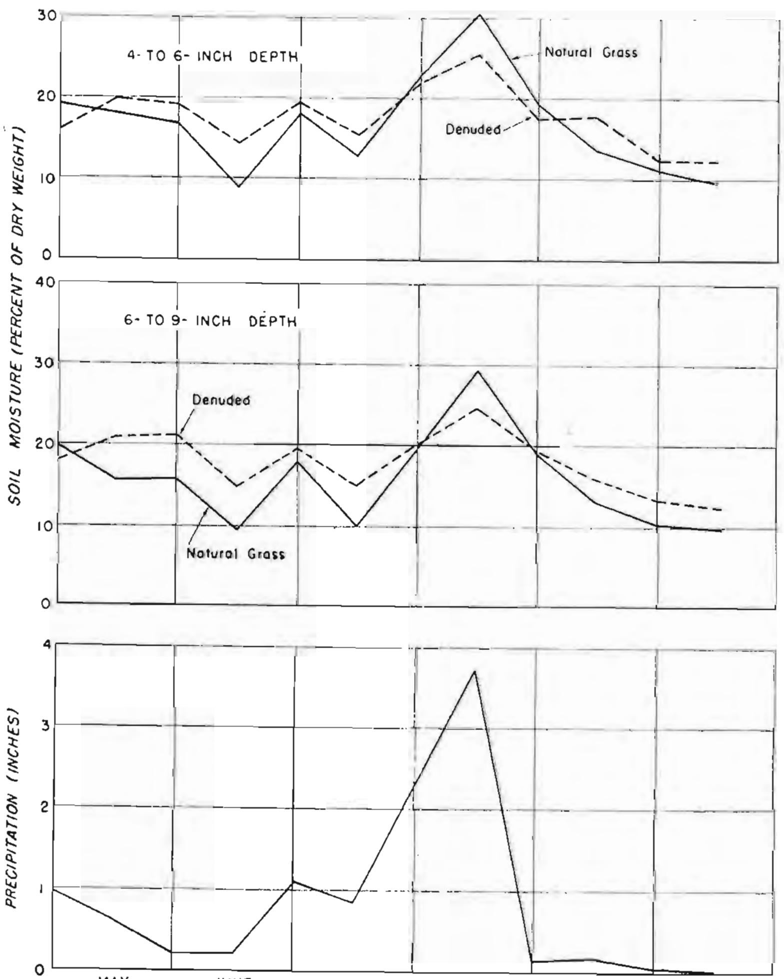

FIGURE 37.—Soil moisture and precipitation in natural grass and on denuded plots, 1934

TABLE 27.—*Survival and height of ponderosa pine seedings under different methods of grass treatment*

Item	Denuded		Clipped to—				Natural, no clipping		Burned in 1928
	Weeded	Not weeded	2 inches	4 inches	6 inches	10 inches	Lot 1	Lot 2	
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
929 sowing:									
Live seedlings:									
1929	374		219		218	91	151	81	271
1930	148		30		8	1	6	11	23
1931	109		16		5	0	1	8	15
1933	71		11		4	0	1	5	8
1941	[1] 18		10		4	0	1	5	8
Seedlings taller than 10 inches in 1933	29		1		1		0	0	0
Seedlings taller than 60 inches in 1941	14		3		1		0	0	0
	Inches		*Inches*		*Inches*		*Inches*	*Inches*	*Inches*
Average height of dominants in 1941	60		42		36		20	30	26
	Number						*Number*		
937 sowing:[2]									
Live seedlings:									
1937	181	183		141			138		
1938	93	61		26			26		
1940	81	28		15			17		
1941	74	20		11			7		
1944	66	7		3			3		
Seedlings taller than 10 inches in 1941	25	0		0			0		
Seedlings taller than 20 inches in 1944	27	0		0			0		
	Inches	*Inches*		*Inches*			*Inches*		
Average height of dominants in 1944	51	10		3			5		

[1] Thinned in order to prevent destructive competition. [2] 1937 seeding was in hills of 2 or 3 seeds each.

with intensity of clipping); and the poorest survival and growth where the grass was undisturbed (fig. 36, *A*). A similar experiment with some modifications was begun in 1937, and gave essentially the same results, the denuded and weeded plot being the only one where survival and growth proved excellent (fig. 36, *B*). Survival and growth of the 1929 and 1937 seedlings carried through 1944 are given in table 27. Figure 37 shows that the soil moisture content at depths of 4 to 6 inches and 6 to 9 inches was much higher during critical dry periods on denuded plots than on natural grass plots.

Climatic Factors in Relation to Germination and Survival

Precipitation

It has been said that the summer rainy season of the Southwest provides ideal conditions for pine regeneration. That is true only of seasons in which the volume and distribution of the rains through July and August are better than average. Really favorable conditions occur only when showers fall almost every day during a month or more. More commonly, rainy periods of a week or 10 days are followed by a dry period of equal or greater length. Exceptionally favorable years at Fort Valley were 1911, 1914, 1919, and 1921. Examples of years when summer rains were poor are 1910, 1915, 1920, and 1922. July rains were very deficient from 1938 through 1945 (table 3), with the result that when germination took place at all it was too late to permit the seedlings to develop sufficiently to withstand the winter and ensuing June drought.

Time of Germination

Midsummer is the usual time for germination. Early in the spring when soil moisture may be adequate, the temperature is too low; later, after temperatures rise, the surface soil is too dry. In July and August both temperatures and moisture tend to approach the optimum. Only in 1919, during the entire period of years from 1909 to 1945, did appreciable germination take place before July in the Coconino and Kaibab National Forests.

In most years a favorable germination period occurs sometime between July 1 and September 15. Germination is less critical than survival through the early stages. The most common adverse factors are drought and frost heaving, the latter being most prevalent in years of late germination.

Sometimes when seeds fail to germinate during a summer of subnormal precipitation, they lie over and germinate the following summer. Such occurrences are rare; the best example on record was in 1928-29 when a 1927 seed crop germinated sparingly in 1928 and remaining seeds germinated in 1929.

Coordination of Seed Supply and Precipitation

As can be readily understood, neither seed supply nor rains alone insure pine reproduction; what is required is coordination of the two. Many a seed crop has been wasted because it was not followed by a summer of adequate and timely precipitation, and many a good summer rainy season has proved of no avail because Nature had sown too little seed the preceding autumn.

The best combination on record was in 1919, a year of exceptionally good summer rains, preceded in 1918 by a generally heavy seed crop. The year 1929 also had good summer rains but the only seed available was a variable hold-over from the 1927 crop. Again in 1930 the summer rains were copious but seed was deficient. Survival of the 1929 seedlings, however, was favored by the 1930 rains and consequently some good reproduction dates back to 1929. Another favorable year for germination was in 1936, but 1935 was not a good seed year. A fair seed crop in 1936 germinated well in places where the June-July rains of 1937 were at their best. Most of the 1937 seedlings, however, succumbed to the unprecedented drought of May, June, and July in 1938 and 1939.

With a record of seed crops and precipitation on the same area it is possible to explain past successes and failures of reproduction with considerable accuracy. It must be borne in mind, however, that both rains and seed crops in any one year may vary greatly within a radius of a few miles.

During the period of 38 years from 1908 to 1945, inclusive, only 1 year of abundant and widespread reproduction has been recorded in Arizona, namely, in 1919. Pole stands point to a similar seedling crop in the early eighties. Good catches were registered locally throughout Arizona in 1914 and 1929. A few seedlings started in 1909, 1911, 1917, 1921, and 1937. As far as rains are concerned there could have been many more good seedling years, but deficient seed supply, unsuitable seedbeds, and inadequate protection have all contributed to failure.

Relations Between Cutting Practice and Regeneration

A deeply rooted belief among foresters is that a "correct" method or degree of cutting can be found that will solve once and for all the problem of natural reproduction. In the Southwest, early research efforts to test different methods took the form of empirical cutting experiments followed by systematic records of germination, survival, and development of seedlings, along with records of growth and mortality of trees.

The Coulter Ranch Study

The most comprehensive experiment in the Southwest is the Coulter Ranch series of cutting plots (S5), in which three methods of cutting (group selection, scattered seed tree, and light selection), were applied on adjacent areas all logged in the same year—1913. Detailed description of th subject to invasion by bunchgrasses, and the annual precipitation is about 20 inches. The reserved volume and number of trees over 20 inches d. b. h. per acre were: Group selection 2,846 board feet, 3.1 trees; scattered seed tree 1,873 board feet, 2.2 trees; light selection 4,510 board feet, 4.6 trees. More trees between 11 and 21 inches d. b. h. were left on the two selection areas, but on the scattered-seed-tree area nearly all were cut. Since the entire area was subject to heavy grazing by both sheep and cattle, a 50-acre unit of each cutting plot was fenced in 1919.

Seedlings appeared in appreciable numbers only in one year—1919. Survival records of this class are given in table 28. Because, as shown later, sheep grazing proved to be a disturbing factor, only the records from the fenced plots are included in this table. No count was made in 1919, but it is estimated that the number of seedlings recorded in 1920 is at least 50 percent below total germination. A marked feature of the annual records from 1920 through 1924 is the pronounced downward trend. Mortality did not end after the second year but continued high through the fifth year and at a lower rate up to the tenth year. Practically all of this mortality was ascribed to drought aggravated by root competition from herbaceous vegetation and trees. In some instances, where plots were located under tree canopies, shade was undoubtedly the dominant factor. Frost heaving also accounted for considerable losses but mainly before the 1920 examination.

As might be expected, the scattered-seed-tree area, with the lowest number of trees both in the class over 20 inches d. b. h. and in the 12- to 20-inch class, had the fewest seedlings in 1920, but in 1929 they almost equaled those on the light selection area, and by 1942 the scattered-seed-tree area presented the best aspect in the series as far as reproduction is concerned. The most plausible explanation is that with fewer trees to create root competition and overhead shade, the seedlings on the heavily cut area had a better chance to grow.

Limitations of Cutting Practice

A moment's reflection should make it clear that in unevenly stocked and generally open ponderosa pine stands as affecting the influence of cutting on regeneration has definite limitations. It is highly improbable that precipitation is influenced one way or another by method of cutting, except as the crown canopy may intercept rain or snow. This effect would be confined to areas within the immediate influence of the tree crown.

Light cutting, as compared with heavy cutting or no cutting at all, tends to increase the total volume of seed, and in the long run this must be regarded as an important factor. However, volume of seed above a certain minimum is not a deciding factor, nor is germination. Successful restocking is determined also by survival of seedlings, and there is no evidence that survival can be favored by light cutting. On the contrary, fairly heavy cutting favors survival, and but for the fact that heavy cutting also endangers seed supply and induces branchy form, it might be recommended as a means of favoring reproduction.

TABLE 28.—*Survival of 1919 seedlings on areas cut by different methods in 1913 and fenced against livestock, Fort Valley Experimental Forest (plots S5-1, 2, and 3)*

Method of cutting	Area of seedling plots	Surviving 1919 seedlings per acre						Estimated stocking in 1942 [1]
		1920	1921	1922	1923	1924	1929	
	Square feet	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	
Light selection	3,440	7,900	2,900	2,000	1,600	1,100	830	60 percent, uneven distribution.
Group selection	2,150	3,900	700	600	400	300	250	50 percent, uneven distribution.
Scattered seed tree	6,150	2,800	1,000	900	800	740	690	80 percent, fair distribution.

[1] Includes advance growth which started before cutting.

In the last analysis, the fact remains that these three cutting areas provide almost every conceivable combination of shade, seed supply, litter, and soil cover. Nevertheless, appreciable regeneration has taken place only once in 35 years, namely, in 1919, when an excellent seed crop falling on a heavily grazed soil coincided with the wettest summer on record. Even then reproduction failed on areas subjected to heavy grazing, and likewise on small areas where complete exclusion of livestock favored luxuriant grass and weeds.

Advance Reproduction

A common condition in virgin ponderosa pine forests which have escaped recent fires is the presence of "advance reproduction." Usually this young age class occupies all the open spaces between tree groups, and in some localities it comes in directly under the old trees where the canopy is not dense. The presence of a younger age class, which may range anywhere from seedlings to poles, is obviously a great advantage. On one Fort Valley area (S9), seedlings and saplings of two age classes, ranging from 2 to 8 feet in height, occupied more than half the area, notwithstanding a volume of 18 M board feet per acre before cutting (fig. 38).

The area occupied by different age groups, before logging, was as follows:

	Percent of area
Yellow pine	22.8
Blackjack	10.4
Poles	3.2
Seedlings and saplings	54.0
Nonrestocked	9.6
Total	100.0

The larger stems may be expected to contribute heavily to "ingrowth" in about 20 years.

If a large volume of timber is removed, logging damage followed by brush burning may destroy a large part of this young growth. As has been pointed out elsewhere, this situation furnishes an added incentive for conservative cutting because trees felled in the next cut can then in many instances be dropped into bare spots or into old groups which have been opened up. On the other hand, judicious felling, skidding, and brush piling may be employed to accomplish a needed thinning in overdense thickets (fig. 39).

Too much reliance should not be placed on advance reproduction, however, because of the ever-present danger of fire after cutting and because in most stands the old groups are too dense and the root competition too severe to permit seedlings to survive underneath and within 20 to 30 feet outside the crowns. If mature groups are cut clean or nearly so, the result is a large open space which may not restock for many years (fig. 40). On the other hand, partial cutting can keep the land occupied and provide seed for a new age class. This practice was applied in the improvement selection cuttings previously described.

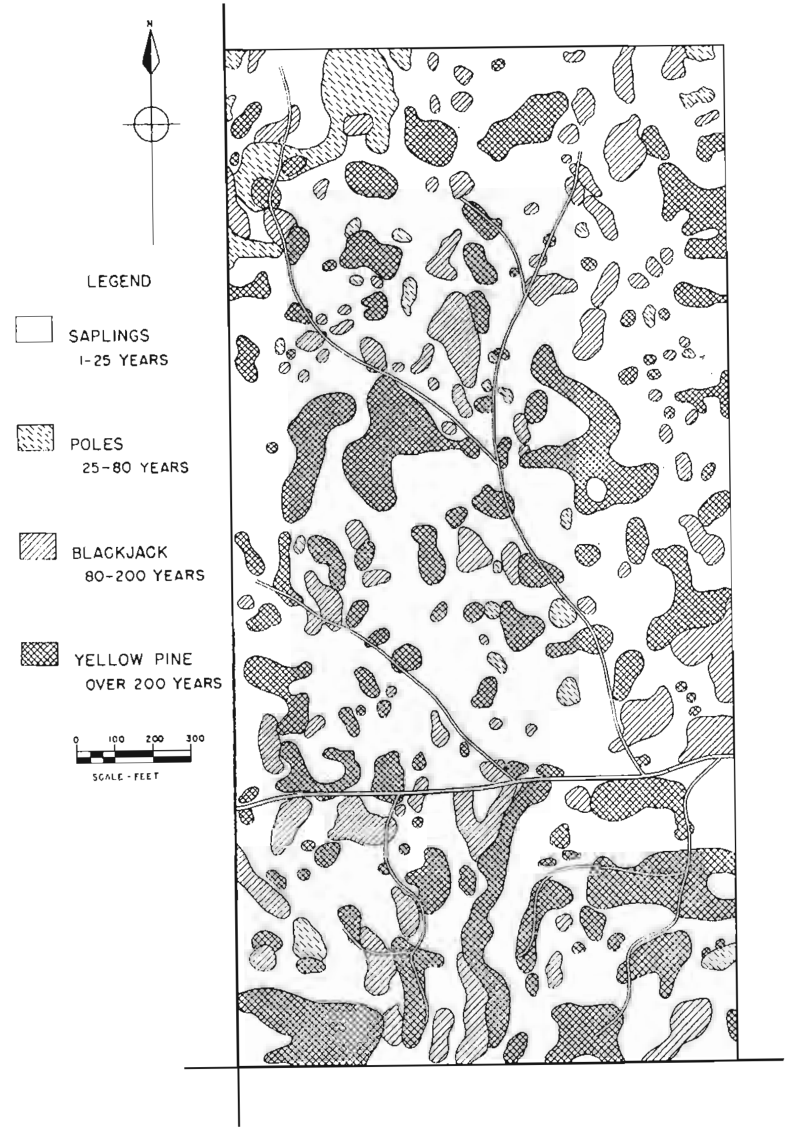

FIGURE 38.—Area distribution of age groups, virgin ponderosa pine, sample plot S9, 85 acres, Fort Valley Experimental Forest.

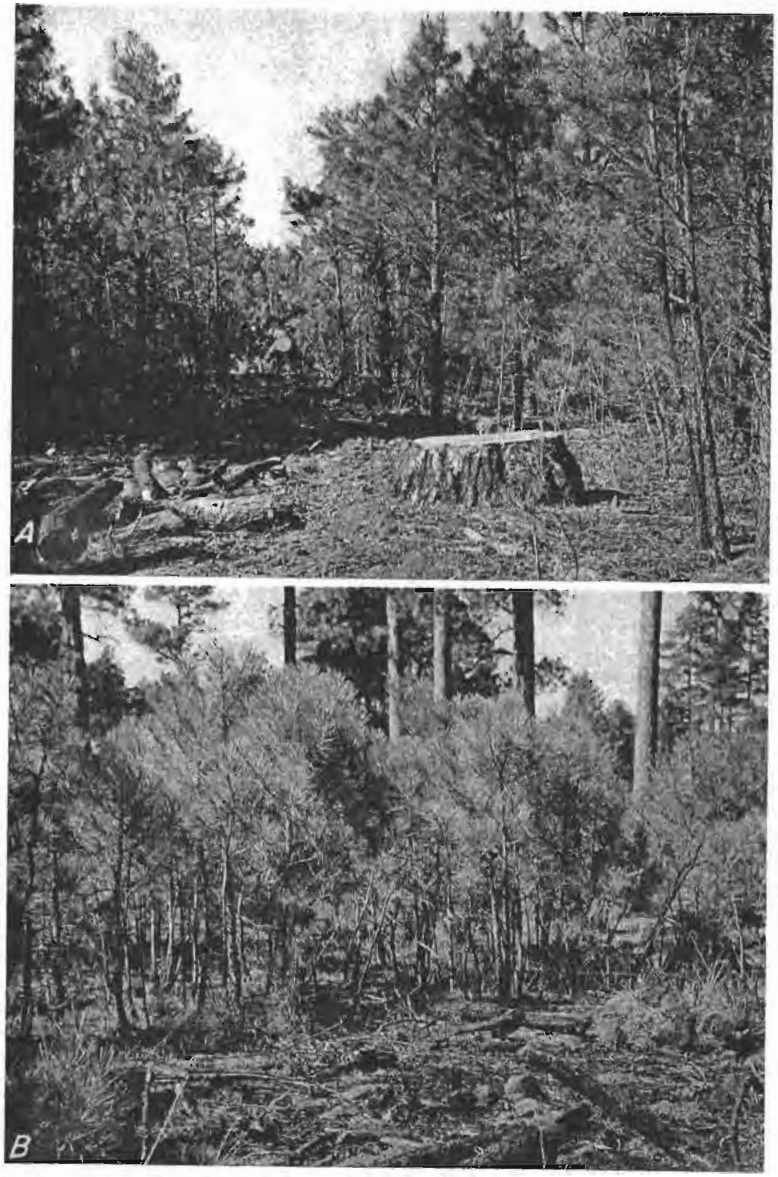

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FIGURE 39.—Logging and slash disposal can be used as cheap means of thinning overdense pine thickets. *A*, A large tree has been felled directly into a thicket. *B*, A brush pile burned within a dense group of saplings has created an opening 20 feet in diameter, releasing border trees.

Secondary Species

Secondary species, generally speaking, do not present a problem in the ponderosa pine type of the Southwest. In the upper transition, white fir, Douglas-fir, and limber pine are often associated with ponderosa pine and reproduce well in its shade and

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FIGURE 40.—A stump patch 14 years after logging. The surrounding thickets were advance reproduction when the area was logged.

litter. Of these species, however, only white fir is regarded as an inferior species. On sites devoted to saw-timber production, white fir seed trees, if not merchantable, could be cheaply eliminated by poisoning. White fir in the sapling stage could be cut on a large scale for Christmas trees. As a rule, however, the sites on which white fir tends to dominate are in the Douglas-fir type.

In the lower fringe of the ponderosa pine type, junipers and oaks mingle with the pine to some extent. These species rarely become dense enough to interfere with pine reproduction; moreover, as ponderosa pine emerges from the cover it overtops the junipers and oaks. More often, pine is the aggressor, especially in juniper. On account of tip moth damage the pines in the lower fringe type gain height slowly, but they grow in diameter at a rapid rate. Here, production of railroad ties may have possibilities.

Protection of Young Growth

Protection as covered in the following pages merely calls attention to the character of damage and closely related circumstances. Since control measures for reproduction are a phase of the broader field of control of damaging agents, a discussion of this subject is reserved for a later section.

The destructive effect of fire on pine seedlings in its path is obvious. Undoubtedly fire accounts for the lack of reproduction, or the absence of certain age classes, on extensive areas in the ponderosa pine type. Even under organized protection scarcely a year passes in which areas of from 100 to 1,000 acres are not virtually denuded of seedlings and saplings. Uncontrolled fire must be kept out of the forest for the benefit of tree reproduction as well as many other interests.

Browsing by livestock, particularly where too heavy grazing is practiced, and stem injury by insects and rodents are other factors which, though less spectacular than fire, may in the long run be more harmful because they cover more territory and unless controlled go on year after year.

Browsing by Livestock and Deer

Ponderosa pine seedlings are browsed by sheep, cattle, and deer—the degree varying with the intensity of stocking and system of management. Sheep eat both growing shoots and needles. Cattle normally eat only shoots. Deer eat buds and shoots, but at Fort Valley they have not been observed to eat pine needles. Where browsing occurs all of these animals normally confine their activities to the current season's growth and to that portion within reach of livestock. In stands of mixed composition, white fir and Douglas-fir are eaten in preference to ponderosa pine.

In the Southwest, all three types of browsing are characteristically seasonal. Buds are eaten by deer early in the spring when the pine shoots first begin to elongate. Stem or shoot-browsing by cattle and sheep starts several weeks later when the new growth is from 2 to 3 inches long. Stems are rarely browsed by cattle or sheep after they cease to elongate and begin to acquire a mature texture. Deer, however, occasionally browse pine shoots when distinctly woody. The period of shoot browsing usually extends from about June 15 to July 15, varying with sites and seasons. Needle browsing by sheep begins when the needles are 2 to 3 inches long, usually about August 1, and continues into November.

Shoot injury acts directly to check height growth and to cause abnormal branching. If only the leader is cut off, a lateral of the upper whorl often rises to take its place; if all shoots of the upper whorl are taken, a lateral from the next lower whorl may assume leadership (fig. 41). When a new leader is formed by a rising branch, a sharp bend is formed in the stem. It becomes straight in a few years, unless injured repeatedly. Sometimes new shoots are formed from adventitious buds at the base of an injury, or in a needle fascicle *(17)*. If all the upper shoots are

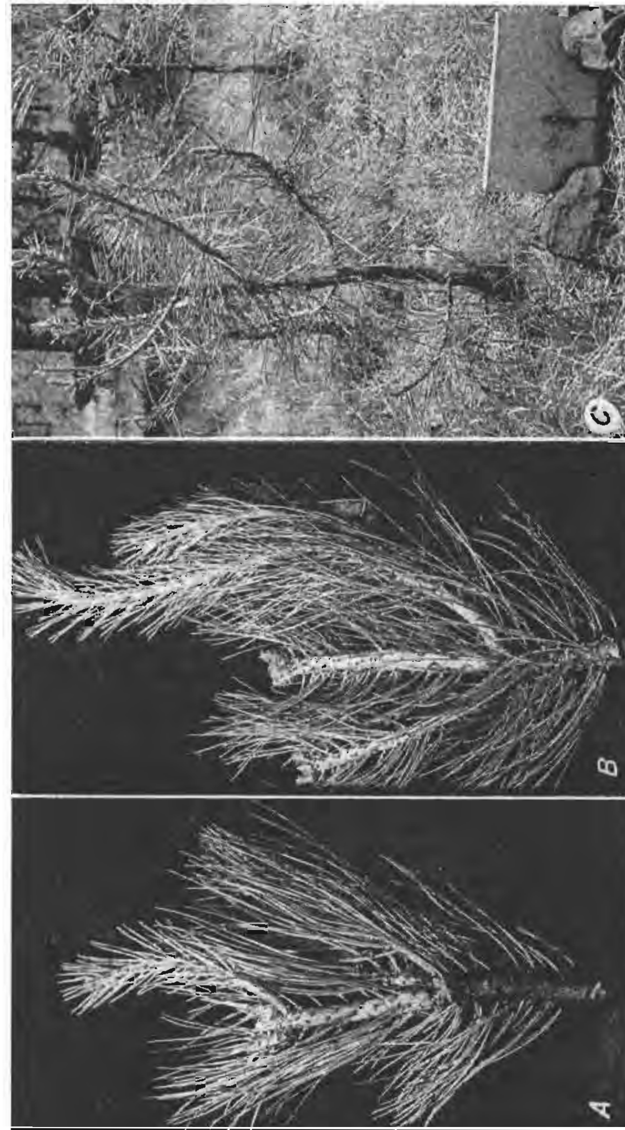

FIGURE 41.—Types of pine browsing and recovery. *A*, All but one shoot in the upper whorl have been bitten off; the remaining shoot is rising to assume leadership. *B*, All the upper shoots removed; a branch from the lower whorl (preceding year's growth) is arching upward to take the lead. *C*, Needle browsing by sheep. Some needles are clipped off, others pulled out of their papery sheaths. Only needles of the current year are eaten at any one time; these trees were browsed in the fall and photographed the following spring after the buds had begun to elongate. If the new shoots are not bitten off, a new set of needles will appear. The small seedling in foreground is ungrazed. This is a common relationship on areas where large and small seedlings occur side by side.

bitten off year after year, bud growth gives rise to a profusion of stems and the tree becomes bushy.

The browsing of needles tends to lower the capacity of the crown for photosynthesis; unless a large proportion of the foliage is taken, however, the effect may not be noticeable. But removal of a substantial proportion of foliage year after year is bound to have adverse consequences because browsed needles are always the newest ones; they are not replaced and those which remain are shed after 3 or 4 years. Death may result from repeated near-defoliation.

Fatalities from browsing are most common in the small seedling stage, when the bite of an animal may remove the entire crown. This result is common in the first and second years and accounts for the wholesale destruction which some investigators *(41)* have reported as taking place in the cotyledon stage. In fact, it extends beyond the cotyledon stage through the primary and secondary leaf stages and into the second year's growth *(54, 58)*.

Survival in critical places is the best criterion of damage. The consequences of seedling loss are not always directly proportional to the number killed or injured but are more nearly related to the number which survive. In dense seedling stands the death of large numbers may cause little or no real damage, whereas in thin stands an equal number of deaths may be serious. It follows that in appraising grazing damage special attention should be given to the areas on which seedlings have started sparingly, such as heavy cuttings or flats with heavy soil. An example of such an area is illustrated in figure 42. Figures on average damage over large areas tend to obscure localized severe damage and thus they present an overly optimistic appraisal.

Damage by Tip Moths

The growing shoots of pine seedlings and saplings are often attacked by the larvae of the pine tip moth (*Rhyacionia neomexicana* Dyar) which devour the tender tissues within the developing shoot. In the course of a few weeks the shoot, above the point of entrance, dies and later becomes hollow and crumbly. Within a year most of the dead tips break off, and to the inexperienced eye the pine shoot appears to have been bitten off by cattle or deer. A distinguishing characteristic of tip moth injury is that the stub where the dead tip breaks off is ragged and hollow or honeycombed, whereas the stub of a shoot that has been bitten off is usually smooth, firm, and pitchy. Recovery from tip moth injury takes place in the same way as recovery from browsing (fig. 41). If only occasional shoots are killed, the young tree continues growing, but if severe attacks kill all the young shoots year after year, the tree eventually dies.

Rodent Damage

Rodents cut off the stems or gnaw the bark throughout the reproduction stage. As previously mentioned, mice and chipmunks may consume seed. In other instances, soon after germination

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FIGURE 42.—Damage on critical areas. An almost clear-cut section on which abundant reproduction started before logging. At least 90 percent of the seedlings are dead and growth delayed on the survivors because of persistent defoliation by sheep. Since few seed trees remain, the heavy damage to seedlings may delay satisfactory regeneration for decades.

the seed caps are sometimes plucked off, including the cotyledons. This is probably the work of mice or chipmunks but could also be done by birds. After the stems become woody, any time from the second to the fifth year, they may be cut off close to the ground, suggesting the action of wood rats. In this stage and later they may also be barked under the snow; where much of this activity is observed it is commonly associated with the runways of mice in dense grass. Abert squirrels and porcupines gnaw the bark of trees of all ages, but their activity is most conspicuous from the pole stage on into older age classes. In total, rodents are an important factor in retarding pine regeneration, beginning as they do with the seed supply, even (in the case of squirrels) before the seed matures, and continuing after the seedlings have passed the critical stage of resistance to adverse climatic factors.

Present Status of Pine Reproduction in Southwest

Much of the cut-over land in Arizona and New Mexico is now fairly well restocked. This naturally gives rise to some satisfaction, notwithstanding the fact that sizable areas are still poorly stocked. Some of the best reproduction, now in the pole stage, goes back to pre-national-forest days. Most of the young stands of all ages started as advance reproduction; but considerable areas are definitely known to have restocked after cutting, mainly in 1919, though the 1914 and 1929 classes are represented in various degrees. Figure 43 illustrates the progress of reproduction from 1909 to 1941, after group selection cutting on a fenced plot (S3A).

The fact that no appreciable restocking has taken place since 1919, a lapse of more than 25 years, should serve as a warning that trouble lies ahead. Cutting in virgin stands, even though advance reproduction may be nearly complete, calls for further regeneration in order to restock spaces opened by cutting and to repair logging damage. Moreover, virgin stands are being cut that lack adequate advance reproduction. Aside from the question of ultimate restocking it should be realized that poles 30 years old at the time of logging have a margin of 50 years over seedlings which start 20 years after logging. In most virgin stands less than half of the space is occupied by trees beyond the pole stage. Management can well begin several decades in advance of logging, with a view toward transforming open spaces into pole groups.

There is no formula for prompt natural regeneration of ponderosa pine. Weather, more than all other factors combined, determines success or failure. Given such seasons as 1919, nothing short of clear cutting or fire can prevent regeneration. But experience has shown that it is not safe to rely on the coordinated recurrence of such weather and a good seed crop. This requires planning a course which aims to take full advantage of the moderately favorable seasons that occur at intervals of 5 to 10 years. The plan should take into account the fact that rarely will full stocking occur over large areas in any one year. In other words, regeneration will, as a rule, be a cumulative process and the result will be stands which are not strictly even-aged, even with the usual latitude of 20 years within an age class. Good silviculture can throw its weight on the side of nature by providing an adequate seed source and a favorable seedbed—the former by reserving ample seed trees supplemented by control of rodents, and the latter by judicious use of grazing, supplemented where necessary by artificial aids such as mechanical soil scarification. Protection of seedlings against animals and fire will be discussed in a later section on control of damaging agents.

Management Holds Key to the Future

Under continuous good management there need be no serious ponderosa pine reproduction problem. The matter lies in the hands of forest managers. As has been stated, management should begin in the virgin stand. Once a good growing stock is established, further restocking will be needed only in small spots here and there. The fact that pine seedlings do not survive under groups of old trees is no cause for alarm, for they will come in after partial cutting. Scattered seedlings in small openings usually develop good form because they are subjected to moderate side shade. The few seedlings which normally start in small openings every few years are adequate for restocking if given full protection. Under light

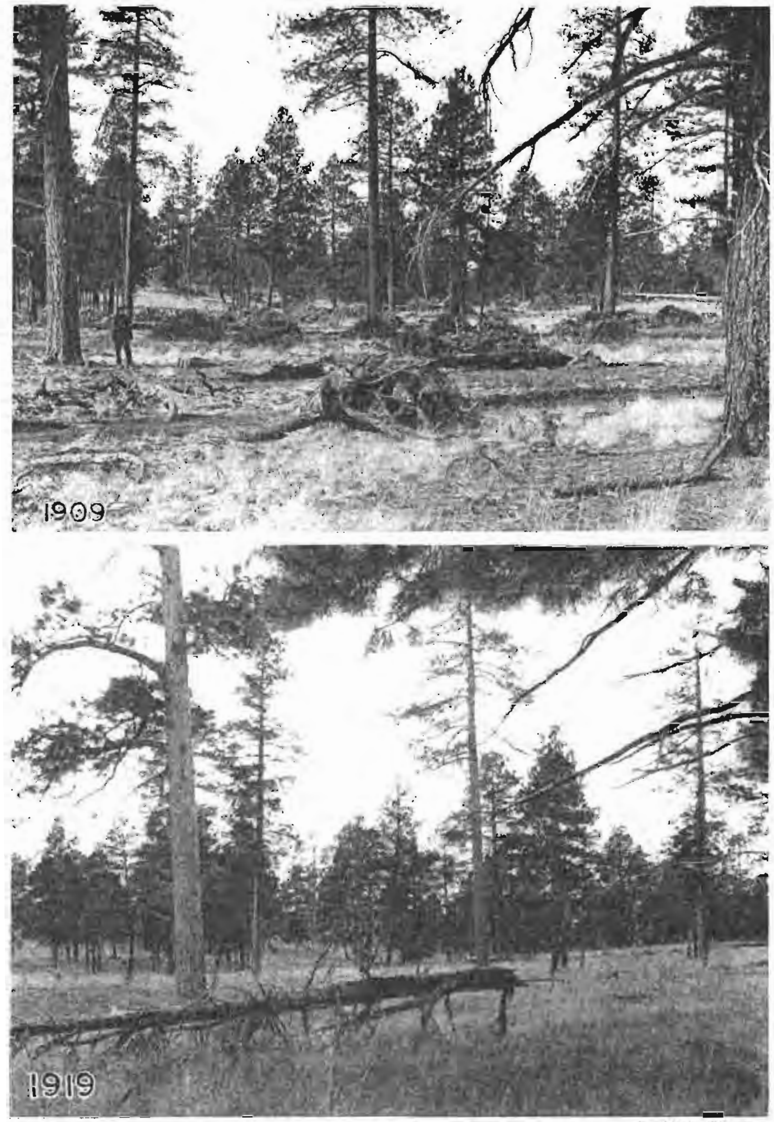

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FIGURE 43.—Progress of pine regeneration with grazing excluded. Views from the same point in 1909, 1919, 1930, 1936, and 1941, within the fenced plot S3A, closed to livestock since 1910. The 1909 photograph illustrates a common condition at that time; absence of advance reproduction and heavy group selection cutting left large spaces unoccupied by trees. The 1919 photograph shows little change except that grass and various annuals have covered the soil, and some of the seed trees are declining. A few seedlings 5 to 10 years old were in evidence here and there, and a bounteous 1918 seed crop was germinating.

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FIGURE 43 continued.—By 1930, the 1919 seedling class was becoming visible and older ones had reached the sapling stage. Six years later, in 1936, pine reproduction was dominating the ground. Several of the seed trees seen in 1909 had been struck by lightning or uprooted by wind.

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FIGURE 43 continued.—The 1941 photograph was taken after the second logging in 1939. Camera moved 20 feet because the original point had become overgrown.

selection cutting, dense reproduction is not required and the uncertainty attending the occurrence of such seedling years as 1919 is largely eliminated.

In a well-stocked stand of balanced diameter distribution, selection cutting does not create large openings. For this reason, the light-demanding grasses such as Arizona fescue do not become dominant, and the prevailing grasses are mountain muhly, muttongrass, and Junegrass, none of which are very aggressive; other herbaceous vegetation will consist of such plants as the vetches, lupines, and yarrow. The volume of forage in such a forest is low, but its palatability is relatively high. The whole arrangement favors pine seedlings with respect to both competition and browsing by domestic livestock.

The conditions visualized above will not be realized without long-range planning and subordination of other interests to timber growing. On large areas of past cutting the desired condition cannot be brought about within 50 to 100 years. Present cutting practice in the national forests creates more favorable conditions, but method of cutting is only one of many factors concerned in natural regeneration. Inadequate control of livestock, game, rodents, and fire can bring to naught the best of silvicultural practices. Management which aims to grow full timber crops can take nothing for granted.

ARTIFICIAL REFORESTATION

Limitations of Ponderosa Pine Reforestation

Ponderosa pine has been planted in many parts of the Southwest, but really successful plantations are few as measured by standards attained elsewhere with other species. Two reasons account for the meager results: one is inherent to the nature of the species and the other is climatic. The two causes combine to the disadvantage of ponderosa pine planting.

Ponderosa pine is a slow starter even under favorable physical conditions. Unlike many other conifers, it makes only one height growth in a season. Terminal shoots push out with the first warm weather, then stop; and no matter how much moisture and warmth are available later, height growth is practically finished for the year. In contrast, the pines of the south Atlantic and Gulf States make three or more flushes of growth in a single summer.

In order to understand the planting problem in ponderosa pine, it is necessary to keep clearly in mind the climatic characteristics of the ponderosa pine type. It is characteristically a dry zone. The species does not demand dry conditions, but it does demand relatively high summer temperatures. In western United States, high temperature and high precipitation seldom coincide.

Protracted drought periods during the growing season, which are the rule throughout the ponderosa pine type, account for most of the high mortality and poor growth in young planted trees. The Southwest with its summer rains may seem to be an exception, but the rains are seldom adequate and often they arrive too late to remedy the damage of a spring drought. Snow is the main source of moisture and most of the height growth takes place during the driest season of the year.

Results of Reforestation in the Southwest

Experiments over a period of more than 30 years in the Fort Valley Experimental Forest have shown how to plant but have also pointed out drastic limitations. A discouraging aspect of the problem is that mortality continues for many years. Plots which show a survival of 90 percent at the end of the first season are usually down to 75 percent in the fifth year and they continue to decline up to the fifteenth year.

Table 29 gives the record of a few of many experimental plots planted at Fort Valley in 1912, 1913, and 1914. The plots were one-tenth acre in size, each planted to 100 trees. The site was an old pre-national forest cutting area used for many years prior to 1909 as a holding pasture for cattle. Competing herbaceous vegetation presented no problem. A uniform method of planting (middle of hole) was employed in this series, but several different classes of planting stock were used. Although the experiment was designed primarily to compare different classes and grades of planting stock, interest now centers on the ultimate outcome.

Survival at the end of the fifteenth to seventeenth growing seasons indicates that even with good stock and careful planting

TABLE 29.—*Record of some ponderosa pine plantings in the Fort Valley Experimental Forest, 1912 to 1928*

Plot [1] No.	Class of stock	Year planted	Survival in percent by number of growing seasons after planting			
			1st	2d	5th	17th
16	Seedlings, 1½ years	1912	74	42	23	15
17	Transplants	1912	87	62	45	38
18	do	1912	92	80	66	65
19	do	1912	81	57	49	45
20	do	1912	94	88	75	64
						16th
33	Transplants, grade 1	1913	95	91	86	73
35	do 2	1913	66	55	25	23
36	do 1	1913	92	90	69	65
37	do 1	1913	86	83	60	42
38	Seedlings, 1½ years	1913	46	39	20	11
						15th
10	Transplants, grade 1	1914	63	39	24	19
11	do 2	1914	63	40	16	8
12	do 1	1914	90	76	52	41
29	Seedlings, 2½ years	1914	67	51	31	27

[1] All plots one-tenth acre in size.

methods, mortality is likely to exceed 50 percent of the original number of plants. Drought was the main factor during the first 2 years, but later on biotic agents including root grubs, gophers, and tip moth were listed as most prominent. Although no counts were made after 1928 it is known that practically no additional mortality has taken place. Porcupines, gophers, and other rodents have, however, damaged considerable numbers on some plots. With an original stocking of 1,000 per acre, the number of effective trees was reduced to an average of 300 to 500 per acre, excluding those plots on which seedling stock was used. The general aspect of the plantation after 30 years was that of a fairly well-stocked natural stand containing some small openings. The trees were 15 to 20 feet tall and mostly of poor form (fig. 44, *A*).

Recent experimental plantings have emphasized the importance of controlling grass competition. On areas which had been fenced against grazing as long as 20 years, practically no survival was obtained without "scalping" the soil around each planted tree. Of more importance has been the effect of browsing by deer, which even on areas fenced against livestock have virtually destroyed most of the experimental plantations of the past decade.

Experiments at Fort Valley have merely served to emphasize a few principles and to demonstrate their application. Matters of first importance are the site, season, character of planting stock or seed, the planting or seeding operation, spacing, and subsequent protection. In the following discussion, the term "seeding" refers to the planting of ponderosa pine seed in small prepared "seed spots." Broadcast seeding in the Southwest has not given any promise of success.

FIGURE 44.—Experimental plantations near Flagstaff, Arizona. *A*, A 30-year-old plantation, trees 12 to 15 feet tall; inhibited by tip moths, porcupines, and gophers. *B*, A 20-year-old plantation on land formerly in cultivation; trees 4 to 6 inches d. b. h. and 15 to 20 feet tall.

Selection of Sites

The best criterion for judging planting sites is material evidence in the form of stumps, logs, or living trees that the site has produced ponderosa pine timber in the past. Such evidence provides fair assurance that trees will grow if successfully planted and protected; additional details, however, furnish valuable suggestions as to the problems to be encountered in establishing a plantation. Survival is better and planting easier in sandy or gravelly soils than in heavy soils. Stony soils also give good survival but digging is difficult, and therefore it may be advisable to employ seeding rather than planting on such sites. A dense stand of herbaceous vegetation, especially grass, is to be avoided; closely utilized areas are generally favorable as far as seedbed conditions are concerned. The foregoing generalizations are supported by much experimental work in both artificial and natural reforestation *(52, 54, 68)*.

Permeable Soils Most Favorable

Soil differences as affecting seedling survival are related primarily to moisture *(57)*. Heavy soils have a higher water-holding capacity than the sandy soils, but when drought sets in the heavy soils withhold a high proportion of the moisture from the plant roots. Summer showers penetrate the lighter soils most readily, and since pine trees are deep-rooted, this difference in penetration may prove to be a vital factor if rains are deficient. Stones tend to aid penetration and since their absorptive capacity is low, the water which falls on them is concentrated in the soil proper.

Experimental plantations have demonstrated repeatedly that survival is best on the stony, sandy, or gravelly sites; and the same relation is true of natural regeneration. It has proved difficult to get a satisfactory stand in the swales or flats of relatively fine alluvial soils, whereas sites so stony that holes could be dug only with great difficulty have given good survival provided the physical obstacles to good planting could be overcome.

Ponderosa pine tolerates a fairly wide range in soil acidity (pH 4.5 to 7.0). The open swales and parks are suggestive of alkali accumulations, but soil analyses do not confirm their presence.

Ponderosa pine is not exacting as to soil fertility, but it does require soil that is permeable and well drained. It is a common observation that pine seedlings thrive in roadside excavations where the subsoil has been exposed. Abandoned railroad grades and highways built up with loose, stony, or gravelly soil are ideal for pine regeneration. On permeable soils denuded by fire, overgrazing, erosion, or mechanical means, ponderosa pine is often the first invader if seed trees are present. Ponderosa pine is said to thrive on soil too poor for herbaceous vegetation; this is literally true, but probably not so much because the pine prefers sterile soil as because of low competition on such soils. Notwithstanding this tolerance of infertile soils, the heaviest stands of old pine are found on sites which have good soil depth and water-holding capacity. What is true of natural regeneration applies also to artificial reforestation.

Competing Vegetation

The influence of herbaceous vegetation likewise is primarily a water relation, although light may also be a factor. Grasses have a shallow but very intensive root system which, during critical drought periods, is able to appropriate nearly all of the moisture in the upper 9 inches of soil. Until young trees have developed a strong root system below this depth they are at the mercy of the grasses. The bunchgrass Arizona fescue *(Festuca arizonica)* is particularly aggressive as a water depleter because it is active throughout the growing season from May until October. Some grasses, notably blue grama and mountain muhly, are less objectionable because they are practically dormant through the dry season preceding the summer rains.

Tall, dense herbage of any kind may create enough shade to injure small pine seedlings. A series of experimental plots carried from 1928 through 1944 (table 27, fig. 36) has shown that survival of ponderosa pine seedlings in undisturbed grass was practically nil as compared with somewhat better survival where the grass was clipped twice annually, and high survival where the grass was eradicated and kept out *(71)*.

Seasons for Planting

Tree planting should obviously take advantage of the good moisture conditions of early spring. Although bud growth does not become active until June, root growth begins earlier, usually about May 1 or when soil temperature in the afternoon reaches 42° F. The roots should be in the ground ready for action as soon as favorable temperatures arrive and before the soil begins to form a dry upper crust. The average spring planting season is April 15 to May 15. It may begin earlier but should rarely extend later. The summer rainy season is not suitable for planting because the volume of precipitation is too uncertain and because the trees at that time are in an active state. October and November is a good time for planting if the soil is moist. If, however, the rains have not penetrated to a depth of at least 1 foot, planting is risky because dry weather may continue through November and December.

Seasons for Seeding

Germination of pine seed calls for continuous surface moisture along with relatively high temperature during a period of about 3 weeks. July, August, and early September is, with rare exceptions, the only time of the year when this combination of moisture and temperature is realized. Seeds sown in the spring remain dormant, at first because the soil is too cold, and later because it is too dry. Since July and August are always warm enough, the only question concerns moisture. On the average, 2 years out of 3 have rains adequate for germination and early survival if the seedbed has been well prepared. Germination may take place as late as September 15, but seedlings which appear after August 15 are likely to succumb to fall drought or frost heaving. July germination is much to be desired because it allows time for deep root penetration and enables the stems to become lignified before winter sets in.

Seed spots, if screened against rodents, may be put in at any time between October 1 and the following July except when the soil is frozen or covered with snow. The usual time is during 2 or 3 weeks preceding July 10, but if a large acreage is to be covered advantage should be taken of the much longer period indicated.

Planting Stock

Experience in the Southwest and in other regions of deficient moisture has shown that transplanted stock gives the best field survival. Transplants designated as 2-1 [7] are usually the most desirable type. The stem is 3 to 4 inches tall and the root 8 to 10 inches long with many branches and subdivisions or feeders (fig. 45). Plants grown only one season in the seedbed are usually too small after a year in the transplant bed, but if left a second year in the transplant bed the tops become too large. Since successful field planting depends on maintaining a favorable balance between

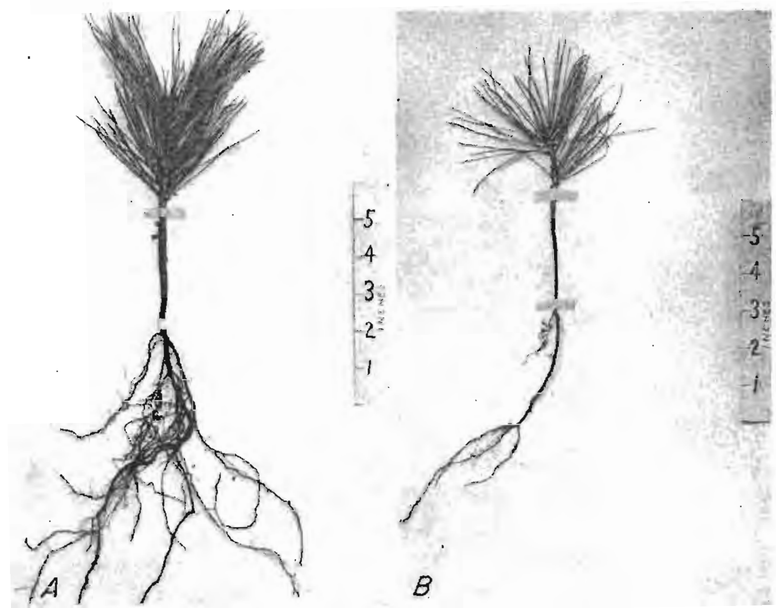

FIGURE 45.—Classes of (2-1) planting stock. *A*, First-grade transplant. *B*, Second-grade transplant which should be culled. Both tops and roots are smaller in the second grade, but note especially the deficiency of fine root laterals.

[7] Two seasons in the seedbed and one in the transplant bed.

water intake by the roots and outgo through the leaves, the leaf surface must be kept within prescribed bounds determined by experience. Theoretically, a smaller stem and a larger root than indicated by the dimensions given for 2-1 stock might be expected to give higher survival. Twice-transplanted stock has shown better survival, but cost limitations discourage this practice except for the most adverse sites.

Source and Character of Seed

The seed supply, whether for nursery or field seeding, should preferably be from local sources. Experience at Fort Valley has shown that seed from California and the Northwest germinates slowly and produces seedlings which, though large, succumb to the winter and spring conditions of the Southwest. Most of the seedlings die in the nursery. Of those which survived long enough to be field planted, all eventually died. Stock grown from Black Hills and Colorado seed proved to be as hardy as stock from local seed; but after several years in the field, the trees were subnormal in size and form. In a Fort Valley plantation 30 years old, the Black Hills and Colorado trees could be recognized at a distance by their smaller size, a distinctive color of foliage, and a marked tendency toward abnormal stem form.

If seed must be imported, it is a wise precaution to select a region whose climate is similar to that of the site to be reforested. However, plant introduction is always attended by more or less uncertainty which can be removed only after many years of trial.

Graded Seed

Experiments at Fort Valley in which pine seeds have been graded as to size have shown marked superiority of large over small seeds with respect to rapidity of germination and initial size of seedlings. It follows that in a season of deficient rainfall large seeds may germinate while small ones await a more favorable period. The large seeds may, on the other hand, germinate during a temporary moist period and die during a subsequent drought. Chance plays a role which cannot be predicted, and therefore it appears safer in the long run to adopt Nature's course in which seeds of different sizes are mixed, thus dividing the chances on the theory that through the vicissitudes of weather some one lot of seeds may find conditions favorable for germination and survival.

According to investigations by Righter *(80)* size or weight of seed is no criterion of inherent vigor of a permanent character. The explanation is that inherent characteristics are transmitted through the embryo which comprises only about 6 percent of the total weight of the seed. The seed coat and the endosperm, by contrast, constitute 44 and 50 percent respectively of the total weight. Thus the variation in weight of different seeds is due almost entirely to variation in these two elements which are regarded as a product of environment rather than hereditary characteristics.

The Planting or Seeding Operation

The technique of planting trees or of establishing seed spots in the Southwest has been described in a previous publication *(68)*, and since the details are largely matters of common knowledge, only the guiding principles will be discussed here. It should be emphasized, however, that although the procedure is simple, meticulous execution is essential to success. The major steps involved are: (1) Location of the tree or seed spot; (2) preparation of the planting hole or seed spot; (3) planting the tree or the seeds.

Locating or selecting the exact place for each tree or seed spot is important. Obviously it is unnecessary to plant near growing trees; their zone of influence ranges from about 10 feet for saplings to as much as 50 feet for groups of large trees.

Competition from grass can be partially evaded by taking advantage of breaks in the cover and enlarging them, if necessary, enough to give the planted tree a clear space at least 4 feet in diameter. Bunches of Arizona fescue extend their roots fully 2 feet. On cut-over areas large spots clear of vegetation may be found near stumps or logs and in slash where merely the removal of litter provides an excellent planting spot. Log landings, truck roads, gullies, and burned brush piles also provide sites relatively free from root competition (fig. 46).

Power equipment has not been employed in reforestation in the Southwest, but it warrants a trial. On sites occupied by brush or dense grass, competing vegetation could be removed by clearing strips with a plow or bulldozer. A disadvantage of such equipment is that natural seedlings on the strip would be destroyed. Care must also be exercised to follow contours in order to avoid starting gullies.

Planting a Tree

The planting hole must be deep enough and wide enough to accommodate the roots in a natural position, spread out in such manner as to bring them in contact with a maximum volume of soil. Where rocks or other obstructions interfere with the digging of such holes, seed spots may be the answer.

In setting a tree one fundamental principle governs: the roots must be placed in the soil in a natural position and covered with fresh soil without permitting undue exposure to sun and wind. Any method which accomplishes this meets the essential requirements. Placing the roots against one wall of the hole is objectionable because they tend to grow away from the wall, forming a one-sided root system. Any "middle-of-hole" method is preferable.

Planting Seed Spots

Preparation of seed spots aims to provide loose soil for covering the seeds and for free development of roots immediately following germination. Deep cultivation is not necessary, but it is desirable to loosen the soil to a depth of 4 to 5 inches and to pulverize the upper 2 inches. Small stones need not be removed. The seed spot is for practical purposes a miniature nursery bed.

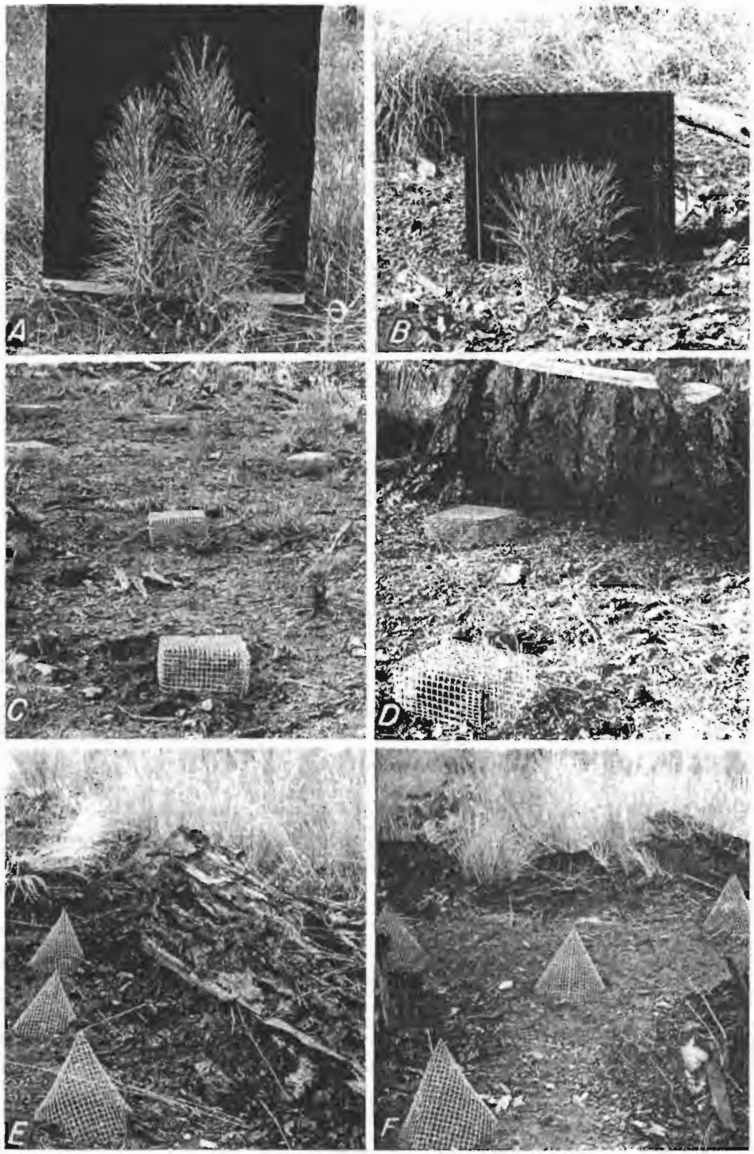

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FIGURE 46.—Reforestation by seed spots. *A*, Successful seed spot 5 years old; seedlings 10 to 14 inches tall; grass was removed in spot 3 feet in diameter. *B*, 4-year-old seed spot in a decayed brush pile, seedlings now 6 to 8 inches tall. *C* to *F*, Newly sown seed spots screened to exclude rodents; *C* on denuded log landing, *D* in deep litter around a stump 2 years after logging, *E* along a decayed log 60 years after cutting, *F* in a group of old stumps after fire.

Quantity of seed presents one of the main questions in seed spots. It would be desirable to sow only the quantity required to produce the required number of seedlings in each spot. Because germination and survival are affected by many unpredictable circumstances, however, a generous margin of safety is desirable. Experience has established the practice of sowing 10 to 15 seeds spaced as uniformly as practical over a spot 4 inches in diameter. If germination and survival are good, thinning may be necessary after 4 to 5 years.

Screening Seed Spots

Exclusion of rodents from seed spots is a precaution which experience has proved essential. Thus far, poisoning methods have not been perfected to a degree where complete reliance can be placed on poisoning. A screen placed over each spot excludes both rodents and birds. After many materials were tested, screens made by hand from hardware cloth of ¼- to ½-inch mesh proved most satisfactory. One serviceable type is a conical screen 7 inches in diameter at the base and 6 inches tall. These can be nested for storage or transportation. At Fort Valley it proved necessary to keep the screens on the spots at least 2 years to minimize rodent damage to seeds and small seedlings.

Spacing

A decision as to the correct distance between trees or seed spots, or the number per acre, is necessarily a compromise between silviculture and economics. Dense stocking is desirable in order to encourage saw-timber form; but to be effective the number must be at least 3,000 per acre. The present cost of planting 3,000 trees would probably be $100 per acre. One thousand per acre, costing about $40, is the minimum number that might be expected to produce a reasonably satisfactory stand.

By reducing the number to 250, the cost per acre could be lowered to about $15. In 30 years the number of survivals would decline to about 100 and they would assume the characteristic branchy form, with short, tapering boles. By timely pruning, however, about 50 per acre could be made to produce one or more good sawlogs. The crop would not repay the cost of growing it, but planting would accomplish the main purpose—that of restoring a forest by providing seed trees for natural reproduction.

Relative Advantages of Planting and Seed Spots

In comparing the two methods, one should consider, first, relative effectiveness and, second, relative costs.

Planting has one outstanding advantage: the young trees are carried through the critical infantile stage in the nursery where they can be watered and given such other care as may be needed to insure survival. Against this stand several disadvantages: (1) The expense of a nursery; (2) the cost of planting; and (3) the short planting season.

Maintaining and operating a large nursery involves a large outlay for personnel and equipment, an enterprise of no small magnitude. Another element of cost is the inflexibility of a nursery operation. The stock that is planted in a given season must be started in the nursery 3 years earlier.

The manpower required in planting is higher than that of seeding in spots. On stony soils this item may be so great as to be a deciding factor in favor of seed spots. Directly related to this problem is the length of the period during which operations are possible. The average planting season is about 1 month in the spring and possibly another month in the fall. Seed spots, on the other hand, can be put in during 5 to 6 months of each year.

These two items involving labor and time combine to facilitate covering much larger areas by seed spotting than would be possible by planting. In point of total cash outlay, however, economy in labor is more than offset by the cost of protective screens which, until rodents can be controlled in other ways, are indispensable.

In an extensive reforestation program both planting and seeding have their place. On the whole, planting is preferable for the sites and during the seasons for which it is adapted. Direct seeding by seed spots is to be regarded as a supplementary method to be used on stony sites and during periods outside of the planting season.

Protection and Care of Plantations

Successful planting or seeding is only the first stage of effective reforestation. Mortality due to drought and biotic agents may be expected to take a toll of 30 to 40 percent during the first decade. Control of herbaceous vegetation by weeding the cleared space around each tree will reduce the drought loss and also increase the growth rate, at the same time lowering the danger from fire. Uncontrollable biotic agents are tip moths, which curtail height growth, and grubs which kill the young trees by cutting the roots. Controllable biotic agents are: Gophers, porcupines, rabbits, small rodents, cattle, sheep, and deer. The high investment in a plantation demands more than the usual precaution against damaging agents; it also warrants cultural measures such as stand improvement in order to make the most of trees which finally emerge from the elimination process. Possible control measures are discussed in a later section.

The Place of Artificial Reforestation

Both the possibilities and the handicaps of artificial reforestation have been pointed out. On the whole, the outlook is not encouraging. Nevertheless, artificial reforestation cannot be entirely dismissed, because there are in the Southwest 424 thousand acres of commercial forest land now classed as poorly stocked or denuded *(91)*. High planting costs and slow growth practically eliminate artificial reforestation as a direct means of economic timber production. But from a public viewpoint a financial loss in the first rotation may be justified if it is possible through planting to restore a forest which will henceforth perpetuate itself naturally. Planting, then, assumes the character of permanent land development.

Control of Damaging Agents

A wide disparity exists between possible timber yields and those actually realized over extensive areas. Records on small, fully stocked plots indicate that average sites in the Southwest are capable of producing ponderosa pine at the rate of 200 board feet per acre annually. Actual yields on cut-over areas average less than 60 board feet. Some of the reasons for this discrepancy, such as poor stocking and high mortality, are fairly obvious. Others are less clear. In the latter class are many different agents which prevent or retard reproduction and others which inhibit growth or cause abnormal form. Some are directly controllable, others are subject only to indirect control.

Following is a list of agents which must be under at least partial control in a well-managed forest: (1) wind, (2) lightning, (3) snow damage, (4) fire, (5) rodents, (6) insects, (7) browsing animals, (8) plant parasites, (9) fungus diseases, and (10) destructive competition. All of these have been discussed and evaluated in their relationship to increment and reproduction. Control measures have been reserved largely for the present section.

WIND

Mortality records on cut-over areas over a period of 30 years credit wind with from 30 to 40 percent of the total volume lost. On five areas of over 100 acres each (table 17) the average annual loss due to windfall ranged from 0.08 to 0.32 percent of the residual volume. Since the loss among trees over 30 inches d. b. h. is about seven times as great as among trees between 12 and 20 inches, an effective measure is to avoid leaving large trees, particularly in the mature class over about 28 inches d. b. h.

If, as is usually the case in unmanaged forests, there is a deficiency of young age classes, the foregoing measure is not easily carried out because removal of all large trees may leave considerable portions of the area greatly understocked. Nevertheless, gradual conversion of old forests into stands of young and relatively small stems should be a long-range objective wherever windfall is an important factor. Such a program would be all the more effective because the rule of mortality rising with diameter applies also to lightning and bark beetles. A graph of the relation between growth and mortality from all causes by diameter classes has been presented in figure 23, page 83.

Selection of tree types which are relatively wind-firm has received much attention in timber marking in the Southwest. In general, trees which have grown more or less in the open have been found to be more wind resistant than trees which have grown in dense stands. The tall, clean-boled trees which are highly esteemed for lumber values are, when isolated by cutting, more susceptible to windthrow than the limby, open-grown type. The reason is that the former, having grown under competition, have a more restricted root system than the latter.

As pointed out earlier, cutting practice that aims to open up dense, immature groups as soon as natural pruning is well advanced accomplishes two things: (1) It stimulates diameter growth; and (2) it renders the remaining trees more wind-firm by providing space for root development. Where, as in most virgin stands, opening of groups has been too long deferred, partial cutting is attended by more or less risk of windthrow. Even the intermediate age class in dense groups is subject to windthrow when the groups are opened up enough to stimulate diameter growth. The danger, however, is not usually so great as to warrant clear-cutting mature groups as was often done in the old group selection practice. The ultimate answer to wind is a forest organization which provides for salvage.

LIGHTNING

Lightning mortality in the Fort Valley Experimental Forest has been practically on a par with windfall and, as in wind, the percent of volume loss increases rapidly with diameter (table 17). Unlike windfall, however, lightning is not always fatal. On two areas, one virgin and the other cut-over, only one-third of the lightning-struck trees died during a period of 15 years *(92)*. Trees which are struck but not killed suffer more or less retardation of growth and deterioration, reflected in cull and degrade, and therefore the total loss due to lightning considerably exceeds the loss due to wind. Since the majority of the trees which survive are among the younger age classes, the reasons for marking large and old trees are even greater than in the case of windfall. Thirty-year records of blackjack groups show that although some trees are struck, the death of a blackjack from lightning stroke is rare. A 20-year cutting cycle would permit salvaging practically all lightning-struck blackjacks, and if the forest were managed so as to harvest all trees before they pass the age of 175 years, lightning mortality would be negligible.

Since cutting in virgin stands as found today must necessarily leave many relatively large, mature trees in order to maintain a growing stock and provide seed trees, areas of high lightning incidence must anticipate much lightning mortality even on a short cutting cycle. The loss will be all the more serious because the tallest and most valuable trees are the ones most likely to succumb before the end of the cutting cycle. As in the case of windfall, the immediate answer to this problem is salvage. Looking ahead 50 years, however, it should be possible to harvest practically all lightning-struck trees in the regular process of commercial logging.

A peculiar form of top injury, until recently thought to be the effect of insects, has been classified by James L. Mielke of the Bureau of Plant Industry, Soils, and Agricultural Engineering, as possible lightning damage. Usually the tip turns brown and over a period of 2 or 3 years the upper part of the crown dies back to a distance of from 3 to about 10 feet; then the dying may cease and the remaining portion of the crown appears normal. In no case does observation reveal the characteristic lightning streak which generally follows the bole to the ground. Baxter *(6)* and Boyce *(9)* cite similar examples of injury in other parts of the country. It should be noted here, without attempting positive identification, that this form of injury—dying at the tip of the crown—is common in the Coconino and Kaibab National Forests.

SNOW DAMAGE

Damage by snow includes breakage and bending. No figures on the extent of these types of injury are available, but they are known to be common. The effect on yield is all the more serious because slender poles, which are potentially the most valuable trees, are more subject to snow damage than are the limby, tapering type. A partial remedy is to avoid undue exposure of the most susceptible stems; thus in timber marking it is often advisable to compromise with partial, as distinguished from complete liberation of subordinate stems where the latter treatment would subject them unduly to snow damage. In stand improvement, as will be shown later, protection from snow damage is an important point in favor of poisoning rather than felling limby trees surrounded by slender poles.

FIRE

Although ponderosa pine forests are seldom destroyed by fire alone, losses from fire through death of occasional merchantable trees and the creation of bole scars on others result in considerable aggregate loss. Greater ultimate losses come about through the destruction of poles, saplings, and seedlings. The technique and facilities for fire detection and suppression have advanced greatly during the past two decades; but fires of 100 acres or more are still too numerous.

Control of Fires by Reduction of Fuel

The technique of detection and suppression of forest fire is a special field which will not be treated here. Instead, the discussion which follows will consider ways in which forest management can aid fire control by disposition of or curtailing production of inflammable material. It should be understood at the outset that the purpose is not to eliminate fuels to the extent of rendering the forest "fireproof." Such treatment would defeat its ultimate purpose by impairment of the resource which it would protect. The purpose is rather to ameliorate the extreme conditions which make prompt suppression difficult or impossible with the facilities at hand in a normally effective fire organization such as every national forest now maintains.

The main types of fuel are: Logging slash, litter of needles and twigs, undergrowth of young trees or shrubs, and grass or other herbaceous vegetation.

Logging Slash

Disposal of slash, or the debris resulting from logging operations, has been made a subject of study for many years throughout the ponderosa pine type *(49, 76, 77)*. The treatment recommended varies by localities and sites from complete elimination of limbs and needles by piling and burning to no disposal whatever except on firebreaks. The criterion everywhere for judging the need and intensity of slash disposal is the relative danger that fires may get out of control and sweep large areas. Fires that cover only small areas, ranging from a few hundred square feet to a few acres, are accepted as more or less inevitable; it is those which burn from 10 to 1,000 acres or more that are the cause of concern. The problem is to prevent small fires from growing into large ones.

Cost is a necessary consideration in slash disposal. Unless important indirect values such as water resources and recreation are involved, it is not good business to spend more in protecting a timber tract than the present and future loss of timber in case of fire would amount to. Because of the many factors involved, however, it is difficult to draw a fine line of distinction between economic and uneconomic fire protection. If the cut is as much as 10,000 board feet per acre and the cost of piling and burning averages 75 cents per thousand cut (a prewar figure), the expense for a large area runs into high figures.

In the Southwest the cut on national-forest lands is generally less than 10,000 board feet per acre. On some areas all the debris below 4 inches in diameter has been piled and burned; on others partial burning has been used. Partial burning may consist of clearing firebreaks at specified intervals, or piling and burning in spots located in such manner as to break up large slash concentrations. Another variation, known as "lopping and scattering" has been used where soil cover is deficient; it presents a lower fire hazard than undisposed slash, but a higher one than complete piling and burning. This method is often combined with piling and burning, alternating between the two according to local requirements. Figure 47 illustrates brush piles before and after burning, and also disposal by lopping and scattering.

An important consequence of leaving large volumes of undisposed slash is that it continues to be a menace that will hamper future management. In the Southwest, 30-year-old slash can still contribute much to the volume of fuel and add to the difficulty of handling slash from a new cutting. Such a condition is especially undesirable after the area has restocked.

A difficulty commonly encountered is that the volume of old down timber, defective logs, and large limbs is so great that even after the usual piling and burning sufficient fuel remains to constitute a severe handicap in fire suppression. Under such conditions, if forest values are high and fire danger great, thought should be given to the removal of all debris from strategically located fire lanes.

A recently developed technique in which bulldozers are employed to assemble down trees, cull logs, and ordinary slash into

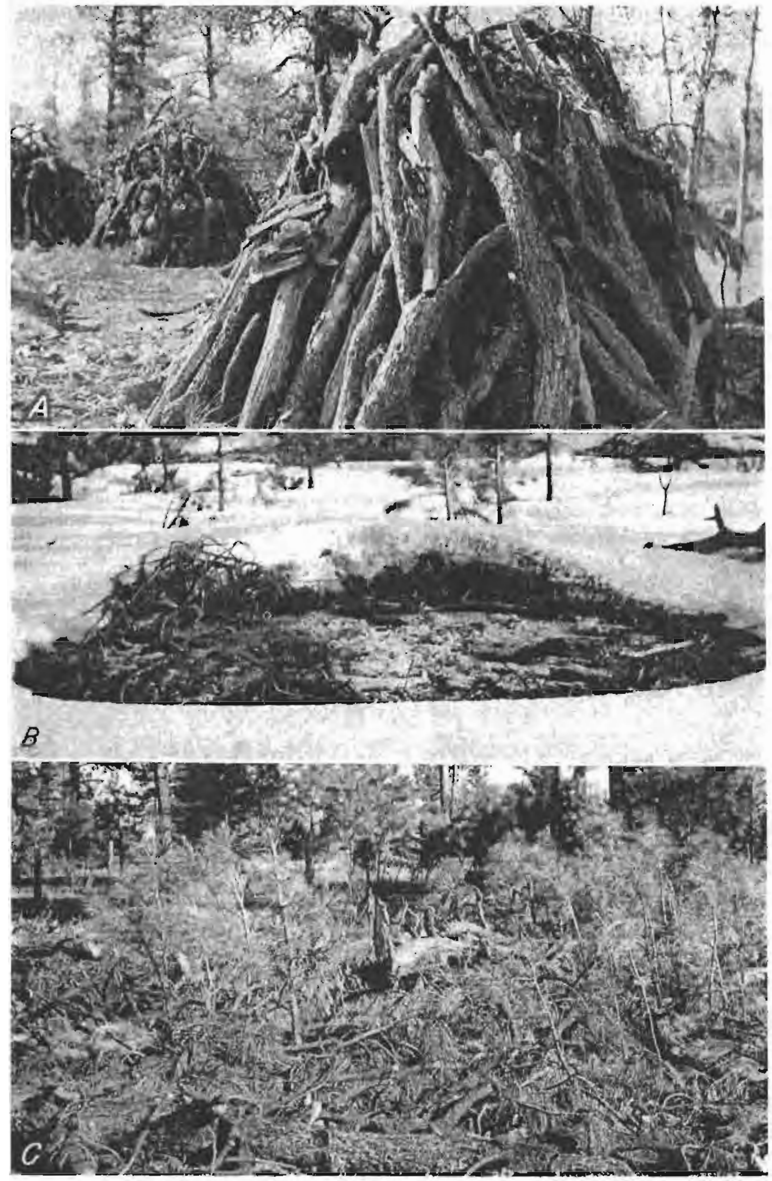

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FIGURE 47.—Slash disposal. *A*, Limbs piled for burning; *B*, Piles burned in snow result in little damage; *C*, Limbs lopped and scattered among saplings.

large piles along roads, appears to be a step in the right direction. Colvill *(16)* and Weaver *(94)* have described this technique. Weaver *(95, 96)* has also reported an experiment in prescribed broadcast burning in the Colville Indian Reservation, with the double purpose of consuming down timber and thinning overdense sapling and pole stands.

During 35 years of timber-sale administration, thought and practice in the Southwest have swung between wide extremes, finally reaching the conclusion that intensity of disposal and subsequent protection should be varied in accordance with the needs of each individual site. There is general agreement among timber-sale men and fire fighters that at least partial disposal by burning is desirable almost everywhere. In recent years extensive inroads of sapling and pole thickets upon open spaces have placed added emphasis on piling and burning.

Silviculture Can Reduce the Volume of Slash.—McIntyre *(76)* has shown that the lowest volume of slash per thousand board feet of merchantable sawlogs occurs in stands of the largest volume per acre. The reason is that trees in heavy stands have relatively short and narrow crowns. Continued management may be expected to reduce the volume of slash if attention is directed toward training a superior type of tree. Young stands should be dense enough so that the crown will be reduced to between 30 and 40 percent of the tree height in the advanced pole stage.

Defect obviously increases the proportion of slash by adding cull logs and by lowering the net volume of merchantable wood produced by a given crown. Stand improvement which eliminates stems of inferior form and removes surplus limbs while below 1½ inches in diameter can be expected to decrease infection by western red rot and the quantity of cull material left following harvest cuttings. Short cutting cycles will permit salvaging many trees which would otherwise become culls to be left as fuel. The lighter the cut at any one time the less will be the fire danger and the simpler the task of slash disposal.

Litter and Undergrowth

The accumulation of litter or duff from needles and dry twigs that fall from trees, poles, and saplings provides enough fuel to support ground fires. Flash fires do not usually result from this class of fuel, but fires run freely when the litter is dry on the surface, even though it may be moist underneath. In high winds dead twigs on standing poles and saplings may be ignited, thus giving rise to crown fires. One complication introduced by litter is the retention of fire underneath the surface after extinction is apparently complete. Notwithstanding increased fire danger, a mat of needles is indispensable because it checks runoff, promotes water infiltration, retards evaporation, and adds organic matter to the soil.

Protection of young stands must rely chiefly on efficient detection and suppression. Management can, however, contribute by measures which tend to ameliorate the most dangerous conditions.

Crown fires are less to be feared under a practice which by timely stand improvement prunes off the lower branches on the best boles and eliminates extremely limby individuals. Windfalls, tops left by logging, and twig cutting by squirrels build up deep accumulations of litter, thereby increasing the likelihood of damage to the boles by ground fires.

In the Southwest, the excellent reproduction of 1919 has greatly changed the fire situation by filling in former stand openings with sapling thickets. Not only has the difficulty of fire suppression increased, but the greater values at stake call for a lowering of the acreage covered by ground fires as well as the more destructive crown fires. The whole future of southwestern timber production hinges on these small saplings and poles which are highly susceptible to fire-kill.

Grass

Under normal conditions perennial bunchgrasses are the prevailing ground cover in the ponderosa pine forests of the Southwest. The summer rains favor grass and other shallow-rooted vegetation over the deep-rooted shrubs. Herbaceous vegetation, like needle litter, performs a useful function in providing soil cover. Of the two, herbaceous vegetation is less effective from the standpoint of timber production because it seldom forms a continuous mat, and because it competes with young trees for soil moisture. When dry, also, herbaceous vegetation is more inflammable because it is better aerated. Unused dry grass generates intense heat of short duration and is dangerous mainly because it ignites quickly and carries fire rapidly to more bulky types of fuel such as needle litter and logging slash.

In the light cuttings now common on the national forests, the cover of highly inflammable slash remaining after the usual forms of disposal is seldom continuous enough to carry fire rapidly over large areas unless fanned by high winds or supplemented by other inflammable material linking slash-covered areas together. Unutilized dry grass provides a connecting medium even with low wind movement.

Grazing Can Aid in Control of Fires.—Grass as well as slash may vary greatly in density and volume. The tall bunchgrasses in the Southwest are particularly hazardous when not utilized or only lightly grazed. Overgrazing is not necessary nor desirable. Bunchgrasses grazed to a height of 6 inches by the end of the season, usually November 1, will maintain an adequate soil cover on level to moderate slopes without contributing unduly to the fire hazard *(82)*. Figure 48, *A* shows a stand of young pine killed by fire on an area where unburned slash and lightly used bunchgrass created conditions making fire suppression difficult. *B* of the same figure illustrates how grass can add to the fuel of unburned slash, and *C* how the grass can be reduced by grazing. Grass can be properly grazed by cattle without undue pine browsing, if the operation is correctly timed. More complete discussion of the proper season of use is presented in a later section headed "Browsing Animals."

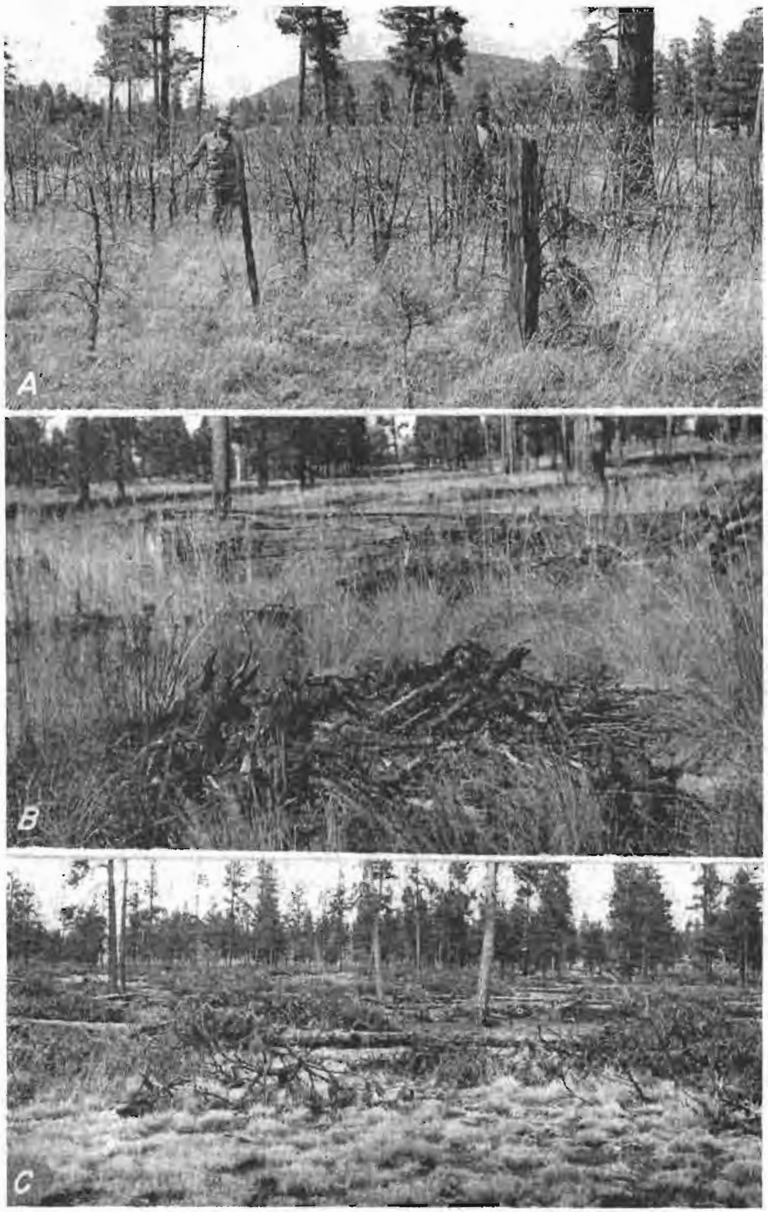

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FIGURE 48.—Fire hazard in grass and slash. *A*, Pine saplings killed by a fire in tall grass and old logging slash; *B*, Grass and logging slash on a lightly grazed area; *C*, Grass volume greatly reduced by grazing.

Effective control of fire calls for coordination of prevention and suppression. Since the ideal of complete prevention is unattainable, a good supplementary measure is to facilitate suppression by restricting the concentration of highly inflammable fuels. Several hundred thousand dollars are spent annually in reducing the volume of slash on recent cut-overs. But where grass is abundant, slash disposal, however intensive, cannot yield full returns unless supplemented by proper management and use of the forage.

RODENTS [8]

Small Rodents

Rodent damage affects ponderosa pine trees from seed to maturity. Mice, chipmunks, mantled ground squirrels, and Abert squirrels are seed eaters. Light or moderate seed crops are largely consumed by these rodents and it is only in exceptionally good seed years that the remaining seed is likely to be at all adequate for regeneration.

Mice and rats are known to gnaw the bark of seedlings or to cut them off completely. In dense stands this may not be serious and may perform a useful service by eliminating surplus stems, but where the stand is already deficient every killed or deformed seedling represents a loss. Winter damage is especially prevalent in dense grass where runways point to mice as the offenders. In plantations a loss of 10 to 20 percent from rodents may be expected after the initial planting loss is past. Seed spots are especially vulnerable. Screens afford protection through germination and early development, but after 2 or 3 years the screens must be removed to permit height growth. It is a common experience in experimental seeding that within 2 weeks after the screens are removed nearly all seedlings are cut down at the ground line.

Although large-scale demonstrations are lacking in the Southwest, experimental work indicates that it is possible to control the small-rodent population by poisoning. In order to be effective, poisoning programs must be on a large scale, covering large, continuous areas simultaneously, and repeated over a period of several years.

Pocket gophers are responsible for much damage by cutting or barking the roots of seedlings encountered in their burrows. They are especially destructive in plantations. Trapping or poisoning is an effective means of control. Of the two, trapping is by far the more expensive method.

Abert Squirrel

Observations at the Fort Valley Experimental Forest indicate that the Abert squirrel can become one of the most destructive of all animals in the pine forests of the Southwest. During the winter months the squirrel cuts twigs and eats the inner bark.

[8] Acknowledgment is made to C. M. Aldous, Regional Biologist, Fish and Wildlife Service, U. S. Department of the Interior, Albuquerque, N. Mex., for review of the material on rodent and wildlife relationships.

Beginning about July 1 and continuing into October he cuts cones (if any are to be had), gnaws through the green scales, and eats the seeds. No cones or seeds are stored by this squirrel.

Twig cutting is on the whole the most injurious of the Abert squirrel's depredations. Shoots of the past year's growth are cut off; a section 2 or 3 inches long is peeled and the remaining portion of the shoot is dropped on the ground. Removal of twigs from the lower branches would not be serious; but the squirrel prefers active shoots from the upper portion of the crown, especially the terminal and the upper laterals. Besides loss of foliage, removal of these stems automatically destroys most of the first-year cones. It is not unusual to find as many as 1,000 excised shoots underneath a single tree. Full-crowned trees may lose half their foliage in a single winter, and it is the most active foliage that is taken (fig. 49, *A*). Saplings, poles, blackjacks, and veterans fare alike. Saplings and poles suffer most because loss of terminals retards height growth and may deform the bole.

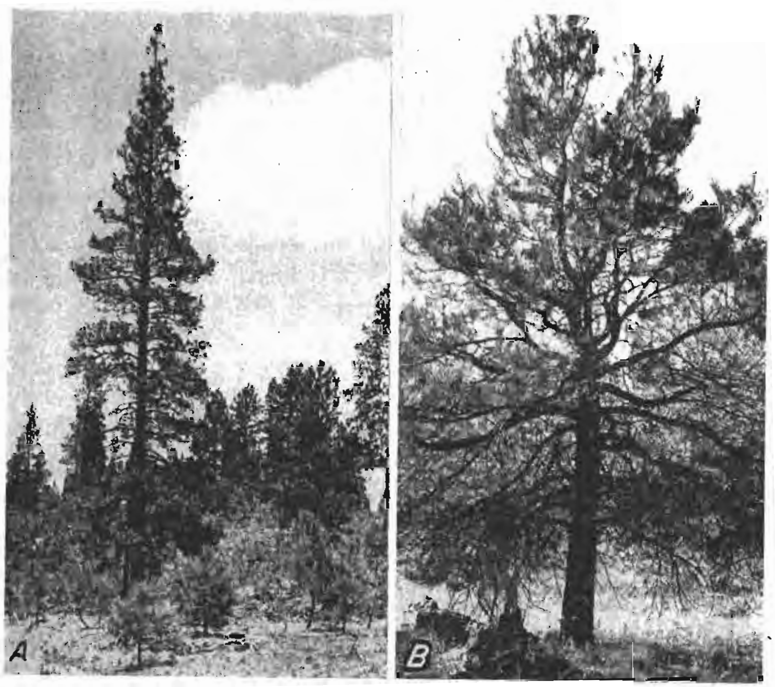

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FIGURE 49.—Trees injured by squirrels and porcupines. *A*, A 27-inch blackjack badly damaged by Abert squirrels; upper half of the crown has been trimmed until the outline resembles a spruce; *B*, A porcupine tree ruined for production of sawlogs.

Although squirrel activity has been noticeable during the past 30 years, it is only in the last decade that damage has attained such proportions as to be a cause of concern. Severe damage has been reported from several localities in Arizona and New Mexico. The Abert squirrel does not occur, however, in the isolated southern mountain ranges. A survey of two 12-acre plots in the Fort Valley Experimental Forest in 1940 showed that from 37 to 49 percent of the trees had been severely injured from twig cutting.

Periodic measurements of a number of trees are being made to determine how much diameter growth is affected by different degrees of injury. The tree shown in figure 49, *A* may be cited as an example. It grew 0.8 inch in diameter during the 5 years 1934 to 1939 when twig cutting was reported as moderate. During the winter of 1940-41 squirrels ravaged the upper half of the crown and it is interesting to note that diameter growth dropped to 0.4 inch for the 5-year period 1939-44, only half the previous rate. In a few instances trees have been killed by squirrels.

Trapping by the Arizona State Game Department temporarily reduced by about 50 percent the squirrel population on several small areas in the Fort Valley Experimental Forest. On three areas comprising 2½ sections, 626 squirrels were trapped from 1940 to 1944 and 59 additional were harvested during a special hunting season of 3 months in 1942. Thus, a total of 685 squirrels was removed from 1,600 acres. The number still remaining was too great for the good of the forest. A 6-month hunting season is the least that can be expected to reduce the number effectively.

Rabbits

Rabbits, where abundant, can be very destructive to young trees in all forest regions. In the Southwest, jack rabbits eat pine needles and buds in winter, and when the snow is deep they are able to reach several feet above the ground. Fortunately, they are not abundant in the pine and higher forest types of the Southwest, but their numbers have increased noticeably during the past 30 years.

Porcupines

Porcupines girdle the stems of seedlings and saplings near the ground. As the trees increase in size the porcupines transfer their activities to the upper portion of the bole *(83)*. Young trees from 4 to 12 inches in diameter are often deformed in such degree as to render them worthless for lumber unless the peeling occurs above the first log length (fig. 49, *B*). Forking or the wolf-tree form is a common result of porcupine activity. After a tree has attained full height porcupine injury becomes less serious, but it is still objectionable.

Effective control can be obtained by poisoning and shooting as complementary measures. The United States Fish and Wildlife Service *(23)* has developed an effective poison bait consisting of 1 part powdered strychnine sulfate to 16 parts of common salt with sufficient melted lard or bacon grease to form a paste. The bait is placed in a wooden receptacle made by boring a hole about 2 inches in diameter and 1 inch deep in the flat face of a wooden block 2″ x 2″ x 4″. The block is nailed on a large horizontal branch high enough above the ground to be out of reach of livestock and deer. In the Fort Valley Experimental Forest as many as three dead porcupines have been found under a single bait tree.

INSECTS [9]

Common insect enemies of living ponderosa pine are of four broad classes: Bark beetles, tip moths, cone borers, and root grubs. Their relative importance varies with both year and locality. Most conspicuous are the bark beetles which kill mature timber. Next in order is the tip moth which kills the leaders of seedlings and saplings. Cone borers and root grubs, though generally receiving little notice, have a far-reaching effect by retarding regeneration.

Bark Beetles

Ponderosa pine beetles have been most serious in the interior regions of California, Oregon, and Washington, where the western pine beetle (*Dendroctonus brevicomis* Lec.) is the common species. The Rocky Mountain region, the Black Hills of South Dakota, and the Kaibab forest of northern Arizona have been visited by epidemic attacks of the Black Hills beetle (*Dendroctonus ponderosae* Hopk.). The Black Hills beetle is not known to have assumed epidemic proportions on the Colorado Plateau south of the Grand Canyon.

Three other species of *Dendroctonus*, namely, *D. barberi* Hopk., *D. approximatus* Dietz, and *D. convexifrons* Hopk., are of widespread occurrence in the Southwest and occasionally become epidemic, although they are less destructive than the Black Hills beetle. They attack mainly old trees of slow growth in virgin stands, but blackjacks may be attacked especially right after a logging operation. The red turpentine beetle, *Dendroctonus valens* Lec., whose activity is rendered conspicuous by large reddish pitch tubes, may injure trees but seldom kills them outright unless they have been previously injured or weakened by other agencies such as lightning.

Several species of the genus *Ips*, mainly *I. confusus* Lec., work almost entirely on young trees from the sapling stage to the advanced pole stage. Occasionally they do serious damage to young growth following a logging operation. They breed profusely in cull logs, tops, and large limbs. If the logging is continuous they

[9] Acknowledgment is made to N. D. Wygant, Forest Entomologist, Bureau of Entomology and Plant Quarantine, Agricultural Research Administration, U. S. Department of Agriculture, Fort Collins, Colo., for review of the material on insects.

confine themselves to the fresh slash, but if the operation ceases they are likely to attack living trees. *Ips* is most active in the lower fringes of the type, where both ponderosa pine and pinyon are sometimes killed on a large scale.

Control of Bark Beetles

The control methods usually prescribed are to peel and burn the bark of infested trees or to spray the bark with a toxic oil mixture before the broods emerge. If many trees are affected this is a laborious and expensive process *(28)*. Large control projects should be undertaken only with the advice and under the direction of a professional entomologist.[10]

Prevention is the most effective cure. Craighead *(19)* and Keen *(31)* have pointed out that logging which removes the old and stagnant trees tends to prevent a build-up of *Dendroctonus* to the degree that fosters epidemics. In California, experimental control operations *(81)* have been based on the finding that susceptibility to bark beetle attack is directly related to the health of the tree (as indicated by length, color, and density of needles and dying twigs). This principle has been demonstrated on two 160-acre blocks in the Fort Valley Experimental Forest. During 15 years of record one of these blocks, in a virgin state, lost 16.5 board feet per acre annually through bark beetles; during the same years the annual loss on an adjoining area logged at the beginning of the period by a method which removed overmature and declining trees was only 1.3 board feet per acre.

If removal of unhealthy or slow-growing trees is helpful, treatment which prevents trees from falling into this condition should also be effective as a long-range measure. After the old and decadent members have been removed, the remaining young stand can be kept in vigorous condition by opening up groups sufficiently to relieve competition and stimulate growth, at the same time taking out individuals showing symptoms of decline. Repeated cutting at intervals of 10 to 20 years is usually necessary to ward off stagnation.

Cone Beetles

In the Southwest the larvae of *Conopthorus scopulorum* Hopk., hatched from eggs deposited within the young cone, feed on the immature seeds. As the cone approaches maturity, affected portions take on a dull brown color and the entire cone becomes dwarfed and distorted in form. In some years fully 50 percent of the seed crop is destroyed by this pest. Damage is especially serious in the lower portion of the pine type where almost complete destruction of the seed crop has been observed year after year on certain areas. No effective control measure is known.

[10] The Bureau of Entomology and Plant Quarantine, U. S. Department of Agriculture, will furnish such assistance.

Root Grubs

White grubs, not definitely identified but related to the June beetles, kill pine seedlings by eating the roots. In nursery stock and young planted trees, the entire root is devoured right up to the ground line. Natural reproduction suffers less than plantations, probably because the insect prefers to work in soil which has been loosened to considerable depth. Losses of 15 percent during a single season in experimental plantings are not uncommon.

Tip Moths

The tip moth *(Rhyacionia neomexicana* Dyar) does not occur throughout the ponderosa pine region, but is the most widespread and persistent insect pest in the Southwest. It attacks ponderosa pine from the seedling stage into the early pole stage but is most active in seedlings from 2 to 5 feet tall.

Adult moths deposit their eggs on the growing shoot in June; the larvae bore into the tender tissues, then eat their way up through the stem. Usually the leader and one or more of the subterminals are attacked. A less prevalent tip moth is *Recurvaria condignella* Busck which, instead of consuming the entire interior tissue of the stem, bores a fine tunnel through the pith. In either case, if a subterminal escapes it rises promptly to assume leadership and within 2 or 3 years the damage is repaired. Unfortunately, all the shoots of the upper whorl are likely to be attacked, in which case replacement of the leader must come from buds or from lower branches and recovery is thus delayed. If the same tree is severely attacked year after year, it assumes a bushy form, height growth is greatly retarded, branches grow overly large, and the effect over a period of years is expressed in poor saw-timber form. Trees are seldom killed by the tip moth except in the seedling stage.

Both immediate effects and method of recovery are much the same as in shoots injured by browsing animals (fig. 41); both forms of injury take place during the early part of the growing season when shoot elongation is most active. Tip moth injury is an important factor in the slow height growth, rapid taper, and coarse branching of ponderosa pine in the seedling and sapling stages.

Tip moth is generally less prevalent within timber stands than in the open, suggesting that the moth prefers warmth and sunlight to partial shade. Damage is also less severe in dense seedling groups than where widely spaced, a relation which has also been pointed out in Sweden where a related tip moth attacks Scotch pine. Natural remedies are thus to be found in the same silvicultural measures which are generally conducive to the development of straight stems and clear boles, namely, dense reproduction and side shade from older trees. The lower transition zone of the pine type suffers more than the middle or upper zones.

No direct control operations have been attempted in the Southwest. Experiments by Afanasiev and Fenton *(1)* in Oklahoma plantations of shortleaf pine, ponderosa pine, and several other species have given promising results in the control of tip moths *(Rhyacionia* spp.) closely related to the southwestern species, by spraying the growing shoots with a 1 percent water dispersible solution of DDT. Since the effectiveness of the spray depends on persistence of a DDT residue during the period of moth emergence, egg laying, and larva burrowing, the dry weather of the Southwest during this period (June) should prove favorable.

BROWSING ANIMALS

Browsing of ponderosa pine by domestic livestock was recognized as a serious problem in the Southwest at the turn of the present century. Lieberg *(41)* reported in 1904 the widespread destruction of small pine seedlings by sheep in the San Francisco Mountains Forest Reserve. Hill *(27)*, after studying the problem on the Coconino National Forest in 1912-14, reported that during this period one-third of the trees of the size subject to grazing had been browsed and one-sixth severely damaged each year. He further pointed out that the young seedlings were most susceptible to severe injury; that the greatest amount of damage occurred during the latter half of June and the first part of July, or when the effects of the spring dry period are most pronounced; and that under normal conditions of grazing, cattle and horses did an inconsiderable amount of damage while sheep, under the same conditions, may be responsible for severe injury to 11 percent of the total stand. Observations in both Arizona and New Mexico led Hill to the conclusion that the suitability of the forage to the class of livestock, the amount of palatable forage available during the grazing season, especially during June and July, and the manner in which livestock is handled, all have an important influence on the amount of damage to timber reproduction.

Following the notable reproduction year of 1919, sizable areas suffered a loss of 50 to 75 percent of the seedlings under 3 years old. Both before and after 1919, fenced areas closed to sheep presented a striking contrast to adjoining areas open to both sheep and cattle (fig. 50).

During the period 1926 to 1929, large reductions were made in the numbers of livestock on the national forests. In northern Arizona reductions of both cattle and sheep varied by allotments from 25 to as much as 100 percent. A program of fencing forest and allotment boundaries was also completed in 1928. This resulted in control and better distribution of livestock and made possible the segregation of cattle from sheep. The influence of these changes on the severity of browsing damage was pronounced. Records on a series of widely separated regeneration plots *(58)* showed that with some exceptions, the percent of seedlings browsed dropped from 80 in 1925 to about 5 in 1930. By 1932, recovery from old injuries was likewise pronounced.

The browsing problem was greatly alleviated by 1930, but was not altogether solved because concentration of livestock continued on a smaller scale, accompanied in many instances by severe

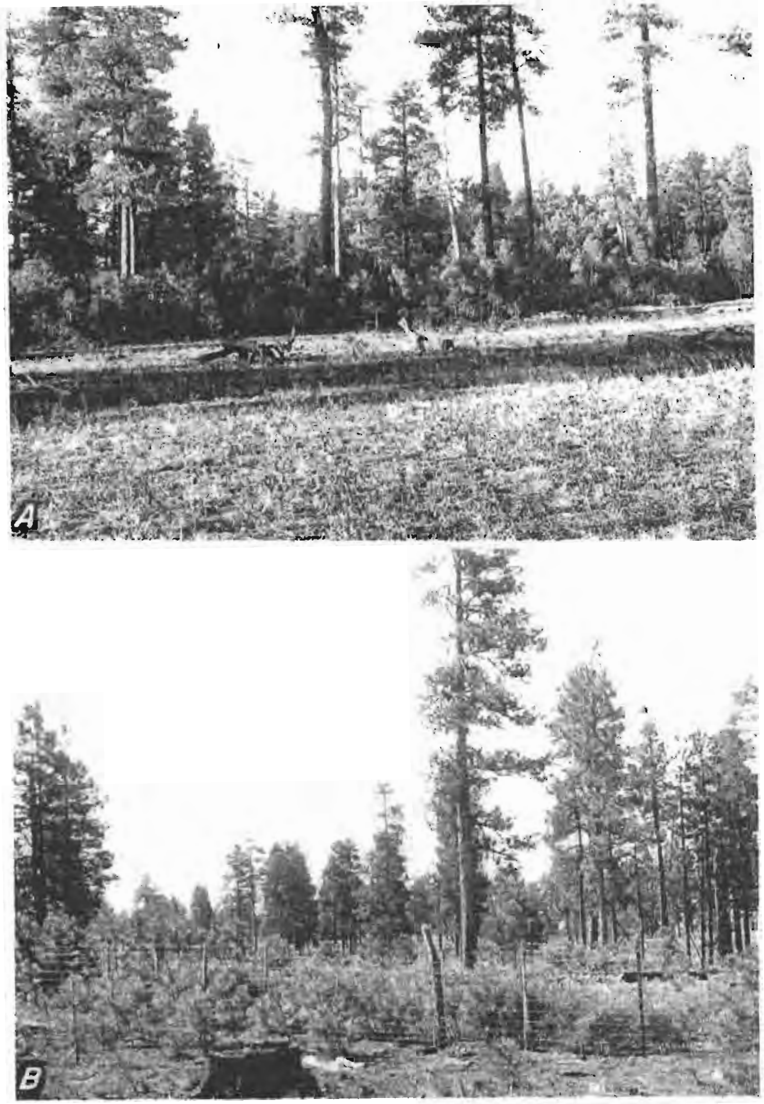

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FIGURE 50.—Pine reproduction virtually destroyed in the early seedling stage on range overgrazed by sheep. *A*, In the background a fine stand of 1914 saplings in a pasture grazed only by cattle and horses; in the foreground, the area was open to sheep as well; photographed in 1936. *B*, Similar conditions relating to 1919 reproduction; the area behind the fence closed to all livestock grazing; foreground open to sheep; photographed in 1932.

localized damage, often in areas where regeneration was scant. This has been true of both cattle and sheep allotments.

Cooperrider and Cassidy conducted an intensive study during the period 1927-36 to determine the relationship of cattle and sheep grazing to the establishment of pine reproduction in northern Arizona. Several phases of the study have been reported *(13, 14, 17, 18)* and the over-all findings are given in unpublished manuscripts.[11]

At the beginning of the cattle study, the number of livestock on the experimental allotment had been reduced to the estimated grazing capacity of the range and the grazing season shortened to 5 months. In 1928, water supplies on the range were supplemented by the addition of several small temporary stock-watering places. Under these conditions, browsing damage was found to be less severe than that reported earlier by Hill for pine-bunchgrass ranges open to both sheep and cattle. During the 9-year study, 23 percent of the established seedlings were browsed annually by cattle, but less than 0.2 percent were killed each year as a result of cattle injury. They confirmed several of Hill's earlier observations, chiefly that (1) livestock usually browse only the current year's growth; (2) shoot browsing is most severe during late June and early July; and (3) browsing injury, if recurrent, seriously retards the height growth of young pine trees. They further reported that browsing of shoots began when shoot elongation was well in progress; it became heaviest in late June and early July when the weather was hot, when stock waters were few, and when early growth of forage plants had ceased and was becoming dry or grazed out within easy walking distance from water. Browsing by cattle ceased under damp conditions and during and following rains. The conclusion was that shoot browsing by cattle occurs mainly under dry conditions, and that this fact furnishes the basis for the development of range management practices that will minimize damage to reproduction.

Cooperrider and Cassidy reported that in the case of sheep 10 percent of the advance reproduction was browsed annually, and during the period of study less than 4 percent of the small seedlings surviving the cotyledon stage were killed. As with cattle, browsing of pine shoots by sheep was mainly during the dry weather under circumstances productive of thirst. Hot weather, dry forage, and long intervals between watering each increased the amount of browsing. Conversely, little browsing took place under wet conditions when sheep had ample succulent forage and were watered often enough to preclude their becoming very thirsty.

Observations over a period of many years have led the author to believe that the stage of development of the pine shoots and

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[11] COOPERRIDER, CHARLES K., and CASSIDY, HUGH O. CATTLE GRAZING IN CUTOVER TIMBERLANDS IN RELATION TO REGENERATION OF PONDEROSA PINE FORESTS OF THE SOUTHWEST. Southwest. Forest and Range Expt. Sta. 1939. [Typewritten report.]

——— and CASSIDY, HUGH O. SHEEP GRAZING IN CUTOVER TIMBERLANDS IN RELATION TO REGENERATION OF PONDEROSA PINE FORESTS OF THE SOUTHWEST. Southwest. Forest and Range Expt. Sta. 1939. [Typewritten report.]

needles exerts a major influence on the season during which browsing damage occurs. This applies to both sheep and cattle and to a lesser degree to deer. Pine shoots start to elongate very slowly in the first part of June, reach a maximum rate of growth after June 15, and decline gradually after July 15. Exact dates vary from year to year, but shoot browsing is most pronounced during the period of rapid elongation and tapers off gradually when shoot growth is completed. In the later stages, the lower portion of the shoot becomes tough and fibrous and forms a woody core; when this period of development is reached, only the growing tip is usually browsed. It has been observed that pine shoots are most attractive to livestock when in a thrifty growing condition. Vigorous seedlings in sunny locations are browsed more than seedlings in partial shade. Likewise, the main leader is usually taken in preference to the slower growing lateral shoots.

The seasonal course of needle browsing by sheep follows a similar pattern. Ponderosa pine needles begin to grow vigorously about the time the shoots reach maximum elongation. The needles emerge from their sheaths in early July and by August 1 they are about 3 inches long. They continue growing into October when they are normally 6 to 9 inches long. Needle browsing begins soon after shoot browsing ceases and continues until sheep leave the range, usually about November 1. Needle browsing is not resumed the following year until new needles are well advanced in growth.

Kind, class, number, and distribution of livestock all exert a pronounced influence on the extent and severity of browsing damage. Character of forage is likewise believed to afford a partial explanation for the presence or absence of browsing in different localities. Sheep and deer choose the foliage and tender twigs of woody plants over dry grasses in their regular diet. The fact that palatable shrubs are scarce on many of the pine-bunchgrass ranges might well be a contributing factor in pine browsing.

Control of Browsing Damage

Use of ponderosa pine lands for grazing use as well as timber production will require the adoption of range management practices that will minimize and, if possible, eliminate browsing damage to pine reproduction.

Reduction in numbers alone does not entirely solve the browsing problem. For example, numbers of cattle on the Wild Bill allotment of the Kaibab National Forest were reduced in 1935 and later years, but serious shoot browsing continued on those portions of the range most used during June and July. Characteristically, damage on lightly stocked cattle ranges is usually most severe on areas near water, along easy routes of travel (roads and trails), and on level ground, as distinguished from steep, rocky slopes.

Better distribution of cattle through fencing, improved salting practice, and additional water development would tend to relieve extreme browsing damage on concentration areas.

Shoot Browsing by Livestock Can Be Virtually Eliminated

Irrespective of the reason why livestock browse young pines, one fact stands out: pine shoots are not browsed appreciably after about July 15. If the opening date on livestock ranges subject to shoot browsing is deferred until July 15, damage will result only in exceptional years. In 1937, cattle grazing began on two areas after July 15 and in both cases plot records showed less than 1 percent of the seedlings browsed up to October 31.

Cattle grazing, if deferred regularly until about July 15 on ponderosa pine ranges, can be used effectively to: (1) Utilize the bunchgrasses in their most palatable state without danger of pine browsing; (2) encourage pine regeneration by relieving grass competition; and (3) lower the fire hazard by reducing the volume of dry grass carried over to the succeeding fire season.

Needle Browsing More Difficult to Control

Needle browsing presents a different problem because it takes place during the months when forage growth is at its best. Since this form of damage is confined largely to sheep bedding grounds and trails, reliance must be placed on better herding and bedding practices. Strict enforcement of a 1-night bedding rule, supplemented by a provision that bed grounds must be at least 0.5 mile apart, would do much toward eliminating the type of injury illustrated by figure 51.

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FIGURE 51.—A sheep bed ground of about 160 acres which has been used intermittently for over 30 years. The damaged saplings are the remnants of a stand of more than 40,000 seedlings per acre.

Better herding may not reduce the total volume of needles eaten, but it would distribute the browsing in such manner that relatively few trees would be seriously injured. Since sheep are also mainly responsible for the killing of small seedlings in the first and second years, sheep grazing must be subjected to rigid inspection on areas in the initial stages of regeneration.

Control of Deer Browsing

Deer browse pines in much the same way as cattle and sheep, although they browse shoots earlier in the season. Deer tend to concentrate on areas where grazing by domestic livestock is light. This situation has been revealed on several areas in the Fort Valley Experimental Forest during the last decade. On two areas in particular, both lightly stocked with domestic animals since 1930, shoot browsing has increased noticeably in recent years; and so has the number of deer. In 1944 both areas were unused by domestic animals, but shoot browsing by deer continued on a sizable scale. This emphasizes the importance of proper stocking by both deer and domestic livestock.

The recommended control measure for damage by deer is reduction of numbers through regulated hunting. On lands primarily valuable for production of timber crops, use by game will need to be carefully regulated to prevent serious damage to the major resource.

MISTLETOE [12]

The pine mistletoe (*Arceuthobium vaginatum* v. *cryptopodum* Gill) directly disturbs the nutrition of the tree. It attaches itself to the branches and sometimes to the bole, and sends its root-like filaments into the living tissue, drawing water and food elements from the tree. Mistletoe also causes distortion of the branches and excites an abnormal pitch exudation in both branches and bole (fig. 52), producing defect or degrade in the form of huge knots, bole cankers, resin-infiltrated burls, and spongy, coarse-grained wood in hypertrophied areas. In the early stages, growth of the bole or branch at or near the point of infection is greatly stimulated; but sooner or later over-all growth of the tree declines, and if infection is severe the tree dies. The parasite is found on ponderosa pine from the seedling stage to maturity and it occurs in varying degrees of abundance throughout the range of the species.

The vigor of a mistletoe infection is directly proportional to the thrift of the host tree on which it becomes established. Where present in a stand, it makes the heaviest inroad on the best growing stock. Studies by Lake S. Gill at Fort Valley indicate that spread of mistletoe from tree to tree and its invasion of new areas is a slow but persistent process. A spot infection gradually radiates outward so that the area affected is more or less circular and it enlarges in geometric progression of the radial spread. For example, if the radial spread is assumed to be 50 feet per decade, an infection now 1 acre in size would cover 7 acres in 40 years, 90 acres in 200 years.

[12] Acknowledgment is made to Lake S. Gill and J. L. Mielke, Forest Pathologists, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Department of Agriculture, Albuquerque, N. Mex., for review of the material on mistletoe and fungus diseases.

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FIGURE 52.—Mistletoe-injured tree worthless for lumber and poisoned in order to check infection of surrounding saplings.

Korstian and Long *(36)* in a study of mistletoe on the Coconino and Kaibab National Forests stated the following among other conclusions: Mistletoe is responsible for a decrease in diameter growth; a reduction in length of needles and total leaf area; a decrease in yield and viability of seed; and deterioration of the quality of wood.

Mistletoe is one of the three main causes of ponderosa pine mortality in the Southwest, ranking about equally with wind and lightning (tables 17 and 18, pages 72, 75). It accounts on the average for about 20 percent of the total mortality, but this figure varies from 0 to 50 percent. Only a small portion of the mistletoe damage is registered in board measure, however, because most of the seriously affected trees die before they are large enough to contain appreciable board-foot volume. Thus, while mistletoe is credited with only 20 percent of the total volume loss on cut-over areas, the corresponding loss in number of trees 12 inches d. b. h. and over amounts to 38 percent.

Loss of increment due to mistletoe mortality is probably less than the loss through retardation of growth by the parasite. Table 30 gives for two 12-acre plots the average 30-year increment of infected and noninfected trees by diameter class. Average increment of lightly or moderately infected trees is slightly higher than that of mistletoe-free trees; the difference is too small and too inconsistent to be given much consideration except as it may indicate a temporary stimulus due to mistletoe. Heavy infection, however, lowered average increment by 35.1 percent and with two exceptions the decline was consistent throughout the range of diameter classes. If the 74 heavily infected trees on these two areas had grown at the same rate as the 178 noninfected trees, the total growth on the 24 acres during 30 years would have increased by 4,474 board feet or 186 board feet per acre.

TABLE 30.—*Average 30-year increment (volumes uncurved) of noninfected and mistletoe-infected ponderosa pine on a sample area of 24 acres (plots S3-A and S3-B)*

Diameter breast high (inches) 1909	Total trees, 1909	Trees not infected	Trees with light to medium infection	Trees heavily infected	Average increment per tree for—		
					Trees not infected	Trees with light to medium infection	Trees heavily infected
	Number	*Number*	*Number*	*Number*	*Board feet*	*Board feet*	*Board feet*
12	34	15	11	8	85	81	66
13	45	25	11	9	136	114	79
14	44	25	11	8	153	142	111
15	25	12	9	4	170	217	66
16	20	12	3	5	198	150	83
17	22	9	8	5	199	200	104
18	21	9	7	5	212	174	162
19	36	16	13	7	251	242	169
20	26	14	5	7	228	245	155
21	23	9	10	4	202	259	292
22	19	5	11	3	331	285	179
23	14	2	8	4	215	285	173
24	12	7	2	3	298	402	186
25	8	6	1	1	318	240	185
26	4	2	1	1	231	287	292
27	3	2	1	----	364	501	----
28	2	1	1	----	402	264	----
29	1	----	1	----	----	523	----
30	2	1	1	----	354	288	----
31	6	4	2	----	477	344	----
32	2	2	----	----	474	----	----
Total, or weighted average	369	178	117	74	205	213	[1] 133

[1] Difference in increment between heavily infected and noninfected trees was 35.1 percent.

Mistletoe mortality on the same area during the same period accounts for a loss of 158 board feet per acre. Total per-acre loss from mistletoe through both mortality and retardation of growth during 30 years can therefore be placed at 344 board feet, or 11.5 feet per acre annually. These figures, however, do not include loss of trees below 12 inches d. b. h., or loss through degrade and cull.

Mistletoe Control

Harvest cuttings, if repeated at least once every 20 years, will make possible the salvage of most infected trees that would die during the cutting cycle and reduce to a low figure the board-foot volume killed by mistletoe. The primary problem, however, is not one of merely salvaging infected trees before they die, but of restricting the spread of the parasite and eventually eliminating it from ponderosa pine areas managed for saw-timber production.

Stands lightly infected or with scattered infections offer the best opportunity for mistletoe control. Here periodic harvest cutting and stand-improvement operations can do much toward mistletoe eradication at relatively low cost. Infected trees in the overstory can be cut to prevent further infection of the younger generation and scattered infections in the sapling and pole classes can be removed by follow-up pruning and thinning measures. Results thus far from pathological studies [13] indicate that light infections in the limbs of small trees can be eradicated by pruning if the infection occurs 1 foot or more from the bole.

In stands moderately or heavily infected, opportunities for mistletoe control through light selection cuttings are limited because many infected trees are left in the overstory. Practical methods for dealing with heavily infected stands remain to be developed.

FUNGUS DISEASES

Western Red Rot

The common heart rot of ponderosa pine, which occurs throughout the range of the tree, is caused by the fungus *Polyporus ellisianus* Sacc. & Trott. In the Southwest heart rot is by far the greatest single item of defect in virgin stands where it commonly runs as high as 20 percent.

According to Long *(42)* the fungus enters living trees mainly through dead branches; it does not enter through fire scars. Fruiting bodies rarely occur on living trees or even on standing dead trees, but are common on the under side of down logs in contact with the earth. Cull logs and down timber of all kinds, over 6 inches in diameter, are the great source of spores for new infections.

[13] Experimental areas designed to test the practicability of mistletoe eradication by cutting and pruning were established in the Fort Valley Experimental Forest in 1933 and 1939 by the Division of Forest Pathology, U. S. Bureau of Plant Industry, Soils, and Agricultural Engineering.

Old trees, especially those bearing dead limbs on the lower portion of the bole, contain by far the greatest portion of heart rot encountered in logging; in some localities, however, especially in the warmer sections of the Southwest, it is found in blackjacks as well as yellow pines. On the whole, however, a relatively short rotation which would leave few trees beyond the intermediate age class should considerably lower the percentage of heart rot in saw timber. In a second cut on the Wing Mountain sample plot, the unmerchantable volume due to heart rot, according to Chapel *(15)* constituted only 6.1 percent of the total scale. (Other forms of defect were: Butt rot 0.2 percent; top rot 0.1 percent; sap rot and lightning 1.5 percent; fire 0.4 percent; miscellaneous, including crook, fork, mistletoe, porcupine damage, and roughness, 2.5 percent.)

Andrews and Gill have recently studied western red rot of ponderosa pine in the Black Hills *(2)* and in the Southwest *(3)* with special reference to young stands. In both regions they found that the fungus enters the heartwood of living trees mainly through recently dead branches, which need not necessarily have formed heartwood. It is able to establish itself only in dead wood surrounded by a sheath of bark which remains intact for several years after infection. These authors point out that the fungus has not been observed to attack exposed sapwood or heartwood through wounds caused by fire, other injurious agencies, or pruning. Large branches are much more subject to infection than are small ones. Rot was found in only 2.4 percent of the branches 0.6 to 1.0 inch in basal diameter inside the bark; in branches 1.1 to 1.5 inches the percent rose to 8.3, and in those over 1.5 inches 16.4 percent contained rot.

In the light of available information it would appear that in a management program looking far into the future, silviculture could greatly decrease the prevalence of western red rot through the following measures:

1. Practice a shorter rotation than has been common, aiming to harvest nearly all trees before they attain an age of 200 years. This would call for encouragement of rapid growth in the blackjack stage, in order to attain merchantable diameters at a relatively early age.
2. Maintain close spacing through the pole stage in order to promote natural pruning. As a supplementary measure, practice stand improvement, eliminating the roughest stems and pruning the best ones before their diameter exceeds 8 inches, and especially before the limbs become large.
3. Reduce to a minimum the volume of cull logs and down timber left in the woods. For many years the great mass of this class of material already present must necessarily remain because the expense of removing it would be prohibitive. In the future there will be little excuse for the growing of cull logs.
4. All commercial cutting should place improvement of boles foremost in the list of objectives. Potential rot hosts can be spotted for removal in the pole stage by the presence of coarse limbs. In many instances the presence of western red rot can be detected from the peculiar white mycelium in broken branches.

Paintbrush Blister Rust

A form of decline occurring in ponderosa pine on some areas in the Southwest is a rust fungus *Cronartium filamentosum* (Peck) Hedgc., which may be recognized by the fruiting bodies appearing as small white sacs on the underside of twigs and branches *(46)*. The crown is attacked, beginning usually at the tip but sometimes at the base or in the middle portion (fig. 53). Death of the affected

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FIGURE 53.—A tree with crown infected in the median zone with paintbrush blister rust, *Cronartium filamentosum*.

parts is rapid, but movement through the crown is slow and consequently the tree may remain alive many years. Under a short cutting cycle nearly all of the trees attacked by this rust can be salvaged. More needs to be known about the rate of spread.

Root Rot

A root rot has been known for many years to attack and kill ponderosa pine seedlings and saplings. James L. Mielke has recently identified two fungi, *Fomes annosus* Fr. and *Armillaria mellea* Vahl., as responsible for root rot of ponderosa pine in the Southwest. *F. annosus* is capable of killing trees of all ages.

Wagener and Cave *(93)* report both of these fungi in California. *Fomes annosus* is especially active on Jeffrey pine and ponderosa pine, mainly in pure or nearly pure pine types on the eastern side of the Sierras, where the climate approaches that of the desert. As in Arizona and New Mexico, trees of all ages from seedlings to veterans are attacked. In both regions, infection appears to be associated with stumps or dead trees, but control methods have not been worked out.

STAGNATION

To the array of directly antagonistic agents described above should be added the death struggle between individual trees which may be characterized as stagnation or destructive competition. As has been pointed out elsewhere, competition is beneficial within limits; but beyond these limits it reacts to the disadvantage of the tree society as a whole. Stagnation can be as depressing as disease; in fact it is a common ally of disease and other direct killing agents *(43)*.

Next to regeneration, regulation of competition within stands is by far the greater part of timber growing. It leads definitely to the short cutting cycle, which automatically sets up a program of improvement cuttings at short intervals. Frequent improvement cuttings not only permit the salvage of diseased and injured trees, but also render the stand more resistant to wind, lightning, and bark beetles by keeping it perpetually young, and by giving individual trees room for vigorous growth. It lowers the slash hazard by removing culls and limby trees early in life, at the same time eliminating the favored hosts of mistletoe and heart rot. Sucessful working of this cutting program is dependent upon full stocking and continuous regeneration so that whenever an inferior tree is removed its place in the soil is promptly taken by neighboring trees, preferably of a younger age class.

TOTAL LOSS DUE TO CONTROLLABLE AGENTS

In the Southwest the loss attributable to any one of the foregoing agents is usually small, but the aggregate loss spells the difference between managed forests and haphazard volunteer growth. The following tabulation gives the estimated percentual reduction

of increment by causes below a possible 200 board feet per acre annually under extensive and intensive management.

	Extensive management percent	*Intensive management percent*
Cause of loss:		
Destructive competition	20	1
Mistletoe	8	2
Wind and Lightning	8	2
Squirrels	6	1
Cattle, sheep, and deer browsing	6	2
Heart rot	6	2
Fire	6	1
Tip moth	3	2
Bark beetles	3	1
Small rodents (mice, chipmunks, etc.)	2	1
Porcupine	2	0
Paintbrush blister rust and root rot	2	1
Miscellaneous	3	1
Total	75	17

Extensive management assumes present silviculture and protection standards on a cutting cycle of 40 to 50 years. Intensive management assumes cutting cycles of 20 years or less under methods aiming at constant improvement of the stand, together with aggressive safeguards against damaging agents. Total losses under extensive management are estimated at 150 board feet annually as compared with 34 board feet under intensive management. The foregoing comparison does not take into account the superior quality under intensive management, except as unmerchantability is decreased. Theoretically, the losses under intensive management can be further reduced, but in practice a considerable margin must be allowed in dealing with large areas.

Timber-Stand Improvement

OBJECTS AND PROCEDURE

Inasmuch as stand-improvement technique has been covered in considerable detail in previous publications *(62, 63, 67)*, the purpose here is more to discuss principles and to amplify previous statements dealing with the broader aspects of the operation.

Stand improvement aims to develop a good growing stock out of the younger generation; it is concerned primarily with trees below saw-timber size, but may also remove or otherwise eliminate large trees considered too poor to warrant handling by the loggers. It supplements the improvement measures carried out in silvicultural harvest cuttings. In brief, stand improvement aims: To put the young stand in condition for rapid growth; to favor the better types of trees by removal of less desirable types that are competing; and to improve the best individuals by special treatment. These objectives are accomplished by three operations: (1) Thinning, (2) improvement cutting, and (3) pruning of boles.

Thinning the Stand

Thinning has as its primary object the removal of surplus stems where the density is too great to permit normal growth. Ideal practice in even-aged stands aims at uniform spacing and uniform development of stems. Intensity of thinning is gaged by number of stems and basal area per acre desired in the remaining stand. European practice contemplates frequent thinnings, beginning at an early age, and gradually reducing the number of trees per acre as their growth makes greater demands for space. This practice assumes a market for the material removed. In the absence of a market for stems of small dimensions, thinning of the conventional type encounters economic limitations which are all but prohibitive. Such is the case in the Southwest.

Thinning, except when combined with improvement cutting, has been practiced sparingly in the Fort Valley Experimental Forest. Stems of good form and health are considered too valuable to sacrifice except in cases where they are so close together that future growth will cause physical interference. Under other circumstances it is considered better to wait until one or more stems in a clump become large enough for commercial use. It is recognized that this philosophy encounters limitations where many stems of uniform height become deadlocked. This condition, prevalent in some regions, is uncommon in the Southwest. When it is encountered, thinning may be employed patchwise to release prospective crop trees instead of undertaking to bring about uniform spacing in entire stands. In the Southwest even the densest sapling thickets usually contain occasional dominants which with a little thinning immediately around their base are able to hold or improve their position. Thinning which involves removal of many stems should for reasons of economy begin in the sapling stage. As the trees increase in size additional thinning will become necessary. If the spacing of saplings is made wide enough to accommodate the trees as they advance to the pole stage, natural pruning will be retarded and the stems will tend to assume a bushy form. Spacing as wide as 10 x 10 feet in sapling stands on the Sitgreaves National Forest has been found to be distinctly too wide (fig. 8, *E*).

Improvement Cutting

When thinning is deferred until the pole stage, ponderosa pine stands tend to become so differentiated that uniform spacing is impractical. In the Southwest the typical 40-year-old stand will be made up of stems ranging from 2 to 10 inches d. b. h. with a marked differentiation into dominants and subordinates. In some regions, notably the Black Hills and even in parts of the Southwest, such differentiation is less marked, with the result that the stands tend to stagnate. In the Black Hills more or less uniform thinning has been practiced on a large scale. In the Southwest the first attempts at thinning quickly developed into improvement cuttings. As far as practical, dominants were favored by cutting out subordinates; but in many instances the dominants were wholly unsuited to leave because of abnormal form, and then they were sacrificed in favor of codominants or distinctly subordinate stems. It was soon observed that the stems of highest potential saw-timber form were among the codominant and intermediate crown classes. It was also found that dominants distinctly taller than their neighbors grow well without removal of subordinates. Finally it was deduced that in a region where reproduction is uncertain, wholesale destruction of subordinate stems is wasteful, because many of these stems can mark time for a hundred years and then spring into vigorous growth when released.

Elimination of Unwanted Trees

If costs must be held to a low figure, elimination of inferior or objectionable trees may well constitute the whole or the major part of stand improvement. First on the list are wolf trees and other low-value dominants which are interfering with the growth of smaller trees of good form. Within limits, however, limby dominants may be employed temporarily to improve the younger stand. They induce natural pruning in the stems immediately surrounding them and, if young trees are very dense, a spreading wolf tree may effect a beneficial thinning by killing out the trees directly under its crown. If the wolf tree is removed at the right time it leaves a vacant space which is quickly appropriated by surrounding trees, many of which are likely to be of the desirable slender, clean-boled type (fig. 54).

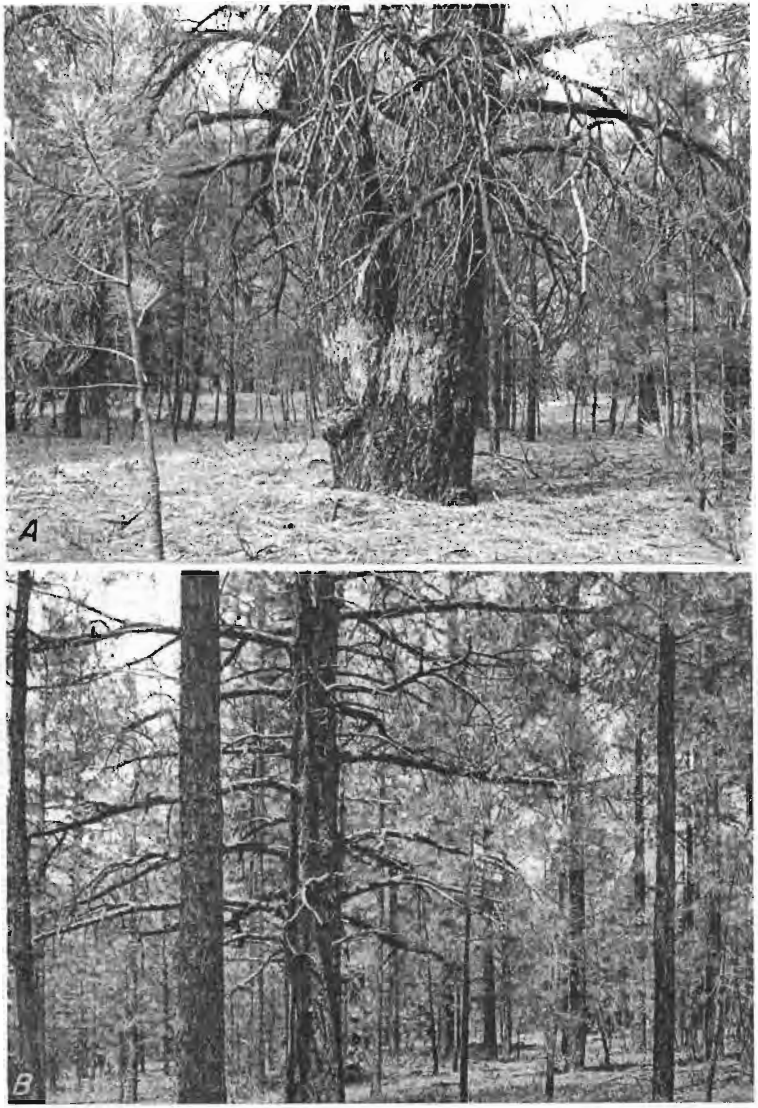

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FIGURE 54.—Unmerchantable trees poisoned in order to release the younger generation. *A*, Removal of double wolf tree will stimulate growth of surrounding saplings, many of which have good form. *B*, Excellent poles 4 to 11 inches d. b. h. have grown in diameter at the rate of 1 to 2 inches per decade since 22-inch wolf tree was poisoned.

Mistletoe-infected trees generally come in this category since mistletoe is a common cause of abnormal form. The most urgent purpose in removing mistletoe trees is, however, to prevent the infection of neighboring trees. If infection has already taken place, eradication may be impractical, but if infection has made but little progress, removal of a mistletoe bearer is to be regarded as a measure of first priority. In many instances a mistletoe-infected wolf tree is surrounded by saplings still practically free of infection. Elimination of the wolf tree then becomes doubly urgent, and this applies also to infected saplings.

Removal by Cutting.—Large unmerchantable trees present a cost problem. Felling is the least item of expense. As a precaution against fire the branches must usually be piled and burned, and as a precaution against bark beetles the bole may have to be peeled. Felling becomes costly as the diameter exceeds 8 inches d. b. h.

Girdling.—Ponderosa pine commonly lives 2 years after girdling and during this period invites attack by bark beetles. Trees over 18 inches d. b. h. are not easily girdled because of their thick bark.

Poisoning.—A 12-percent solution of sodium arsenite has proved effective and economical in killing trees of all sizes up to and over 30 inches d. b. h.[11] The poison is introduced in holes about 4 inches deep, bored at an angle of about 45° from the horizontal with a brace and bit. The required number of holes increases with the size of the tree and especially with the area of the crown.

Since sodium arsenite is a deadly poison, it should of course be handled with caution. The solution should not be allowed to come in contact with the hands, nor should it be spilled where animals can get at it. A convenient way to apply the solution is with a battery filler of the type in general use at service stations. The battery filler fits snugly in the mouth of a 1-gallon vinegar bottle, which usually has a handle to facilitate carrying. This simple equipment, plus a brace, 5/8-inch bit and an ax for removal of obstructing branches, is all that is necessary. A two-man crew works most effectively.

Some experience is required to judge the required number of holes. Since the poison acts directly on the foliage, the quantity of solution and thus the number of holes is related to the size of the crown. For large-crowned trees of the type usually selected for poisoning, one 4-inch deep hole is sufficient in stems under 6 inches d. b. h., two holes 6 to 11 inches d. b. h., and three holes 12 to 16 inches d. b. h. In the case of very large, irregular crowns an additional hole adds to the certainty of results, but even so, occasional trees may need a second application. As the size of bole exceeds 16 inches d. b. h., a fairly good rule-of-thumb is to space the holes 12 inches apart, decreasing the distance to 6

[11] Recently ammonium sulfamate ("Ammate") a chemical nontoxic to humans and wildlife has also been tested at Fort Valley and found to merit further trial. Current findings from the ammate study are presented in a research note *(26)*.

inches in boles above 30 inches. In large trees considerable work can be saved by refilling the holes; the solution applied in the first filling is usually absorbed in 15 to 20 minutes.

In dense stands there is danger of secondary poisoning, that is a portion of the poison goes from the intended victim to a neighboring tree which may be the best one in the group. What probably takes place is that the poison solution passes into the roots and is transferred from one tree to another through root grafts. Under these circumstances it is advisable to apply the poison sparingly, and leaving some trees for a second treatment after the effects of the first one are known. A further precaution is to substitute cutting for poisoning in critical situations.

Poisoned trees, even of large size, rot with astonishing rapidity after death. But for this fact trees large enough to contain substantial cores of heartwood would stand indefinitely. Poisoned trees as large as 30 inches d. b. h. go down within 10 years.

Poisoning is cheap and gives quick results. Trees as large as 18 inches d. b. h. can be killed for about 5 cents each and smaller ones at a lower cost. During summer, death results within 2 weeks after application of the poison; if treated after November, however, the foliage is likely to remain green until the following spring. Only in rare instances have bark beetles *(Ips)* been known to attack standing poisoned trees. The dead trees do not present much of a fire hazard because the needles and twigs fall gradually, merely creating a deep litter.

An important advantage of poisoning over felling is that the poisoned tree remains standing 5 to 10 years and provides shelter for slender poles which, if abruptly exposed, are subject to snow bend. When a poisoned tree eventually goes down, the damage to smaller trees is much less than when a green tree is felled.

Crop Trees

The crop-tree method concentrates attention on relatively few selected trees; it is the essence of improvement cutting. Whereas conventional thinning practice leaves perhaps 600 trees per acre after the first thinning, with the expectation of ultimately reducing the number to 100 or less, the crop-tree method selects a much smaller number with the expectation that most of them will live through to the harvest cutting. These selected trees are released by removal of competitors, and under intensive practice they are also pruned. Theoretically, at least, the crop-tree method is more economical since it does not intentionally expend labor on stems which in the ordinary course of events will drop out of the stand before the harvest cutting. It leaves undisturbed a great many subordinate stems which may come into the picture later. The method is especially adapted to many-aged stands, or large even-aged groups that will be gradually converted to a selection type of forest.

In the Southwest, the crop-tree method has completely supplanted earlier attempts at uniform thinning. The objective also has shifted from an attempt to force rapid growth of crop trees to a more conservative purpose which seeks merely to encourage

normal development by enabling trees of good form to attain and hold a dominant position.

The ponderosa pine forest of the Southwest is a mosaic of many age classes occurring mainly in groups which, though essentially even-aged within themselves, nevertheless vary greatly in the diameter of individual stems. Besides several pole stages, there are stems of sawlog size in the overstory and sapling groups below. Between groups are areas of various sizes occupied only by isolated trees, poles, or saplings. Under these circumstances it is impractical to specify an arbitrary spacing or number of trees per acre.

Crop trees must be taken where they can be found; in some places they will be 6 feet apart and in others 50 feet apart. Since they vary greatly in age, size, and growth rate, they cannot be expected to mature uniformly. Stand improvement, like harvest cuttings, therefore must be on a selective basis; crop trees will be released and pruned as they reach the right size and this process, though intermittent, will go on indefinitely. As a rule, stand improvement should follow each cutting, but if the cutting cycles are longer than 20 years intermediate stand improvement operations are desirable.

Selection of Crop Trees.—Assuming that the primary crop is saw timber, crop trees should be of good form and of a type and size that will shed their limbs naturally or respond to artificial pruning if such operation is necessary. Trees which meet these qualifications are not always the dominants; more often they are subordinates which have been subjected to side shade. Removal of a single rough dominant or wolf tree commonly releases several potential crop trees which already have relatively smooth boles. In openings, on the other hand, it may be necessary to retain trees of low future value simply because they are the best available.

In most stands of the Southwest there are at least 40 good poles per acre, and not uncommonly there are several hundred. The number actually selected for special treatment must also consider cost limitations, especially if they are to be pruned. In the Fort Valley Experimental Forest, the number on experimental areas varies from 80 to 160 per acre.

Release of Crop Trees.—If the crop tree is distinctly dominant, immediate removal of competitors is not necessary; in fact moderate competition is desirable. Crop trees from the codominant or intermediate class require more liberation than dominants. In either case it is well to remove stems which stand so close to the bole of the crop tree that the two may grow together. Complete release from competition in the pole stage is not only unnecessary but distinctly undesirable. The ideal crop tree is one with a crown whose length is somewhat less than half the total height of the tree. Release cuttings aiming to stimulate rapid diameter growth should be deferred until the tree has attained a breast-high diameter of 12 inches and a height of 40 to 50 feet. In short, the rule for growing saw timber is to keep the stand crowded through the pole stage, then open up to maintain or accelerate diameter growth by providing the space necessary for good root development, always remembering that side shade is essential to good form and that in a region of deficient precipitation, soil moisture rather than light is the limiting factor in volume production.

The selection and release of crop trees should be closely coordinated with timber marking. Assuming that logging precedes stand improvement, the timber marker should visualize the whole stand after it has been logged—not only trees over 12 inches d. b. h. but the entire growing stock. With such a picture in mind, timber marking would be influenced by considering not only what a given log-size tree will do if left but also what several associated poles will do if the larger tree is cut. The same picture will help decide whether an individual pole shall be held until full maturity or left temporarily to be cut in the relatively near future. Timber marking and stand improvement are no longer to be viewed as independent operations but as related phases of the larger enterprise of growing timber crops.

Pruning

Under ideal conditions nature clears the boles by natural pruning. Because spacing and other conditions are seldom perfect, however, the natural process must usually be aided by artificial pruning in order to produce clean boles.

Natural Pruning

The basic factors concerned in natural pruning have been discussed under "Silvicultural Foundations." It is desirable, however, to review some of the relationships directly concerned in stand improvement. Mutual shading by the trees in dense stands is the primary cause of death of lower limbs, although moisture deficit may be a contributing factor. The dense stocking necessary to bring about early natural pruning also tends to create a shortage of soil moisture. Since diameter growth in dense young stands is retarded more than height growth, the stems become slender. Within limits, this is a desirable feature since it helps prevent development of high taper in stems as well as limbiness.

If soil moisture is reasonably adequate, height growth tends to offset the dying of the crown from below; and thus it becomes possible to carry natural pruning in pole stands to a height as great as two log lengths. Abundant evidence exists that in young ponderosa pine a crown length equal to 30 percent of the total height is adequate for photosynthesis concerned in diameter growth up to 2 inches per decade. Reduction of the crown much below this proportion usually signifies water shortage severe enough to have checked height growth. This calls for opening up the stand to restore height growth as well as diameter growth, and above all to permit development of the root system which governs growth in both height and diameter.

To be fully effective, natural pruning should come into play while the branches and the bole itself are still small. Death alone does not insure the shedding of limbs from the bole; this takes

place only after wood-destroying fungi have weakened the limb to the extent that it breaks off under the weight of rain or snow or some other form of pressure. A dry rot in sapwood is common in the Southwest; heartwood is more resistant, especially if impregnated with pitch. Branches 2 inches or more in basal diameter at the time of death tend to persist indefinitely, and because they form loose knots in the wood deposited around them, they are more objectionable than live branches of the same size. Moreover, dead limbs are the point of entrance of western red rot. As previously stated, the prevalence of this heart rot increases rapidly as the basal diameter of dead limbs exceeds 1 inch inside bark. When it is considered that in ponderosa pine pole stands limbs are commonly over 2 inches in diameter, the need for improvement in this respect becomes clear.

Artificial Pruning

Under good management artificial pruning is to be regarded primarily as supplemental to natural pruning. In pole stands which have been densely stocked since the sapling stage the branches generally are small enough to shed naturally. Removal of such branches by artificial means hastens clearing of the bole, but may not be economically justifiable in management which contemplates growing timber to diameters of 20 inches or more. Even in well-stocked stands, however, fast-growing dominants often are coarse-limbed. By pruning such trees, which may be expected to reach diameters of 18 inches in 80 to 100 years, they may be harvested early, thus providing much needed growing space for subordinates having relatively clean boles.

As pointed out elsewhere, codominant and intermediate trees in dense stands may mark time indefinitely, growing moderately in height but very slowly in diameter. They develop slender, relatively clean boles of high potential timber value and are capable of rapid growth when released by the removal of dominants. Directly after such release is the opportune time to prune occasional coarse branches or stubs from their boles.

Pruning in Open Stands.—The greatest need for pruning is in open-grown pole stands. Low branches are commonly over 2 inches in diameter in trees 10 to 12 inches d. b. h. By pruning the best stems and eliminating the poorest ones in stand improvement or preferably some form of commercial cutting, advantage can be taken of the opportunity to grow large timber in a short period. Open-grown blackjacks 30 to 40 inches d. b. h. at an age of 140 years are not uncommon in the Southwest. Pruning at an early age serves to convert what would otherwise be worthless wolf trees into stems of high value (fig. 55).

Size Limitations.—Most economical diameter limits for pruning of crop trees are between 6 and 12 inches d. b. h. Smaller stems are desirable if they can be kept in dominant positions and if tall enough to insure a straight bole. Boles as large as 14 inches d. b. h. make good crop trees if natural pruning is already well advanced. Always the maximum permissible diameter must bear a direct relation to the ultimate diameter. A general rule is that the layer of

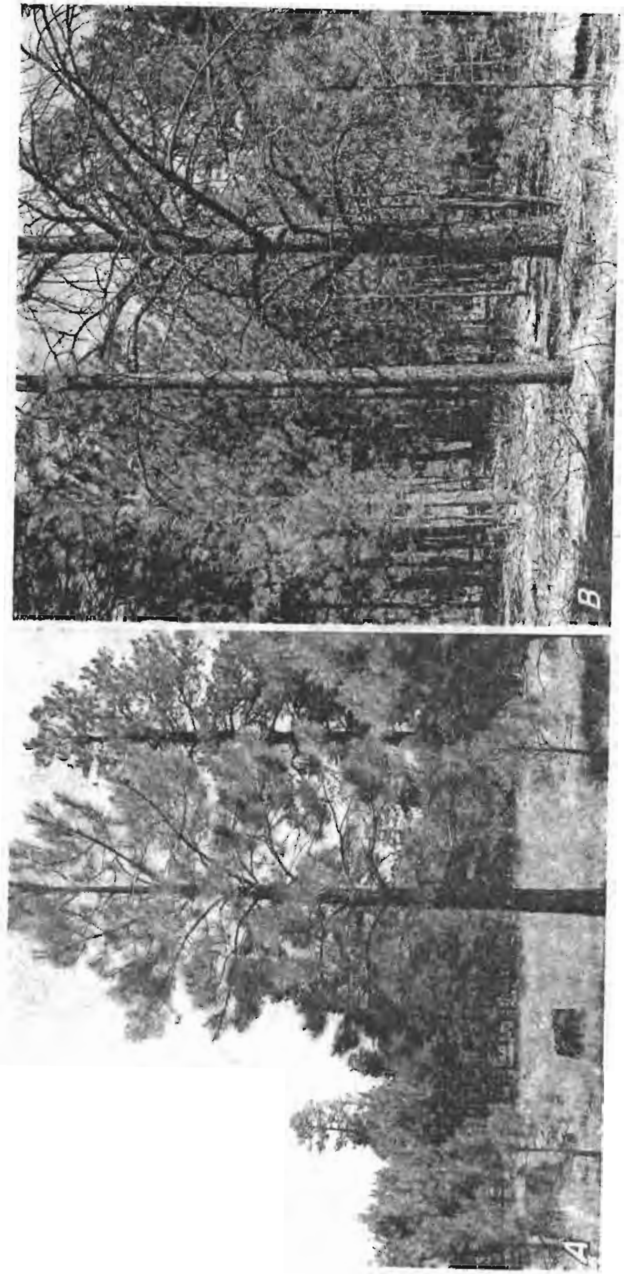

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FIGURE 55.—Trees in openings respond well to pruning because abundant space enables them to attain large size at an early age. *A*, An open-grown pole 6 inches d. b. h. which can become a good tree if pruned at an early date. *B*, An excellent pole which required little pruning because of side shade from limby dominant. Since poisoning the dominant, the pole has grown rapidly.

wood deposited after pruning scars are healed should be at least 3 inches thick. This would call for an increase in diameter of 8 to 10 inches after pruning. Here again the initial character of the bole may have considerable bearing. For example, if a bole is relatively smooth and regular in shape at the time of pruning, the promise of a substantial yield of clear lumber is better than if the bole is rough and irregular.

Healing of Pruning Wounds.—The time required for the healing of pruning wounds depends upon a number of circumstances such as the rate of diameter growth, diameter of limb removed, and length of stub left in cutting the limb. Obviously, a bole which is growing rapidly in diameter can place layers of wood over the wound in fewer years than are required if the bole is growing slowly. For this reason pruned trees should be well released and, vice versa, released trees should be pruned if necessary to form a smooth bole. Since removal of large limbs leaves a wide surface to be covered, healing is slow; this, together with cost, makes the pruning of limbs over 2 inches in diameter a questionable operation. If the limb is not cut flush with the bole, growth must build up layers of wood equal in thickness to the length of the stub before covering can begin. In thick-barked trees such as ponderosa pine, stubs at least ½ inch long are likely to remain even in close pruning, and in boles over 12 inches d. b. h., the stub may easily be 1 inch long.

Investigations by Paul *(50)* and others have shown that healing is most rapid if the limbs are alive when pruned, because the limb tissue is then an integral part of the living bole. The cut should be made well into the thickened limb base, since stubs beyond this base tend to die and act for practical purposes like the stub of a dead limb. In ponderosa pine a cut into live tissues quickly becomes covered with pitch which presumably excludes the spores of fungi.

Frequency of Pruning.—The ideal program would be to begin pruning when the tree is about 4 inches d. b. h., taking at first only the lower limbs and extending the pruning height every few years. In dealing with unmanaged stands, however, the trees must be taken as found. Many are already too large; others, though possibly worth pruning, are beyond the stage where the treatment can yield maximum returns on the investment in labor; others fall within what may be called the optimum diameter range which has been placed at 6 to 12 inches d. b. h. A compromise must be made in the frequency with which a given area is covered. Ideally, this might be once in 5 years, but economic considerations will extend the period to 10 or perhaps 20 years. Notwithstanding the need for economy in labor, however, it must be understood that pruning, like other phases of stand improvement, cannot be disposed of in a single operation.

Height of Pruning.—Pruning aims to clear the butt log to a height of 16 feet above the stump. Obviously the smaller crop trees cannot be pruned to that height in one operation. This does not bar pruning, because stand improvement must be regarded as a series of successive steps in which each tree receives individual attention at times calculated to give the best results. An old rule in the Southwest which specifies retaining a live crown equal in length to one-half the tree height can be safely modified to permit reduction to one-third of the tree height. Likewise, another rule restricting pruning to dead or dying limbs should be disregarded because unless the tree is in the open several whorls of limbs will die at the base within a period of 10 years.

Pruning Equipment.—Pruning equipment consists of axes, hand saws, and pole saws. Dead branches to a height of 4 to 5 feet can be removed most readily with axes (fig. 56, *A*). In addition to economy in labor, the ax has the advantage of breaking the dead limb off well within the bark, thus reducing to a minimum the length of stubs which commonly remain on the bole. Above a height of 5 feet, especially if inexperienced labor must be employed, the hand saw has advantages that offset those of the ax. Most important of these advantages is the avoidance of bole injuries, which are likely to result from use of the ax above a certain height, varying with the individual workman. Pole saws are required above the height of about 6 to 7 feet (fig. 56, *B*). Handles of several lengths up to 12 feet can be used to advantage by a crew of workers, the 12-foot saws being reserved for trees ready for pruning to the full height of 17 feet.

Time Required.—Pruning costs vary greatly, the main factor being the character of limb growth. Ideal trees for artificial pruning are those which have shed most of the limbs naturally and have been fully released through harvest or improvement cuttings. Under these circumstances, artificial pruning merely insures a complete job. In close-grown trees branches rarely exceed 1.5 inches in diameter and the larger boles will have shed all but a few branches. Under such conditions 5 minutes of one man's time is sufficient to prune a tree to a height of 17 feet. Most trees in unmanaged stands require more attention. Open-grown trees bearing whorls of coarse limbs at intervals of less than a foot may consume a half hour of pruning time. Fifteen minutes per tree is regarded as an economic maximum to be exceeded only in rare instances. Ten minutes per tree is a fair average for the better class of stems in ponderosa pine stands as now found in the Southwest.

FINANCIAL ASPECTS OF STAND IMPROVEMENT

Costs

Costs vary so greatly that an average figure is of doubtful value when applied to an individual stand. Important variables are the number and character of crop trees to be pruned and the number and size of trees that must be cut out or poisoned. Another variable is the height to which crop trees are pruned, since on some areas a large proportion of those selected are not tall enough to be pruned to 17 feet in one operation. Still another variable is the class of labor.

Experience in the Fort Valley Experimental Forest, on about 1,200 acres of old cut-over areas well stocked with poles, gives an

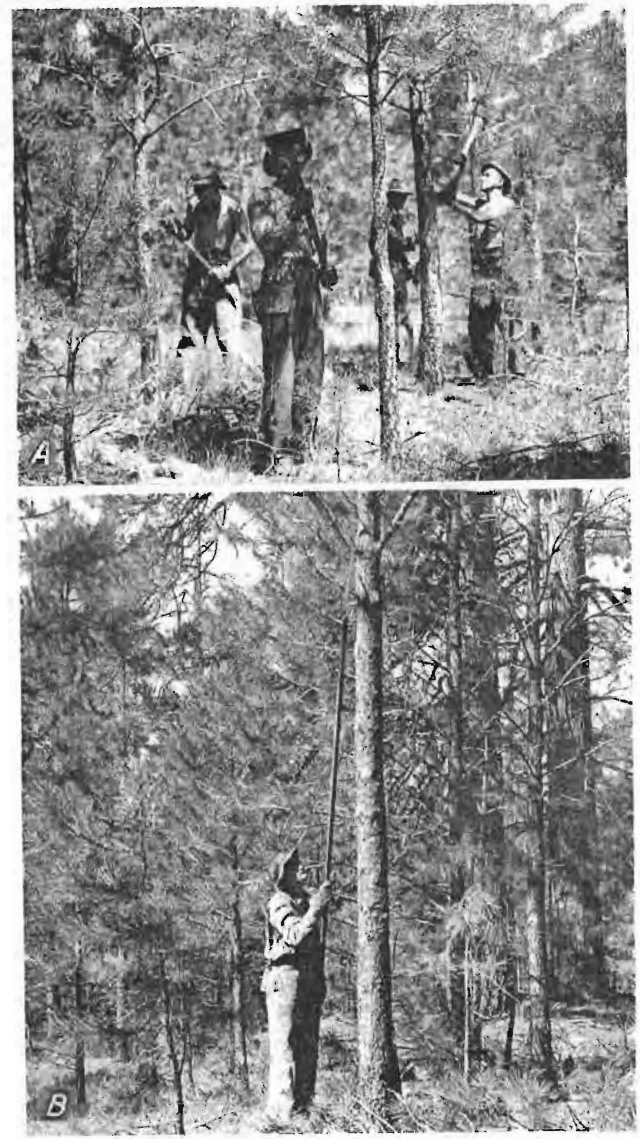

FIGURE 56.—Pruning. *A*, Low pruning with axes removes limbs to a height of about 5 feet. *B*, High pruning with pole saws aims ultimately to clear the bole to a height of 17 feet, but in small trees this height is reached only after 2 or more prunings.

average of 15 to 20 man-hours per acre with Civilian Conservation Corps labor for the complete stand-improvement operation. About 100 crop trees per acre were pruned and enormous numbers were poisoned because of old porcupine injury. A high proportion of the crop trees pruned were of the extremely limby type. On another area where stand improvement directly followed logging in a virgin stand, equivalent operations with seasoned labor required only 10 man-hours per acre. Additional treatments at 10- to 20-year intervals are estimated to require 4 to 6 man-hours per acre for each operation.

Financing

Stand improvement can be accomplished most economically as a current operation keeping pace with logging. Under this procedure, a relatively small number of trained men can do the work with a minimum of supervision, in contrast with the close supervision required when large crews of green labor are employed.

The Knutson-Vandenberg Act, applicable to national-forest lands, provides an effective working fund. Under the provisions of this Act the logging operator is required to deposit in a cooperative fund a sum to be used for planting, seeding, or stand betterment on the area concerned. In the Fort Valley Experimental Forest, during the prewar period, $1 per thousand board feet of timber cut was deposited in the "K-V" fund. On this basis, the first cutting in virgin stands returned ample funds for the initial stand-improvement operation; and it was estimated that subsequent cuttings would provide for supplementary operations. Stands which were logged the first time prior to enactment of the K-V Act (1930) present a problem because the volume available for removal in the second cutting is usually too light to provide sufficient funds for the heavy stand-improvement job needed.

Returns on the Investment

In the absence of experience from which actual figures may be drawn, only rough estimates of returns are possible. A conservative opinion is that for cut-over areas in the Southwest as they exist today, stand improvement can increase volume yields by 50 percent and double the value of the timber crop available in 80 years.

A classification of trees 18 inches d. b. h. and larger on the 480-acre Wing Mountain plot in 1939, by log grade [15] showed that 83 percent of the 17,621 logs on the area fell in the two lowest grades—Nos. 5 and 6; less than 0.5 percent graded No. 1 or "surface clear" (table 34, p. 204). Since trees whose butt log grades as low as No. 5 are rated as of minus value on all but highly accessible areas, early treatment which would raise the butt logs of crop trees into grades 1 and 2 could be expected to easily double their maturity value.

[15] Pacific Northwest log grades for ponderosa pine, as modified for use in the Southwest. The acreage mentioned includes that of the intensive plots.

According to such estimates as are now possible, returns would be increased sufficiently to repay the cost of stand improvement with a margin for supervision and a low rate of interest *(67)*. Private capital would be justified in demanding assurance of a reasonable interest on its investment. On public lands, however, the question assumes a different aspect. If it is true that the Nation and the world at large are confronted by a shortage of high grade coniferous timber, returns on the investment may well become a subordinate issue. Probably no other single measure can contribute so much toward averting a future shortage of quality timber as stand improvement.

STAND IMPROVEMENT IN EXTENSIVE PRACTICE

Selection of Areas

As a general practice, stand improvement should follow rather than precede logging. Exceptions may be made in the case of virgin stands where logging is to be deferred 10 years or more, or at times when large supplies of labor are available. Areas which have been logged during the past 50 years, including lands which were cut under "logger's selection," could in an emergency employment program provide 3 million man-days of work in Arizona and New Mexico. Inclusion of virgin stands could increase this figure. Poorly stocked areas present the most urgent need because open stands will remain permanently in the low-value class unless pruned.

Accessibility is a prime essential since, obviously, there is no point in improving stands which cannot be logged economically. On the other hand stand improvement, by raising the standard of log grades, is one of the most practical means of rendering what is generally considered inaccessible timber more economically accessible. Looking ahead half a century, a good objective is to grow only trees whose high value will enable them to absorb high logging and transportation costs.

Intensity of Operation

The character and intensity of stand improvement will vary with the make-up of the stand and the object of management. Although sawlogs will probably always be the main product of ponderosa pine stands, many trees may be harvested as railroad ties, mine props, or poles. Generally these secondary products will be cut from stems which have not been pruned, but this need not be an invariable rule. Sawn railroad ties may well become a major product of pruned trees because few unpruned trees will be sufficiently free of large knots to yield ties meeting modern specifications.

An ironclad limitation in most instances will be the amount of money available in advance of stumpage returns. On old national-forest cut-overs, where Knutson-Vandenberg deposits will usually be inadequate to cover a thorough job of stand improvement, short-cut procedures may become advisable. Partial treatment embodying only the most urgent work is preferable to no treatment at all.

Complete stand improvement calls for: (1) Poisoning or cutting inferior dominants of pine or associated species where they are interfering with better trees; (2) poisoning or cutting mistletoe bearers where the infection of a younger generation is imminent; (3) cutting occasional stems in dense clumps where they will grow together if all are left; and (4) pruning crop trees up to 160 per acre, depending on the number of good stems available. Thinning in the conventional sense is prohibitive in cost unless there is a market for the material removed.

As a last resort, pruning could be omitted, thus cutting the cost by 50 to 75 percent. This would reduce the operation to liberation of the better class of trees by removal of inferior dominants and to sanitation measures. Although far from adequate, such treatment would greatly improve cut-over stands as usually found.

A more adequate, though still inexpensive, program would, in addition to releasing promising trees, prune a limited number of crop trees. First on the pruning list would come open-grown individuals of the type shown in figure 55, *A*, followed by released poles such as the slender one in figure 55, *B*. Limby dominants such as the three largest stems in figure 57, *A* (d. b. h. 8 to 10 inches) would not be pruned if, as in this case, better boles are found among the subordinates. This class of tree will never become valuable, but it has the making of a merchantable log 20 to 30 years hence. The ultimate crop trees in the group shown in figure 57, *A* are the subordinates now 3 to 6 inches d. b. h., of good form and fine limb development. Under intensive practice, they should be pruned when the dominants are cut or poisoned.

Figure 57, *B* illustrates two types of dominants found in dense young pole stands. One is an ideal crop tree; the other (at left) has a crooked top due to porcupine injury, and is of value only to suppress the surplus saplings near it.

The postwar period has seen both wages and stumpage prices more than doubled, and there is little likelihood that either will decline to prewar levels. Since justifiable expenditures for stand betterment on publicly owned forest lands must in the long run be governed by stumpage receipts, an equitable adjustment might allocate a given proportion of those receipts. One-third in first cuttings and one-half or more in subsequent, lighter cuttings would permit a satisfactory stand-improvement job on most areas now in a virgin condition.

The critical stand-improvement job now confronting the administration of ponderosa pine forests in the Southwest is on the several million acres logged prior to 1935. Heavy cuts and lack of K-V deposits hinder the financing of needed improvement work. Improvement of these stands must await a second cutting; and because that cut will rarely exceed 3,000 board feet per acre, even half of the stumpage receipts would scarcely suffice to meet labor costs.

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FIGURE 57.—Treatment of groups on a low cost basis. *A*, The three dominants (8 to 10 inches d. b. h.) are too limby for economic pruning. Under intensive practice they would be poisoned to make way for smaller, clean-grown subordinates which would then be pruned as crop trees. Left 20 to 30 years, the dominants will suppress many of the saplings, their boles will grow into small sawlogs, and when cut their removal will stimulate growth of the subordinates, some of which will have developed fairly good boles without artificial pruning. *B*, A younger group in which many of the dominants, such as the one in the right foreground, are of excellent form; they could be pruned cheaply but have the making of fair boles without artificial pruning.

Until more information on the costs and returns from stand betterment becomes available it is advisable to handle the operation on a conservative basis. This does not imply postponement but rather an aggressive program in carrying out a number of common-sense measures such as the elimination of inferior dominants, and the separation of doubles or clumps. Improvement of quality will be brought about more cheaply by elimination of inferior types than by expensive artificial pruning. This presupposes full stocking or overstocking in the pole stage, so that stems of inferior form may at the same time be regarded as surplus stems. Good reproduction is the first step in the development of a good growing stock; stand improvement should attempt to direct and aid rather than revolutionize the forces which Nature has employed in producing her best stands.

Management of Cut-Over Stands

The foregoing sections have dealt primarily with cutting in virgin forests and the reaction to different methods of cutting. Already the area of cut-over land in the ponderosa pine type of the Southwest equals that of uncut stands, and the time is fast approaching when virgin stands will play a minor role in forest management. Management plans must necessarily take into account the growth on cut-over lands; but as a rule present growth estimates deal only with current growth rather than with potential growth attainable under management. Thus far little effort has been made to bring increment up to specified standards through application of silviculture. The purpose here is to show what has been accomplished in that direction through experimental management in the Fort Valley Experimental Forest.

Response to cutting and to a dozen or more other influencing factors has been essentially the same on six relatively large experimental areas under study for 20 to 30 years. Increment per acre has been greatly accelerated, as compared with a similarly recorded virgin stand. But the period of high acceleration has lasted only 10 to 15 years, to be followed by a period of continuous decline which shows no signs of abatement after 30 years. On some areas the rapid rate of decline in net increment has been partially obscured by the entrance of "new" trees or "ingrowth"; but a separate account of the trees 12 inches and over at the beginning of the record shows that there has been no deviation from the downward trend.

Mortality is only one of the causes of the slow-down of increment. Decline due to lightning injury, mistletoe, paintbrush blister rust *(Cronartium)*, or squirrel damage all exert a retarding influence. Unexpected but easily explained was the discovery that apparently vigorous groups of immature trees tend to stagnate. Still more surprising, though equally understandable, is the rather abrupt decrease in diameter growth of healthy, isolated trees after encroachment of sapling thickets upon their root zone. Climaxing this array of depressing influences comes the realization that the trees which really grow are often the poorest in quality, meaning that a large part of the slender margin of board-foot increment is on paper only.

Analysis of periodic growth and mortality records of thousands of trees in all possible situations points to a simple remedy—frequent cutting. Silvicultural cutting at short intervals permits salvage of dying and deteriorating trees, and thus forestalls nearly all the usual mortality loss. But salvage is only incidental in a silvicultural program whose highest objective is rejuvenation of the living and potentially fast-growing trees of good quality by elimination of inferior competitors. There is an endless supply of inferior stems, and without improvement cutting they are continually growing into positions of dominance.

SECOND CUTTINGS IN FORT VALLEY EXPERIMENTAL FOREST

In order to test the theory of improvement by cutting, or more specifically, to determine whether the descending increment curve can be reversed by silvicultural cutting, two large sample plots in the Fort Valley Experimental Forest (S3 and S7, tables 11 and 12) have been logged a second time since 1938. A 5-year record of growth since the second cutting is available for the Wing Mountain plot (S3). So far as is known, this plot was the first ponderosa pine area to be logged twice under Forest Service supervision. The two sample plots, S3 of 480 acres (including S3A and S3B) and S7 of 160 acres, apparently are the only twice-cut areas in the West on which all trees have been measured periodically through the entire period between the first and the second cuttings.

The Wing Mountain Sample Plot—After the First and the Second Cuttings

A discussion of the first cutting on the Wing Mountain sample plot is given in the section on cutting in virgin stands. Increment and mortality during the ensuing 30 years are discussed in detail in the section on growth after partial cutting. A few important facts on the first cutting are here summarized to provide a background for the discussion of the second cutting.

After the First Cutting

1. Logging by group selection in 1909 reduced the original gross volume of about 12,000 board feet to 3,520, thus adhering closely to the two-thirds cut which was standard at that time.
2. Logging left approximately one-third of the area occupied by trees 8 inches d. b. h. and larger, mainly in dense and widely separated blackjack groups. Virtual absence of advance reproduction necessitated leaving many large, isolated yellow pines as seed trees. All but about 15 percent of the unoccupied area became stocked with pine, mainly in 1919 but with some representation of 1910, 1914, and 1929 classes.
3. Net annual increment per acre rose from 85 board feet during the first 5-year period to 115 in the second, then fell by irregular but persistently downward steps to 52 in the sixth and last period before the second cutting. The trend of the periodic net annual increment pointed toward a further decline to about 40 board feet in 1944 and 28 board feet in 1949.

After the Second Cutting

The area was logged a second time in 1939, 30 years after the first cutting. The average volume per acre had by that time increased to 5,939 board feet, of which 2,925 board feet was removed. Cutting and stand improvement left an average volume of 2,995 board feet per acre on the extensive plot of 456 acres. Because of divergent opinions as to how a stand should be marked for a second cutting, three methods were applied on approximately equal portions of the area *(75)*. Before proceeding with a comparison of the three methods, however, the aggregate effect on the whole area will be analyzed since many important effects are common to all three methods of cutting.

Table 31 shows the periodic annual increment and mortality of the Wing Mountain area for the first cutting cycle of 30 years as well as for the 5 years following the second cutting. Annual gross increment per acre fell from 88 board feet at the end of the first cycle to 70 following the second cut, but net increment rose from 52 to 67 during the same period. The actual improvement was probably greater than the 15 board feet indicated, because the trend of net increment was headed downward in 1939 (fig. 59). Assuming that if the second cutting had been postponed, annual net increment would have dropped to 40 board feet in 1944, the improvement can be placed at 27 board feet per acre per year.

TABLE 31.—*Annual gross and net periodic increment and mortality in board feet per acre on the Wing Mountain area, 1909–44 (measurements at 5-year intervals* [1]*)*

Item	Five-year periods						
	After 1909 cutting						After 1939 cutting (7)
	1	2	3	4	5	6	
Gross increment	96	134	110	103	85	88	70
Net increment	85	115	86	76	69	52	67
Mortality	11	19	24	27	16	36	3

[1] An area of 49 acres used in a mistletoe-control experiment in 1939 was eliminated from the 1944 computation because portions of the area were almost clear-cut. This reduced the acreage from 456 in the first six periods to 407 in the seventh.

The conditions which have affected increment are briefly reviewed in the following paragraphs.

The effect of removing trees which would have died if allowed to stand needs little comment. When marking anticipates mortality, however, it makes a large difference whether the marker looks ahead 5 years or 30 years. In this instance, a cutting cycle of at least 20 years and possibly 30 was assumed. Some trees were accordingly marked which if left would have lived 5 or 10 years and raised both gross and net increment during this initial period.

In addition to visibly declining trees, some large pines were cut in 1939 because they were thought to represent a high mortality risk. According to figure 23 the chances are that the average tree over 32 inches d. b. h. will return a net loss over a period of 20 years. Although removal of such trees could be expected to result in a net gain over a 20-year cutting cycle, this effect would not be registered during the first 5 years.

On a portion of the area a considerable number of growing trees of low value were cut in order to liberate smaller ones of good form; and clearly unmerchantable trees were cut or poisoned over the entire area. To a large extent the inclusion of such trees in the growth records prior to 1939 resulted in fictitious increment. Their removal has not always been offset by a volume gain of the liberated trees; but in the long run the volume balance will be restored, and low-value increment can be replaced by high-value increment.

Although mistletoe trees were cut mainly as a salvage measure, a higher objective was to prevent infection of the sapling stands which commonly surround such trees (fig. 58, *A*). Some blackjack groups were cut almost clean (fig. 58, *B*), to safeguard nearby saplings from infection.

The records show that when dense blackjack groups are opened up judiciously, increment of the group as a whole generally rises, but there may be exceptions to this rule. The most common exception is when the released trees are too small to register a large, immediate gain expressed in board feet. Poles, of course, show no board-foot increment until they reach the 12-inch class.

Reversal of the Downward Trend.—A concise appraisal of the effects of the second cutting is expressed by the graph in figure 59 which shows that a sharp downward trend was reversed into an equally sharp upward trend. The measures designed to convert a falling growth curve into a rising one were not concerned merely with immediate effects; if they had been, the rise of increment could have been much greater. Extension of the solid-line graph beyond 1944 indicates a continued rise for another 5 years. This extrapolation is based on the performance of all but one of six large plots after the first cutting. In view of the fact that most of the old trees have been cut and many blackjack groups opened up, there is reason to hope that at the end of 10 years the graph will level off instead of starting down as it did after the first cutting. There can be little doubt, however, as to the silvicultural desirability of a third cut in 20 years instead of 30.

What would have taken place had the second cut been deferred from 30 to 40 years was boldly prophesied by the descending increment graph. The same train of circumstances seems to justify extension of the graph along the course marked, "assuming second cut in 20 years." No actual measurements determine the direction of the broken line, however, and the assumption that it would run parallel to the solid line from the 30th to the 35th year is therefore subject to experimental check.

Present Condition of the Stand.—Can the remaining stand be built up to the production recorded in 1919? Eventually, but not until younger age classes come into the picture. The deficiency

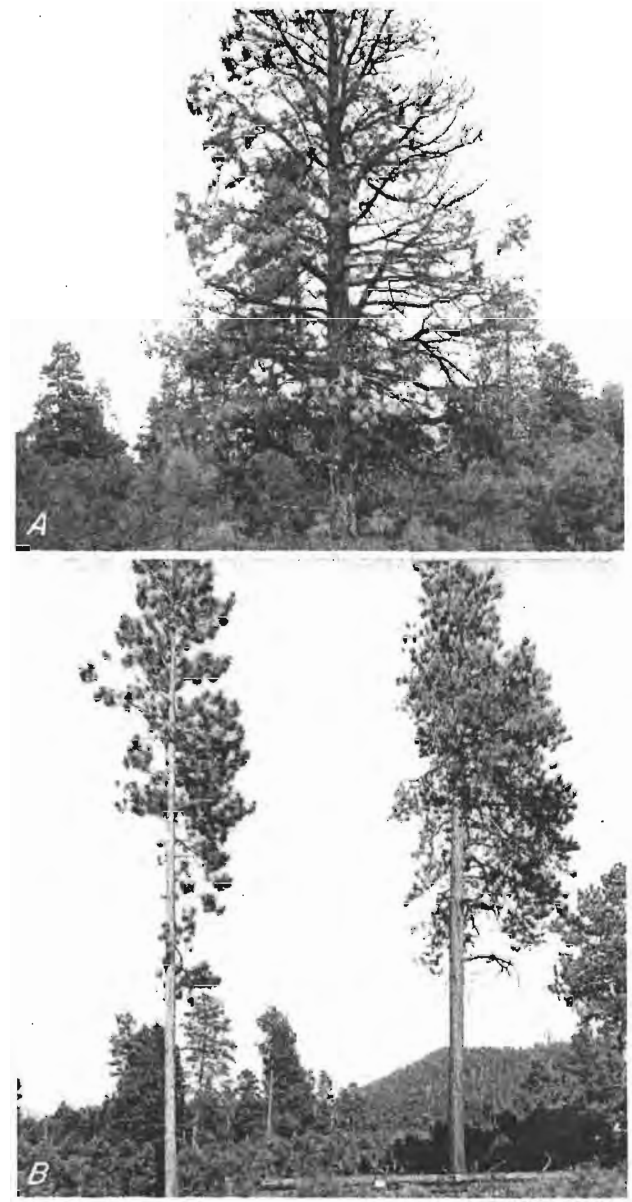

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FIGURE 58.—*A*, A fast-growing but unmerchantable mistletoe tree poisoned in order to check infection of young growth. *B*, All but two trees cut from a mistletoe-infected blackjack group.

of the present growing stock lies less in volume than in distribution. Scarcely more than one-fourth of the soil is being used by trees whose growth is measured in board feet. Both understocking and overstocking exist side by side. Mature groups are practically gone, though generally replaced by reproduction. Blackjack groups are, as a rule, still too dense; but some were almost clean cut in the war against mistletoe. Spaces as large as 5 acres bear only occasional trees as large as 12 inches d. b. h., though usually well stocked with saplings and small poles (fig. 58).

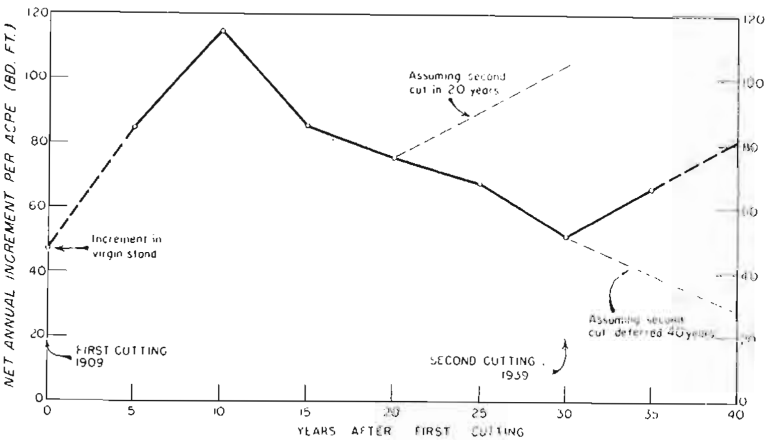

FIGURE 59.—Net annual increment of ponderosa pine by 5-year periods after 1909 and 1939 cuttings (broken lines by extrapolation). Wing Mountain area, Fort Valley Experimental Forest.

Mistletoe is the scourge of the stand. The second cutting accomplished much toward checking the spread of this pest, but it came 10 years too late. Many unmerchantable mistletoe hosts were poisoned a year or two in advance of the logging, but this also was too long deferred. By 1980, extensive areas now in the sapling stage will have grown into the pole stage, with dominants of small sawlog size. The future of these young stands will depend upon frequent cutting and stand improvement directed toward mistletoe control and maintaining a good growth rate in the best stems.

Methods of Cutting.—As previously stated, three methods of cutting were employed on subdivisions of the Wing Mountain area in 1939. The names applied to the three methods are essentially self-explanatory: (1) Favoring dominants; (2) favoring subordinates; and (3) salvage. The proportion of gross volume removed was: 57, 59, and 33 percent, respectively. Table 32, page 194, shows the numbers of trees and volume in the residual stands.

In the favoring-dominants method, the underlying philosophy is the belief that a good large tree is better growing stock than a good small tree. For obvious reasons, stems of poor physical condition, or of extremely low merchantability, or of such large size as to constitute a high risk, were cut. Since the average tree ceased

to yield net increment beyond a diameter of 32 inches (fig. 23), a flexible diameter limit of 30 inches was used for yellow pines; blackjacks representing a lower risk to lightning kill were left regardless of size, if otherwise desirable. Favoring dominants does not imply actual removal of all subordinates because it is assumed that the dominant is normally capable of holding its own in competition. It likewise does not imply that no dominants will be cut. In tree groups where several large dominants were competing with each other, one or more were removed for the good of the group as a whole.

The favoring-subordinates method is essentially equivalent to the old European practice of cutting from above. Its trial in the Fort Valley Experimental Forest was suggested by the observation that relatively small subordinate trees, even if the crown is small, respond vigorously when relieved of intensive root competition. Since a high proportion of such trees have clean boles, the advantage of encouraging their growth is obvious. In cutting under this method on the Wing Mountain area, dominants (almost invariably limby) were cut where their removal would liberate smaller trees of good bole form, free of mistletoe or other visible ailments. Even overtopped class D trees or those whose tops had been injured by porcupine were left if they were thought to have the making of one relatively clear log. Assuming healthy appearance, the three principal criteria in marking were, in the order named: (1) Bole, (2) spacing, and (3) crown. Other things being equal, blackjacks were favored over yellow pines and the latter were cut to a general diameter limit of 26 inches.

Salvage cutting aimed to remove all trees whose appearance indicated that they could not be expected to live 30 years. This included most lightning-struck trees, heavily mistletoe-infected trees, and a considerable number which for no known reason had dying tops or conspicuous dead limbs in the crown. Trees in this condition were of course also removed in the preceding two methods. For healthy trees of the yellow pine age class, the cutting limit was placed at 34 inches d. b. h. (4 inches higher than where dominants were favored, and 8 inches higher than in the favoring-subordinates method). Marking paid no attention to release of subordinates, although such release sometimes came about incidentally.

Differences between the three methods as applied were not always clear-cut. For example, more than half of the volume cut in the favoring-dominants and favoring-subordinates methods represents salvage, or trees likely to die during the cutting cycle. Both methods assume a profitable operation, which means that the volume must come mainly from relatively large trees. Both methods aim to practice good forestry, in conformance with the laws of silviculture and economics; disregard of these laws for the sake of adhering to a rule can lead to absurd results. Only in the salvage method was silviculture ignored, and here it was with the understanding that the salvage program is only temporary.

Results Under Different Methods of Cutting.—Table 32 shows the net increment under the three methods of cutting. Although increment follows roughly the course of residual volume, it is by no means proportional to such volume. Favoring subordinates with a margin of 328 board feet of growing stock yielded 9 board feet more in increment than favoring dominants; but the salvage cutting with 1,312 feet more growing stock led the favoring-subordinates cutting by only 2 board feet of increment.

TABLE 32.—*Increment and mortality following second cutting by three methods, Wing Mountain sample plot (S3), 5-year record (1939-44)*

Method of cutting	Area	Reserve stand per acre: Volume	Reserve stand per acre: Trees 12 inches and up	Average annual increment and mortality per acre: Increment (gross)	Average annual increment and mortality per acre: Mortality	Average annual increment and mortality per acre: Increment (net)
	A.	*Feet board measure*	*Number*	*Feet board measure*	*Feet board measure*	*Feet board measure*
Favoring dominants	122	2,477	6.4	60	0	60
Favoring subordinates	125	2,805	8.4	71	2	69
Salvage	160	4,117	9.8	77	6	71

The low increment of the salvage cutting area is especially noteworthy. With a reserve of 4,117 board feet per acre, it produced a net board foot increment of only 71 board feet, or 1.7 percent annually. In the first 5 years after the 1909 cutting, the entire area of 456 acres yielded 85 board feet per acre annually, or 2.4 percent on a reserve of 3,520 board feet. Obviously, the growing stock was not functioning as well in 1939-44 as it did following the 1909 cutting. The explanation is found mainly in the distribution of the growing stock over the plot area.

The growing stock on the salvage-cutting division, though exceeding that of the 1909 cutting by 600 board feet per acre, actually utilized less soil than did the 1909 growing stock. The 1909 cutting left numerous relatively large, widely spaced yellow pines for seed; nearly all were in a position to favor rapid growth. During the ensuing 30 years about a third of them died and most of those remaining had deteriorated to such degree that they were cut in 1939. It is estimated that large, more or less isolated trees in 1909 occupied 15 percent of the land area on S3; the second cut in 1939 reduced the area thus occupied to about 5 percent (fig. 60). Sapling thickets subsequently occupied most of the space vacated by seed trees. In 40 years' time this younger generation will contribute heavily to the increment, but for the time being its growth is not registered in board feet. Even for blackjack groups, the land area actually utilized was reduced through the death or cutting of border trees.

The Tree Group as a Basis for Comparison.—Because of the wide variation in growing stock, the best comparison of the three methods of cutting is by natural tree groups, and even here yield per acre is out of the picture because the area actually utilized

FIGURE 60.—The Wing Mountain area: *A*, before and *B*, after the second cutting. Reproduction followed the first cutting and was 20 years old at the time of the upper photograph. In addition to declining trees, yellow pines over 30 inches d. b. h. were cut.

by a group can only be approximated. This brings the basis of comparison down to a matter of response; in other words, how much is growth rate of a given group improved by cutting?

Some 50 blackjack groups on the Wing Mountain plot were analyzed to compare diameter and volume growth during the 5 years before and after the second cutting. Table 33 summarizes

F-427515

FIGURE 61.—Blackjack group (1a) cut to favor dominants. Five smaller trees (stumps designated by X) were cut to stimulate diameter growth of two largest stems (28 and 27 inches d. b. h.). In both cases, 5-year diameter growth increased from 0.3 inch before cutting to 0.5 inch after cutting.

the growth record for three representative groups under each cutting method. Volumes are from Hornibrook's table *(29)*; because of their sporadic occurrence, mortality and "ingrowth" were both omitted in computing volume increment. Figures 61, 62, and 63 show three of the groups listed in table 33 as they appeared immediately following the 1939 cutting. They further illustrate how the three cutting methods differed in application.

Diameter growth has in all cases shown a consistent response to cutting (table 33). In seven groups where one or more trees were removed, there has been a gain in average diameter growth. This is true of the six groups cut to favor either dominants or subordinates as well as the one group (48b) where three trees were removed under the salvage method. In contrast, diameter

F-423665

FIGURE 62.—Blackjack group (18) cut to favor subordinates. Three outside dominants 18 to 21 inches d. b. h. (stumps indicated by white cards) were cut to liberate smaller subordinates of better form. Two additional interior dominants should be taken out in the next harvest cut. Average 5-year diameter growth increased from 0.69 inch before cutting to 0.81 inch after the second cut.

F-427517

FIGURE 63.—Under the salvage method, no trees were removed from this blackjack group (3B-1). Average 5-year diameter growth declined from 0.60 inch before cutting to 0.42 inch after cutting.

growth declined in both groups (3B-1 and 48a) of the salvage area where no trees were removed.

In terms of total volume increment of the group, response has been more variable. Of three groups on the favoring-dominants cutting, two have registered an increase since cutting while the third has declined (table 33). On the favoring-subordinates cutting, one group has increased in volume increment and two have dropped slightly. All three groups on the salvage cutting showed a substantial drop in board-foot growth after the second cutting.

TABLE 33.—*Response in diameter and volume growth to three methods of second cutting, by individual blackjack groups. Wing Mountain Sample Plot. 1934 to 1939 (before cutting) and 1939 to 1944 (after cutting)*

Group designation	Stand before cutting (1939)			Stand cut (1939)		Average 5-year diameter growth [3]		Total 5-year volume growth [4]	
	Large poles [1]	Saw-timber trees [2]	Total volume [2]	Saw-timber trees	Volume	Before cutting	After cutting	Before cutting	After cutting
	Number	*Number*	*Board feet*	*Number*	*Board feet*	*Inches*	*Inches*	*Board feet*	*Board feet*
FAVORING DOMINANTS									
3 (a and b)	7	11	2,008	1	234	0.68	0.70	300	308
1a	5	19	6,604	5	2,046	.50	.62	467	382
12	1	22	8,690	4	2,433	.60	.94	665	843
FAVORING SUBORDINATES									
16	4	19	4,734	5	1,725	0.79	0.95	625	615
18	5	10	1,717	3	777	.69	.81	254	207
36	0	27	11,683	10	5,073	.47	.84	634	783
SALVAGE									
3B-1	4	17	4,384	0	-------	0.60	0.42	469	311
48a	8	12	4,251	0	-------	.75	.64	412	368
48b	9	11	4,368	3	1,863	.48	.52	243	202

[1] Trees 7.6 to 11.5 inches d. b. h.
[2] Trees 11.6 inches d. b. h. and larger.
[3] All trees 7.6 inches d. b. h. or larger.
[4] No allowance for mortality and ingrowth.

The response shown by two of the groups is noteworthy. For group 12 (favoring dominants) volume growth increased 27 percent after 28 percent of the growing stock had been removed. For group 36 (favoring subordinates), volume increment increased 24 percent, following removal of 43 percent of the growing stock. This rise in group increment after a substantial part of the growing stock was taken out strikingly demonstrates the benefits that can be derived from frequent release cuttings in crowded groups. Lack of a similar trend in groups 3, 1a, 16, and 18 is due in part to the greater number of pole-size trees present in the group. These smaller trees are aided by the cutting, but acceleration in diameter growth is not reflected in volume growth of the entire group because the pole stems are too small to be credited with a board-foot volume.

Application in Cutting Practice.—Both the favoring-dominants and the favoring-subordinates methods are effective in preventing group stagnation and in arresting the downward trend of diameter growth and increment. Where cutting is confined to the salvage of dying trees, however, groups will do well merely to hold their own.

From the standpoint of sustained quality increment, the favoring-subordinates method appears to offer the most far-reaching opportunities. It recognizes that large dominants as a class are inferior in quality and inefficient growers, and that large stems must be the financial backbone of the harvest operation. It removes large, low-grade trees, regardless of vigor, if they are interfering with the growth of smaller trees of good form, and it maintains a larger number of small stems in the group to serve as recruits for future yields.

Strict adherence to a favoring-subordinates or a favoring-dominants rule is neither desirable nor practical in most cut-over stands. In many instances the available subordinates are not suitable to leave; they may be of poor form, defective, or mistletoe-infected. It may then be preferable to leave a dominant, especially if it is of the better type. Moreover, enough relatively large trees must be left to provide for the next cut. In practice the two methods tend to merge into one another.

A review of results under the three methods of cutting described and analyzed in the foregoing pages leads inevitably to one conclusion: there is no inflexible formula for marking in cut-over stands. In some spots best results can be obtained by favoring dominants, in others by favoring subordinates, and in still others (temporarily) by merely salvaging declining or defective trees. In other words, marking resolves itself into the selection of individual trees, each on its own merits, not on the preconceived merits of a class. Over and over again, the marker is confronted by the problem of choosing, not an ideal tree but the best available in a group where perhaps all are poor or mediocre according to customary standards. The choice is not easy, for it involves many factors—age, size and character of bole, spacing, condition of crown, disease, injuries, probable response to release, and probable effect on neighboring trees if left. An effective coordination of principles and practice has found expression in a modified form of selection cutting called "improvement selection." This method, developed from experience on the Wing Mountain area, has been described and discussed on pages 59–65 and 104–107. It is equally applicable in virgin and cut-over stands.

Economic Aspects of Ponderosa Pine Management

The business of producing lumber from virgin stands is not concerned with costs of growing the crop. If the operator can sell his product for more than the cost of logging and manufacture, plus whatever he must pay for stumpage, the enterprise is considered financially sound. In the case of private owners who have paid interest and taxes on their holdings during a long period of years, the cost may approach that of growing a crop, but it is still not actually a timber-production cost.

After the mature timber has been cut, the expense of regrowth immediately assumes importance. One policy is to leave the cut-over land without further care except fire protection, in the hope that nature will in the course of time produce enough to warrant one or more harvests. Another policy is to step in and apply those measures deemed necessary to insure yields commensurate with site capacity. This is silviculture. Progressive decline of increment in cut-over stands after their tenth or fifteenth year (table 24, p. 92) is a sample of what may be expected under the first policy. Results after a second cutting on the Wing Mountain area (figure 59) give an inkling as to what is possible with dynamic silviculture.

A long-range silvicultural program does not necessarily contemplate expensive cultural measures. The most essential work can usually be done in the course of commercial cutting, if begun during the first harvest of the virgin stand. To what extent stand improvement can justify itself financially depends on circumstances; certainly such inexpensive measures as poisoning inferior dominants and pruning isolated poles will pay out. Under a continuous silvicultural program, regulation of stand density will reduce artificial pruning to a supplementary measure, adding finishing touches to Nature's scheme of self pruning. Even the least expensive cultural measures may be prohibitive for the private owner who lacks capital for long-term investment, but not so the simple silvicultural measures which can be applied in commercial cutting. On public lands self-liquidating cash outlays are entirely in order because public forest agencies are less concerned with immediate income than with the assurance of a dependable source of wood products. Public forestry must not lose sight of costs; but, on the other hand, costs must not be allowed to stand in the way of permanent benefits. Judicious use of the Knutson-Vandenberg Act in the national forests can return manyfold the sums expended on stand improvement.

SILVICULTURE LOWERS PRODUCTION COSTS

Major items in the future cost of lumber production are (1) growing the timber, (2) logging, (3) transportation of logs to the mill (or of lumber sawn in the woods to distributing points), (4)

milling, and (5) shipping. Abnormal costs in any one of these items may wipe out the margin between profit and loss.

The Federal Government has spent millions of dollars on access roads to make possible the utilization of less accessible timber. Such measures are justified in time of war and other national emergencies, but after the roads have been built timber yields should bear a fair share of the cost of maintenance. Here the management of the cut-over lands assumes great importance. A timber access road will obviously come nearer to being self supporting if the area which it serves yields annually 2 million board feet of lumber worth $50 per thousand than if it yields only one-half that volume valued at $30 per thousand.

Good silviculture on well-selected areas can, to a large extent, obviate the necessity for going into out-of-the-way places for logs. Assuming, for example, that a production goal of 500 million board feet per year might be set up for Arizona and New Mexico, such a volume could be grown more economically on 5 million acres of the best and most accessible sites than on the entire 10 million acres sometimes classed as commercial timberland, but known to include large areas which are economically submarginal because of location, topography, poor site, or past abuse. The matter of log-trucking alone can give the more accessible lands a wide margin of advantage. If, for example, it costs on the average $4 more per M to truck logs to the mill from areas of low accessibility, then, other things being equal, stumpage on the more accessible areas is really worth $4 more per M. Looking into the future, this difference will usually justify the building up of a first-class growing stock on the most accessible and most productive lands.

Unfortunately, sizable areas of accessible ponderosa pine land have been so overcut and otherwise abused that restoration of a productive stand will require great expense and years of delay. Because of high costs and uncertain results, artificial reforestation will play a minor role. But where 50 normal and fairly well-distributed saplings or poles per acre remain, a stand of commercial possibilities can be built up by artificial pruning. This will cost only one-tenth to one-fifth of the cost of planting.

Labor normally constitutes nearly half the cost of finished lumber at the mill. Considering waste, much more labor is required to produce 1,000 board feet of lumber out of knotty and defective logs than out of clear, sound logs, and the finished product of the latter brings many times as much money. In a well-organized forestry program, it costs no more, and probably less per M, to grow logs of high grade than of low grade.

VALUES IN RELATION TO LOG GRADES

The logs of different trees and in different parts of the same tree vary greatly in the grades of lumber they yield in the mill. Logs in standing trees are graded mainly on the number, size, character, and arrangement of knots. Local grading systems for ponderosa pine developed independently, in California, the Pacific Northwest, and the Northern Rocky Mountain region, were harmonized and combined in 1939 into one standard system *(87)*.

Since, however, two areas referred to in this monograph were previously classified as to log grades by the Pacific Northwest rules, that classification is here retained. Briefly, this system recognizes six grades: *Grade 1* is practically surface-clear; *grade 2* permits a few small sound knots; and *grade 3* many of the same class. Going down the scale, number and size of knots increase, and in the lowest grades there may also be "black" or loose knots. Bruce *(12)* has classified standing trees according to the grades of the first two logs, from the ground up. Thus, a tree which has a grade 1 butt log and a grade 3 second log is classed 1-3, and one whose corresponding logs are in grades 5 and 6 is classed 5-6.

In the preparation of figure 64 by Mason and Bruce, consulting foresters, in cooperation with the Pacific Northwest Forest and Range Experiment Station, the logs from a large number of trees in a logging operation on the Coconino National Forest were followed through the mill in 1937 and the actual output of each tree tallied by lumber grades. The product was then converted into dollar values for the average tree in each of 11 classes representing different combinations of log grades. It should be understood that the entire log-content of each tree was graded; only the first two logs are used in the classification because they have been found to provide a good index to the entire tree.

The term "marginal value" expresses the difference between the cost of converting a tree into lumber and the selling price f. o. b. the mill. Assuming that the operator is purchasing timber on the stump, marginal value is the price he can pay without losing money. Values below the zero line indicate that the cost of logging, trucking, milling, and other conversion costs exceed the selling price; in other words, the marginal value is negative. A rise in lumber prices or a lowering of production costs would tend to lower the zero line, and thus increase the marginal values; contrary trends in either prices or production costs would have the opposite effect.

The graphs in figure 64 bring out several relationships of silvicultural significance: (1) In all log-grade classes the marginal value rises with tree diameter, reflecting mainly a decreasing labor cost; (2) the upper classes, that is, trees containing a grade 1 or a grade 2 butt log, rise more rapidly and attain higher ultimate values than the lower classes; (3) classes in which the butt log is below grade 3 remain below the zero line until the tree diameter reaches 38 inches.

Soaring prices of both lumber and labor have upset prewar value relations. But high stumpage prices indicate much higher marginal values than those prevailing before the war. The difference is probably more in the lower than in the higher grades; in other words, if a new set of graphs were drawn, there would be less spread between the 1-1 graph and the 6-6 graph, and the zero line would be near the foot of the chart. These relationships represent what might become a permanent condition without silviculture, when all lumber might be so scarce that the lowest grades would command prohibitive prices. There could be no surer way

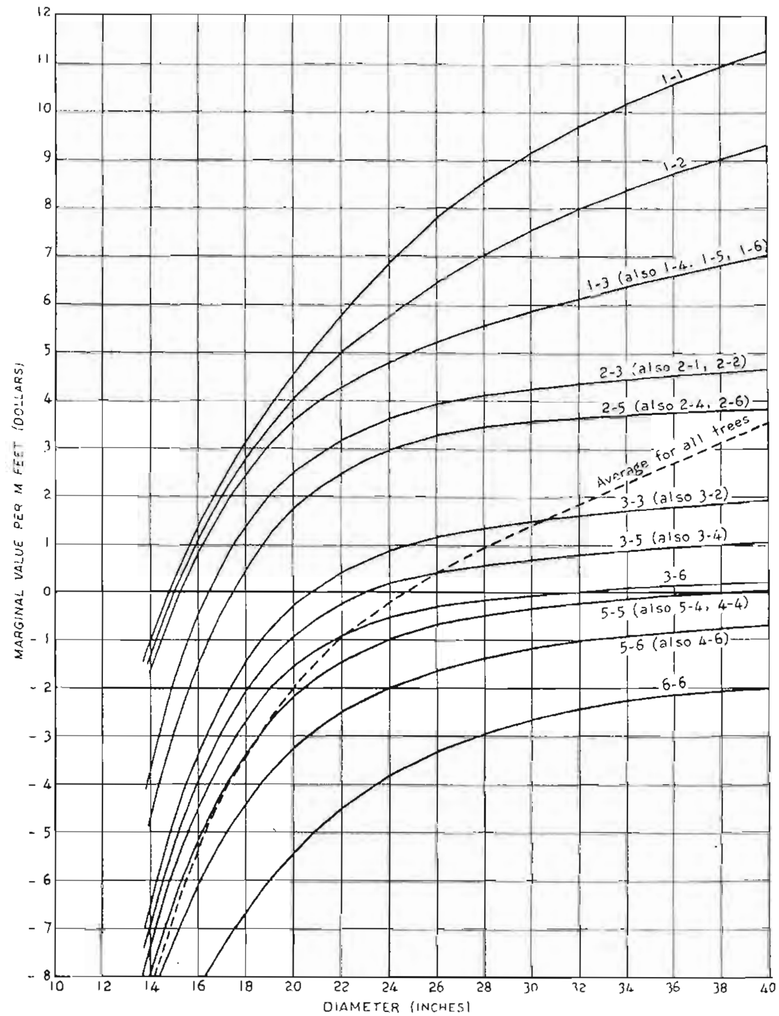

FIGURE 64.—Marginal values per M feet (shipping tally) on the stump for trees of various log grade classes as related to tree diameter. Only the butt and 2d logs need be considered in the determination of the log grade, or marginal value class. (By Mason and Bruce in cooperation with Pacific Northwest Forest and Range Experiment Station.)

of driving the lumber industry out of business. The goal of forestry must be to provide an abundance of good lumber at reasonable prices to the consumer.

As a permanent pattern, figure 64, perhaps with the zero line considerably lower, represents a desirable relationship between tree grades. A program which would seek ultimately to eliminate trees of the three lowest classes (butt logs below grade 3) is worth striving for, not only from the standpoint of profit to the grower and operator, but also from the standpoint of public service. As forest management undergoes the inevitable transition from harvesting natural stands to the *growing* of timber, a preponderance of low-grade logs will become a sign of professional incompetence.

Figure 64, however, does not tell the complete story since log-grade class can be expected to improve as trees increase in size. A butt log grading 2 at 14 inches d. b. h. will usually improve to grade 1 by the time the tree has grown to 24 inches. A rise in grade of the butt log in trees of the lower value classes is also possible, but the chances that a grade 6 butt log will ever attain grade 1 or even grade 3 without artificial pruning are extremely remote. The smaller the tree, however, the greater is the possibility that it may rise to a higher value class, and this fact together with the higher increment percent should place a premium on stems of relatively low diameter as members of the growing stock.

Conversion of a low log-grade stand into one of high log grades is a long, painstaking process. It cannot be accomplished by a single cutting, and seldom in less than three. The Wing Mountain area is an example fairly typical of the Southwest. A classification of logs in the standing trees in 1939, 30 years after the first cutting, is presented in table 34. Less than 3 percent of the logs were in grades 1 and 2 and 83 percent were in grades 5 and 6. The few grade 1 and grade 2 logs were mainly the butt logs of large yellow pines or of small subordinates left in the 1909 cutting. Blackjacks over 20 inches d. b. h. were almost invariably of the limby type found in open-grown or border trees which seldom produce a clear log even at 40 inches d. b. h. The stems which have the best chance to produce a surface-clear butt log are usually those in the interior of groups. The answer to the grade problem is not so much artificial pruning as dense stocking and frequent commercial cutting, always aiming at removal of inferior stems to make room for good ones.

TABLE 34.—*Log grades on the Wing Mountain sample plot, in standing trees 30 years after the first cutting (classified* [1] *by W. G. Thomson, 1939, just before the second cutting)*

Log grades	Number of logs	Percent of total number
1	86	0.5
2	387	2.2
3	1,943	11.0
4	646	3.7
5	7,849	44.5
6	6,730	38.1
Total	17,641	100.0

[1] Pacific-Northwest grading system, as modified in Region 3, S-SALES POLICY-Utilization letter of February 17, 1939.

THE ECONOMIC FUTURE OF PONDEROSA PINE LANDS

Whether it will pay financially to *grow* timber in the ponderosa pine type of the Southwest is a question which cannot be answered at present. The answer depends on many circumstances, first among which are future lumber prices in relation to cost of production, attainable timber yields, and the possibility of greatly raising the average quality above present standards. Considering present trends of demand in the face of a dwindling supply of accessible virgin timber over the country as a whole, it seems safe to predict that future lumber prices will be fixed by the cost of production. Offhand it might be concluded that ponderosa pine grown in the Southwest will not be able to compete with conifers in regions of more rapid growth; but other factors such as low fire hazard, easy logging, and superior quality may offset this handicap. Since local markets will likely be able to absorb the entire regional output, home-grown timber will enjoy a substantial advantage in freight over competing timber from distant regions.

Whatever may be the final answer, one thing is certain: there are in the Southwest some 4 or 5 million acres of ponderosa pine, mainly in public ownership, whose greatest direct commercial value lies in timber production. Livestock and big game, as well as certain other types of wildlife, exact a toll from the forest through injury of the trees. Unless these animals are carefully controlled and managed, any revenue derived from them may be far outweighed by a decrease in timber yields.

It is universally recognized that ponderosa pine forests have great value as watersheds and recreational areas. The private owner may realize little direct benefit from these resources, but nevertheless they are important public assets which should be taken into account in reckoning the returns from a forest. There need be little conflict between the utilization of these resources and full utilization of the timber crop. Admittedly, some nature lovers deplore timber cutting under the mistaken apprehension that any and all logging is destructive. Sportsmen, on the other hand, advocate heavy cutting in order to increase the supply of feed for game, and too often they encourage unlimited propagation of game animals, notwithstanding inordinate damage to the trees.

Timber management must demonstrate by example that ponderosa pine forests can be logged without creating eyesores or damaging watershed values. Overcutting, ruthless logging, and slovenly slash disposal are revolting to an esthetic nature; but they are also a menace to the forest itself. Admittedly, the first cutting in decadent stands presents problems because of the enormous volume of waste material which, left in the woods, is not only unsightly but also a fire menace. Silviculture, improved utilization, and time will correct this difficulty. Silvicultural measures which strive to restock large openings and open up dense groups will at the same time promote penetration of water and render the forest more attractive. Openings sufficient for a sizable game population will never be lacking. Dynamic timber management which strives to build up soil, water resources, and esthetic qualities along with timber yields will be rewarded by public good will; and it will also pay dividends in greater monetary returns from timber products.

THE BUSINESS OF TIMBER GROWING

Timber growing for profit is usually thought of as strictly a private enterprise. Private industry is more directly dependent on current income, but public forestry, too, should in the long run be profitable. The indirect benefits—watershed, grazing, and recreation—are often heavily relied on as a means of justifying public forestry. This may be necessary for submarginal timberlands, but not with the forest areas best suited to commercial timber production. On such lands, timber growing is capable not only of paying its own way but also of carrying much of the load imposed by watershed protection, recreation, and other public benefits. European states, cities, and municipalities have for many years depended on the yield of publicly owned forests as a continuous source of revenue.

Financial success in forestry calls for the same scientific management and attention to details that is required in other branches of agriculture. The timber manager who specializes in logging and selling but neglects silviculture is like a farmer who keeps up to the minute on markets but neglects to cultivate his corn or keep the cows out of his wheatfield. Management plans whose felling budgets and cutting cycles are based on natural growth without silvicultural aids are merely programs of orderly liquidation.

Fostering the principle of sustained yield without specifications as to volume and quality production may be conservation, but it will not put forestry on a self-supporting basis. Successful timber management must pay attention to every detail from natural regeneration all the way to logging and marketing. Whether or not the grower is also a lumber manufacturer, his practice must be based on the knowledge that a well-stocked stand will produce more and better logs than one which is only partially stocked, that grade 1 logs are worth perhaps 10 times as much per M as are grade 5 or 6 logs, and that it requires no more growing space or moisture to grow the better grade of log.

Because of a low rate of increment, ponderosa pine in the Southwest requires a large acreage to continuously support a commercial operation of any magnitude. Heavy initial cutting and deficient restocking aggravate this situation. Even in the national forests there are few cut-over units as large as 100,000 acres which, under extensive management, can be expected to average over 50 board feet per acre annually during the next 50 years. Merely holding these lands under protection will not greatly increase the volume because increment declines rapidly after the first 20 years. What is needed to stimulate growth is silvicultural

cutting repeated as often as economic conditions permit. During the process of rehabilitation, virgin stands or old-growth reserves in cut-over stands may bridge the gap but when the old timber is gone, growth alone stands in the way of depletion. From every viewpoint, both economic and silvicultural, future cutting programs should embrace both virgin and cut-over stands, with a view toward putting the largest possible acreage into good growing condition in the shortest time.

A Program for Better Ponderosa Pine Management

The ponderosa pine type in the Southwest is America's near-desert forest; this fact determines its composition and growth habits, and must never be forgotten in its management.

Soil moisture is the critical factor; the annual precipitation is generally under 25 inches and evaporation is high. Forests are able to persist through wide spacing, which enables individual trees to draw upon the moisture of a relatively large soil mass. Young groups are often extremely dense, but as the trees increase in size, competition for the limited supply of water becomes intense, with the result that many individuals succumb. This struggle for existence goes on throughout the life of the stand—first saplings, then poles, then trees of log size, and finally veterans drop out, but always the demand of the survivors exceeds the limited water supply. Mature groups stagnate almost completely, except for members whose roots have access to open spaces, and in this stage the groups sooner or later become decimated by drought or indirectly by bark beetles, which prefer stagnant stands. Under these circumstances salvage cutting accomplishes little toward arresting further decline. A major objective of silviculture must be to assist nature in making the necessary adjustments to moisture conditions, thereby forestalling stagnation of growth and the appalling waste which is inevitable under the law of "survival of the fittest," a phrase which from the standpoint of lumber production means survival of the unfittest.

Light is abundant throughout the interior type, and becomes deficient only when obstructed by the crown canopy. A limited amount of screening is essential for the development of saw-timber form. Pine seedlings demand direct solar radiation through at least half of the day, and this is true also of the upper crown of larger trees. As a general rule it may be said that free overhead sunlight is necessary, but so also is side shade. Overhead sunlight stimulates height growth; side shade retards branch growth and is the first step in the natural pruning which produces clear boles.

Silviculture must take into account reaction to both light and moisture. Close spacing in youth is necessary to develop good bole form and to promote natural pruning; later in life dense stands should be opened up in order to relieve competition for moisture. The opening process should be gradual, seeking to keep pace with increasing moisture demands while still retaining the desired side shade. Lack of side shade in open-grown trees and outside members of groups results in limby boles of high taper, in contrast with the clean, cylindrical boles developed under the influences prevailing within tree groups.

Growth is related more to root development than to crown size. Large-crowned trees usually grow rapidly because they started

more or less in the open where abundant soil space permitted extensive root spread. The large crown followed rather than preceded this root development. Encroachment upon the root zone of such trees by younger age classes results in a decline of growth, notwithstanding the persistence of a large crown. On the other hand, small-crowned intermediates, if still healthy and under about 20 inches d. b. h., respond vigorously when fully released by cutting. In the Southwest, a crown-height ratio of 30 to 40 percent is ample for trees up to 30 inches d. b. h.; larger crowns result in excessive water use and place large volumes of wood upon useless limbs at the expense of the bole.

Virgin stands are predominantly overmature. There is a general deficiency of the younger age classes which alone can be counted as effective growing stock. Replacement of old with relatively young age classes cannot take place all at once but it should be a constant objective in silviculture. After a century of management, trees over 200 years old will become rare. Age classes will range from seedlings to young yellow pine, with about six intermediate stages decreasing numerically with advancing age.

National-forest cutting in the ponderosa pine type has almost invariably employed some form of the selection system. The heterogeneous character of virgin stands compels application of the selection principle. Whether, after many years of management, there will be a swing toward even-aged stands is doubtful because natural regeneration is, with rare exceptions, so slow and uncertain that conversion into even-aged stands would be attended by grave risks and long periods of soil idleness. Moreover, young trees need the side shade of older ones in order to develop saw-timber form.

Experimental management on large sample plots in the Fort Valley Experimental Forest has made use of four forms of selection and one of scattered-seed-tree cutting. Viewed from the present vantage point, all the older selection cuttings, dating from 1909 to 1924, have four common shortcomings: (1) They left too many large trees of the older age classes; (2) they cut too heavily among subordinates of the mature class; (3) too many wolf trees of all age classes were left; and (4) immature groups were not opened enough to prevent stagnation. The scattered-seed-tree method clearly removed too much of the young growing stock. In 1941 and 1942 a modified form of selection, called improvement selection, undertook to correct the deficiences of earlier selection methods. It aimed at a superior growing stock, but placed more stress on tree form and spacing than on volume per acre.

Increment on all the old cutting areas has been disappointing. Periodic growth has followed a uniform pattern—fairly high the first 10 to 15 years, then a rapid and persistent decline (table 22). This experience has added a fifth corrective measure to the four listed in the preceding paragraph, namely short cutting cycles. In order to salvage declining trees and encourage continuous growth in groups, the interval between cuttings should be not over 20 years and preferably less, especially between the first and the second cuttings. The 1941 improvement selection cutting (S9) shows, in the first 5 years, a marked increase in rate of growth (table 26, p. 100); but groups are still overstocked, a condition which the second cutting, in 10 years, will remedy. Subsequent cuttings at 20-year intervals are expected to ward off much of the mortality, stagnation, and general decl.ne that has characterized earlier cuttings.

Large mature trees, especially those over about 24 inches d. b. h., contribute heavily to mortality, deterioration, and slowdown in growth. Assuming, for example, a residual volume of 6,000 board feet per acre, the gross increment in 20 years at Fort Valley is nearly twice as high for a growing stock averaging 16 inches d. b. h. as for one averaging 24 inches (table 19, p. 81). The mortality rate in the Southwest climbs rapidly as diameter passes the 24-inch class; at 31 inches d. b. h., average mortality balances growth so that the average net increment becomes zero (fig. 23, p. 83). Large and old trees are most susceptible to wind, lightning, and bark beetles; the larger the tree the greater is its handicap in the struggle for moisture. Large, healthy trees of good form and in isolated positions, even though mature, have a place in managed stands; but if dominating smaller trees of good form the large ones should be removed.

Damaging agents, of which there are no less than 12, take a combined toll estimated at 55 percent of the possible increment in the Southwest. Some, such as fire, disease, insects, rodents, deer, and domestic grazing animals, call for aggressive control measures commensurate with their activity in specific cases. As a long-range program, good silviculture can go far toward lowering losses or aiding corrective measures where fire, lightning, wind, mistletoe, bark beetles, and heart rot are concerned. The simple expedient of discouraging overdevelopment of crowns can greatly lower the volume of slash and thus the fire danger. Elimination of limby dominants and others of poor form while still young will not only lower the slash hazard but also help ward off heart rot. General reduction of age and size of trees will lessen the mortality from lightning, wind, and bark beetles. Keeping groups open enough to maintain vigorous growth may be expected to make the trees less susceptible to bark beetles, and at the same time develop root systems resistant to windfall. Short cutting cycles permit the removal of mistletoe hosts and the salvage of stems likely to die during the period between cuts. As standing snags, such stems invite lightning fires; as down material, they propagate heart rot and add to the volume of highly inflammable fuel.

An example of the possibilities of low-cost protection by timely action is afforded by the mistletoe situation in northern Arizona. When the wave of reproduction came in 1919, seedlings in infected stands were exposed to showers of mistletoe seed from overstory trees. Second cuttings and the poisoning of unmerchantable host trees (at a cost of about $1 per acre) within 10 years could have removed the major sources of infection. When whole groups of young growth are once infected, mistletoe eradication becomes expensive, although partial control may be effected by commercial cutting directed toward that end.

Ingrowth, or the advance of poles into merchantable diameters, must be the means by which eventually the growing stock is maintained and augmented in the face of mortality and cutting. Virgin ponderosa pine stands are generally deficient not only in trees of small log size but also in poles and often in saplings and seedlings. On some of the Fort Valley management areas, notwithstanding deficient reproduction at the time of cutting, stems which entered the 12-inch class after the records began were at the end of 20 years contributing as much increment as the original trees 12 inches and over (table 24). It follows that all possible precautions should be taken to preserve young growth in virgin stands and to encourage its development after the first cutting.

Timber-stand improvement, involving mainly the liberation and pruning of promising poles, is a direct means of building up growing stock of desired quality. But costs, even if ultimately self-liquidating, tend to put a damper on extensive application of measures involving a large cash outlay. Although some handwork is necessary and justifiable, management should be so conducted that pruning will be accomplished largely by natural means and release of crop trees by commercial cutting. Supplemental measures which may be expected to pay big dividends are pruning the better type of isolated poles and poisoning low-grade wolf trees when dominating smaller trees of good form. Pruning should preferably begin while the stem is under 8 inches d. b. h., but wolf trees, whether merchantable or not, may well be left until they have exerted the desired thinning and pruning effects among smaller stems.

Natural regeneration, the original source of ingrowth, assumes an increasingly important role as cutting progresses through a series of cycles. Advance reproduction simplifies the first cutting but does not eliminate the reproduction problem. Logging damage and group cutting create blank spots which if not promptly restocked will sooner or later count heavily against increment. Successive cuttings on the same area tend to increase the number and size of denuded or poorly stocked openings.

The earliest Fort Valley cuttings were in stands devoid of or deficient in advance reproduction. Abundant regeneration in 1919 restocked all but one of the experimental management areas; method of cutting was in all cases subordinate to weather and protection. The spots on which the 1919 seedlings failed or were subsequently destroyed generally remain unstocked.

Adequate natural regeneration can be favored, but not assured, by providing seed trees, a suitable seedbed, and protection against damaging agents. Every advantage which Nature concedes must be capitalized to the fullest extent possible. On many areas, timely regeneration will call for control of seed-eating rodents, including tree squirrels, subjection of herbaceous vegetation by regulated grazing or by mechanical means, and control of browsing animals, whether domestic livestock or big game. Exclusion of fire is obviously necessary. Here again, grazing can be put to good silvicultural use if directed toward reduction of herbaceous vegetation.

Management is assumed to begin with harvest cutting; but on nearly all ponderosa pine cut-over lands silviculture is marking time, awaiting a second cut. Even with the most painstaking application of silvicultural principles in the first cutting, the results fall far short of what is desirable because virgin stands rarely contain the representation of young age classes and quality classes required for an efficient growing stock. Briefly stated, the timber marker cannot leave the right kind of growing stock if the necessary elements are not there to leave. Assuming good regeneration, repeated cuttings can gradually bring about a conversion from predominantly old to predominantly young age classes, and from a low quality stand to one of high quality. But a second cutting and even a third or fourth may not suffice to accomplish complete rehabilitation. The immediate objective is not necessarily a so-called "normal" growing stock, but merely a sufficient range of diameter classes to insure continuous cutting and a high level of increment.

Quality will inevitably decline with the removal of old age classes, until such time as silviculture can put quality into the younger classes. Aside from what can be accomplished by limited artificial pruning or release, improvement of quality must be brought about largely through commercial cutting—continually eliminating inferior stems in favor of better ones, and always bearing in mind that as the trees of a well-stocked stand increase in size their number must be reduced from time to time to maintain a satisfactory growth rate and avoid destructive competition.

Second cuttings in ponderosa pine have generally been too long delayed. Twenty years should be the maximum period between the first and the second cuttings. Improved growth and quality of the remaining stand, rather than salvage, should be the objective. Removal of 33 to 59 percent of the volume on three subdivisions of the Wing Mountain area, 30 years after the first cut, resulted in a substantial rise of net increment on all three units. On areas where the first cutting left too low a volume for an economic recut in 20 years, road building and concessions in stumpage rates are warranted in order to promote the necessary silvicultural betterment. Even in light stands the remaining blackjacks commonly occur in groups too dense for good growth; in such cases, removal of one or more large stems is usually followed by a pronounced rise in the increment of the group as a whole. Since the largest trees are almost invariably of inferior form, improvement in quality outweighs the increased volume production. It is not volume of growing stock that counts so much as its character and distribution.

Profitable timber growing is inseparable from large yields and superior quality. Instead of 50 board feet per acre, it is possible to grow 150 to 200; and instead of a log crop which is 90 percent in the lower grades and only 10 in the higher, good silviculture can reverse the order. Contrary to prevailing impressions, attainment of these objectives does not involve large expenditures of money; it does call for time, persistence, and strategy. Examples of ponderosa pine stands which have been brought to a high state of production through the conscious efforts of man are lacking. Research must pave the way to their development. The major problem is no longer how to harvest old timber, but how to grow new crops which should become available 50, 100, or 200 years hence.

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