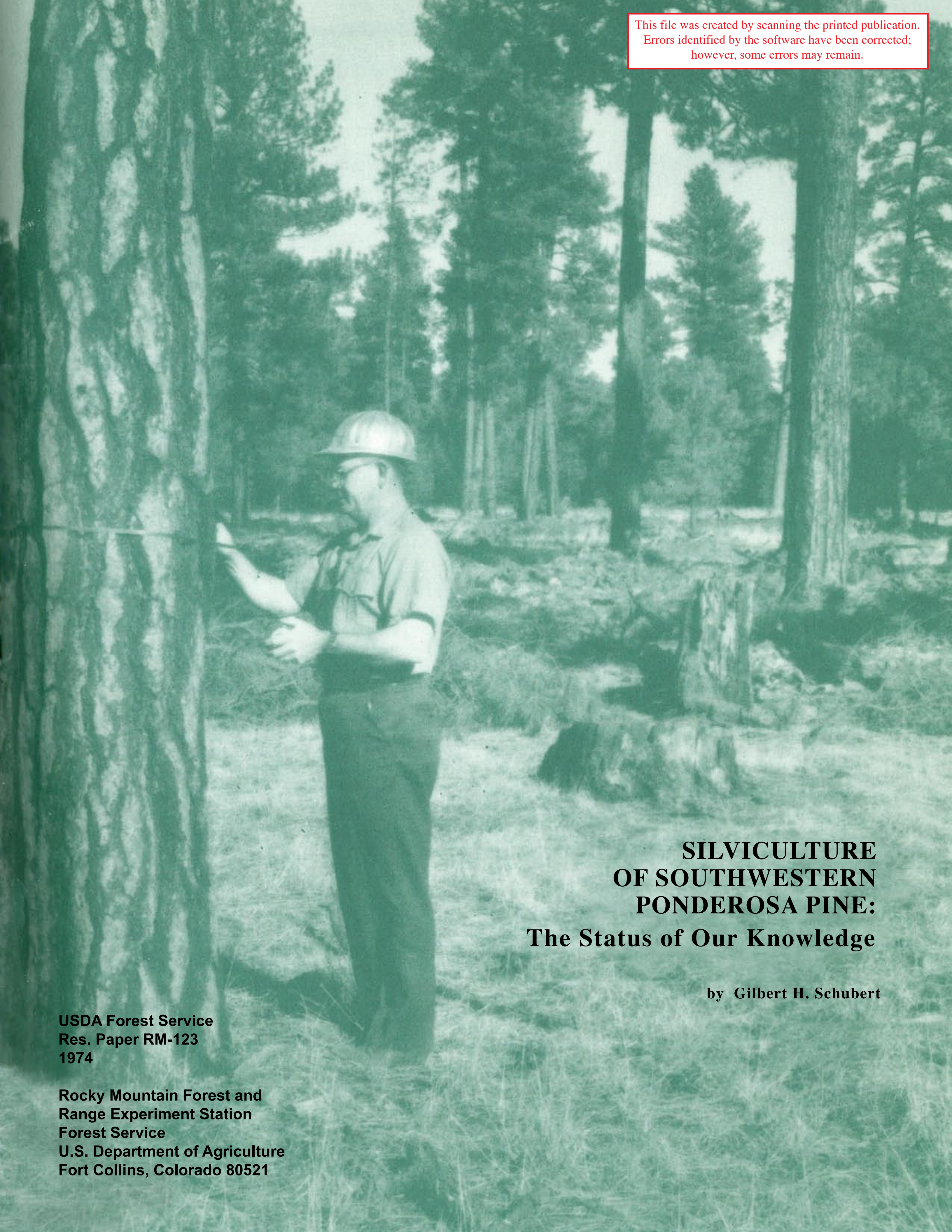

SILVICULTURE OF SOUTHWESTERN PONDEROSA PINE: The Status of Our Knowledge

by Gilbert H. Schubert

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Abstract

Describes the status of our knowledge of ponderosa pine silviculture in the southwestern States of Arizona, Colorado, New Mexico, and Utah. Economic value, impact on other uses, and the timber resource are discussed first, followed by ecological background, site quality, growth and yield, and silviculture and management. Relevant literature is discussed along with observations, experience, and results of unpublished research. Treatise is intended to serve as a reference tool for guidance in making management decisions and prescribing silvicultural treatments. Research needs are also considered.

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Gilbert H. Schubert

INTRODUCTION

Ponderosa pine[2] forests have featured in the development of the Southwest since the Gold Rush days of the mid 1800's. These lands have not only supplied a wide variety of timber products, but also have produced abundant forage and long have been grazed by livestock. These forests produce much of the region's deer, elk, antelope, turkeys, and other wildlife.

Other uses of these lands are becoming increasingly important. Recreational use has been expanding at a rapid rate. A major portion of the usable water is produced in this timber type. Hunting has always been an important use and is expected to increase. Each year, more people are enjoying the esthetics and becoming more concerned about the use of these forests. Timber management activities have an impact on virtually all these uses of the forests. Forage production and habitat for big-game animals may be benefited by opening up timber stands. Water yields are influenced by stand manipulations. Recreational and esthetic values may be improved following the short period required for development of ground vegetation. Current approaches to forest management are being increasingly oriented to enhancing these aspects of multiple use.

Forest managers in the Southwest have noticeably shifted their emphasis to more intensive practices, particularly on the more productive lands and lands with special qualities. Managers are now faced, however, with an increasing demand to improve their forestry practices, particularly on Federal and State lands. These demands stem from a need for more timber and other forest-related resources, and a need to produce these goods and services without irreparable environmental damage or visual degradation. To make sound management decisions, foresters must be able to find and use the considerable pool of knowledge on the ecology, silviculture, and management of southwestern ponderosa pine forests accumulated through research during the past 60 years.

This publication summarizes technical information and observation that is now available in many separate reports, including some hitherto unpublished data. Therefore, the primary emphasis in this report will be to bring together the more important facts to serve as a reference tool to the forest manager. The coverage is admittedly timber oriented. The manager may require more detailed information. Literature citations will help direct him to specific publications. This report will also serve to identify areas in which information is fragmentary or entirely lacking. Scientists should find this useful in development of research programs and specific studies.

HISTORICAL REVIEW

Past Activities

The first harvest cutting in the southwestern ponderosa pine forests occurred in the Front Range of the Southern Rocky Mountains in Colorado about 1860 (Clapp 1912, Pearson 1910, Pearson and Marsh 1935). During the Gold Rush years, tens of thousands of acres were virtually clearcut for fuel, mine timbers, and

[2]Common and scientific names of plants, animals, diseases, and insects commonly associated with southwestern ponderosa pine type are listed in the appendix.

lumber. Elsewhere in the Southern Rockies, areas that escaped the early clearcuttings were selectively cut. Many of the clearcut areas are now occupied by second-growth, and the sites are often understocked or unstocked as a result of destructive fires. Selectively cut areas are in better condition.

Cutting in Arizona and New Mexico became commercially important with the construction of the transcontinental railroad in the 1870's and 1880's. The big demand was for bridge timbers and railroad ties, although considerable amounts of timber were also cut for mine props, lumber, and land clearing. By 1890, a flourishing lumber business had been established.

Many of the early cuts in Arizona and New Mexico were heavy (Pearson 1910, Pearson and Marsh 1935). Cuts during the railroad logging days generally removed 70 to 80 percent of the merchantable volume. Some areas were laid waste, and huge amounts of slash accumulated which lead to some disastrous fires.

With the advent of truck logging in the 1930's, the cuts throughout the Southwest became lighter. However, some cuts were still made to a minimum 10- to 12-inch diameter limit on both private and railroad grant lands. Cuts on Federal lands averaged about 50 percent of the volume, primarily removing mature and decadent trees. Earlier recommendations were followed which suggested that cuts in virgin stands not exceed two-thirds of the merchantable volume, and in some areas should be considerably less than 50 percent (Clapp 1912). The objective during this period was to select the old decadent groups near areas with advance reproduction first.

On many of the Federal forests, selective cuttings were made in a series of light cuts which generally amounted to the shelterwood method (Clapp 1912, Pearson 1910). These light cuts eventually removed 60 to 70 percent of the volume, and then a removal cut was made 10 to 20 years later after reproduction was established. Specific references were made to these series of light preparatory cuts under the shelterwood method on the Prescott National Forest. Similar cutting treatments were probably applied on other Federal and private lands as well. The reproduction following these cuts was frequently rated as good to excellent.

Many earlier foresters recognized the importance of groupwise stand structure and the need to modify their cuttings accordingly. Many stands had very little advance reproduction, and numerous references were made to the open parklike appearance (Pearson 1950). In certain areas, foresters recognized a need for constraint on cutting unless reproduction was already established.

One of the needs recognized early in the history of man's manipulation of the forest was for sanitation-salvage cuttings. Heavy natural mortality was common due to the high proportion of overmature stands. Mortality has been considerably reduced in these partially cut stands (Myers and Martin 1963a, 1963b; Pearson 1950). Lightning, wind, dwarf mistletoe, and insects have been the main causes of mortality, with oldest and least vigorous trees being most susceptible.

In the early 1940's, sanitation-salvage gave way to improvement selection (Pearson 1942). The improvement selection method has the additional objectives of improving the quality and reducing the density of the growing stock.

Grazing has also had an impact. Livestock was first introduced into the ponderosa pine forests in the mid 1500's by Coronado (Stoddart and Smith 1943), but serious forest range deterioration did not occur until the late 1880's (Dutton 1953). Foresters have frequently expressed concern over the injury to pine seedlings caused by the browsing of cattle and sheep, but the damage often is only of consequence where the area is overgrazed (Arnold 1950). Overgrazing was severe primarily in the 1880's and during the war years of 1916-18.

The nature of the forest has changed considerably over the years. Perhaps the greatest change occurred during the early 1900's. The change from open forests to dense stands of young growth resulted from improved logging practices, protection from fire, reduction in livestock grazing, and a 30-year wet climatic cycle which started about 1905.

Lessons Learned

Many of the earlier "facts" learned were based mainly on observations. Information passed on to succeeding foresters by men with a strong ecological background has stood the test of time. Research on a formal basis had its start at Fort Valley, Arizona, in 1908 with the establishment of the first forest experiment station in the United States (Pinchot 1947). A few of the early findings are reported here.

Ponderosa pine is not a "fire-type" (Clapp 1912; Pearson 1910, 1923, 1950; Woolsey 1911). Although old, mature, thick-barked trees are highly resistant to light ground fires, old trees are killed or severely damaged by severe crown fires. Seedlings and small saplings are killed by light ground fires. Fire is not required for seedbed preparation, but may be beneficial to reduce a heavy litter layer which would hamper seed germination. Severe crown fires within the ponderosa pine type would convert the pine forests to a grass or brush type.

Large clearcuts and burns, where all reproduction and seed trees were killed, were converted to grass or brush (Pearson 1910). During the early railroad logging days, large clearcuts covered several townships south and west of Flagstaff, Arizona. All failed to regenerate. Areas which were cut by the strip clearcut method, where strip widths ranged from one to three tree heights, frequently have excellent stands of vigorous second growth. Large clearcuts, where advance reproduction was not destroyed, are frequently fully stocked with young trees. These cuts were actually overstory removals and not true clearcuts. Overstory removal was successful only when the cut was made while the advance reproduction was under sapling size.

Some clearcuts made during a good seed year have regenerated satisfactorily (Pearson 1910, 1923; Woolsey 1911). The trees should be cut during the period between seed maturity in the fall and seed germination in the summer. The area must be cleared of competing herbaceous vegetation prior to the July after seedfall.

Excellent reproduction was obtained with the seed tree, shelterwood, and group selection methods during heavy seed years, whereas practically none occurred when areas were cut during a nonseed year (Pearson 1950). On the Coulter Ranch Plots south of Flagstaff, natural restocking was directly related to amount of shelter and seed. These plots were cut during the heavy seed year of 1913.

High rodent populations were found to be a major obstacle to establishment of natural regeneration (Pearson 1923, 1950). The adverse impact of rodents was least on areas cut during a good seed year, and thoroughly disturbed during logging.

Heavy grazing just prior to a harvest cut made during a good seed year has increased survival in some areas (Arnold 1950, Pearson 1923). Severe grazing was found to be a partial, but not a complete, substitute for mechanical site preparation. Areas grazed after cutting and before seedlings were well established are now unstocked or poorly stocked.

Where advanced reproduction was present in adequate amounts, lopping and scattering of the slash was found to be beneficial (Pearson 1950). The slash, where not too dense, protected seedlings from excessive browsing by livestock, deer, and elk.

THE TIMBER RESOURCE

The basic information needed for the timber management plans and for coordination of all other resources is obtained from resource inventories. These inventories may be either extensive or intensive. The USDA Forest Service makes extensive inventories at 10-year intervals on a nationwide basis. The intensive inventories or compartment examinations are made at shorter intervals on a Forest-District basis.

The limited data collected in previous extensive inventories were lumped together for the entire Forest. These summary data were statistically sound for the Forest as a whole, but seldom depicted true on-the-ground conditions in any one specific location. The sampling intensity was too light and too few kinds of data were collected at each sample point to provide reliable information for local use. Recent procedural changes and intensification of data collection have improved the usefulness of extensive inventories in the Southwest.

Commercial Areas and Volumes

Stands more or less dominated by ponderosa pine occupy nearly 11 million acres of the 26.5 million acres of commercial forest land of Arizona, Colorado, New Mexico, and Utah (table 1). New Mexico has the largest acreage in ponderosa pine, and Utah the least.

Although much of the forest indicated as ponderosa pine cover type is essentially pure ponderosa pine, part of it may be more accurately described as mixed conifer. For example, some of the area on the Mogollon Plateau in central Arizona and the Kaibab Plateau in northern Arizona, which is classified as ponderosa pine type, has stands composed of ponderosa pine, southwestern white pine, Douglas-fir, white fir, spruces, and juniper.

Most of the area in the four States is in the sawtimber size class (table 1). Arizona and New Mexico have the greatest area in sawtimber, with nearly equal amounts in each State.

Over 500,000 acres are nonstocked. The greatest unstocked areas occur in Colorado with over 12 percent of the commercial forest land in the category.

This imbalance in stand size-class distribution poses a challenge to forest managers. Under proper management, a near balance in size-class distribution could be accomplished in about three 20-year cutting periods. It will also take a greatly expanded reforestation program to regenerate the unstocked lands and obtain prompt regeneration on areas receiving a final harvest cut.

Ponderosa pine growing stock and sawtimber are highest in Arizona (table 2). Arizona has 50 percent of the growing stock and 51 per-

Table 1.--Area of commercial forest land in ponderosa pine type by stand-size classes, 1962

State	Stand-size class: Saw-timber	Pole-timber	Saplings and seedlings	Non-stocked	All stands	Total commercial forest land	Total in ponderosa pine
	M acres						*Percent*
Arizona (Spencer 1966)	3,468	89	37	64	3,658	3,977	92
Colorado (Miller and Choate 1964)	1,504	553	5	285	2,347	12,275	19
New Mexico (Choate 1966)	3,885	154	101	194	4,334	6,269	69
Utah (Choate 1965)	403	14	8	7	432	3,999	11
Total, four-State area	9,260	810	151	550	10,771	26,520	41

cent of the sawtimber volume. About 86 percent of the southwestern ponderosa pine timber volume is in Arizona and New Mexico.

Stocking is also highest in Arizona, intermediate in New Mexico, and lowest in Colorado. Average growing stock volume is 1,423 ft^3 per acre and average sawtimber volume is 6,256 fbm (bd ft) per acre in Arizona. New Mexico ponderosa pine forests average 885 ft^3 per acre while sawtimber volumes average 3,735 fbm per acre. The average growing stock volume is 433 ft^3 per acre and sawtimber runs at 1,816 fbm for Colorado.

Table 2.--Volume of ponderosa pine growing stock and sawtimber on commercial forest land, in four States, 1962 (Wilson and Spencer 1967)

State	Growing stock		Sawtimber	
	Million ft³	*%*	*Million fbm*	*%*
Arizona	5,204	50	22,883	51
Colorado	1,017	10	4,261	9
New Mexico	3,837	36	16,188	36
Utah	434	4	2,019	4
Total	10,492	100	45,351	100

Comparison of Cut to Growth

Low volume cuts in the Southwest are a reflection of the area imbalances of stand-size classes and low per-acre volumes. The cut in Arizona is 68 percent of its growing stock growth and 104 percent of its sawtimber growth (table 3). The appearance that Arizona is overcutting its sawtimber volume is deceptive because of the imbalance in age classes. Growth considerably exceeds harvest, but much of the growth is in trees not yet measurable in fbm. It does, however, contribute greatly to future sawtimber.

The combined cut for the four States equals 59 percent of the growing stock and 90 percent

Table 3.--Net annual growth and cut of ponderosa pine growing stock and sawtimber, in four States, 1962 (Wilson and Spencer 1967)

State	Growing stock: Growth	Growing stock: Cut		Sawtimber: Growth	Sawtimber: Cut	
	M ft³	*M ft³*	*%*	*M fbm*	*M fbm*	*%*
Arizona	84,669	57,558	68	340,022	353,899	104
Colorado	14,992	4,269	28	62,406	23,112	37
New Mexico	40,543	21,587	53	153,582	131,558	86
Utah	6,337	2,390	38	23,371	13,222	57
Total	146,541	85,804	59	579,381	521,791	90

of the sawtimber growth. Arizona and New Mexico combined are cutting 63 percent of their growing stock and 98 percent of their sawtimber compared to 31 and 42 percent respectively for Colorado and Utah. About 89 percent of the sawtimber in Colorado and Utah is under 21 inches in diameter.

Stocking Conditions

Stocking is too low for high timber production in the four States (table 4). Only 3.7 million of the 10.8 million acres of commercial forest land is 70 percent or more stocked. Nearly the same amount (3.8 million acres) has a stocking of 40 to 70 percent, with over 3 million acres having less than 40 percent stocking.

Many stands in the Southwest are overstocked. Reported inventory data reflect area occupancy by stocking classes within stand-size classes, but do not indicate stocking density of individual stands. Half of the forested area classed as 40 percent or more stocked probably contains overstocked stands. Based on this assumption, over 4 million acres may be occupied by stands in which the trees have too little space for optimum growth and are in need of thinning.

Utah forests are in the poorest condition with respect to stocking. Over 46 percent of the

Table 4.--Estimated acreage of commercial ponderosa pine forest land, by stocking classes, within stand-size classes for four States, 1962 (estimates based on proportion of ponderosa pine within data for all types)

Percentage of area stocked by State	Stand-size classes				
	All classes	Sawtimber	Poletimber	Saplings and seedlings	Nonstocked
	M acres				
70 percent or more:					
Arizona	1,515	1,497	9	9	--
Colorado	598	412	184	2	--
New Mexico	1,508	1,438	36	34	--
Utah	128	117	5	6	--
Subtotal	3,749	3,464	234	51	--
40 to 70 percent:					
Arizona	1,516	1,465	30	21	--
Colorado	1,002	734	265	3	--
New Mexico	1,223	1,167	43	13	--
Utah	97	91	5	1	--
Subtotal	3,838	3,457	343	38	--
10 to 40 percent:					
Arizona	563	506	50	7	--
Colorado	462	358	104	0	--
New Mexico	1,409	1,280	75	54	--
Utah	200	195	4	1	--
Subtotal	2,634	2,339	233	62	--
Less than 10 percent:					
Arizona	64	--	--	--	64
Colorado	285	--	--	--	285
New Mexico	194	--	--	--	194
Utah	7	--	--	--	7
Subtotal	550	--	--	--	550
All stocking classes	10,771	9,260	810	151	550

Note: -- means no data available.

ponderosa pine forests of Utah have a stocking of only 10 to 40 percent. Colorado has the greatest number of acres classified as less than 10 percent stocked, with about 12 percent in this category.

HABITAT CONDITIONS

Southwestern ponderosa pine grows under a wide variety of physiographic, edaphic, climatic, and biotic factors. The variation in habitat conditions throughout this zone is too varied to treat here in any great detail.

Clearly, ponderosa pine is quite adaptive to a great range of conditions. Since it occurs under such varied conditions, one would expect important genetic differences relating to its establishment, growth, yield, and quality. Consequently, attempts to transfer progeny from one location to another within the zone may prove unsuccessful and at times quite costly.

PHYSIOGRAPHIC FEATURES

Physiographic conditions exert a strong impact on the establishment and development of the ponderosa pine forest and the harvesting of timber products. The topography is frequently rugged, sometimes too steep to permit harvesting without serious environmental impairment. Other areas present problems due to deeply incised canyons. On the whole, however, most timbered areas can be managed to produce harvestable products.

Geology and Topography

Ponderosa pine occurs in the four major physiographic provinces of the Southwest: (1) the Colorado Plateau, (2) the Southern Rocky Mountains,(3) the Great Plains, and (4) the Basin and Range Provinces (fig. 1). Each province exhibits a uniformity of topographic expression

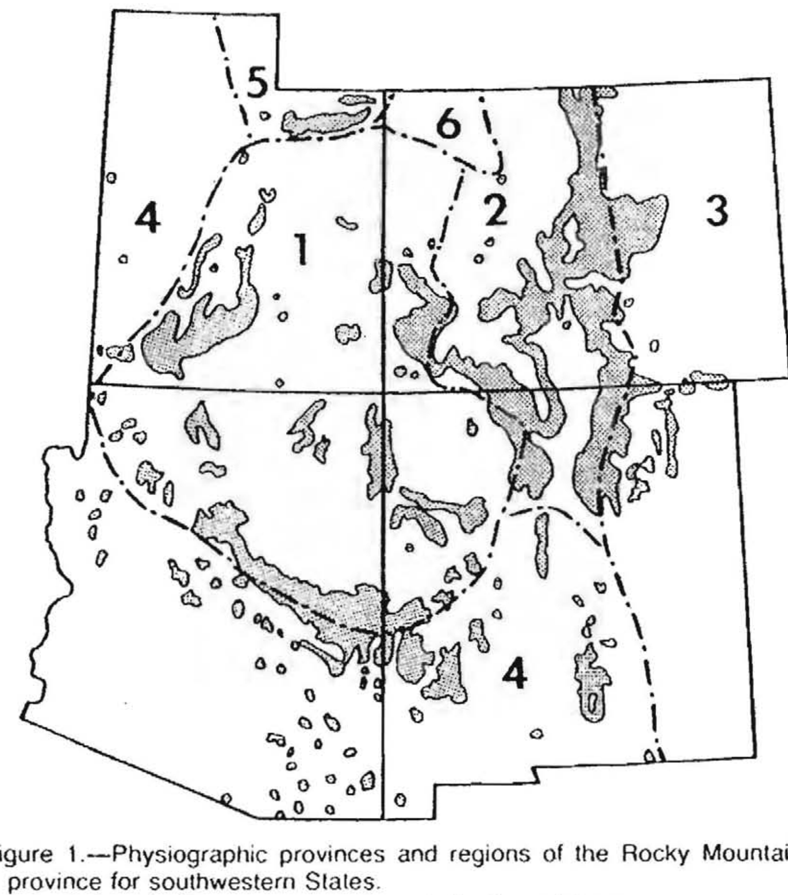

Figure 1.—Physiographic provinces and regions of the Rocky Mountain province for southwestern States.

1. Colorado Plateau
2. Southern Rocky Mountains
3. Great Plains
4. Basin and Range
5. Middle Rocky Mountains
6. Wyoming Basin

in which geologic structure, physiographic process, and stage of development characterize the region (Bowman 1914, Hunt 1967).

Relief and Landform

Elevation

The ponderosa pine cover type in the Southwest occurs primarily between 6,000 and 8,500 ft elevation (Woolsey 1911). At lower elevations it gives way to the pinyon-juniper type and at higher elevations to the mixed conifer type.

Temperatures are most favorable at low elevations and moisture regimes at relatively high elevations (fig. 2) so that highly favorable growing conditions are seldom found. As one factor approaches optimum for ponderosa pine, the other becomes increasingly unfavorable.

Ponderosa pine reaches its best development between 7,000 and 7,800 ft, where it is the climax dominant over large areas. On moister locations, individuals occur in the pinyon-juniper type below 6,000 ft (Kearney and Peebles 1960). Individuals also occur as high as 10,000 ft (Hull and Johnson 1955), mainly on the dry sites in the mixed conifer forest, and sometimes dominate even mesic sites above 9,000 ft following fire.

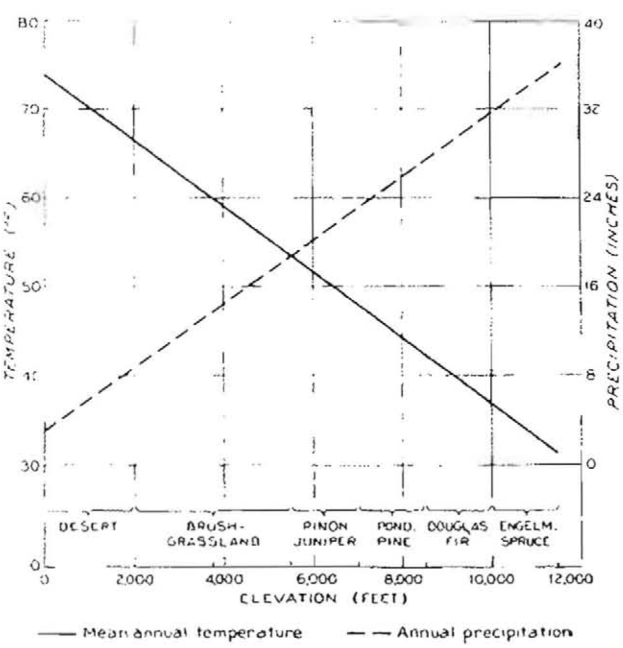

Figure 2.—Temperature and precipitation in relation to altitude in Arizona (Pearson and Marsh 1935).

Strong evaporative winds restrict ponderosa pine from some high plateaus and mesas, even though precipitation is the same as in timbered areas.

Attempts to extend the ponderosa pines into higher or lower elevational zones often end in failures (Pearson 1931). Where irrigation is feasible, ponderosa pines have been successfully planted in the pinyon-juniper type, but without irrigation they usually die the first or second growing season (Pearson 1920).

Slopes

Slope steepness has a strong impact on ponderosa pine due to shallowness and dryness of the soil. Steep slopes, especially when deforested by logging or fire, are generally subject to rapid erosion, rapid water runoff, and very little water penetration and retention. In the ponderosa pine type on the San Francisco Peaks, however, the soils are derived almost entirely from volcanic rocks, contain considerable gravel and rocks, have a high humus surface layer, and are very porous and easily penetrated by tree roots. Water runoff from the Peaks is very low as most of the precipitation sinks into the ground (Martin 1969). Similar situations may occur on other volcanic mountains in the Southwest.

Aspects

Ponderosa pine occurs at higher elevations on south and east aspects than on northern and western exposures. Ponderosa pine, being more drought resistant than Douglas-fir and white fir, can tolerate the drier south slopes, whereas on the wetter north slopes it is replaced by the more shade-tolerant species. At the higher altitudinal limits of the species, temperature becomes more limiting than moisture. Response to these climatic factors related to exposure must be considered in reforestation.

SOIL-TREE RELATIONSHIPS

Southwestern ponderosa pine is not exacting in its soil requirements (Pearson 1931). It grows on a wide variety of soils derived from igneous, metamorphic, and sedimentary rocks. These soils vary considerably in texture, pH, nutrient level, moisture holding and release capabilities, compactness, depth, and other characteristics which have a strong influence on tree establishment and growth. The effects of soil are confounded, to a degree, by the effects of climate and topography. Soils in the southwestern ponderosa pine type have been studied only in limited areas.

Soil Origin

Soils derived from basalt cover about half of the area in the Southwest forested by ponderosa pine (Lutz and Chandler 1947). The remainder are developed from a great variety of rocks formed during the different periods of geologic history. Soils derived from a given kind of rock will be similar in different areas provided that alterations and the environmental conditions under which weathering occurs are similar (Lutz and Chandler 1947).

Soils derived from igneous and sedimentary rocks are generally more productive than those from metamorphic rocks, but not all igneous and sedimentary rocks produce productive soils. Among the igneous rocks, basalts and granite weather into more productive soils than do the rhyolites; the andesite-diorite group gives rise to soils which are more fertile than those derived from the rhyolite-granite group; and black cinders, which cover sizable areas in the Colorado Plateau in Arizona, generally support sparse stands of timber where the cinders are 4 to 5 ft deep. Shallow cinder soils support tree growth where they are well weathered, underlain by clay, and contain organic material.

Basalt weathers more slowly than granite and gives rise to shallower, rocky soils. On steep slopes basalts often form talus, but if moisture is plentiful, ponderosa pine stands may develop. Reproduction is relatively easy to obtain on deep soils of basaltic and granitic origin. Establishment of reproduction is impossible on deep cinders due to rapid drainage, low field capacity, and extremely high surface temperatures. Where cinder soils are shallow (less than 2 ft) and underlain with clay, seedling survival is strongly correlated with depth of the cinder layer.

Limestone, sandstone, and shale are common in many locations of the Southwest, and produce soils of different productivity. Limestone generally weathers rapidly, particularly the porous and impure varieties. The nature of the developed soil depends on the amount and kind of impurities, since the calcium carbonate is dissolved and removed and the soils are probably more variable than those derived from any other kind of rock (Lutz and Chandler 1947). Soils from very pure limestone may be very poor and are characterized by a high content of fine earth, stoniness, and dryness.

Porous limestone may support poor tree growth due to the rapid drainage of water down cracks and cavities caused by solution of the calcium carbonate.

Limestones in the Southwest contain fair proportions of impurities, weather to deep clay or clay loam soils, and have good underground drainage. Kaibab limestone, one of the top strata at Grand Canyon, is found at surface levels in various parts of the Colorado Plateau in Arizona. Soils derived from it produce the highest volume stands in the Southwest. Some stands east and south of Flagstaff average 35,000 fbm per acre. Soils derived from limestone high in calcite are generally of low productivity.

Soils from weathered sandstones vary in amount of weathering and fertility, depending on the size and chemical composition of individual grains and differences in the amount and composition of the cementing materials (Lutz and Chandler 1947). The more siliceous Coconino sandstone gives rise to soils of lower productivity than sandstones which have a greater amount of calcium carbonate and feldspars. Coconino sandstone is present in many areas where it has been exposed through faulting, or where the Kaibab limestone has been eroded away.

Soils derived from shales are quite variable and usually weather to heavy clay soils of low productivity unless underlain by sedimentary or igneous rocks. These soils occur in the Painted Desert of Arizona, in other parts of the Colorado Plateau, in the Great Plains, and in local areas of the other provinces. Tree cover is generally lacking where the shale soils are deep.

The metamorphic schists, gneisses, and quartzites usually produce poor soils (Bowman 1914). These rocks occur in all the provinces and have only minor importance in the ponderosa pine type.

Soil Texture

Soil texture has been recognized as one of the important factors in tree establishment and growth (LeBarron et al. 1938, Lutz and Chandler 1947, Pearson 1931, Roberts 1939). Deep, moderately sandy or gravelly soils were found to be favorable for tree growth. In general, site quality increased as the proportion of material smaller than 0.2 mm increased. Loam soils are generally more favorable for tree growth than either coarse sands or fine clays. Coarse sandy or cinder soils are relatively poor unless underlain by fine-textured material. Ponderosa pine in Montana had best root development in medium-textured soil and poorest on fine-textured soils (Cox 1959).

Clay soils are generally difficult to regenerate, but they favor good tree development after the seedling stage (Pearson 1931). Clay soils often inhibit germination, particularly where heavy use by cattle or logging equipment have caused compaction.

Soil Structure

Soil structure strongly influences moisture relations, aeration, and root penetration. Most of the soils have good structure except the heavy clay soils. Soil structure is perhaps the most easily damaged of the physical properties and is difficult to repair.

Logging and other woods operations with heavy equipment should not be permitted on fine-textured soils during wet periods, particularly on the heavier clay soils. These soils are easily compacted, especially when wet, to the point that the soil structure is unsuitable for tree establishment. Too often, woods operations and heavy use by cattle are not adequately controlled during wet weather.

Soil Depth

Site index is strongly correlated with soil depth (Cox et al. 1960, Myers and Van Deusen 1960, Roberts 1939). Ponderosa pine growth response in Montana was related to soil type, effective soil depth, landform, and moisture availability. High water table on seeps was found to increase site productivity regardless of the soil type or landform (Cox et al. 1960). In the Southwest, shallow soils and high water tables increase the susceptibility of ponderosa pine to heavy windthrow.

Soil depth in the Southwest is extremely variable. In many areas, the soil mantle is too shallow to support trees except where large cracks occur in the rock formation. Areas with shallow soils on the Colorado Plateau are often underlain by basalt and metamorphic rock. Areas with granite, sandstone, and limestone generally weather rapidly and give rise to deep soils.

Soil Nutrients

Soils in the Southwest generally have adequate nutrients for plant growth (Pearson 1950), although some are deficient in nitrogen and phosphorus for adequate top and root growth. Some studies are underway to determine optimum nutrient levels to improve survival of seedlings and growth rate of plantation trees, and to stimulate cone production.

Forest fertilization has been tried in some regions. Fertilizers show most potential for improving young mature forest stands and plantations, and for stimulating cone production (Wilde 1958, Schubert 1956a). Root elongation was increased when the level of nitrogen in the soil was brought up to 25 p/m (parts per million) and phosphorus to 5 p/m (Wagle and Beasley 1968). Levels in excess of this amount produced little additional growth. Fertilizer may damage roots, however, if they are in direct contact (Schubert and Roy 1959).

Cone production has been increased by the addition of fertilizers. In California, the addition of ammonium phosphate more than doubled cone production on sugar pines (Schubert 1956a). Similar results were reported for Douglas-fir in the Pacific Northwest (Steinbrenner et al. 1960).

Fertilizer trials with southwestern ponderosa pine were started in 1973. Results of these studies should be available in about 1978.

Changes in soil reaction also affect nutrient availability (Buckman and Brady 1965, Lutz and Chandler 1947).

Soil Acidity

Many forest soils in the Southwest have a near-neutral reaction (Pearson 1931, 1950). Soil pH of some good ponderosa pine sites on the Colorado Plateau ranges from 5.7 to 7.5 (Anderson et al. 1963, Williams and Anderson 1967). Soil reaction of 4.5 to 6.0 has been identified with good quality sites elsewhere (Lutz and Chandler 1947).

Pine seedlings suffer the greatest loss by damping-off fungi when pH exceeds 7.0 (Baxter 1952). Mechanical site preparation which exposes the soil to sunlight may be the only practical silvicultural control method for damping-off in the forest.

Site index and pH are not strongly correlated. This lack of correlation may be due to the rather wide range in pH values normally encountered on good forest sites, and the variability of pH in the rooting zone of site trees. Limiting pH levels are very uncommon.

CLIMATIC REGIME

The climate of ponderosa pine forests in the Southwest is cool and mostly subhumid. The forests occur in a climatic zone between the relatively warm-dry pinyon-juniper or oak woodland types and the relatively cold-moist mixed conifer or lodgepole pine types. Ponderosa pine forest is common only in parts of the four-State area: in eastern and northern Arizona, in various sections of New Mexico, in southern Utah, in southwestern Colorado, and in the Colorado foothills bordering the Great Plains. Climates of these areas will be discussed briefly here.

Precipitation

Seasonal Distribution

The seasonal pattern of precipitation differs from place to place (table 5). In general, however, winter precipitation, mostly snow, is sufficient that soils are wet at winter's end. Some areas get heavy snows that produce abundant runoff during spring and winter thaws.

The major ponderosa pine areas can be characterized as either dry spring or wet spring areas. Spring is dry in Arizona, southern Utah, southwestern Colorado, and all the pine areas of New Mexico except that which borders the Great Plains in northern New Mexico. Where winter snows accumulate to substantial depths, the impact of dry spring weather is somewhat delayed. In May and June, however, the combination of low precipitation, increasing temperature, largely clear skies, low humidities, and persistent winds bring general drought.

Where spring drought is the rule, it is usually broken by summer rains beginning in July or late June. These rains tend to be lighter and less reliable north of the Grand Canyon. Summer rains commonly begin first in southern New Mexico and last in southern Utah.

Usually, spring is relatively wet in the ponderosa pine forests bordering the Great Plains in Colorado and northern New Mexico. In the northern half of this section, April and May are normally the wettest months (in striking contrast to conditions in Arizona); June is usually drier than May. Frequent showers are likely in July and August.

Drought

At Fort Valley, where precipitation normally exceeds 22 inches, 6 of the 60 years had less than 16 inches of precipitation. June has been the driest month, with only a 47 percent probability of getting a half inch or more of rain (fig. 3). Every month of the year, including the two wettest months of July and August, has had at least four times when less than an inch was recorded. For the ponderosa pine type in Arizona, analysis of 37 years of records indicated only 44 days per year in which the precipitation exceeded 0.10 inch (Green and Sellers

Table 5.--Mean monthly and annual precipitation at 17 stations in major southwestern ponderosa pine areas (values are for 20 or more years unless otherwise indicated)

Station	Elevation	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
	Feet	Inches												
ARIZONA														
Chevlon R.S.	7,006	1.49	1.37	1.23	0.37	0.52	[illegible]	2.78	3.35	1.84	1.67	1.17	1.74	18.50
Fort Valley Exp. Forest	7,347	2.32	2.27	1.92	1.32	.53	.76	2.65	3.65	1.83	1.52	1.14	2.07	22.34
Grand Canyon N.P.	6,950	1.40	1.59	1.35	[illegible]	.59	.43	1.46	2.06	1.65	1.10	.73	1.51	14.77
Jacob Lake[1]	7,920	1.43	.96	2.10	1.48	1.12	.36	2.01	2.70	1.10	1.75	1.45	2.15	19.07
McNary	7,320	2.18	1.99	2.56	1.22	.66	.69	3.25	3.98	2.34	2.74	1.58	2.76	25.45
COLORADO														
Hawthorne	5,923	.87	1.03	1.92	3.36	3.74	1.34	1.59	1.54	1.45	1.52	1.11	.75	20.32
Monument 2W	7,400	.55	.82	1.46	2.57	2.37	1.65	2.55	2.54	1.34	1.02	.81	.56	18.55
Pagosa Springs	7,238	2.03	1.61	1.58	1.48	1.13	.98	2.17	2.48	1.97	2.38	1.43	1.81	21.09
Red Feather Lakes 2SE	8,237	.61	1.02	1.28	2.35	2.46	1.55	2.08	1.63	1.49	1.03	.99	.75	17.28
Tacoma	7,500	1.77	1.21	1.47	1.25	1.23	1.02	1.92	2.47	2.34	1.74	1.06	1.41	18.89
NEW MEXICO														
Gascon[2]	8,250	.57	1.06	1.43	1.40	1.75	1.50	5.08	5.20	1.58	1.82	.81	.93	23.13
Lake Maloya	7,400	.80	1.39	1.55	1.50	3.20	2.11	3.90	3.11	1.40	1.47	1.43	1.05	22.91
Los Alamos	7,410	.78	.64	.88	.92	1.35	1.33	2.73	3.92	1.89	1.65	.70	.83	17.67
Luna R.S.	7,050	1.04	.80	.76	.62	.48	.73	2.59	2.90	1.71	1.36	.59	.55	14.53
Ruidoso 2NNE	6,838	.91	1.14	1.31	.53	.75	1.98	4.54	4.05	2.57	1.20	.74	1.57	21.29
Wolf Canyon	8,135	1.64	1.77	1.90	1.50	1.45	1.04	2.91	3.28	2.14	1.62	1.16	1.51	21.92
UTAH														
Alton	7,040	1.74	1.69	1.46	1.10	.73	.64	1.35	1.61	1.38	1.37	.93	1.80	15.80

[1] Monthly averages for 13-15 years.
[2] 13-year averages for August, September, October, and November.

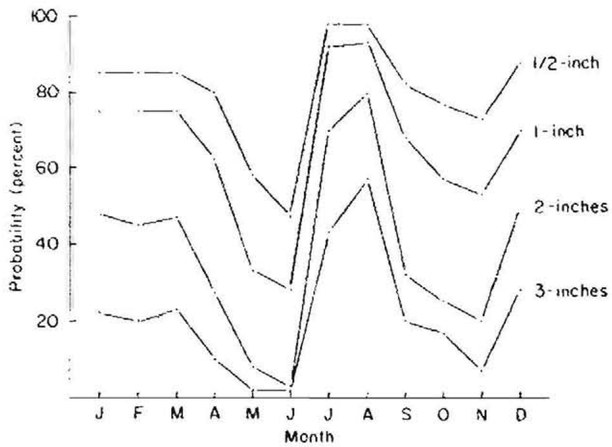

Figure 3.—Probability of getting various amounts of precipitation each month at Fort Valley Station, near Flagstaff, Arizona (Basis 1909-68).

1964). During this period, relative humidity averaged 66 percent at 6 a.m. and 44 at 6 p.m.

Snowfall

Snow cover is extremely important in the ponderosa pine type. It greatly reduces frost heaving. Without enough snow cover to prevent deep soil freezing, new seedlings are likely to be killed by drying. Even older, shallow-rooted trees may be seriously damaged when all soil moisture in their rooting zone is frozen. Where snow accumulates to substantial depth, its lingering presence in the spring delays development of a serious forest fire hazard.

Average annual snowfall for 15 locations in the ponderosa pine forests of Arizona ranged from a low of 12 inches at Painted Canyon in the Basin and Range province to a high of 94 inches at McNary in the Colorado Plateau province, with a mean annual average of 46 inches for all examined locations. Snowfall at these stations is not consistent from year to year. Fort Valley averages 91 inches, yet in 13 out of 60 winters (October 1-April 30), less than 60 inches fell. During 34 percent of these winters, snowfall averaged less than 1 ft per month for 4 consecutive months.

Temperature

Temperatures sometimes drop below 0°F (-18°C), occasionally far below, yet daily highs in winter frequently exceed 40°F (4.4°C). In the summer, afternoon temperatures in Arizona may reach 80°F (27°C) and higher and then drop to 35°F to 40°F (1.7°C to 4.4°C) at night (Kangieser 1966). Similar trends have been reported for Colorado (Berry 1968).

Table 6 summarizes mean monthly temperatures for the pine type in different parts of the Southwest. Various temperature parameters for Fort Valley (fig. 4) summarize the temperature climate of a fairly representative pine area.

Elevation, slope, aspect, and storms all affect temperature. Temperature at similar elevations in northeastern and southwestern New Mexico differed by only 3°F, while two stations

Table 6.--Mean monthly temperatures in the ponderosa pine type, by physiographic provinces

Month	Colorado Plateau		Basin and Range		Southern Rocky Mountains		Great Plains		Pine type	
	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C
January	26	-4	35	2	28	-2	31	0	30	-1
February	29	-2	37	3	28	-2	32	0	31	0
March	35	2	44	6	34	1	38	4	38	3
April	43	6	49	10	41	5	45	7	44	7
May	50	10	57	14	48	9	52	11	52	11
June	60	16	66	19	60	16	63	17	62	17
July	66	19	71	22	64	18	66	19	67	19
August	64	18	68	20	62	17	64	18	65	18
September	57	14	63	17	54	12	57	14	58	15
October	46	8	52	11	46	8	48	9	48	9
November	36	2	43	6	35	2	38	4	38	3
December	26	-3	36	2	27	-3	30	-1	30	-1
Mean annual	45	7	52	11	44	7	47	8	47	8

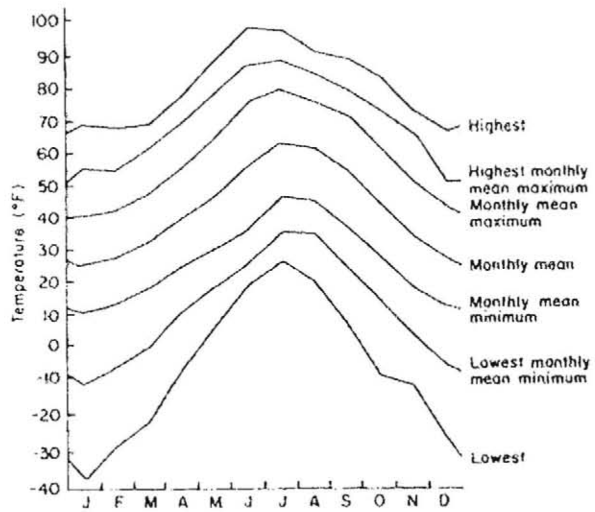

Figure 4.—Highest, lowest, and mean monthly temperature data for Fort Valley Experimental Forest, 1909-68.

only 15 miles apart but differing by 4,700 ft elevation differed by 16°F (Houghton 1972). A north-facing slope in Frijoles Canyon, New Mexico was 13°F cooler than the south-facing slope (Tuan et al. 1969). The average temperatures of west-facing slopes are warmer than the east-facing ones. The average range in daily highs and lows varies from 25°F (14°C) to 35°F (20°C).

Growing Season

The average frost-free period within the pine type is about 135 days, but varies greatly from place to place. Pine seedlings are not killed by 32°F (0°C) temperatures, but growth slows. The variation in frost-free periods between different areas may be related to the problem of planting seedlings raised from offsite seed sources.

EFFECT OF MOISTURE

Precipitation

The seasonal distribution, frequency, and intensity of precipitation are all of critical importance to the establishment and growth of ponderosa pine. Spring planting is more likely to be successful in the southern Rocky Mountains than in the Basin and Range due to the higher precipitation in April and May. Planting on the Colorado Plateau is handicapped by the low probability of rains in spring totaling at least 1 inch. Furthermore, unless the planted trees develop a deep root system, they will have only a slim chance of making it through the winter without adequate protective snow cover.

Winter precipitation is generally sufficient to restore soil moisture to field capacity by early March. However, winters with substantially subnormal snowfall may fail to rewet the entire soil profile, and worsen the effect of a dry spring.

Seed germination during the summer depends on the maintenance of high moisture levels. Although summer precipitation may average about 3 inches per month in July and August, surface soil moisture is often inadequate for seed germination due to the storm distribution pattern. Seeds that germinate in late summer develop into seedlings with only a shallow root system that succumb to fall drought, frost heaving, or winterkill (Larson 1960, 1961, 1963; Schubert et al. 1970).

To be effective, seedfall must coincide with good late spring or early summer rains. These rains do not always occur at opportune times. An outstanding exception in Arizona was the 3.54 inches of rain that fell during May 1919 following the bumper seed crop of 1918. Seed germinated in early June and resulted in the excellent 1919 seedling crop over most of the Colorado Plateau and in some other areas. Similar timing of spring rains can account for the other good seedling years of the past.

Soil Moisture

The moisture-holding capacity of most soils of ponderosa pine forests is sufficient to sustain tree growth (Pearson 1931). Soils derived from basalt and granite, particularly the deeper soils containing fine material, have good moisture retention which may favor the establishment of pine reproduction (Lutz and Chandler 1947). Soils with a high clay content, however, may not release the moisture to the seedling. Limestone soils commonly have good moisture-holding capacity, but some are too porous and drain too rapidly. Reproduction can be difficult to establish on limestone soils, due either to compactness with accompanying poor infiltration or too rapid surface drying, but once established, trees make good growth. Cinders and coarse sandy soils drain too rapidly.

As a general rule, tree roots extend out beyond the edge of the crown to a distance equal to about 70 percent of the tree height. Because soil moisture within this zone may be greatly depleted during dry periods, the possibility of establishing either trees or herbaceous vegetation is diminished except where tree roots are sparse. The curve of available moisture characterizing the site would probably show a strong positive correlation with distance from the tree to some point at which other factors become dominating. In general, seedlings should not be planted within that distance, or within the root zone of other vegetation.

Infiltration Rates

The influence of soil surface conditions on water infiltration and runoff is well documented (Colman 1953, Kittredge 1948, Lowdermilk 1930, Lutz and Chandler 1947, Rowe 1948, Wilde 1958, and others). Infiltration rates in the ponderosa pine forests of Colorado were found to be 2.4 inches of water per hour for a pine-litter cover compared to 1.9 for pinegrass, and 1.5 for grasslands (Dortignac and Love 1961). The infiltration capacity of forest soils is usually decreased as a result of heavy grazing and repeated burning (Lutz and Chandler 1947). Repeated burning in the chaparral type reduced infiltration rates by 95 percent (Rowe 1948). The thick layer of fine ashes in burned slash piles on the Stanislaus Experimental Forest in California prevented water movement into the soil over a 2-year period (Schubert and Adams 1971). Light burns in Oregon were found to increase percolation rate in the 0- to 3-inch layer but severe burning reduced it (Tarrant 1956). Infiltration rates are also reduced as a result of soil compaction during logging, especially when the soil is wet.

Evaporation

Wind, temperature, exposure, and air humidity all affect the amount of soil moisture lost through evaporation and thereby the amount available for plant growth. Slash reduced moisture loss and was decidedly beneficial in aiding establishment of ponderosa pine seedlings (Pearson and Marsh 1935). Scattering slash rather than burning has been suggested as a measure to conserve soil moisture on light-textured and shallow stony soils (Lutz and Chandler 1947, Pearson and Marsh 1935).

Shade cast by logs, stumps, rocks, and other nonliving material reduces water loss and thereby favors early seed germination and survival of young seedlings (Heidmann 1963b, Schubert and Adams 1971, Schubert et al. 1970). In areas where the soil surface is subject to rapid drying, such as south slopes and large openings, some shade may be essential for seed germination.

Moisture Stress

Moisture stress conditions reduce seed germination and initial seedling development (Larson and Schubert 1969a). Seed germination, root penetration, root dry weight, and cotyledon length decreased as the stress increased beyond 7 bars. Seedlings that germinated under high moisture stresses grew poorly even when watered. New seedlings that developed under high moisture stresses frequently were unable to cast off their seedcoats. Seedlings with their cotyledons tightly encased in the seedcoats rarely survive.

Water balance of pine seedlings varied both with season and treatment. The needle moisture content (NMC) and water saturation deficit (WSD) data indicated that internal moisture stress of needles was low at time of planting and very high during early summer drought (Larson and Schubert 1969b). During this drought period, pine seedlings in unwatered plots containing Arizona fescue and mountain muhly developed greater internal moisture stresses than pines in denuded or watered plots.

Pine needles displayed various symptoms of drought damage. These symptoms were related to NMC as follows: needles green, 150 percent; needles light green, 111 percent; tips of needles brown, 107 percent; needles with purplish cast, 101 percent; needles with necrotic yellow spots, 84 percent; and needles yellow, 55 percent. A needle moisture content (based on ovendry weight) less than 110 percent combined with a WSD greater than 45 percent appears to be the "point of no return" for ponderosa pine seedling survival. Additional studies of moisture stress effects are being made with the "pressure bomb," which measures the internal moisture stress in living plants.

Several methods have been tried to improve moisture relations in ponderosa pine tissue, but none have proved successful. Treatment of ponderosa pine seedling foliage with transpiration retardants had no effect when soil moisture was limiting (Fowells and Schubert 1955, Mowat 1961, Rietveld and Heidmann 1969). Even a three-rock mulch around the base of newly planted trees had no real beneficial effect on pines where competing vegetation had been eliminated (Heidmann 1963b).

Seed Germination

Early germination of ponderosa pine seed is extremely important. The dependence of germination on amount and frequency of rainfall has lead to numerous problems in establishing seedlings. Seedlings which get started by the third week in July survive best (Larson 1963). Root penetration, number of lateral roots, and seedling dry weight in November were all greatest for seedlings that germinated earliest. Seedlings that started after mid-August were generally killed during the fall drought or by frost heaving before the next growing season.

Seeds sown directly on the ground surface have an extremely poor chance to germinate. Covering the seed with a light layer of soil is highly beneficial. A layer of pine needles also improves germination and survival, especially during dry years (U.S. Department of Agriculture, Forest Service [USDA-FS] 1937). Shade cast by other dead material also aids seed germination at lower elevations where soil moisture is a limiting factor.

Rooting Characteristics

Because ponderosa pine has a deep taproot with long laterals, it can become established and grow under conditions too dry for Douglas-fir, white fir, corkbark fir, blue spruce, and Engelmann spruce. In loosened and watered soil, root penetration to depths of 20 inches or more have been reported for seed that germinated in early July (Larson 1963). Root growth of pine seedlings was uninhibited by grass as long as moisture was kept abundant (Larson and Schubert 1969b).

Ponderosa pine will put down a root to depths of 6 or more ft in porous soils, but seldom more than 3 ft in heavy clay soils. Exceptions occur in soils underlain by rock with deep fissures, where roots have been observed along cut roadbanks at depths of 35 to 40 ft. In open stands, lateral roots may extend 100 ft, while in dense stands they are limited more to the crown width (Pearson 1931). The main mass of roots is concentrated within the top 2 ft of the soil mantle.

In areas with shallow soils or a high water table, ponderosa pine is susceptible to windthrow. The rooting characteristics under these situations must be considered in planning harvesting operations to minimize blowdown.

Winterkill

Young ponderosa pines are frequently damaged by severe winter drying (Bates 1923, Pearson 1931). Winterkill occurs when the soil moisture within the root zone is frozen and unavailable to the plant, while the plant continues to transpire and use water.

Trees are particularly susceptible to winterkill during open winters, especially if day temperatures and winds increase. During 17 of the 60 years of snowfall records at Fort Valley, snowfall has averaged less than 12 inches per month from the first of November to the end of February. During these relatively open winters, soil freezes to a considerable depth.

Unless the water stress conditions are too severe, only the needles are killed. As long as the buds remain undamaged, the tree will recover during the summer rainy season. Often by fall all the dead needles have been shed and the tree appears healthy. Winterkill can be detected only by examination of the needle whorls. Undamaged trees will have their normal 3-year needle system, while the winterkilled will have only the current needle crop.

Growth of trees damaged by winterkill is probably greatly reduced during the year damage occurred. Growth reduction may be equivalent to at least one annual ring, but such growth losses have not been documented. Any correlation of ring width with drought years should be verified with snowfall records.

EFFECT OF LIGHT

As a general rule, ponderosa pines benefit from all the light they can receive (Tinus 1970). Under field conditions, other factors than light usually prevent or limit their establishment and growth. Ponderosa pines are most influenced by the absence of sunlight during the seedling stage, when young trees may be completely shaded by older trees, shrubs, or grass. Direct sunlight has not been reported to injure young ponderosa pines, except possibly by its indirect effect on temperature, transpiration, and soil moisture. Full utilization of light and heat energy in photosynthesis is restricted by the availability of moisture (Helms 1972, Pearson 1950).

Shade Tolerance

Ponderosa pine is classified as intolerant to shade (Baker 1949). Open stands do not always indicate intolerant species, nor does the occurrence of young seedlings under an overstory prove that they are shade tolerant (Pearson 1931). Some woodland species such as junipers and pinyon are widely spaced because of insufficient moisture to sustain a dense stand. Frequent fires before the advent of fire protection destroyed most young seedlings and saplings and kept the forest open and parklike.

One of the main benefits of shade during the early life of a ponderosa pine is to improve moisture conditions. Shade in itself is not important, since the seeds will germinate in full sunlight provided moisture is maintained at adequate levels. Furthermore, pine seedlings that start under dense shade seldom survive for more than a few years unless they outgrow the shade or the shade is removed (Pearson 1950). Older trees can survive under conditions of up to 50 percent overhead shade, but both diameter and height growth are reduced. Height growth is unaffected on trees whose tops receive full sunlight.

Stem Form and Branch Characteristics

Young ponderosa pines were found to need side shade to induce good stem form and fine branching (Pearson 1940b, 1950). High stand densities were also thought to be necessary through the pole stage to achieve natural pruning. Self-pruning has not been found to be strongly correlated with stand density, however. Lower branches die in dense stands, but are retained on trees down to ground level on trees for at least 50 years. Furthermore, trees in the Taylor Woods growing stock levels (GSL) study at Fort Valley, growing at a stand density of 200 ft^2 basal area per acre, have a weak, slender form and averaged less than 3 inches in diameter at age 40 (Schubert 1971).

Open-grown trees generally, but not always, have a low form factor and coarse branches. The Taylor Woods GSL study at Fort Valley, and others located in the species range, will provide answers to the relationship between tree form and stand density.

Amount of Light Needed for Full Growth

Light intensity at saturation for ponderosa pine is 12,000 fc (footcandles). A tree is "light-saturated" when a further increase in intensity ceases to increase photosynthesis. An increase in light intensity beyond the maximum required may damage the photosynthetic mechanism (Ronco 1970). For comparison, light intensity of full sunlight on a clear day ranges from 8,000 to 10,000 fc (Tinus 1970) with intensities of 13,000 to 16,000 fc at elevations of about 11,000 ft (Ronco 1970). An arc light in a growth chamber has an output of 8,000 to 15,000 fc, while conventional fluorescent lamps are rated at 500 to 2,000 fc (Tinus 1970). These comparisons take on importance as the production of planting stock shifts from the nursery to the greenhouse.

EFFECT OF TEMPERATURE

Temperature significantly influences height and diameter growth, seed crops, seed germination, and tree mortality. At times temperature may be the limiting factor, but more frequently it exerts an indirect influence. Often it is difficult to isolate temperature from other factors affecting plant responses due to the intricate interrelationships. Many errors in management could perhaps be avoided if we knew more about the effects of temperature on plant and animal life.

Air Temperature

Low temperatures determine the upper altitudinal range of ponderosa pine primarily by limiting growth processes (Bates 1923, 1924; Pearson 1920, 1931). Net photosynthesis of ponderosa pine was found to increase with an increase in air temperature, but the amount of increase would become less as environmental stresses become more severe (Helms 1972). Although moisture conditions improve with a rise in elevation, the average air temperature during the growing season is about 10°F (6°C) cooler in the spruce-fir type than in the ponderosa pine type. This temperature difference may be sufficient to reduce pine growth to permit the spruces and firs to gain dominance.

Top growth of pine was found to be influenced more by air temperature than root temperature. Optimum day temperature for pine top growth is about 74° to 77°F (23°-25°C) (Larson 1967, Tinus 1970). Day temperatures of this magnitude and higher are reached about the end of May and last until about the middle of September.

Soil Temperature

Although soil temperature has been correlated with ponderosa pine growth responses to a lesser degree than either air temperature or soil moisture, it exerts considerable influence on seed germination and tree growth. Southwestern ponderosa pine seeds are noted for their high temperature requirement for germination. The seeds normally do not germinate until the soil temperature reaches 55°F (13°C) even though moisture conditions are favorable (Larson 1961, Pearson 1950). Under field conditions, root growth normally does not start until the soil temperature exceeds 40°F (5°C) (Pearson 1931). Root growth was found to respond more to soil temperature than to air temperature. Best root growth occurs at a soil temperature of about 74°F (23°C) (Larson 1967).

A study involving the root regenerating potential (RRP) of ponderosa pine in California showed a significantly greater number of seedlings initiated new roots at 68°F (20°C) than at 77°F (25°C) for one seed source, but no significant differences for the other seed source (Stone and Schubert 1959). However, total root elongation was significantly greater at 77°F than at 68°F for both seed sources. Seedlings with the greatest root extension would have a distinct survival advantage in dry areas. The nursery climate was found to have a major influence on the RRP, with the greatest root production associated with the warmest nursery (Schubert and Baron 1965).

Soil temperature data are generally lacking for the southwestern ponderosa pine type. An analysis of soil and air temperature data (Pearson 1931) shows a strong correlation between mean air temperature and soil temperature. Air and soil temperature data were collected during 1917-19 on an area having 25 percent shade from surrounding pines. Soil is a sandy loam derived primarily from basalt. The curves (fig. 5) are intended primarily to obtain an estimate of the soil temperature from mean monthly air temperatures. The growing stock levels study at Fort Valley will furnish soil-air temperature relationships by stand density levels at a future date.

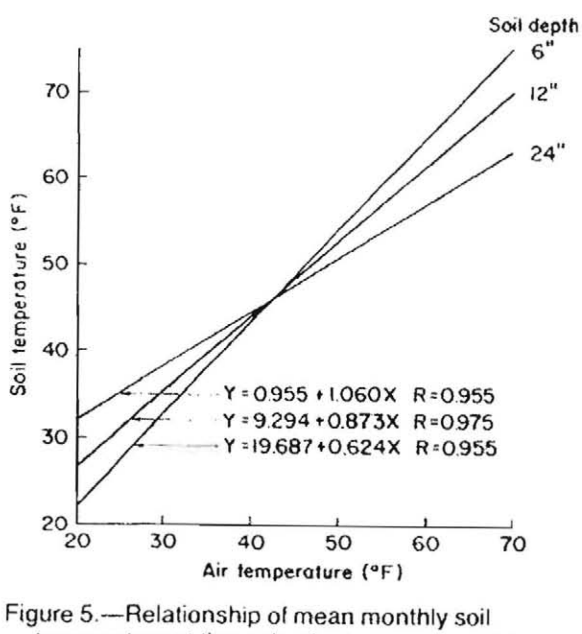

Figure 5.—Relationship of mean monthly soil temperature at three depths to mean monthly air temperature at Fort Valley Experimental Forest, Arizona.

Freezing Injury

Low temperatures normally cause only minor damage (Pearson 1931). Young seedlings are more susceptible than older trees to freezing. Older trees have withstood temperatures of -41°F(-40.6°C) without damage. Freezing injury to young seedlings occurs most frequently in the fall before the seedlings have hardened off and in the spring after growth starts when the temperature drops below 27°F (-3°C) (Schubert 1955, Schubert and Adams 1971).

Shaded seedlings are less likely to be injured (Pearson 1950), while seedlings planted outside their natural habitat are most likely to suffer freezing injury. Pines from nonlocal seed sources were severely damaged in the provenance study at Fort Valley (Larson 1966).

Young ponderosa pine conelets have been killed by late spring freezes (Fowells 1948, Fowells and Schubert 1956), but the amount of damage in the Southwest is unknown.

Frost Heaving

Frost heaving is a serious reforestation problem in the Southwest (Schubert et al. 1970). Loosening of the roots of young seedlings seriously impairs their capacity to survive through the spring and fall droughts (Larson 1960). The degree of overhead shade and the soil surface condition both influence the amount of frost heaving and the ability of the seedling to survive. Soils with a high silt content and high bulk density are especially susceptible to frost heaving.[3] The causes of frost heaving and ways to reduce it are being studied.

Growth Periods

When ponderosa pine begins and ends growth depends on temperature and moisture conditions (Pearson 1918, 1931). Phenologic data for ponderosa pine in the Fort Valley Experimental Forest, collected during 1917-19, were as follows:

Diameter growth starting (tentative estimate)	May 15-30
Vegetative buds swelling	May 1-15
Vegetative buds elongating or opening	May 15-25
Root growth starts	Mar. 15-30
Shoots making rapid growth	June 10-30

[3]*Personal communication from L.J. Heidmann, Rocky Mt. For. and Range Exp. Stn., Flagstaff, Ariz.*

Needles emerging from papery scales and making rapid growth	June 15-July 30
Shoot growth ceased	July 1-10
Seed germination[4]	July 1-Aug. 30
Staminate buds appearing	May 20-31
Pollen falling	June 10-20
Diameter growth completed (tentative estimate)	Sept. 1-20
Cones full grown	Sept. 15-20
Seeds mature	Oct. 1-20
Needles falling	Oct. 1-30
Root growth stops	Nov. 15-30
Period of active growth	May 15-Sept. 20

The starting dates for diameter growth have not actually been determined, nor has the effect of stand density been related to growth periods. Both beginning and ending dates of diameter growth are important in growth studies. On May 22, 1973, no discernible diameter growth was noted for trees cut on the 30 ft^2 basal area growing stock level (GSL) plots at Fort Valley. Diameter growth starts about mid-April on ponderosa pine at 6,000 ft elevation in California (Fowells 1941). In most years, diameter growth is completed by the end of August. Growth will continue into late September in some years when both temperature and moisture remain favorable.

Stand density affects start of height growth. At the May 22 date indicated above, trees in the GSL-30 plot had already grown 4 to 6 inches, whereas trees in the adjacent unthinned plot (about 200 ft^2 basal area) showed no discernible growth. The effect of stand density on growth will be included in the GSL study.

Roots normally grow when soil temperature exceeds 40°F (5°C). From the information shown in figure 5, root growth would vary by rooting depth. It would start about the middle of March when the mean monthly air temperature has reached 33° to 37°F (1° to 3°C) and would stop at the end of November. In years when the ground is covered by snow, and at lower elevations where the average monthly air temperature remains above 35°F (2°C), root growth may continue slowly throughout the winter.

VEGETATION REGIME

Ponderosa pine occurs mainly in the Transition Zone (Merriam 1898), which occupies an altitudinal range from about 6,500 to 8,000 ft, and occurs in the broad climate regime described as warm-moist.

Climax and Succession

Southwestern ponderosa pine occurs as a climax type between 6,000 and 8,000 ft elevation, but disturbance by fire or heavy logging has partially or completely converted many climax ponderosa pine stands to other plant communities (Pearson 1931). The kind of vegetation initially occupying the site usually determines the length of time it will take to return to a ponderosa pine forest. At higher and lower elevations, where ponderosa pine integrates into mixed conifer and pinyon-juniper forests, it loses its climax characteristics.

Stand Conditions

In the Southwest, ponderosa pine forests are usually open grown, and poorly stocked, although many groups are often overstocked. They are interspersed with occasional meadows and parks (Pearson 1931). These forests occur

Figure 6.—Southwestern ponderosa pine occurs mainly as irregular, uneven-aged stands consisting of small even-aged groups.

[4]*Seed germination occurs about 1 week after the summer rains begin and continues until completion or soil temperatures drop below 55° F (13° C).*

mainly as irregular, uneven-aged stands consisting of small even-aged groups, varying in size from a few trees to several acres (fig. 6). Past cuttings, involving a variety of selection methods, have tended to preserve the uneven-aged structure (Myers and Martin 1963a). Occasional stands are even-aged where fires, open areas, and early clearcuttings have regenerated.

Pure ponderosa pine stands occur where the species is climax. One of the largest continuous ponderosa pine forests is found on the Mogollon Plateau, within the Colorado Plateau province, where it extends about 300 miles from central Arizona into western New Mexico. Pure stands of lesser extent are found throughout the ponderosa pine zone. Mixed stands are not common. Both pure and mixed stands may have an understory of younger trees and other herbaceous vegetation. Where stands are dense (a basal area stocking greater than 180 ft^2 per acre) lower vegetation is usually absent, unless shade-tolerant conifers are invading.

The ponderosa pine forests have not yet been classified into habitat types. Such a classification into ecological subdivisions for improved forest description and management has been recognized as a major need. The classification is complicated by past activities which have altered the natural forest stands.

Maintenance of a ponderosa pine cover will be more difficult on some habitat types than on others. Prompt reforestation is essential regardless of habitat type, but some types will present greater challenges. A few habitat types can be used for illustration. Much of the Colorado Plateau could be classified as ponderosa pine-Arizona fescue. If regeneration is not started promptly, the area will convert to grass. Examples can be found near Flagstaff where the ponderosa pine climax has not returned 50 to 100 years after timber harvesting. Parts of the Mogollon Plateau and the Tonto Basin could be classified as ponderosa pine-juniper. Many of these areas are reverting to juniper after harvesting. Much of the San Juan area has a ponderosa pine-Gambel oak type which is being converted following cutting to oakbrush. These areas will require special silvicultural treatments to obtain prompt pine reproduction. Where pine regeneration is initially delayed, conversion to tough competitors may postpone return to pine dominance for many years.

The reverse is also true. The Gila Wilderness has a number of mountain meadows which are converting to ponderosa pine. Overuse by livestock has resulted in deep erosion ditches and a lowering of the water table. Managers are now faced with the problem of halting this change and to restore the site to grass. Other habitat types also present problems requiring research.

EFFECT OF PLANT COMPETITION

All plants within the forest environment compete for moisture, nutrients, and light. This competition varies greatly. The presence of other plants in the ponderosa pine community may at certain stages of development be beneficial and at other times detrimental. Furthermore, not all plants have been studied thoroughly enough to know which ones impede the development of ponderosa pine.

Competition for Moisture

All plants compete for the limited supply of moisture. Competition between ponderosa pine and other species is most detrimental when the trees are young (Larson and Schubert 1969a, 1969b; Pearson 1936, 1942, 1950; Schubert et al. 1970), but it continues throughout the life of the tree (fig. 7). In the early stages, competition is between small pine seedlings and grass, shrubs, and larger trees. In later stages, it is between trees of the same or older age classes.

Some plant species compete more severely than others for moisture (Larson and Schubert 1969b, Pearson 1950). For example, Arizona fescue and black dropseed grow during the spring drought when moisture is critical. However, mountain muhly, blue grama, and most weeds

Figure 7.—Competition for moisture between older trees is often too intensive to permit establishment of an herbaceous ground cover.

do not begin rapid growth until after the start of summer rains when moisture is more abundant. As tree stands develop, competition between trees increases with stand density, and trees with the most extensive root systems have the advantage.

Investigation of the nature and effect of competition between ponderosa pine seedlings and grass has provided growth comparisons and reasons why pines survive and grow better in grass-free environments (Larson and Schubert 1969a, 1969b; Pearson 1950; Schubert et al. 1970). Some of the more pertinent results are: (1) pine seedlings on denuded plots showed an elevenfold greater gain in dry weight than those grown in competition with Arizona fescue and mountain muhly; (2) mountain muhly, a warm-season grower, retarded growth of ponderosa pine seedlings less than did Arizona fescue, a cool-season grower; (3) net gain in dry weight of pines growing with muhly was nearly four times that of pines growing with fescue; (4) grass roots grew 50 percent faster than pine roots; (5) Arizona fescue and mountain muhly were more drought tolerant than ponderosa pine seedlings; (6) grass roots responded faster and more completely than pine roots to rains following the late spring-early summer drought; (7) roots of both grass and pine became dormant as the soil dried out; (8) grass roots resumed growth after rewetting, while most of the pine roots died or remained dormant; (9) grass roots depleted soil moisture to lower levels than did the pine roots; and (10) established pines were able to tolerate competition for moisture by grasses (Larson and Schubert 1969b).

Older trees benefit from reduction in stand density (Schubert 1971). Pine stands thinned to a GSL of 30 ft^2 basal area per acre grew about five times faster in diameter than did unthinned stands with a basal area of 210 ft^2 per acre. Furthermore, ponderosa pine stands thinned to a GSL of 30 produced about 470 pounds forage per acre per year, while unthinned stands produced none (fig. 8).[5]

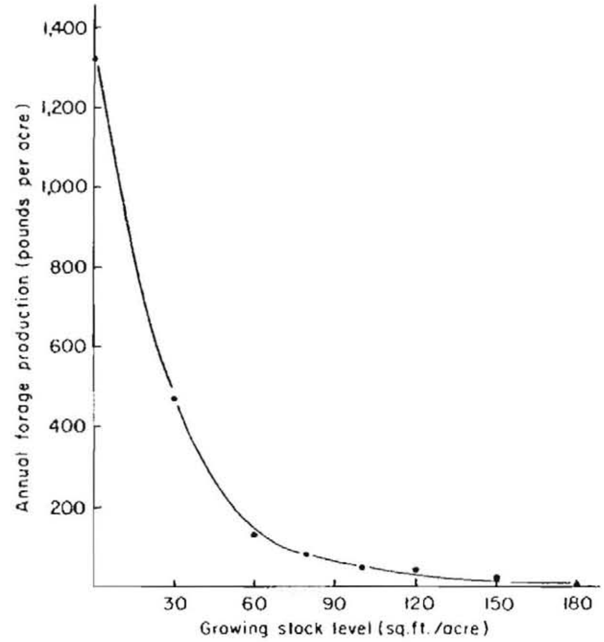

Figure 8.—Annual forage production per acre by tree density level.

Competition for Light and Nutrients

Growth of ponderosa pine decreases as the amount of light is reduced. One of the objectives of thinning is to provide more light for photosynthesis. Pines need about 50 percent overhead sunlight to survive (Pearson 1950). Growth rates have not been correlated with quantity of overhead light. We know that light is only one of the limiting factors, since trees growing at GSL of 80 and lower receive full sunlight, yet their diameter growth rates increase with decreased stand density.

Shade benefits seedlings by conserving moisture; during the pole stage, side shade improves tree form and fine branching (Pearson 1940b).

The nutrient supply in the forest soils is sufficient to maintain tree growth, although growth can often be improved through fertilization (Wagle and Beasley 1968). Competing plants and litter-decaying fungi often deprive ponderosa pine seedlings of needed nutrients, particularly nitrogen and available phosphorus, which are deficient in many soils.

Phytotoxic Effects

Some grass species produce inhibitors that reduce seed germination and seedling growth (Jameson 1961, 1968). Arizona fescue has been identified as one of the grasses containing phytotoxic substances. Ponderosa pine seed covered overwinter with Arizona fescue litter had 63 percent germination, compared to 90 percent for uncovered seed (USDA-FS 1957). Current research indicates that the strongest inhibition occurs in extracts prepared from green foliage and newer litter, and the least

[5]*Personal communication from William Kruse, Rocky Mt. For. and Range Exp. Stn., Flagstaff, Ariz.*

from older grass litter.[6] Young ponderosa pine roots growing in close association with Arizona fescue and mountain muhy roots showed no evidence of growth inhibitors (Larson and Schubert 1969b). The inhibitor, identified as a glycoside, most likely breaks down rapidly in well-aerated soils but could accumulate in heavier soils.[6] The seed or seedling must be physiologically active for inhibition to occur, so concentration of inhibitor at time of germination and initial growth is important.

EFFECT OF DAMAGING AGENTS

Southwestern ponderosa pine can be damaged by many agents throughout its life. It is most vulnerable during early life. As the tree reaches maturity, the number of injurious agents decreases, but the damage becomes greater in terms of lost volume.

Figure 9.—Snow damage in a young stand of ponderosa pine shortly after thinning, Fort Valley Experimental Forest near Flagstaff, Arizona.

Snow

Heavy wet snows cause some breakage and bending of trees (Pearson 1950). No data are available on the extent of these types of injury, but they are quite common in young dense stands. In the Taylor Woods GSL plots, heavy wet snows in the spring of 1965 severely bent or broke 12 percent of the trees in the third year after thinning (Schubert 1971). The smaller, weaker trees were damaged most (fig. 9). Almost no damage has occurred since 1965, even though the plots were subjected to the heaviest snowfall on record in December 1967, when 94 inches fell within 9 days.

A partial solution to snow damage in small trees is early thinning of dense stands to strengthen the residual trees. Many of the older trees that are broken are infected with heart rot. These infected trees should be removed in a salvage or improvement cutting.

Wind

Wind is one of the primary causes of damage to ponderosa pine (Myers and Martin 1963b, Pearson 1950). Pearson reported that wind caused 20 to 40 percent of total volume lost over a 30-year period at Fort Valley Experimental Forest. Damage is concentrated in mature and overmature stands during heavy windstorms in the fall in years with heavy precipitation in late September and October (fig. 10). Areas suffering heavy blowdown usually have shallow soils. Damage may also be heavy when strong winds come from the opposite direction of the prevailing winds.

Partial cuttings in the subordinate crown classes have improved windfirmness, particularly in dense stands. Trees with heart rot and low, sharp-angled forks should be cut in a salvage or improvement cut. Residual trees after thinning a tight clump are susceptible to windthrow. All trees with their bases within a foot or so of each other should be cut or all left for the next intermediate cut.

Figure 10.—Ponderosa pines in tight clumps, on shallow soil, and on areas with high water table are susceptible to windthrow if the stand is opened.

[6]*Personal communication from W.J. Rietveld, Rocky Mt. For. and Range Exp. Stn., Flagstaff, Ariz.*

Lightning

Lightning kills as many trees as windfall in northern Arizona (Pearson 1950). Unlike windfall, lightning is not always fatal, however. Mature and overmature trees are more frequently killed by lightning than are younger trees. Pearson indicated lightning mortality was rare in stands under 175 years old. Isolated trees or trees with their tops considerably higher than the general crown canopy are prime candidates for lightning strikes. Trees, young or old, that have been struck hard enough to split the bole or loosen the bark seldom survive.

Old overmature, particularly isolated trees should be harvested as rapidly as the allowable cut permits. Hard-hit trees should be cut immediately if merchantable.

Fire

Fire damage occurs mainly in the young age classes such as poles, saplings, and seedlings (fig. 11). Older trees are quite resistant, but hot wildfires will destroy all trees in the burned areas. Many large trees have large fire scars which reduce the value of the butt logs. Fires cause the greatest damage in dense young stands.

Figure 11.—Severe damage by wildfire in October 1948 on the Coconino National Forest, Arizona.

Young dense thickets should be thinned to reduce probability of crown fires. Fuel breaks should be placed along heavily traveled roads, around high-value sites, and at intervals along the contours of steep slopes. Heavily thinned strips, 2 to 3 chains wide, make good fuel breaks. In heavy use areas, thinning slash should be chipped or burned.

Diseases

Various diseases infect ponderosa pine from seedling stage to maturity (Boyce 1961). The more important fall into five main groups: (1) seedling diseases, primarily damping-off, (2) stem diseases such as dwarf mistletoe, limb rust, and Atropellis canker, (3) root diseases such as Armillaria root rot and Fomes root rot, (4) needle diseases such as Lophodermella and Elytroderma needle blights, and (5) stem rots, primarily western red rot.

Seedling Diseases

Damping-off fungi are primarily of importance in nurseries, but also occur in forest soil. Damping-off fungi are not considered a serious forest problem (Pearson 1923), but no assessment has been made. Most damage is confined to first-year seedlings growing in moist, shaded locations in alkaline soils. In nurseries, damping-off can be reduced by treatment with fungicides, by increasing the soil acidity, and by watering early enough to permit drying by evening. No control measures are normally used under field conditions.

Stem Diseases

Dwarf mistletoe is one of the four major causes of mortality in southwestern ponderosa pine (Hawksworth 1961, Myers and Martin 1963b). It has caused up to 36 percent of the mortality on the Fort Valley Experimental Forest (fig. 12). On trees not killed, it is responsible for about 15 percent reduction in growth.

Dwarf mistletoe occurs on about one-third of the commercial acreage (Andrews 1957). It infects trees of all age classes, and may kill trees up to small pole size within a few years of infection (Andrews 1957). Older trees are killed more slowly from the top down until all branches are dead (Hawksworth et al 1968). It has a serious impact on pine seed production,

Figure 12.—Dwarf mistletoe damage on ponderosa pines in the Fort Valley Experimental Forest near Flagstaff, Arizona. The older trees are killed from the top down. Young trees in the vicinity are all infected.

and is reported to reduce seed viability by up to 20 percent (Korstian and Long 1922).

The only methods for reducing dwarf mistletoe are pruning infected branches or killing infected trees (Hawksworth 1961, Hawksworth et al. 1968). Pruning infected branches will eliminate or reduce the parasite on lightly infected trees with no infections near the main stem. Since pruning is expensive, however, and pruned trees may harbor many latent infections, the operation is of limited usefulness. Silvicultural control of dwarf mistletoe is the only practical method of reducing the disease (Hawksworth 1961). The recommended treatment includes the following operations: (1) removal of all infected overstory trees, (2) removal or pruning of all infected trees in the understory, and (3) followup operations in all size classes.

Bole infections are relatively unimportant, and only trees with infection classes of 5 or 6 showed a significant decrease in radial growth (Hawksworth 1961). Trees are rated by lower, middle, and upper thirds of the crown, with a rating of 1 for light and 2 for heavy. Where trees are heavily infected (classes 5 and 6), clearcutting is recommended followed by planting (Heidmann 1968). The shelterwood method may also be applied, since young seedlings under 10 years show little or no infection. Further research is needed on the shelterwood method to determine the impact of dwarf mistletoe on pine seed production and seed viability.

Limb rust kills ponderosa pine throughout the western United States (Boyce 1961, Peterson 1966). It is a systemic disease with the infection spreading throughout the tree. Typically, it kills the branches near the middle of the crown first (fig. 13) and the infection continues in both directions until the tree is dead (Peterson 1966). The rust normally occurs on older trees, and is always fatal (Peterson and Shurtleff 1965). The only control method is removal of infected trees during normal silvicultural operations.

Figure 13.—Mature ponderosa pine infected with limb rust. The disease kills branches near the middle of the crown, and then proceeds in both directions until the tree is dead.

Atropellis canker most frequently damages young ponderosa pines from 5 to 25 years (Boyce 1961). It does not kill trees, but deforms the main stems and branches. Cankered trees have been noted mainly in overcrowded pure stands in the Southwest, but the extent of damage has not been assessed. The disease may be controlled through removal of infected trees during thinning operations.

Root Diseases

Armillaria root rot causes rotting of the bark and wood, and eventual death of weakened trees (Boyce 1961). It is widespread throughout the Southwest, primarily in overmature trees, but is also present in young trees of poor vigor. The fungus is not reported to attack thrifty trees. Visual symptoms are short, yellow needles, abnormal resin flow from the root collar, and decayed bark or wood at the base of the tree. Diseased trees usually occur in clumps, but may be randomly scattered individuals. These trees are very susceptible to wind breakage. The volume lost has not been determined. Control can be achieved through sanitation, salvage, and improvement cuttings.

Fomes root rot also has a widespread distribution, and kills young trees in the vicinity of older infected trees or stumps (Boyce 1961). The fungus spreads from roots of diseased trees to young seedlings. Visual evidence in young killed trees includes the thin, tissue-paperlike mycelium belt between the bark and wood, resin flow from some butts, and conks at the root collar partially hidden by litter. Older trees are susceptible to wind breakage near the butt. Control requires that seedlings not be planted in the vicinity of diseased trees or stumps, and that spacing between planted trees be increased to reduce the possibility of root contacts.

Needle Diseases

Two needle cast diseases occur on young southwestern ponderosa pines. Heavy defoliation reduces tree growth but rarely causes mortality, except of small seedlings. Lophodermella needle blight, locally known as Prescott needle cast, is periodically conspicuous and is known to persist in an area for 15 years.[7] Elytroderma causes needle blight on trees of all sizes from seedlings to mature trees (Lightle 1954). Elytroderma causes "witches' brooms" that badly deform trees and are sometimes mistaken for mistletoe brooms. The only control of Elytroderma is to remove the infected trees, or prune off the infected branches. No control has been reported for Lophodermella.

Stem Rot

Western red rot is the most important heart rot of ponderosa pine in the Southwest (Andrews 1955, 1971). As much as 20 percent of the gross volume in virgin sawtimber stands has been culled because of this rot. It is the most important fungus causing slash decay (Andrews 1971, Boyce 1961).

Harvest cuttings have materially reduced red rot in virgin ponderosa pine sawtimber stands (Andrews 1971). Future cuttings in these stands will progressively reduce the volume of infected wood as the proportion of old trees decreases. Thinnings which favor small-branched and discriminate against large-branched trees also lower the probability of infection. Pruning eliminates future entrance points, as well as branch infections that have not entered the bole. Pruning also creates conditions which inactivate or kill the red rot fungus that may already have extended into the knots. Very little infection occurs in young-growth sawtimber.

Insects

Numerous insects damage ponderosa pines (Keen 1950). Of these insects, the five groups which have done the greatest damage are: (1) bark beetles, which includes the mountain pine beetle, the western pine beetle, the roundheaded pine beetle, the turpentine beetle, and the Arizona five-spined ips;(2) seed and cone insects, primarily pine seed moths and cone beetles; (3) root feeders, primarily root grubs and cutworms; (4) shoot moths, primarily the southwestern pine tip moth and pine shoot moths, and (5) scales, primarily the Prescott scale.

Bark Beetles

The mountain pine beetle is the most aggressive and destructive insect enemy of mature southwestern ponderosa pine (Keen 1952). It normally kills only old, weakened, decadent trees, but during epidemic conditions may also kill young trees. Control measures[8] consist of:

[7]Personal communication from John Staley, Rocky Mt. For. and Range Exp. Stn., Fort Collins. Colo.

[8]Consult forest pest control specialists about details of direct control.

(1) felling and peeling; (2) felling, piling, and burning; and (3) spraying with insecticides. These three methods must be completed prior to July 15. The two currently registered insecticides are lindane and ethylene dibromide (McCambridge 1972, McCambridge and Trostle 1972). Cacodylic acid (dimethylarsenic acid) has also shown some promise (Chansler et al. 1970, Stevens et al. 1974). Silvicultural control methods involve sanitation-salvage cutting in mature and overmature stands to remove poor vigor trees, and thinning in young stands to remove poor quality and vigor trees.

The western pine beetle mainly attacks trees over 6 inches d.b.h. that are in a weakened condition. It can be controlled through silvicultural treatments such as removal of mature and overmature trees of low vigor, and by thinning sapling and pole stands to improve tree vigor.

The roundheaded pine beetle periodically infests ponderosa pine over thousands of acres in the Southwest. During epidemic periods, infestations develop in dense stands on ridge tops or poor sites or where trees are infested by other bark beetles. They may build up rapidly and spread to stands on better sites. Control measures are the same as for the western pine beetle.

The red turpentine beetle attacks the base of injured, dying, or healthy trees, and freshly cut logs and stumps of southwestern ponderosa pine (Keen 1952). It is not an aggressive tree killer, but frequently weakens trees, making them susceptible to other bark beetles. Their attacks are characterized by large reddish pitch tubes on the lower portion of the trunk, and frass around the base of the tree (fig. 14). The damage is seldom serious enough to warrant control in the forest, but in recreation or other high value areas, the attack can be reduced by cutting out the beetles as soon as pitch tubes form or by chemical treatment indicated for mountain pine beetles.

Figure 14.—Frass at base of tree attacked by the red turpentine beetle.

The Arizona five-spined ips attacks young ponderosa pines, and at times is extremely destructive. The beetles prefer fresh slash or injured young trees (Massey 1971). When populations exceed five larvae per ft^2, the adults may kill young, vigorous trees. The beetles are also beneficial, however, in that they help destroy slash. Unless populations are epidemic, the beetles will enter fresh slash and cause little damage. Therefore, one of the "control" methods is to schedule thinnings to provide new slash for the emerging adults. Where this is impractical, ips can be killed by spraying with ethylene dibromide.[8] Cultural controls consist of prompt disposal of all slash 3 inches and larger in diameter by chipping, piling, and burning. Scattering slash in open areas to dry out rapidly, or piling the infested slash and then covering with plastic material, also effectively controls ips. Ips also may be killed when winter temperatures drop below -5°F (-21°C).

Cone Insects

Seed and cone insects have destroyed up to 50 percent of the seed crop in some years (Pearson 1950). In California, seed and cone insects frequently prevent the occurrence of two successive heavy seed years (Fowells and Schubert 1956).

Pine seed moth larvae are found in the axis of pine cones or in seeds (Keen 1958). They bore through seeds, cone scales, and cone axis. In ponderosa pine, from 12 to 100 percent of the cones may be infested and up to 50 percent of the seeds destroyed. Several hymenopterous parasites feed on the larvae. No control methods have been developed.

Cone beetles attack small immature cones in their second year of development, bore into the axis and kill the cones, and then riddle the interior (Keen 1958). Cones attacked by this insect have an aborted appearance. All cones on some trees may be killed. No special control measures are used for cone beetles in forest stands. Insecticides may be used in seed orchards or seed production areas, but timing is critical. Aborted cones which have fallen to the ground may be piled and burned to reduce the insect population. Forest insect control specialists should be consulted for chemical control treatments.

Root Feeders

White grubs (larvae of June beetles) **and cutworms** (larvae of "millers"—night-flying moths) do considerable damage to first- and second-year seedlings (Keen 1952, Pearson 1950, Schubert and Adams 1971). These larvae are generally numerous in most grass-covered areas. They feed on all young tender roots, at times eat entire newly germinated pine seedlings, and can cause complete failure of seeded areas. Clean cultivation is one of the most effective control methods (Schubert and Adams 1971, Schubert et al. 1970). Prolonged drought helps reduce their numbers but may also reduce seedling vigor. Many rodents and birds feed on the larvae. Chlordane is effective against these insects in spot seedings. Severely burned and bare areas generally have too few root-feeding insects to warrant special control measures.

Tree Moths

Tip and shoot moth larvae may severely damage tender new shoots (Keen 1952). The damage to new growth on older trees is considerably less serious than on younger trees. Tip and shoot damage is seldom serious except on trees on cutover lands, plantations, and residential areas where it may be disastrous. Attacks by these insects are evidenced by dead terminals and lateral shoots, and deformed or many-branched trees. The tree may even be killed after heavy repeated attacks. Destruction of the shoots reduces height and volume growth.

Control of these insects is often difficult. The larvae of southwestern pine tip moths leave the tips during July and August and spin cocoons, usually in the bark crevices at the base of the tree below the litter. Here they transform to pupae and pass the remainder of the summer, fall, and winter. The moths fly in late spring and lay their eggs on the branch tips. Control with insecticides requires critical timing during emergence, and expert advice should be sought. Handpicking of infested tips offers some control on small, valuable plantations and special-use areas.

Scale

The Prescott scale often kills branches on southwestern ponderosa pine (Keen 1952, McKenzie 1943, McKenzie et al. 1948). The adults emerge early in the spring and complete their life cycle in 1 year. The females lay their eggs mainly at the first and second nodes from the terminals, and cover the eggs with a white fluffy wax. The larvae feed at the base of needles and in the cracks and crevices of twigs. These scale insects are one of the primary causes of dead branch tips known as flagging.

Pruning the infested branch tips at the third node and then burning may be the only control method needed. The scale has not been reported to kill trees, but at times creates an alarming appearance.

Birds

Carothers et al. (1973) discuss the birds of coniferous forests in northern and eastern Arizona in a collection of four papers.

Many species of birds feed on pine seeds, and some eat buds and newly germinated seedlings. The beneficial aspects of birds outweigh the harmful effects, however. The most beneficial birds feed primarily on insects. The many seed-eaters (Eastman 1960, Smith and Aldous 1947) are nuisances primarily during forest regeneration (Fowells and Schubert 1956, Larson and Schubert 1970, Schubert and Adams 1971, Schubert et al. 1970). Juncos, in one study, destroyed 69 percent of the newly germinated seedlings (Larson 1961). Many other bird species damage newly germinated seedlings when they bite off the seedcoat and the cotyledons.

The only bird control needed may be during direct seeding. Thiram, a nonpoisonous chemical, has been used successfully as a bird repellent (Schubert and Adams 1971).

Two effective methods, both nondestructive, are to cover the pine seed with soil and to coat the seed with aluminum flake or a bright color to discourage seed eating.

Mammals

Many mammals seriously damage ponderosa pine, particularly young trees (Pearson 1950, Schubert and Adams 1971, Schubert et al. 1970). Older trees are damaged by fewer animals, but the results may be just as serious (Keith 1965, Larson and Schubert 1970, Pearson 1950). At least 44 species of mammals feed on conifer seeds (Smith and Aldous 1947).

Small Mammals

Mice, rats, chipmunks, and ground squirrels represent the first real threat to reforestation by seeding (Pearson 1950, Schubert et al. 1970). These rodents consume vast quantities of seed, and injure or kill many young seedlings from the time they first emerge above the ground surface. Some girdle stems or feed on buds of older seedlings. White-footed and deer mice are the most prolific seed eaters (Fowells and Schubert 1956, Keyes and Smith 1943, Pearson 1950, Schubert and Adams 1971, Schubert et al. 1970). These small rodents are one of the primary reasons why many natural and artificial seedings fail.

Lethal bait has been used to reduce rodent populations, but has not always been effective (Schubert and Adams 1971). Endrin-thiram has been used as a repellent, but the quantity currently permitted by law for seedcoating has been ineffective (Schubert et al 1970). Direct seeding has the best probability of success in years when heavy seedfall on adjacent areas makes an influx of rodents onto the seeded area improbable.

Gophers, rabbits, and hares also do considerable damage in some areas (Pearson 1923, 1950; Schubert et al 1970; Ward and Keith 1962). Pocket gophers confine most of their activity to the root system. In areas with high populations, they may destroy all young seedlings. Rabbits and hares, where abundant, have girdled many young pines (Pearson 1950).

Gophers may be reduced in number by placing strychnine-treated carrots in their tunnels at a rate of 160 to 380 baits per acre (Dingle 1956, Nelson 1960) or by clean cultivation to remove their food supply. Rabbit and hare damage can be reduced by spraying the young trees with a repellent containing thiram (Dietz and Tigner 1968, Hooven 1966, Schubert et al. 1970).

Porcupines have caused serious damage to ponderosa pine (fig. 15) in the Southwest (Pearson 1950). Porcupines do most of their damage on pole-sized trees and young sawtimber, but they also debark or completely girdle seedlings and saplings (Schubert 1970, 1971).

Porcupines are protected by law in Arizona. In special areas, such as seed orchards, a wide metal band around the tree trunk can be used to prevent porcupines from climbing trees. Porcupines have been controlled by placing poison bait in their rest trees or dens (Faulkner and Dodge 1962, Lawrence 1957, Spencer 1950).

Tree squirrels have their greatest adverse impact in destruction of pine cones (Keith 1965, Larson and Schubert 1970). The damage done

Figure 15.—Ponderosa pine severely damaged by porcupines over a period of years.

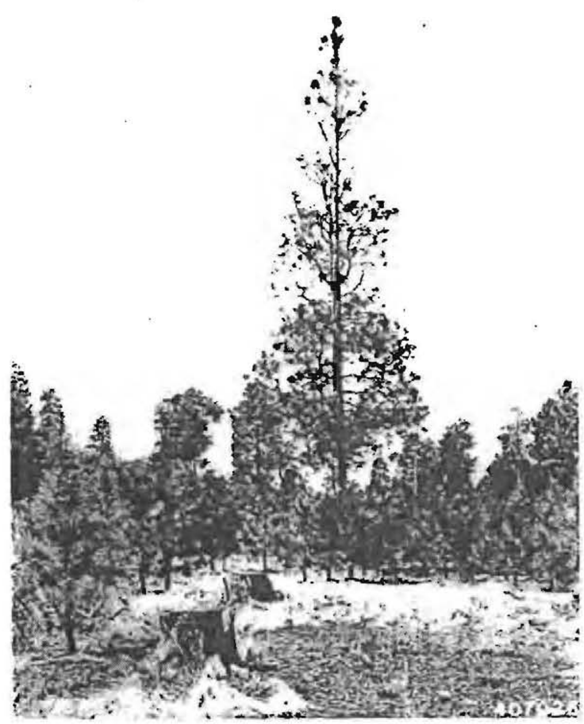

Figure 16.—Young ponderosa pine severely defoliated by Abert squirrels.

may be significant, though not critical. Red squirrels confine most of their activity to cutting cones, and then caching them for winter food. Abert and Kaibab squirrels cut cones to eat the seed, and clip twigs to eat the inner bark and cambium (fig. 16). These two squirrels do far more damage to ponderosa pine than do the red squirrels. On the Fort Valley Experimental Forest, cone cutting by Abert squirrels reduced cone production 20 percent over a 10-year period (Larson and Schubert 1970). At times, twig cutting by Abert squirrels has been so severe that trees died or were so weakened that insects killed them. Twig cutting also reduces tree growth and causes formation of multiple tops.

Squirrels can be kept out of trees by placing a wide aluminum band around the trunk about 6 ft above the ground. Bands may be required on trees in seed orchards or seed production areas if the damage warrants protective measures. Since squirrels climb to adjacent trees where branches intermingle or jump where branches are close enough, all trees within a group would required bands.

Figure 18.—Fifty-year-old ponderosa pine seedlings of 1919 origin repeatedly and severely "hedged" by deer on the Fort Valley Experimental Forest. Saplings in background are of the same age.

Browsing Animals

Deer, elk, and sheep are generally more destructive than **cattle and horses**, though cattle (fig. 17) in overgrazed stands of young trees may be just as damaging (Cassidy 1937a, 1937b; Cooperrider 1939; Hill 1917; Parker 1948; Pearson 1950). Horses normally cause little damage, but this may be due to their lower numbers in forested areas. Deer (fig. 18) and sheep (fig. 19), which cause the most serious damage, often do not cause mortality—except of small seedlings—but continuous browsing has stunted larger seedlings for 50 years or more. Many trees, if not damaged too severely or con-

Figure 17.—Cattle damage on ponderosa pine seedlings on the Fort Valley Burn plantation. Nearly 94 percent of the seedlings were browsed or trampled within a few months after planting.

Figure 19.—Ponderosa pine regeneration in foreground destroyed by heavy sheep grazing during early seedling stage. Area in background has an excellent stand of 1914 saplings in a pasture lightly grazed only by cattle and horses (Photo taken in 1936. Fort Valley Experimental Forest, Arizona).

tinuously, recover when the area is closed to grazing or the trees have grown out of reach and make normal growth (Cooperrider 1938).

Deer and elk damage has been reduced by treating trees with repellents containing thiram (Heidmann 1963a). Sheep, cattle, and horse damage is best controlled by fencing to exclude the animals from regeneration areas. Light grazing by cattle may cause little damage during the summer wet season after the seedlings are about 1 ft high.

Logging Damage

Logging damage is the major man-caused mortality factor (Pearson 1950). The damage starts with the construction of roads, and continues with each successive phase of the operation. Young reproduction is damaged or destroyed, and residual merchantable trees injured, by tree felling, skidding, construction of landings and roads, and during slash disposal. Injured trees are often killed by insects. Other serious forms of damage are: soil compaction, especially where logging is permitted during wet weather; erosion channels following skidding; and stream channel damage. There are no actual data on the extent of the damage. On the other hand, many logged areas show little or no damage, even where relatively heavy volumes were removed.

Logging damage can be reduced in many ways. For example: (1) lay out spur roads and skid trails to take maximum advantage of existing openings; (2) do not lay skid trails diagonally downslope; (3) keep stream crossings to a minimum; (4) where live streams are to be crossed, use road fill and culvert instead of fording; (5) fell trees into openings wherever possible; (6) fell trees in a herringbone pattern to spur roads and skid trails; (7) use smallest skid cats needed without dozer blade or with narrow blade; (8) do not hook up to two logs at the same saw cut; (9) do not use residual trees as pivot points for turns; (10) do not permit use of heavy equipment in woods when soil is saturated; (11) keep landings small and take advantage of natural openings; (12) use "hot-logging"; (13) do not permit log hauling during wet weather; and (14) use two-stage cutting for heavy cuts.

SITE QUALITY

Significance

Site class or quality is a measure of the relative productive capacity of an area based on the volume, height, or maximum mean annual increment attained or attainable at a given age. It reflects the effects of the total environment. Classification of land into site quality or productivity classes provides a valuable aid in concentrating and intensifying practices on land with the greatest potential for improved production.

It is important to know site quality, whether management is extensive or intensive. Timber is only one resource the manager must consider. Other resources and uses may justify a more intensive treatment on marginal or submarginal timber lands than could be justified by timber production alone. Measures to protect the land resource and to improve the esthetic quality may be required on all lands, regardless of site quality.

Determination of Site Quality

Site Index

Height, in ft, of dominant and codominant ponderosa pines of average diameter at age 100 years (Meyer 1961) is used as an indicator of site quality (site index) by Forest Survey in the Southwest. The site quality of an area is determined from Meyer's interregional ponderosa pine site index curves. These interregional curves tend to underestimate site quality in the Southwest due to factors which reduce height growth during the seedling-sapling stage. Furthermore, ponderosa pines from the Southwest were not included in the interregional study (Meyer 1961). Site index curves presently

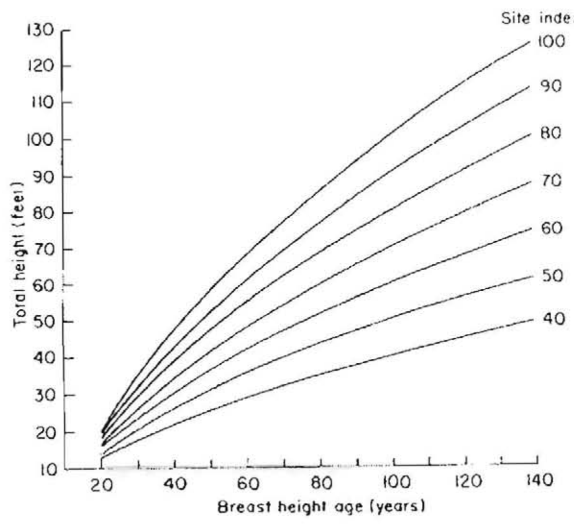

Figure 20.—Site index curves for young-growth ponderosa pine in northern Arizona (Minor 1964).

used in the southwestern States are: (1) Meyer's interregional curves in Utah and western Colorado, (2) Minor's (1964) curves for Arizona and New Mexico, and (3) Mogren's (1956) curves for low-quality sites in the Colorado Front Range.

Minor's site index.—These site index curves (fig. 20) are for dominant trees with breast-height ages of 20 to 140. They cover site index classes 40 to 100 (Minor 1964). These site indices cover the range of age classes planned for the future on National Forests. Some areas may exceed Site Index 100 and may require extension to higher classes. Site indices over 100 can be calculated by means of the equation:

$$S = \frac{H + 1.4003\,(\sqrt{A} - 10)}{1 + 0.1559\,(\sqrt{A} - 10)}$$

where
S = site index,
H = dominant height in ft,
A = age at breast height in years.

To record site index closer than the nearest 10-ft class, the same equation may be used instead of interpolating within the graph.

Dominant trees were selected because of the relative stability within this crown class. "Years-to-breast-height" ranged from 6 to 29 years, with an average of 14.3.

Mogren's site index curves.—Mogren (1956) found that the site index curves developed by Meyer (1934, 1961) did not apply to the adverse ponderosa pine sites on the eastern slope of the Front Range in northern Colorado. The trees on the Front Range were too short to meet even the poorest site class (40 ft at base age of 100 years). His site curves apply primarily to north-central Colorado (fig. 21).

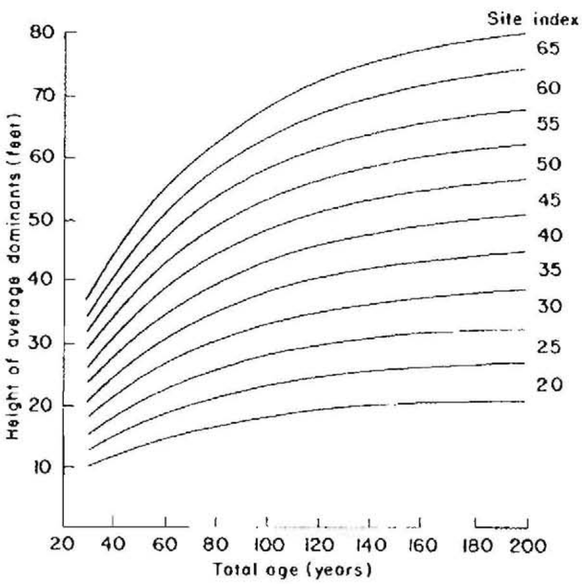

Figure 21.—Site index curves for ponderosa pine, eastern slope of the Front Range in northern Colorado. Reference age: 100 years (Mogren 1956).

Region 3 site classes.—Forested land in Arizona and New Mexico has been grouped for management purposes into three broad site classes using Minor's site indices: Site Class 1 = site index 75 or above, Site Class 2 = site index 55-74, and Site Class 3 = site index 54 or below. Most timber production activity is concentrated on Site Class 1 lands, with some in Site Class 2. Site Class 3 lands are submarginal for timber production. It could be argued that the three site classes are too broad for satisfactory determination of management alternatives.

Timber Suitability Groups

Parts of the Southwest, where intensive surveys have been completed, have been classified into five timber suitability groups in order of their estimated relative productivity potential (Williams and Anderson 1967). The classification is based on soil characteristics, and ties into the R-3 site index. Clary et al. (1966) reported that grouping areas by soil management units and topography reduced the sampling variance for herbage production on areas cleared of timber, and for site index on areas supporting timber.

GROWTH, YIELDS, AND QUALITY

Forest management in the southwestern ponderosa pine type is becoming more intensive. Silvicultural practices are focused on stand manipulation to: (1) improve growth rates by controlling stand density, (2) accelerate replacement by prompt reforestation and increased rate of ingrowth, (3) reduce mortality by removal of high-risk trees, (4) maximize yields by improvement of stocking and by frequent stand re-entry to maintain growth rates, reduce losses, and improve utilization, and (5) improve quality by removal of inferior trees.

GROWTH

Growth rates are a function of site quality and stand density. Growth is determined in terms of diameter, basal area, height, and volume. Each of these is affected by site quality, stand density, and tree vigor.

Diameter Growth

Trees of all age classes can grow in diameter at about the same rate, provided they are given adequate growing space. Ponderosa pine remains physiologically young and responds to thinning up to an age of at least 200 years (Pearson 1950). Weighted average diameter growth rates in a virgin stand for a 10-year period was 1.14 inches, compared to 1.68 inches in a cutover stand.

Dense stands of slow-growing ponderosa pines have responded well to release (Schubert 1971). Forty-three-year-old stands, with an average density of 5,800 stems per acre and an average diameter of 2.6 inches, were thinned in 1962 to test six residual growing stock levels (GSL). The GSL's are numerical indices representing future basal areas when average tree diameter reaches 10 inches or more, and range from 30 to 150 ft^2 per acre. Net diameter growth during the first 5 years after thinning exceeded the prethinning rate by 4.6 times at GSL-30 and 2.2 times at GSL-150 (fig. 22). The effects of thinning on growth rates remained large at the end of 10 years.

Diameter growth was strongly correlated with stand density (fig. 23). For the 10-year period after thinning, 98 percent of the interplot variation in annual diameter growth was associated with stand density. The periodic annual diameter increment for the 10-year period is closely estimated by the equation:

$$Y = 0.037 + 0.448e^{-.015x}$$
$$R = 0.981, S_{y \cdot x} = 0.012$$

where

Y = increment, in inches,

X = residual basal area immediately after thinning, in ft^2,

e = 2.718 . . . , the base of hyperbolic logarithms.

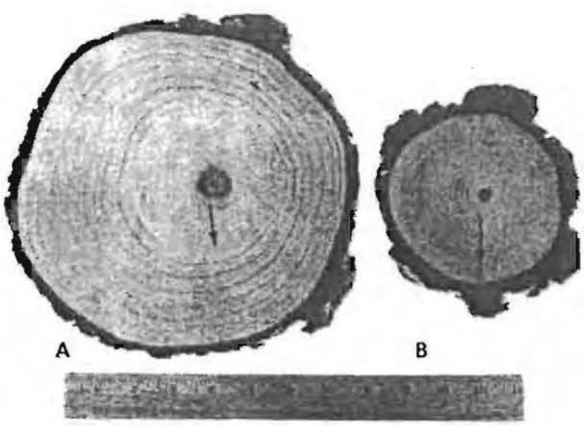

Figure 22.—Growth response of ponderosa pine following stand density reduction in fall 1962, Taylor Woods Growing Stock Level study near Flagstaff, Arizona: **A**, Reduction to 19 ft^2 basal area per acre (GSL-30); **B**, Reduction to 72 ft^2 basal area per acre (GSL-150).

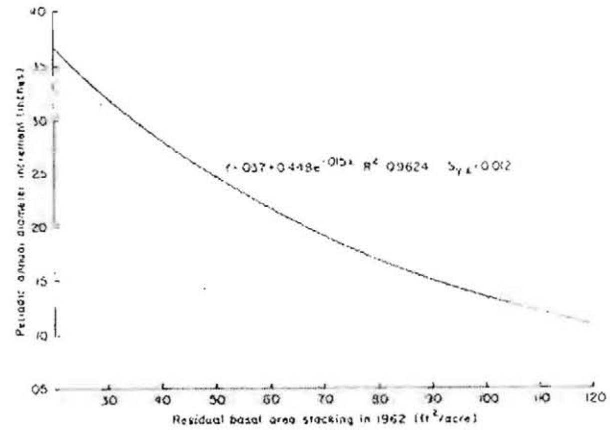

Figure 23.—Relation of periodic annual diameter growth to basal area stocking.

Both the graph (fig. 23) and the above equation should give useful, if rough, estimates for young stands elsewhere on the Colorado Plateau, and probably throughout the Southwest.

The reduced diameter growth during the last 2 years (fig. 22) may reflect the 1971-72 drought as well as decreasing growing space. The outermost ring is the full annual ring for 1972. This outer ring may appear to be incomplete since the summerwood laid down in late July and August is indistinct adjacent to the bark without staining.

Basal Area Growth

In contrast with diameter growth, net basal area increment was greater at higher residual stocking levels throughout the range of GSL-30 to 150 (fig. 24); at low stocking levels, trees were too few to use the site's full potential for basal area growth. Above GSL-80, increased stocking made less difference.

On the 100 largest trees per acre, however, basal area increment was greatest at GSL-30 and slightly less at each succeeding level to 120, then sharply less at 150.

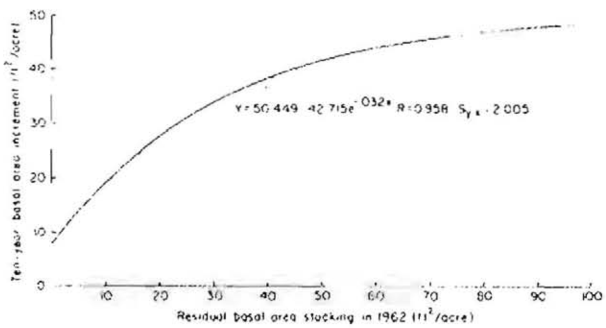

Figure 24.—Relation of periodic basal area growth to basal area stocking.

Basal area increment for the 10-year period after thinning was very highly correlated with stocking level (R = 0.958), and is estimated for the site by the equation:

$$Y = 50.449 - 42.715e^{-0.032x} \qquad S_{y.x} = 2.005$$

where

Y = increment in ft^2 per acre

X = residual basal area immediately after thinning, in ft^2

e = 2.718 . . . , the base of hyperbolic logarithms.

Height Growth

Height growth increases with site quality (Minor 1964, Pearson 1950), but is not affected by stand densities from GSL-30 to 150 (Schubert 1971). Height growth of southwestern ponderosa pine is slow even on the best sites (fig. 25). Growth is most rapid on young trees and then decreases with age. Annual height increment for trees on site index 90 lands is about 1.3 ft at breast height age of 20 years compared to 0.5 ft at 140 years. Trees beyond breast height age of 160 years add very little height growth.

Volume Growth

Volume growth is strongly related to tree size (Pearson 1940a, 1950) and to stand density (Schubert 1971). Total growth in the GSL study increased with stand density except for GSL-150. Annual total volume increment for the four highest growing stock levels, GSL-80, 100, 120, and 150, was essentially the same, however: 50 to 55 ft^3 per acre. For the 100 largest trees, total ft^3 volume increment per acre did not differ significantly for GSL-30 through GSL-120, but dropped significantly at GSL-150. Site index for the study plot was 88, based on Minor's site index which uses age at breast height.

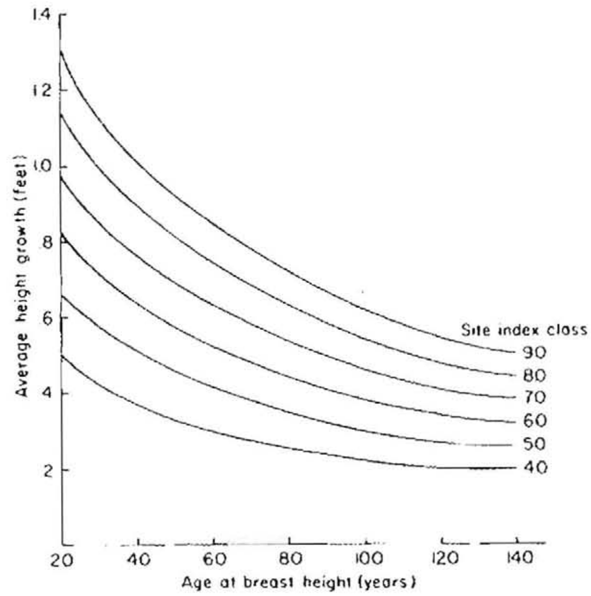

Figure 25.—Approximate periodic annual height growth curves for southwestern ponderosa pine as related to age at breast height and site index.

Increment of merchantable volume on the GSL plots increased significantly for growing stock levels up to 80, but was quite variable at higher stocking levels (Schubert 1971). Analysis of volume added during the 10-year period after thinning has not been completed.

Volume growth needs to be determined for stands of different tree sizes by stocking densities on an array of lands of different site quality. The volume growths cited above were for young, even-aged stands on better-than-average sites.

Mortality

Mortality is highest in unmanaged forests. In southwestern ponderosa pine forests, mortality amounts to about 16 percent of the gross ft^3 volume increment and 18 percent of the fbm increment (Choate 1966, Miller and Choate 1964, Spencer 1966).

Mortality is highly variable. It may amount to half of the gross volume growth. In the G. A. Pearson Natural Area, during the period 1925-50, annual mortality averaged 61 fbm compared to a gross annual growth of 107 fbm per acre (Pearson 1950). Sound silvicultural practices can reduce mortality to a negligible amount (Myers and Martin 1963a, 1963b). Most of the mortality occurs in large trees, generally over 28 inches (Pearson 1940a).

Table 7.--Major causes of mortality of ponderosa pine in the Southwest, by States

State	Growing stock						Sawtimber					
	Fire	Insects	Disease	Weather[1]	Other	Unknown	Fire	Insects	Disease	Weather[1]	Other	Unknown
	Percent											
Arizona	41.5	12.4	35.1	7.0	4.0	--	41.8	10.6	38.9	4.9	3.9	--
Colorado	.3	41.8	39.6	--	15.6	2.7	.2	42.8	39.0	--	15.7	2.3
New Mexico	10.9	33.8	42.3	--	13.0	--	3.8	36.8	44.1	--	15.3	--
Weighted average	7.8	36.3	39.6	.9	13.6	1.8	7.1	36.7	40.1	.7	13.9	1.5

[1]Primarily windthrow.

Diseases, particularly dwarf mistletoe, cause the greatest losses (table 7). Insects, particularly the bark beetles, rank a close second, with most losses in overmature stands. Windthrow may be high in years (Heidmann 1968) when strong winds strike from the opposite direction of the prevailing winds, and following heavy rains in areas with shallow soils.

Fire has caused heaviest losses in Arizona (table 7). The fire losses are reported primarily for areas occupied by sawtimber. Severe fires in seedling, sapling, and pole stands usually kill most of the trees.

YIELDS

Yields are affected by the amount of commercial land that is stocked, stand density, site quality, time required for replacement of harvested trees, volume lost through unsalvaged mortality or other factors, how completely the cut or killed trees are utilized, and by management decisions on the use of the land. Yields may be expressed in terms of timber, forage, water, wildlife, and other goods and services where the total land yield may outweigh any single use.

Timber Yields

Timber yields of southwestern ponderosa pine lands have been low, due in part to unstocked lands, overstocked stands, and large acreages still occupied by old-growth timber. These yields can be increased through more intensive management.

The average gross annual increment on large sample plots on the Fort Valley Experimental Forest has ranged from 70 to 116 fbm per acre (Pearson 1950). Mortality has reduced these annual yields to a range of 25 to 93 net fbm per acre. Small, well-stocked plots which have

Table 8.--Estimated yield of even-aged ponderosa pine per acre, by growing stock levels (GSL) to produce a final harvest stand averaging at least 24 inches in d.b.h. (site index 88)

Growing stock level[1] (Index)	Rotation age	Average diameter	Growth rate[2] rings/inch	Gross volume: Sawtimber[3]	Gross volume: Total[4]
		Inches	*No.*	*Fbm*	*Ft³*
30	100	28	6	19,600	4,600
	120	35	6	24,900	5,400
60	100	21	8	22,300	6,200
	120	26	8	31,200	7,500
80	100	17	10	17,000	5,600
	120	21	10	27,000	7,200
	140	25	10	35,800	8,500
100	100	15	11	15,800	5,800
	120	19	11	26,700	7,900
	140	22	11	35,400	9,200
	160	26	11	46,700	10,900
120	100	14	12	15,900	6,100
	120	17	12	24,000	8,000
	140	21	12	39,000	10,300
	160	24	12	48,700	11,800
150	100	12	15	10,700	5,700
	120	14	15	18,000	7,300
	140	17	15	28,200	9,600
	160	20	15	41,200	11,700
	180	23	15	54,100	13,600
	200	25	15	61,300	14,700

[1]Numerical designation of level assigned is basal area per acre that will remain after thinning when stand diameter is 10 inches or more.

[2]Based on mean annual increment of diameter for first 10 years after thinning Taylor Woods Growing Stock Level plots.

[3]Merchantable stem excluding stump and top, based on regression equations for table 5a in Myers (1963), using local height data for d.b.h. 9 inches and over.

[4]Total volume in trees 6 inches and over for local volume tables based on regression equations for table 1a in Myers (1963).

Table 9.--Estimated gross per-acre volume available for harvest at 20-year intervals, by basal area stocking levels, for a ponderosa pine selection forest on areas with site index of 85-90

Basal area stocking (Ft^2/acre)	Stocked stand volume[1]		Volume growth per 20 years[2]	
	All timber	Sawtimber	All timber	Sawtimber
	Ft^3/acre	*Fbm/acre*	*Ft^3/acre*	*Fbm/acre*
30	510	1,620	1,110	4,190
40	680	2,120	1,220	4,560
50	850	2,700	1,230	4,530
60	1,020	3,240	1,190	4,450
70	1,190	3,750	1,160	4,220
80	1,360	4,320	1,110	4,110
100	1,700	5,390	1,010	3,650

[1]Volume needed for full stocking at start of 20-year period.

[2]Gross volume growth based on growth rates of Taylor Woods Growing Stock Level study. These volumes are based on the assumption that average growth rate for each density level will not decrease and that no losses occur.

received several intermediate cuts show a net yield of 103 to 232 fbm per acre. Trees in these stands range up to 300 years in age and over 40 inches in diameter. Stocking densities were not reported.

For rotation periods of 120 years, yields are estimated to be greatest for even-aged stands reduced to a growing stock level of 60 ft^2 per acre every 20 years up to rotation age (table 8). These estimates are based on the assumptions that the average growth rate will remain the same for a 20-year period and there will be no mortality. Stands at higher stocking levels would produce roughly similar ft^3 volumes, but progressively less sawtimber, in the form of more but smaller trees. Since diameter growth is less at greater basal areas, more frequent thinning may be required to maintain the growth rates used for these estimated gross yields.

Annual growth of fully stocked ponderosa pine selection forests should average about 180 to 230 fbm per acre. The estimated 20-year annual yields, based on growth rates in the Taylor Woods plots, show little variation by stand density (table 9), but may be expected to show greater differences by site quality. Estimated 20-year yields, based on growth rates adjusted for stand density and no losses, range from 4,200 fbm per acre for the GSL-30 stand density level to 3,600 for the 100 level. These yields have occurred on the Fort Valley Experimental Forest on a stand basis, but not on a plot basis because of variation in stocking.

Forage Yields

Forage yields in southwestern ponderosa pine forests are less where tree basal area is greater (Clary and Ffolliott 1966, Jameson 1967). Clearings in a forest were found to produce over 600 pounds of herbage per acre compared to under 50 pounds where tree density exceeded 100 ft^2 per acre (fig. 26) (Jameson 1967). At a basal area of 60 ft^2 per acre, forage yields approached their minimum. Total herbage production in the Taylor Woods GSL study decreased as stand basal area increased after thinning.[9] Thinning slash in the Taylor Woods study was lopped and scattered, which may have adversely affected forage production.

Utilization

Scaled volume from timber sales has been 15 to 20 percent below cruised volumes. Some of this difference is due to the difficulty in accurately estimating cull. The remainder represents unutilized wood due to breakage during felling, improper bucking, and merchantable logs left in the woods. The net ft^3 volume of logging residues from saw-log operations in Arizona and New Mexico was found to be about 12 percent of the net product volume (Setzer et al. 1970). Development of new products to utilize low grade timber has improved

[9]*Personal communication from William Kruse, Rocky Mt. For. and Range Exp. Stn., Flagstaff, Ariz.*

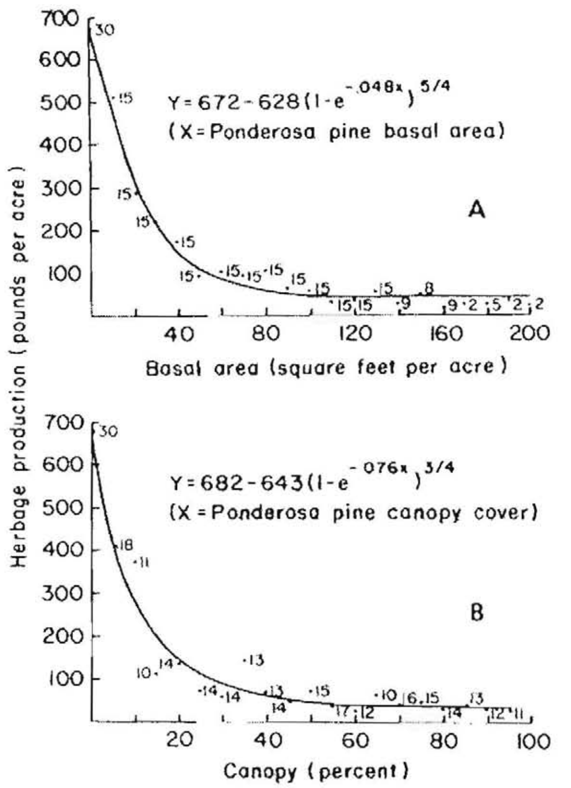

Figure 26.—Relationship of herbage production to stand density **(A)** and crown canopy **(B)** (Jameson 1967).

Figure 27.—"Utilizer" being tested in the Southwest which converts much of the logging residues normally left in the woods into chips for transport to the pulpmill.

utilization (Barger and Fleischer 1964, Mueller et al. 1972). Pulpmills in the Southwest are using logs which were formerly classed as cull. A new approach being studied is to debark and chip small, crooked, or otherwise defective material at the logging site—material constituting much of the volume usually left as slash. The chips are then loaded into a van and hauled to the pulpmill (fig. 27).

Stand Tables

Stand tables for fully stocked even-aged (table 10) and uneven-aged (table 11) ponderosa pine forests indicate the number of trees required by diameter classes. The number of trees present after cutting would remain the same in even-aged stands until the next scheduled cut. After the cut, the number of trees would reflect the change needed to reduce the stocking level to the new residual stand.

Expected future gross stand tables for selection forests reflect the change in number of trees by diameter class resulting from the various growth rates. The example (table 12) is a 20-year projection of table 11, based on growth rates of trees in the Taylor Woods plots. These growth rates are affected by stand density, site quality, climate, and injury, but not by age of the tree under at least age 200. Expected future stand tables may vary by habitat types and other factors not listed here.

Stock Tables

Stock tables are primarily of local value. All the various factors affecting growth will have an impact. Stock tables may have wider application after completion of the habitat classification currently underway. The yields reported here for selection forests were derived from stock tables for residual stands in ft^3 per acre (table 13) and fbm per acre (table 14) and the estimated stock tables in ft^3 (table 15) and fbm (table 16) based on local volume tables developed for site index 85-90.

Volume and Taper Tables

Numerous volume and taper tables have been prepared for southwestern ponderosa pine using scaled volumes and taper of sample trees, graphic methods, and various formulas. Blackjack and old-growth pines of equal heights were found to vary greatly in taper and volume, so separate tables were prepared for the two groups of trees (Hornibrook 1936). Most of

Table 10.--Number of trees per acre, by d.b.h. classes, for various growing stock levels, after thinning an even-aged stand of southwestern ponderosa pine

D.b.h. class (Inches)	Basal area											
	20	30	40	50	60	70	80	90	100	120	150	180
	Number											
1.0	168	252	336	420	505	589	665	757	841	1,009	1,261	1,514
1.5	150	226	301	376	451	526	602	677	752	902	1,128	1,354
2.0	141	212	282	353	423	494	565	635	705	846	1,058	1,269
2.5	130	195	260	324	389	454	518	584	649	779	973	1,168
3.0	120	180	240	300	360	421	480	541	601	721	901	1,081
3.5	111	166	222	277	332	388	443	449	554	665	831	997
4.0	101	151	202	252	302	353	403	454	504	605	756	907
4.5	93	139	186	232	279	325	371	418	464	557	696	789
5.0	86	128	171	214	257	300	343	385	428	514	642	770
5.5	78	117	156	195	235	274	313	352	391	469	586	704
6.0	72	108	144	180	216	252	288	324	360	433	541	613
6.5	66	99	133	166	199	232	265	298	331	398	497	597
7.0	61	92	123	153	184	214	245	276	306	368	459	551
7.5	56	84	113	141	169	197	225	253	282	338	422	507
8.0	52	78	104	130	156	182	208	234	260	312	389	467
8.5	48	72	96	120	143	167	191	215	239	287	359	430
9.0	44	66	88	110	132	153	175	197	219	263	329	395
9.5	40	60	80	100	120	140	161	181	201	241	301	361
10.0	37	55	73	92	110	128	147	165	183	220	275	330
11.0	30	45	61	76	91	106	121	136	152	182	227	273
12.0	25	38	51	64	76	89	102	115	127	153	191	229
13.0	22	33	43	54	65	76	87	98	108	130	163	195
14.0	19	28	37	47	56	65	75	84	94	112	140	168
15.0	16	24	33	41	49	57	65	73	81	98	122	147
16.0	14	21	29	36	43	50	57	64	72	86	107	129
17.0	13	19	25	32	38	44	51	57	63	76	95	114
18.0	11	17	23	28	34	40	45	51	57	68	85	102
19.0	10	15	20	25	30	36	41	46	51	61	76	91
20.0	9	14	18	23	28	32	37	41	46	55	69	83
21.0	8	12	17	21	25	29	33	37	42	50	62	75
22.0	8	11	15	19	23	27	30	34	38	45	57	68
23.0	7	10	14	17	21	24	28	31	35	42	52	62
24.0	6	10	13	16	19	22	25	29	32	38	48	57

these tables were found to apply only to the local area and have found little use in practice. Recently a new series of volume, taper, and related tables were prepared for southwestern ponderosa pine (Myers 1963c). Each table was developed by regression equations which give the highest correlation for the various factors based on regionwide data. These regression equations can be used to prepare local volume and taper tables for young-growth and old-growth ponderosa pine.

Other tables prepared for southwestern ponderosa pine include: (1) taper tables for pole-sized trees which are useful for small product estimates with adjustment for local cull factors due to decay, crook, and fork (Myers 1963a), (2) composite aerial volume tables which give fbm and ft^3 volumes per acre by total height and crown classes (Moessner 1963), (3) pulpwood volume tables which give volumes by total and merchantable height (Minor 1961b), and (4) a simple rapid method for converting basal area to sawtimber volume in fbm, and to merchantable pulpwood volume in ft^3 and rough cords (Minor 1961a).

Yield Prediction

Foresters have the means of evaluating site quality, but have lacked management goals which optimize timber yields within the con-

Table 11.--Number of trees per acre, by d.b.h. classes, for various growing stock levels, for southwestern ponderosa pine selection forest

D.b.h. class (inches)	Basal area						
	30	40	50	60	70	80	100
	Number						
1	18.0	24.0	30.0	36.0	42.0	48.0	60.0
2	15.0	20.0	25.0	30.0	35.0	40.0	50.0
3	12.3	16.4	20.5	24.6	28.7	32.8	41.0
4	9.9	13.2	16.5	19.8	23.1	26.4	33.0
5	8.2	11.0	13.8	16.5	19.2	22.0	27.5
6	6.6	8.8	11.0	13.3	15.5	17.7	22.1
7	5.5	7.3	9.2	11.0	12.8	14.6	18.3
8	4.5	6.0	7.5	9.0	10.5	12.0	15.0
9	3.72	4.96	6.20	7.44	8.68	9.92	12.40
10	3.03	4.04	5.05	6.06	7.07	8.08	10.10
11	2.52	3.36	4.20	5.04	5.88	6.72	8.40
12	2.07	2.76	3.45	4.14	4.83	5.52	6.90
13	1.71	2.28	2.85	3.42	3.99	4.56	5.70
14	1.39	1.85	2.32	2.78	3.24	3.70	4.63
15	1.15	1.53	1.91	2.29	2.67	3.06	3.82
16	.94	1.26	1.58	1.89	2.20	2.52	3.15
17	.78	1.04	1.30	1.56	1.82	2.08	2.60
18	.63	.84	1.05	1.26	1.47	1.68	2.10
19	.52	.70	.87	1.04	1.22	1.39	1.74
20	.43	.58	.72	.86	1.01	1.15	1.44
21	.35	.47	.58	.70	.82	.94	1.17
22	.29	.38	.48	.58	.67	.77	.96
23	.24	.32	.40	.48	.56	.64	.80
24	.20	.26	.32	.39	.46	.52	.65
Total	100.0	133.3	166.8	200.1	233.4	266.8	333.5

straints of multiple uses. Considerable progress has been made since 1968 to provide the manager with these management tools. Some of the available tools, which will come into greater use as the manager becomes more familiar with them, are:

1. A computer program for simulating the growth of even-aged stands. This permits the manager to evaluate the effects of different growth rates, silvicultural treatments, and catastrophic losses, and to convert these to annual costs and returns on which to base management decisions (Myers 1968).
2. A computer program that analyzes inventory data to determine actual and optimum growing stock, allowable cuts, and other values needed for management planning (Myers 1970). The computed volumes and areas are summarized in a timber management guide to replace the conventional management plan. The computer program will show the effects of cultural operations and other changes for both actual and optimum conditions.
3. Field and computer procedures to develop yield tables for managed stands (Myers 1971). The manager can use these procedures to develop yield tables showing probable results of various management alternatives, to aid in decisionmaking. These yield tables can be made available quickly and at low cost from data obtained from temporary plots.
4. A procedure has been developed for simulating yields of dwarf mistletoe infected even-aged stands of ponderosa pine in Arizona and New Mexico (Myers et al. 1972). Stand age at time of initial infection can be varied as desired. Other control variables, such as stand age at initial thinning, stocking goals, frequency of thinning, and regeneration system, can be varied to arrive at an optimum silvicultural treatment. Since stand condition and severity of dwarf mistletoe infection change with time and in response to

Table 12.--Estimated number of trees per acre, by d.b.h. classes, following 20 years' growth of a fully stocked southwestern ponderosa pine selection forest on site index 85-90 for several growing stock levels

D.b.h. class (Inches)	Basal area[1]						
	30	40	50	60	70	80	100
	- - - - - - - - - -	- - - - -	- - - - -	Number	- - - - -	- - - - -	- - - - -
1	52.0	62.0	69.0	73.0	79.0	84.0	92.5
2	42.8	51.0	56.7	60.0	64.9	68.0	76.0
3	35.1	41.9	46.6	49.3	53.4	55.9	62.5
4	28.9	34.4	38.3	40.5	43.9	45.9	51.4
5	23.7	28.3	31.5	33.3	36.1	37.8	42.2
6	19.5	23.3	25.9	27.4	29.6	31.0	34.7
7	16.0	19.1	21.3	22.5	24.4	25.5	28.5
8	13.2	15.7	17.5	18.5	20.0	21.0	23.4
9	10.84	12.92	14.38	15.22	16.47	17.24	19.28
10	9.91	10.62	11.82	12.51	13.54	14.17	15.85
11	7.32	8.73	9.71	10.28	11.12	11.64	13.02
12	6.02	7.17	7.98	8.44	9.14	9.57	10.70
13	4.95	5.90	6.56	6.94	7.52	7.87	8.80
14	4.06	4.85	5.39	5.71	6.18	6.47	7.23
15	3.34	3.98	4.43	4.69	5.07	5.31	5.94
16	2.74	3.27	3.64	3.85	4.17	4.36	4.88
17	2.25	2.69	2.99	3.16	3.42	3.59	4.01
18	1.85	2.21	2.46	2.60	2.82	2.95	3.30
19	1.52	1.82	2.02	2.14	2.31	2.42	2.71
20	1.25	1.49	1.66	1.76	1.90	1.99	2.23
21	1.03	1.23	1.36	1.44	1.56	1.64	1.83
22	.84	1.01	1.12	1.18	1.28	1.34	1.50
23	.69	.82	.92	.97	1.05	1.10	1.23
24	.57	.68	.75	.80	.86	.90	1.01
25	.47	.56	.62	.66	.71	.74	.83
26	.38	.46	.51	.54	.58	.61	.63
27	.31	.38	.42	.44	.48	.50	.56
28	.26	.31	.34	.36	--	--	.46
29	.22	.25	--	--	--	--	.38
30	.18	--	--	--	--	--	.31
Total	290.83	344.72	373.42	402.93	439.89	462.95	515.26

[1]Based on 20 years' diameter growth by density as follows, for--
30 = 5.5 inches 50 = 4.2 inches 70 = 3.2 inches 100 = 2.2 inches
40 = 4.8 inches 60 = 3.7 inches 80 = 2.8 inches

intermediate cuttings, different treatments or combinations of treatments can be simulated, and the promising ones field tested. This simulation would greatly reduce time-consuming and costly field trials.

The real importance of these tools is their capacity to produce a series of yield tables which show how outcomes will vary in response to changes in cultural treatments and/or variations in original stand or site conditions. They allow the manager to examine the probable results of alternative operations before money is spent on them (Myers 1971).

Allowable Cut

One of the main objectives of forest management is to achieve balance between growth and harvest. Calculation of net growth to arrive at a defensible annual allowable cut has involved many techniques which are often complicated and poorly understood by foresters. The calcu-

Table 13.--Residual ft^3 volume per acre, by d.b.h. classes, for fully stocked southwestern ponderosa pine selection forest on site index 85-90 at several growing stock levels

D.b.h. class (Inches)	Basal area						
	30	40	50	60	70	80	100
	- - - - - - - - - - - -			ft^3	- - - - - - - - - - - -		
1	10.8	14.4	18.0	21.6	25.2	28.8	36.0
2	10.5	13.4	16.8	21.1	23.4	26.8	33.5
3	10.5	13.9	17.4	20.9	24.4	27.9	34.8
4	12.5	16.6	20.8	25.0	29.1	33.3	41.6
5	14.3	19.0	23.8	28.6	33.3	38.1	47.6
6	16.1	21.5	26.8	32.2	37.6	43.0	53.7
7	18.0	23.9	29.9	35.9	41.9	47.9	59.8
8	20.0	26.6	33.3	40.0	46.6	53.3	66.6
9	22.0	29.3	36.6	44.0	51.3	58.6	73.3
10	22.2	29.6	37.1	44.5	51.9	59.3	74.1
11	22.6	30.1	37.7	45.2	52.7	60.3	75.4
12	24.7	32.9	41.2	49.4	57.6	65.8	82.3
13	27.3	36.4	45.5	54.6	63.7	72.8	91.0
14	28.4	37.8	47.4	56.8	66.2	75.6	94.6
15	28.7	38.1	47.6	57.1	66.6	76.3	95.2
16	28.8	38.6	48.5	58.0	67.5	77.3	96.6
17	28.5	38.0	47.6	57.1	66.6	76.1	95.1
18	27.2	36.3	45.4	54.4	63.5	72.8	90.7
19	26.3	35.4	44.0	52.6	61.6	70.2	87.9
20	25.2	34.0	42.2	50.4	59.2	67.4	84.4
21	23.6	31.7	39.2	47.3	55.4	63.5	79.0
22	22.1	29.0	36.6	44.2	51.1	58.7	73.2
23	20.8	27.8	34.7	41.7	48.6	55.6	69.4
24	19.4	25.2	31.0	37.8	44.6	50.5	63.1
Total	510.5	679.5	849.1	1,020.4	1,189.6	1,359.9	1,698.9
Merchantable	451.9	602.2	752.3	903.2	1,054.2	1,205.0	1,505.4

lations become particularly difficult when irregular uneven-aged stands composed of small even-aged groups are mixed among essentially even-aged stands.

Complexity can be considerably reduced by recognizing the fact that net growth is equal to present net growth plus the future net growth as altered by management. This net growth (Y) can be calculated for any year after treatment starts (x) using the linear regression equation: $Y = a+bx$, where a = the present net annual growth (G_1) and b = the rate of change in net growth due to management $(G_2 - G_1)/T$ where G_2 is the site potential or estimated future net annual growth and T is the number of years set to complete treatment of the entire forest tract. The net annual growth (Y) can then be calculated for any particular year (t) within the cutting period or cycle by inserting the appropriate volumes. This equation would be: $Y = G_t + [(G_2 - G_1)/T]\ t$. If the average annual net growth is desired for a particular period, the annual yields derived by the above equation could be summed or obtained by the slightly modified equation: $Y = G_t + [(G_2 - G_1(/T]\ t/2$.

The volume data for growth may be in either fbm, ft^3, or cords for the total forest tract or on a per-acre basis. If the data are for the entire forest, then the solution of the equation leads directly to the annual allowable cut. If the data are on a per-acre basis, then the average annual net growth must be multiplied by the total tract acreage to get the annual allowable cut.

Data from one of the southwestern ponderosa pine forests will illustrate the computations. Recent inventory data show that the present net annual growth (G_1) is 23 million fbm on a tract of 360,000 acres with a growing stock in sawtimber-sized trees of 1.5 billion fbm. The site potential indicates a future net annual growth (G_2) of 68 million. The plan is to treat the entire forest over a period of 20 years (T), with an equal area treated annually during the

Table 14.--Residual fbm volume per acre, by d.b.h. classes, for fully stocked southwestern ponderosa pine selection forest on site index 85-90 at several growing stock levels

D.b.h. class (Inches)	Basal area						
	30	40	50	60	70	80	100
	Number						
9	4	5	6	7	9	10	12
10	27	36	45	54	64	73	91
11	43	57	71	86	100	114	143
12	66	88	110	132	155	177	221
13	86	114	142	171	200	228	285
14	97	130	162	195	227	259	324
15	105	139	174	208	243	278	348
16	110	147	185	221	257	295	369
17	112	149	186	223	260	297	372
18	112	150	187	224	262	299	374
19	118	158	197	235	276	314	393
20	120	162	202	241	283	322	403
21	119	159	197	237	278	319	397
22	115	150	190	230	265	305	380
23	112	149	186	224	261	298	373
24	107	139	171	208	245	277	346
Total	1,453	1,932	2,411	2,896	3,385	3,865	4,831

cutting period of 20 years (t). Substituting into the above equation yields $Y = 23 + [(68-23)/20]\,20/2 = 45.5$ million fbm = annual allowable cut. If the growth data had been converted to an acre basis, the inserted volumes would give $Y = 64 + [(189 - 64)/20]\,20/2 = 126.5$ fbm per acre per year. When multiplied by the total 360,000 acres, the annual allowable cut would be 45.5 million, as above.

A more complete discussion of this method for determining the allowable cut, some of the considerations with respect to total growing stock and imbalance of size or age classes, alternative cutting budgets and their effect on growing stock, and on selection of a cutting budget to maximize growth will be covered in a separate report at a future date.[10]

QUALITY

Log quality of southwestern ponderosa pine is low (Choate 1966, Miller and Choate 1964, Spencer 1966). Less than 2 percent qualify as select logs, while nearly 83 percent are low common.

Specific Gravity

Specific gravity has been widely accepted as a major criterion for estimating wood quality (Cockrell 1943, Conway and Minor 1961, Echols and Conkle 1971, Markstrom and Yerkes 1972, Paul 1963, Paul and Meagher 1949, Voorhies 1972). Specific gravity of wood in the six rings formed after thinning in the Taylor Woods GSL study was not significantly different from that in the six rings before thinning.[11] This suggests that wood quality may not have been affected adversely by thinning. Specific gravity of wood after thinning increased as stand density increased, but the average change was only 3.2 percent.

[10]*Larson, Frederic R., and Gilbert H. Schubert. Estimation of allowable cut for southwestern ponderosa pine forests. (Manuscript in preparation at Rocky Mt. For. and Range Exp. Stn., Flagstaff, Ariz.)*

[11]*Alford, Lee T., and Gilbert H. Schubert. Effect of thinning on specific gravity of young ponderosa pine in northern Arizona. (Manuscript in preparation at Rocky Mt. For. and Range Exp. Stn., Flagstaff, Ariz.)*

Table 15.--Estimated future gross total and merchantable ft^3 volume per acre, by d.b.h. classes, following 20 years' growth of a fully stocked southwestern ponderosa pine selection forest on site index 85-90 for several growing stock levels

D.b.h. class (Inches)	Basal area[1]						
	30	40	50	60	70	80	100
	- - - - - - - - - - - -	- - - - - -	- - - - - -	Ft^3	- - - - - -	- - - - - -	- - - - - -
1	31.2	37.2	41.4	43.8	47.4	50.4	55.5
2	28.7	34.2	38.0	40.2	43.5	45.6	50.9
3	29.8	35.6	39.6	41.9	45.4	47.5	53.1
4	36.4	43.3	48.3	51.0	55.3	57.8	64.8
5	41.0	49.0	54.5	57.6	62.5	65.4	73.0
6	47.4	56.6	62.9	66.6	71.9	75.3	84.3
7	52.3	62.5	69.6	73.6	79.8	83.4	93.2
8	58.6	69.7	77.7	82.1	88.8	93.2	103.9
9	64.1	76.4	85.0	90.0	97.3	101.9	113.9
10	72.7	78.0	86.8	91.8	99.4	104.0	116.3
11	65.7	78.3	87.1	92.2	99.7	104.4	116.8
12	71.8	85.5	95.2	100.7	109.0	114.2	127.7
13	79.0	94.2	104.7	110.8	120.0	125.6	140.4
14	82.6	98.6	109.6	116.1	125.7	131.6	147.1
15	83.3	99.2	110.4	116.9	126.4	132.4	148.1
16	84.0	100.3	111.6	118.1	127.9	133.7	149.7
17	82.3	98.4	109.4	115.6	125.1	131.4	146.7
18	79.9	95.5	106.3	112.3	121.8	127.4	142.6
19	76.8	92.0	102.1	108.1	116.7	122.3	136.9
20	73.3	87.4	97.3	103.2	111.4	116.7	130.7
21	69.6	83.1	91.9	97.3	105.4	110.8	123.6
22	64.1	77.0	85.4	90.0	97.6	102.2	114.4
23	59.9	71.2	79.9	84.2	91.1	95.5	106.8
24	55.3	66.0	72.8	77.6	83.4	87.3	98.0
25	50.8	60.5	67.0	71.3	76.7	79.9	89.6
26	46.0	55.7	61.8	65.4	70.3	73.9	82.4
27	41.5	50.9	56.2	58.9	64.2	66.9	--
28	38.3	45.7	50.1	53.0	--	--	--
29	35.6	40.4	--	--	--	--	--
30	31.5	--	--	--	--	--	--
Total	1,733.5	2,022.4	2,202.6	2,330.3	2,463.7	2,580.7	2,810.4
Merchantable	1,566.4	1,823.1	1,980.8	2,095.8	2,209.6	2,314.0	2,513.1
Residual	451.9	602.2	752.3	903.2	1,054.2	1,205.0	1,505.4
Growth	1,114.5	1,220.9	1,228.5	1,192.6	1,155.4	1,109.0	1,007.7

[1]Based on 20 years' diameter growth by density as follows, for--
30 = 5.5 inches 50 = 4.2 inches 70 = 3.2 inches 100 = 2.2 inches
40 = 4.8 inches 60 = 3.7 inches 80 = 2.8 inches

Fiber Length and Fibril Angle

Both fiber length and fibril angle influence wood quality. In young ponderosa pine, there is a gradual change in fiber length and fibril angle as age increases up to about 50 years (Voorhies 1971). Stresses set up in boards of young ponderosa pine due to excessive longitudinal shrinkage frequently result in warped boards. Some residual trees, even though perfectly vertical, have been found to develop compression wood following partial cutting.[12]

These factors which cause warp and other degrade in wood quality need to be studied as they relate to thinning levels.

[12]*Personal communication from Roland L. Barger, Intermt. For. and Range Exp. Stn., Bozeman, Mont., and Peter F. Ffolliott, Assoc. Prof. of Watershed Manage., Univ. Ariz., Tucson. Research reported was conducted when Barger and Ffolliott were with the Rocky Mt. For. and Range Exp. Stn., Flagstaff, Ariz.*

Table 16.--Estimated future gross fbm volume per acre, by d.b.h. classes, following 20 years' growth of a fully stocked southwestern ponderosa pine selection forest on site index 85-90 for several growing stock levels

D.b.h. class (Inches)	Basal area						
	30	40	50	60	70	80	100
				Fbm			
9	11	13	14	15	16	17	19
10	89	96	106	113	122	128	143
11	124	148	165	175	189	198	221
12	193	229	255	270	292	306	342
13	248	295	328	347	376	394	440
14	284	340	377	400	433	453	506
15	304	362	403	427	461	483	541
16	321	383	426	450	488	510	571
17	322	385	428	452	489	513	573
18	329	393	438	463	502	525	587
19	344	411	457	484	522	547	612
20	350	417	465	493	532	557	624
21	349	417	461	488	529	556	620
22	333	400	444	467	507	531	594
23	322	382	429	452	489	513	573
24	304	362	400	426	458	480	538
25	285	339	376	400	430	448	503
26	263	319	353	374	402	423	471
27	241	295	326	341	372	388	--
28	225	268	294	311	--	--	--
29	211	240	--	--	--	--	--
30	189	--	--	--	--	--	--
Total	5,641	6,494	6,945	7,348	7,609	7,970	8,478
Residual	1,453	1,932	2,411	2,896	3,385	3,865	4,831
Growth	4,188	4,562	4,534	4,452	4,224	4,105	3,647

[1]Based on 20 years' diameter growth by density as follows, for--
30 = 5.5 inches 50 = 4.2 inches 70 = 3.2 inches 100 = 2.2 inches
40 = 4.8 inches 60 = 3.7 inches 80 = 2.8 inches

Branch Size and Tree Form

Stand density has been reported to affect branch size, natural thinning, and tree form of ponderosa pine (Myers 1963b, Myers and Van Deusen 1960, Pearson 1950). An increase in stand density generally results in reduced stem taper and branch size. Open-grown trees have a tendency to be tapered and coarse branched. Thus the advisability of heavy thinnings has been questioned. Ponderosa pine is also a poor natural pruner. Dead branches frequently remain down to the base of pines, even in dense thickets.

The correlation between branch size and stand density needs to be determined for young-growth ponderosa pine. When should young dense stands be thinned? Is early thinning advisable to get greater diameter growth, if it is achieved at a sacrifice in tree quality (large, coarse branches) or merchantable sawtimber volume (high taper)? Branch size and tree form are inherited characteristics which are sometimes modified by the environment. How much modification of the environment is needed to improve tree quality to an acceptable standard? Answers to these questions will require further study.

Pruning

Wood quality can be improved by pruning, but the costs may be prohibitive. Costs can be kept down by pruning dead branches from potential sawtimber trees immediately after thinning. Live branches can be pruned without significantly affecting growth, provided that at least one-third of the tree height is left in live crown (Heidmann 1963c).

SILVICULTURE AND MANAGEMENT

GUIDING PRINCIPLES

Silviculture and management are interdependent. Silviculture is directed to the creation and maintenance of the kind of forest that will best fulfill the objectives of the manager. The silvicultural prescriptions must be varied to meet the particular needs of the site, the stand, and the land manager.

The practice of silviculture is not limited to growing trees as a crop, but also encompasses growing trees for other purposes, such as natural beauty or outdoor recreation. Silvicultural prescriptions, coordinated through multiple use survey reports or environmental analyses, are the first step toward achieving quality in timber management on National Forests. Management decisions are required on: (1) the form of management, even-aged or uneven-aged, (2) best rotation age for even-aged management, (3) the best stand reentry schedule for stated goals, (4) the kinds and quantities of products needed, (5) the alternative use or combination of uses for each parcel of land, and (6) the combination of goods and services that produce the maximum return.

REQUIREMENTS FOR NATURAL REGENERATION

During the past 60 years, we have learned what it takes to get natural regeneration:

1. A large supply of good seed,
2. On a well-prepared seedbed,
3. Free of competing vegetation,
4. A low population of seedeating pests,
5. Sufficient moisture for early seed germination and seedling growth,
6. And protection from browsing animals and certain insect pests.

The difficulty has been to get these six requirements to coincide. A deficiency of any one of the six may either completely or partially negate any or all of the others. In the excellent seedling year of 1919, most of these requirements were met at least to some degree. During other years, the requirements were reasonably well met in a few areas but not over as widespread an area as in 1919.

Seed Requirements

Seed Supply.—About 200,000 seeds per acre (about 20 pounds) are required to produce 2,000 seedlings for adequate stocking (Pearson 1950). This estimate was based on the assumption that only one seed out of 100 would produce a seedling that survived under moderately favorable field conditions. Under more favorable conditions, about 40,000 to 80,000 seeds would be adequate. In California, seedling survival at the end of the tenth year averaged 22 to 25 percent (Fowells and Schubert 1951).

Cone-bearing trees.—The number of seeds produced by a tree will vary considerably by diameter, age-vigor class, stand density, amount of insect damage or squirrel cutting, and by tree dominance (Larson and Schubert 1970). The large, vigorous, mature trees produce the heaviest cone crops.

Cone production may also vary by tree size at different locations. At Fort Valley and Long Valley Experimental Forests, trees under 16 inches had few to no cones in 1968, while at the Chevelon District on the Sitgreaves National Forest trees 4 to 6 inches in diameter frequently had 40 to 50 cones. The differences in cone productivity may be due to genetic qualities or habitat conditions.

Frequency of cone crops.—Good cone crops were reported on the Coconino and Kaibab National Forests in 1908, 1913, 1918, 1927, 1931, 1936, 1942, 1945, 1954, 1956, 1960, 1965, 1968, and 1971 (Larson and Schubert 1970; Pearson 1923, 1950; Schubert and Pitcher 1973). The only other published records were for the Fremont Experimental Forest in Colorado, which had a good crop in 1926 and 1931 (Roeser 1941). Based on these data, good cone crops may occur at intervals of 3 to 4 years, with lighter crops in some of the intervening years. Annual cone crop reports are needed to determine cone crop frequency by habitat types.

Time of flowering.—Flowering dates of southwestern ponderosa pine have been reported only for central Colorado (Roeser 1941) and north-central Arizona (Pearson 1931). In Colorado, staminate flowers started to open about 2 weeks before the pistillate flowers; pollen release coincided with female bud burst.

For the 9-year study, male flowers opened between May 22 and June 8, while female flowers opened between June 1 and June 25. At the Fort Valley Experimental Forest in Arizona, appearance of staminate buds ranged from May 20 to 31, with pollen shedding between June 10 and 20. Flowering dates may differ in other parts of the Southwest. In California, growth started earlier at the lower elevations (Fowells 1941).

Time of seedfall.—Seedfall at Fort Valley starts about the middle of October, and is about 65 percent complete by the first week of December and 95 percent by the first of April (Larson and Schubert 1970). In some years, seedfall may start earlier in October or be delayed longer into the following year. About 16 percent of the 1960 seed crop fell between July 1 and September 26, 1961. Seeds that fall too late in the summer to germinate will germinate the following year. Strong, dry winds in the fall may cause most of the seed to drop during October and early November (Fowells and Schubert 1956).

Seed dissemination.—Ponderosa pine seeds are not disseminated far from the seed tree (Fowells and Schubert 1956). Based on seedfall rates of 15.2 ft per second in still air (Siggins 1933), seed from the top of a 100-ft ponderosa pine would be blown about 150 ft by a 5 mi/h (mile per hour) wind. A 10 mi/h wind would carry seed about 300 ft. Since the center of the seed mass would be at about 75 percent of the tree height, most of the seed would fall within a distance of one to two times the tree height.

Seed quality.—The largest cone crops produce the best quality seeds (Larson and Schubert 1970). The large crops in 1960 and 1965 produced seeds that were at least 65 percent filled, compared to 10 to 45 percent for the smaller seed crops at Fort Valley. For the 1965 crop, 72 percent of the seeds that fell before December 6 were filled, compared to only 54 percent for seeds that fell after that date.

Seeds per cone.—Cones at Fort Valley averaged only 31 seeds each, with the number of seeds increasing with size of the cone crop (Larson and Schubert 1970). The 5 smallest cone crops during 1956-65 averaged only 14 seeds per cone, compared to 33 for the 5 largest crops. Cones at Long Valley and Chevelon in central Arizona averaged about 76 seeds per cone during the heavy 1968 seed year. Seeds per cone averaged about 70 in California (Fowells and Schubert 1956) and ranged from 64 to 92 in Idaho (Curtis and Lynch 1957).

Seed losses.—Ponderosa pine seed supply may be reduced by insects, birds, mice, and squirrels. Cone beetles have at times destroyed 50 percent of the seed crop (Pearson 1950). Abert squirrels reduce the cone crop by about 20 percent (Larson and Schubert 1970). Data on amounts of seed consumed by birds, mice, chipmunks, and ground squirrels have not been reported. Some flower buds and 1-year-old conelets may also be killed by late June freezes.

Predicting size of cone crops.—The cone crop can be estimated by counting small conelets in the spring with the aid of binoculars, or by checking the twigs cut by squirrels (Larson and Schubert 1970). Since heavy losses may occur the first year of cone development, it is best to make estimates in the spring prior to

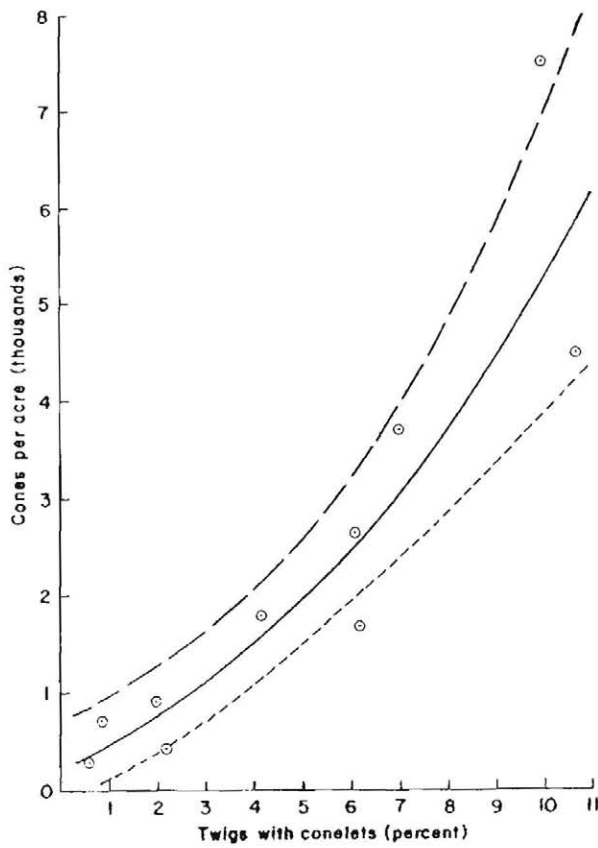

Figure 28.—Relationship between total cone production per acre and the percentage of twigs with conelets found during the spring preceding the maturation of cones. The calculated regression line is $Y = (16.41 + 5.64x)^2$, $F = 47.41$. Dashed lines indicate upper and lower 95 percent confidence limits.

cone maturation. Cone crops may also be estimated from the relationship of cones per acre to twigs with conelets cut by Abert squirrels (fig. 28).

Seed tree specifications.—Healthy, mature trees of large diameter and with exposed crowns are usually the best seed producers (Dunning 1928, Fowells and Schubert 1956, Larson and Schubert 1970). Past fruitfulness, as indicated by the accumulation of old cones under a tree, is a good criterion for choosing seed trees. The best trees to retain for seed production are those that:

1. Are about 24 to 28 inches in diameter,
2. Are dominant or a good codominant if suitable dominant not available,
3. Have a vigor class rating of A or B,
4. Are free from disease or damage,
5. Show evidence of having produced good cone crops,
6. Have straight boles with about 50 percent of tree height in live crown,
7. Have medium to small branches.

Factors Affecting Seed Germination

Moisture.—In Arizona, ponderosa seed seldom germinates until the advent of the summer rains in July. When the summer rains are too light to keep the seeds continuously moist or the rains are late in coming, germination may be delayed until August or early September (Larson 1961, Pearson 1950, Schubert et al. 1970). High moisture stress reduces germination markedly (Larson and Schubert 1969a). In Arizona, seeds have germinated in June when rainfall of 2 or more inches occurred in June or late May. Where spring rains are common, as in the Colorado Front Range, spring germination may be the rule.

Seedbed conditions.—The best seedbed is loose soil with sufficient dead pine litter to facilitate water penetration and seed coverage (Lowdermilk 1930) and to prevent excessive drying of the soil during germination (Krauch 1936, Pearson 1950). Seed coverage is also important because of reduced losses from seed-eating birds and rodents (Pearson 1923, 1950). A loose granular soil was reported to be better than a tight clay soil (Krauch 1956).

Shade.—Ponderosa pine seeds germinate best under partial shade. In the shelterwood study on the Long Valley Experimental Forest south of Flagstaff,[13] germination was highest on plots with a residual basal area of 40 ft^2 per acre and lowest on clearcut plots. Most of the seedlings on the clearcut plots were within the area receiving shade from the trees along the south and west borders.

Factors Affecting Seedling Establishment

Site preparation.—Seedling establishment has been best on areas where competing ground vegetation has been removed and the soil has been loosened. Most failures have occurred on areas which received no site preparation (Larson and Schubert 1969a; Pearson 1923, 1950). Grass was found to be more detrimental than shrubs or trees. Of the grass species, Arizona fescue, bluegrass, and black dropseed were most competitive for soil moisture. These species are all early season growers. Mountain muhly, blue grama, and orange sneezeweed—which make most of their growth during the summer rainy season—have less effect on seedling establishment. Pine seedlings seldom become established in areas covered by dense oak brush.

Competing vegetation may be removed by mechanical, chemical, or burning treatments (Johnsen et al. 1973). Mechanical site preparation is best and can often be accomplished in conjunction with slash disposal. Chemical site preparation has been effective (Heidmann 1967, 1969, 1970), but success has not been universal and present restrictions on herbicides limit their use. Fire has been used to a limited extent, primarily in slash disposal. Fire is not effective on grassy areas or areas covered with sprouting brush.

The best time to prepare the site for natural regeneration is just prior to seedfall. Site preparation at this time provides a loose surface with small depressions into which seed may fall and be covered. The second best is in the fall during or after seedfall. The third choice is during spring and early summer prior to seed germination. Site preparation a year or two in advance of seedfall is generally ineffective.

Shade.—Trees left for seed and shelter should be retained until seedlings are about 1 ft high. Seedlings of this size are flexible. Seedlings over 2 ft in height are often broken during the overstory removal cut.

Grazing.—Livestock should be excluded from regeneration areas until the seedlings are

[13]*Unpublished data on file in study 1203.18, Rocky Mt. For. and Range Exp. Stn., Flagstaff, Ariz.*

out of danger from browsing. Cattle cause little damage after the seedlings are several feet high if there is sufficient forage available. Trees are most likely to be browsed during the spring and fall drought periods (Cassidy 1937a, Cooperrider 1939, Parker 1948). Light grazing during the summer rainy season may be beneficial by reducing the amount of grass competition. Sheep should be kept out of regeneration areas until the trees are 5 to 6 ft high, and then not permitted to bed down more than one night in the same area (Cassidy 1937b).

REQUIREMENTS FOR ARTIFICIAL REGENERATION

Many of the factors that render natural regeneration ineffective also jeopardize planting and seeding (Pearson 1950, Schubert et al. 1970). Drought during fall combined with abundant competing vegetation is foremost. Where spring normally is dry, ponderosa pine generally germinates only during the summer wet period. If summer drought delays germination into August, the seedlings cannot establish deep roots in the remainder of the growing season. Many of the shallow-rooted seedlings are then heaved by frost during the fall and spring or are winterkilled during open winters. Attrition by soil insects, tip moths, rodents, and browsing animals may be severe for as long as 15 years after initial establishment.

Planting, the most successful method of artificial reforestation, has several advantages over direct seeding. Seedlings are less subject to destruction by rodents and birds. The larger root systems of the seedlings, placed deeply in the soil, are less likely to suffer damage from a fast-drying surface layer. Furthermore, planted trees (1) can begin their season's growth 2 to 3 months earlier, (2) start with a larger root system which continues to develop faster to tap more moisture, and to resist frost action better, and (3) can better withstand partial loss of tops and roots by insects, rodents, and browsing animals than seedlings started from direct seeding.

Seed Requirements

Seed source.—The importance of seed source is widely recognized; many plantation failures have been directly attributed to "off-site" planting stock. Although some exotic species or hybrids may grow better than native species, nonlocal seed sources are not recommended for reforestation projects in the Southwest until their compatibility with local environmental conditions is proved. At Fort Valley, all ponderosa pines from California seed sources died within the first 2 years, while trees from Black Hills and Colorado seed have been subnormal in size and have abnormal stem form (Larson 1966).

Arizona and New Mexico have recently been divided into 10 physiographic-climatic regions, with each further subdivided into five to nine seed collection zones (fig. 29) (Schubert and Pitcher 1973). Provenance tests will be conducted to determine variation and need for adjustment. For the present, seed used for reforestation should be limited to that collected within the local zone.

Seed collection.—Seed should be collected only from trees with good form and vigor, and free of insects and disease. Poor form and excessive limbiness as well as susceptibility to pests may be hereditary. Seed should not be collected from isolated trees because of the strong probability of being self pollinated. Such seeds produce a high proportion of poor-quality progeny. No seed should be collected from plantations of unknown or questionable seed origin.

Cones should be collected only during good seed years. Seeds collected during light seed years may appear fully developed, but they are likely to be self pollinated and of low viability.

Cone collections should not be started until the seeds are mature. The viability of mature seeds is usually high and the derived seedlings are normal. In contrast, the viability of immature seeds may be low, and many of the seedlings may be abnormal and worthless (Schubert 1956b).

Specific gravity of the cones is one of the most reliable indicators of seed ripeness. Maki (1940) found that ponderosa pine cones were mature when they would float in SAE-30 motor oil or kerosene. Kerosene is preferred since its specific gravity of 0.80 coincided with the highest seed viability (Schubert 1956b). Cones were found to open on the tree when the specific gravity dropped to 0.62 (Schubert 1956b). The specific gravity test must be made on freshly picked cones, since detached cones lose moisture rapidly and immature cones would then pass the test.

Cones are frequently collected from squirrel caches. Although viability tests may be high, the unknown seed parentage would generally make this practice inadvisable in a tree improvement program.

Cones should be processed as soon as possible after collection (Schubert et al. 1970). Sacked cones should be kept dry and provided with adequate air space between sacks to pre-

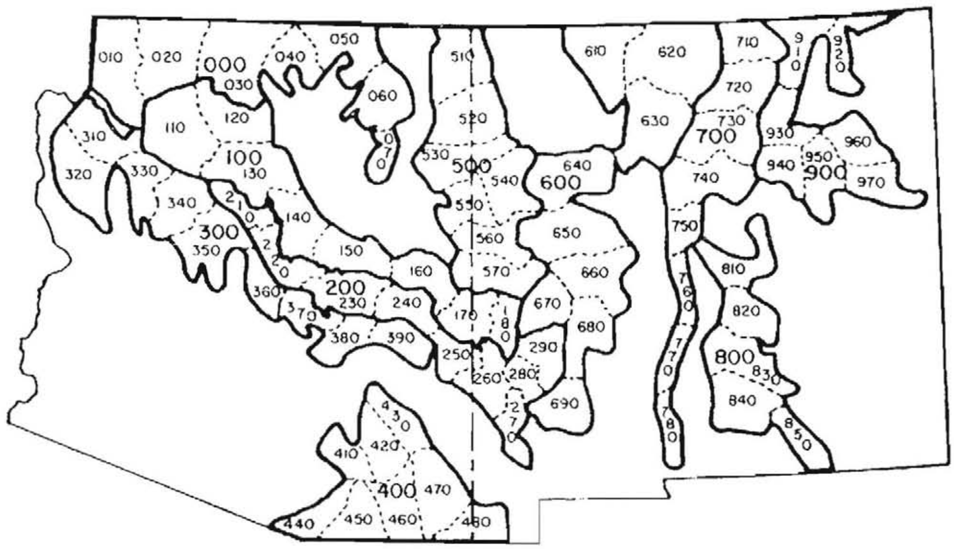

Figure 29.—Seed collection zones for the Southwestern Region (Schubert and Pitcher 1973):

000 Northwest Plateaus (Seed Zones 010-070)
100 Central Plateaus (Seed Zones 110-180)
200 Mogollon Slope and Highlands (Seed Zones 210-290)
300 Central Highlands (Seed Zones 310-390)
400 Southeast Desert Highlands (Seed Zones 410-480)
500 Chuska-Zuni-Gallo Highlands (Seed Zones 510-570)
600 East Continental Highlands (Seed Zones 610-690)
700 East Rio Grande Highlands (Seed Zones 710-780)
800 Sacramento-Guadalupe Range (Seed Zones 810-850)
900 Northeast Plains (Seed Zones 910-970)

vent overheating and molding. Fully mature cones require less predrying, and the seeds are less likely to be damaged during extraction.

Seed storage.—Ponderosa pine seed will maintain high viability when dried to a moisture content of 4 to 8 percent, placed in airtight containers, and stored at 32°F (0°C) or less and preferably at 0°F (−18°C). At least a 4-year supply is needed to keep long-term projects going between seed crop harvests.

Seedling Requirements

Nursery stock.—Planting stock must be in good physiological condition to survive well. Stock for fall planting should not be lifted from the nursery until it has completely hardened off. Stock for spring planting should be lifted before root growth starts.

All planting stock should meet established size and quality specifications (Schubert et al. 1970). A good plantable tree should: (1) have a stem diameter of at least 0.16 inch, (2) have a well-developed top and root system, and (3) be undamaged and free of disease.

Stock shipment.—For short distances, trees are usually transported by unrefrigerated trucks. For long distances, the trees should be shipped by refrigerated trucks, rail, or air. During transit, trees must be kept moist and cool (ideally between 34° and 38°F).

Stock storage.—If trees must be held even for short periods before planting, they should be in a well-ventilated room at a temperature of 34° to 36°F and a relative humidity above 90 percent. Cold storage with controlled temperature and humidity is preferable to heeling-in. Baled trees may be stored in snow. There should be about 2 ft of snow beneath the first tier of bales. Bales (bundles or crates) should be laid about 6 inches apart in the rows with snow packed between them. If more than one tier is required (limit to three tiers), place 6 inches of snow between tiers. Then completely cover stack with snow. Pick a shaded spot where snow melts slowly. Do not place a tarp over heeled-in trees without providing for ventilation. Trees removed from storage should be limited to 1 day's planting needs, and be kept moist at all times.

Containerized stock.—Containerized seedlings were planted in the summer of 1972 on several National Forests in Arizona and New Mexico. The seedlings were started in styrofoam flats containing 192 holes 1 inch in diameter and 4.5 inches deep. The seedling "plugs" were planted in 4-inch-diameter auger holes.

Seedlings can be grown to plantable size in 6 to 8 months in a controlled-environment greenhouse (Tinus 1972). Costs per thousand surviving trees in the Rocky Mountains were estimated to be $460 for 2-0 bare-root stock and $393 for containerized greenhouse seedlings (Colby and Lewis 1973).

Success of summer plantings depends on early planting and at least moderate, consistent rains during July through September. Success has been hampered by late plantings (August) and sparse, sporadic summer rains followed by a drought in September.

Site Preparation

Thorough site preparation is necessary if planting or direct seeding is to succeed (Schubert et al. 1970). With only partial site preparation, such as scalped spots or narrow cleared strips, more plantations fail than succeed. With few exceptions, plantings on unprepared sites have been failures.

Site preparation involves removing or reducing established vegetation, preparing a good seedbed, removing obstacles to planting, and rendering the sites less favorable for destructive insects and rodents. The most important reason for site preparation in the Southwest is to conserve soil moisture for seedling establishment and early rapid growth (Larson and Schubert 1969a, 1969b; Pearson 1950; Schubert 1970; Schubert et al. 1970). For most sites, mechanical site preparation is best. Chemical site preparation is cheaper and results in higher soil moisture on grass-covered areas provided the grass is deadened (Heidmann 1969).

Planting

Planting ponderosa pine sites has been more successful than direct seeding in the Southwest (Schubert et al. 1970). However, even planted trees die when the job is not done correctly. To establish a successful plantation: plant only healthy, vigorous trees of the local seed source; plant them on well-prepared sites; plant only when the soil is moist; keep the seedling roots moist; do a professional job of planting; and then provide the needed care and protection.

Planting methods.—Seedlings may be planted by hand or machine, depending upon the condition of the site and the availability of equipment. Hand planting in holes dug by auger is preferred to planting in holes dug with handtools. The dibble or planting bar should be used only on light-textured soils because of the difficulty of getting complete hole closure. On suitable areas, machine planting is the easiest, quickest, and most economical method of planting. The machines operate best on level or gentle slopes where the soil contains few large rocks, roots, stumps, and other debris. Heavy-textured soil presents problems, particularly when the soil is too wet to get proper closure of the trench.

Proper attention to details in planting are of greater importance than whether planting is done by hand or machine. Following suggestions given in "Here's How—a guide to tree planting in the Southwest" (Schubert et al. 1969) and "Artificial reforestation practices for the Southwest" (Schubert et al. 1970) will lead to greater planting success.

When to plant.—Spring has been by far the best time to plant (Schubert et al. 1970). Summer planting with containerized stock may be successful, but has not been demonstrated to date. Spring planting should begin as soon as the site is free from snow, and should end about May 15 or sooner if soil does not feel moist and hold together when squeezed in the hand. Summer planting of containerized stock should not begin until soil moisture has been restored to field capacity within the top foot of soil. Fall planting should be delayed until the soil is thoroughly moistened to a depth of 1 ft and the trees have hardened off. South slopes should be planted first in the spring because they are the first to be free of snow and the first to dry out. North slopes should be planted first in the fall because they are the first to become inaccessible when the snows start.

How many trees to plant.—It is recommended that 680 trees per acre be planted at about an 8- by 8-ft spacing. However—and this is important—plant in the best spots, even at the expense of consistent spacing between trees. The number of trees above is based on a survival of 50 percent when the trees attain a diameter of 5 inches. The 340 5-inch trees are needed for a growing stock level of 80. A different survival rate or different growing stock level would affect the number of trees to plant per acre.

Direct Seeding

Direct seeding, while at least initially more economical and flexible than planting, is less reliable. With a large seed bank, areas can be seeded promptly when the need arises, whereas planting requires 6 to 8 months to produce containerized stock or 2 to 3 years to produce nursery stock. Seeding costs average about one-fourth to one-half planting costs.

Seeding methods.—Regeneration areas may be broadcast seeded, spot seeded, or drill seeded (Schubert et al. 1970). Broadcast seeding, either from the air or ground, is faster than the other two methods, but it has been the least effective and requires the most seed. The effectiveness of broadcast seeding may be improved by preparing a loose seedbed or by disking after sowing. Spot seeding has been the most effective and requires the least amount of seed. The seeds can be placed in more favorable spots and covered with soil to improve germination and reduce losses to rodents and birds. Drill seeding has been tried only a couple of times where site conditions permitted its use. The two small areas drill seeded on the Coconino National Forest gave adequate stocking.

Time to seed.—Where spring is dry, the best time to seed is in late June and early July following a good seed crop the preceding fall. Seeding at this time exposes the seed to rodents and birds for only a short time before the summer rains cause germination. Also at this time, food for rodents and birds is abundant in adjacent areas, thus reducing losses on the seeded site. Where spring is wet, seed should be sown shortly before germination would be expected.

Southwestern ponderosa pine seed does not require stratification (Larson and Schubert 1969a). Furthermore, any advantage of using stratified seeds would be rapidly lost under field conditions, since the seeds gain or lose moisture rapidly to the surrounding media.

Where to seed.—Fresh timber burns and logged areas are the most promising for direct seeding. Frequently, these areas can be seeded without additional site preparation. Fresh burns may pose a serious problem if the hydrophobic ash layer is not broken up. Unless the salvaging logging operation does a good job of breaking up this layer, it is best to use spot or drill seeding.

How many seeds to sow.—The seeding rates will vary considerably, depending on sowing method, seed quality, and specific site. Per-acre rates with good seed range from 1,700 to 4,800 for spot seeding; from 10,000 to 12,000 for drill seeding; and from 16,000 to 48,000 for broadcast seeding on moist, well-prepared areas. Seeding rates for spot seeding were prepared for the California Region (Schubert and Fowells 1964) based on expected stocking for various probabilities of success (fig. 30). The same procedure can be used in the Southwest (Schubert et al. 1970).

Seed origin.—Only seed from the local seed zone should be used in direct seeding (Schubert and Pitcher 1973).

Plantation Care

Successful seeding (natural or artificial) or planting is only the first step in reforestation (Schubert et al. 1970). New plantations must receive care and protection. A mortality of 30 to 40 percent may be expected during the first

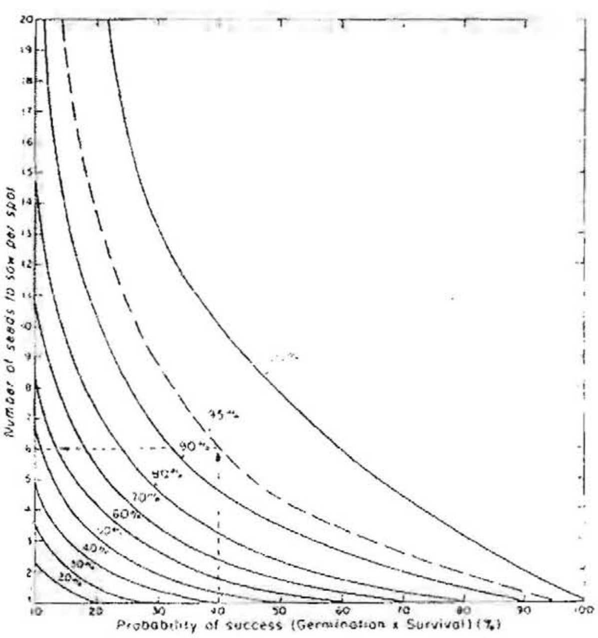

Figure 30.—Expected stocking curves (percent of seedspots with one or more seedlings) for various probabilities of success and sowing rates (Schubert and Fowells 1964). For example, (see dotted line) if you want 95 percent of the spots to have at least one seedling, you should sow six seeds per spot (Schubert et al. 1970).

decade. Mortality may be caused by such physical factors as climate and environment, including fire, or by such biotic factors as insects, disease, animals, or other vegetation. Proper management can greatly reduce the effect of many of these factors. Details of plantation care are fully covered in "Artificial reforestation practices for the Southwest" (Schubert et al. 1970) and under the section "Effect of damaging agents" in this report.

SILVICULTURAL TREATMENTS

Silvicultural treatments must be geared to the needs of the people, but are constrained by site and stand characteristics. These sites, and the stands that grow on them, collectively form the basis for multiple use and sustained yield. The most used silvicultural systems for southwestern ponderosa pine are group selection and shelterwood (Schubert 1973). The existing structure and condition of many stands can be manipulated to produce either even-aged or selection forest. Fortunately, many silvicultural treatments, when based on stand characteristics, also satisfy objectives other than timber production. The treatments must be scheduled and properly coordinated with other uses from the day the stand is first entered and treated through scheduled reentries for intermediate harvest cuts, final harvest, and renewal of the stand.

Stand Condition Classes

The basis for applying any silvicultural treatment in a forest is the condition of the stand. Dunning[14] recognized the need in California for stand condition classification to break away from a uniform treatment of an entire forest or compartment, so that individual groups or stands could be treated according to their specific ecological needs. This need for specific silvicultural treatments by even-aged groups lead Dunning to his "Unit Area Control" concept, as described by Hallin (1951, 1954, 1959).

Stand condition classes are used to describe groups and stands, usually small in area and homogeneous in their attributes. These attributes are described in terms of: (1) age or size of the overstory and understory, (2) species composition, (3) degree of stocking, (4) presence of seed trees, (5) presence of disease, and (6) ground vegetation.

[14]*Personal communication from Duncan Dunning, formerly with Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.*

Stand condition classification would be a new approach to forest management in the Southwest. Three primary objectives of this system would be to: (1) aid silviculturists in determining the most appropriate silvicultural treatment for each group or stand, (2) provide managers a basis in assigning priorities to accomplish short- and long-term management objectives, and (3) provide foresters with an effective means to communicate among themselves in particular and with conservationists in general. These objectives are not fully met at present.

Purposes for classification.—The purposes for classifying the forest into condition classes are (Hallin 1959):

1. To divide the forest or compartment into natural units sufficiently small and homogeneous for practical, uniform treatments such as harvest cuts, regeneration, and stand improvement.
2. To determine those unit areas which have stands suitable to carry as growing stock, and those which should be harvested to release advanced reproduction or to free ground for new regeneration.
3. To provide the basis for a cutting plan, cutting budget, allowable cut, and other steps in a management plan that will produce healthy stand components of a forest with an acceptable age-class distribution as soon as feasible.

Identification of these stand condition classes should be the manager's first step in the management of a forest. He then has a good grasp of what he has to work with, where it is located, which areas need immediate treatment, what treatments are needed, and which areas can be deferred for future treatment. Without this information, the forest manager is working haphazardly, and his replacement has no idea of what has been done or needs to be done in the future.

A code for condition classes and its application in treatment prescriptions is proposed here. It needs further development before it is ready for use.

Code for condition classes.—Many attributes of a stand or a group of trees could be coded to supply the forest manager with the information he needs to prescribe silvicultural treatments. These attributes could be expressed in a two-digit, two-line code form to describe the overstory (above line) and understory (below line). These attributes may be grouped as: (A) size class and species, (B) stocking density and desirability, (C) damaging agent and severity, and (D) seed tree stocking and size over ground vegetation and abundance. The various attributes could be coded as:

A. **Size Classes (d.b.h. in inches) (first digit)**

1. 29.0 and over	6. 9.0 - 12.9
2. 25.0 - 28.9	7. 5.0 - 8.9
3. 21.0 - 24.9	8. 0.1 - 4.9
4. 17.0 - 20.9	9. Under 4.5 ft high
5. 13.0 - 16.9	0. None

Species Composition (second digit)

1. Ponderosa pine	6. Douglas-fir, true fir, and pine
2. Spruce	7. Spruce, Douglas-fir, true fir, pine
3. Douglas-fir	8. Spruce, Douglas-fir, true firs
4. True fir	9. Spruce, true fir
5. Aspen	

B. **Stocking Density (ft^2 basal area per acre) (first digit)**

1. 181 and over	6. 61 - 80
2. 151 - 180	7. 41 - 60
3. 121 - 150	8. 21 - 40
4. 101 - 120	9. 1 - 20
5. 81 - 100	0. <1

Desirability Class (second digit)

1. Areas 70 percent or more stocked with desirable trees.
2. Areas 40-70 percent stocked with desirable trees and having favorable conditions for improved stocking.
3. Areas 40-70 percent stocked with desirable trees and with 30 percent or more of the area controlled by other vegetation, and/or surface condition that prevents occupancy by desirable trees.
4. Areas 10-40 percent stocked with desirable trees but expected to restock naturally.
5. Areas 10-40 percent stocked with desirable trees and requiring planting and/or stand conversion to improve stocking.
6. Areas less than 10 percent stocked with desirable trees but expected to restock naturally.
7. Areas less than 10 percent stocked with desirable trees and requiring planting or artificial seeding.

C. **Damaging Agents** (Indicate most serious causal agent in first digit and severity in second digit as 1 = light, 2 = moderate, and 3 = heavy, except for dwarf mistletoe, use the 6-class severity rating system (Hawksworth and Lusher 1956))

1. Dwarf mistletoe	6. Squirrel
2. Limb rust	7. Tip moth
3. Root rots	8. Cattle or horses
4. Bark beetles	9. Sheep, deer, or elk
5. Porcupine	0. No damage

D. **Seed Trees** (Basal area in seed trees in first digit and their average size class in second digit)

1. 41 - 45	6. 16 - 20
2. 36 - 40	7. 11 - 15
3. 31 - 35	8. 6 - 10
4. 26 - 30	9. 1 - 5
5. 21 - 25	0. <1

Ground Vegetation (List most abundant species as first digit and next most abundant as second digit)

1. Arizona fescue	6. Manzanita
2. Mountain muhly	7. Locust
3. Other grasses	8. Ceanothus
4. Oak brush	9. Weeds
5. Juniper	0. Bare or litter

For example, a ponderosa pine stand with trees over 29 inches in diameter, a stocking density of 200 ft^2 basal area and no desirable crop trees, heavily infected with dwarf mistletoe, no suitable seed trees, and a ground cover of pine litter would be coded as:

$\frac{11}{00}$ = $\frac{\text{Overstory of trees 29 inches and over—ponderosa pine}}{\text{No understory}}$

$\frac{17}{00}$ = $\frac{\text{Overstory 200 ft}^2\text{ basal area—no desirable trees}}{\text{No understory}}$

$\frac{16}{00}$ = $\frac{\text{Heavy infection of dwarf mistletoe in overstory}}{\text{No understory}}$

$\frac{00}{00}$ = $\frac{\text{No suitable seed trees}}{\text{Pine litter understory}}$

The sequence of stand condition attributes would be coded as

$$\left(\frac{11}{00} - \frac{17}{00} - \frac{16}{00} - \frac{00}{00}\right)$$

A two-storied ponderosa pine stand consisting of scattered overstory trees ranging from 25 to 28 inches in diameter, with a basal area stocking of 25 ft^2 all in trees showing a moderate infection of limb rust, and a healthy, well-stocked understory of trees averaging 6 inches in diameter and a stand density of 170 ft^2 per area would be coded as

$$\left(\frac{21}{71} - \frac{87}{21} - \frac{22}{00} - \frac{00}{00}\right)$$

The recognition of condition classes based on the above attributes is not unduly complicated. Although the combination of criteria could theoretically lead to many condition classes, such would not be the case in management units. Most stands would fall within a relatively few condition classes that are repeated throughout the forest.

Application of condition classes for treatment prescriptions.—The condition class description helps lead directly to the appropriate treatment or series of treatments. The immediate objective is to establish or maintain a desirable tree cover, with a long-term objective of organizing the forest property to obtain a continued yield of products and other values. Other information needed might be habitat class and knowledge of stand-site response to possible treatments.

The system of classifying forests by stand condition classes was originally designed for group selection (Hallin 1959), but where units are 1 acre or larger or a series of smaller units can be combined, the shelterwood, seed-tree, or clearcut methods may be appropriate. Therefore, size of the unit area would be considered in prescribing a silvicultural treatment. If the stand described as 11/00-17/00-16/00-00/00 occupied an area up to 1 acre, all trees might be cut and the area regenerated by seed from the adjacent trees, or planted if the trees in the adjacent stand were too young to produce seed. If the stand occupied more than 1 acre, all the trees might be cut and the area planted.

The second stand, described as 21/71-87/21-22/00-00/00, would receive an overstory removal cut and a commercial thinning. Area size would have no bearing on the treatment unless the stand was to be treated with other objectives in mind. The moderate amount of limb rust infection may permit leaving some of the larger trees to provide stand diversity, seed production for wildlife, or nesting places for birds. The understory could also be treated to provide some diversity in tree arrangement for other uses.

Stand Conversion

In the management of our forests, the stand is the essential unit for silvicultural treatment. The stand is defined as a contiguous group of trees, sufficiently uniform in size, species composition, arrangement of age classes, and condition to be a homogeneous, distinguishable, and manageable unit. Ponderosa pine forests consist of many stands, both even-aged and uneven-aged, that vary considerably in area. These stands collectively form the basis for multiple use and sustained yield management of the forest.

Ponderosa pine forest management units have deficiencies or surpluses in certain tree size classes, and great variation in size of individual even-aged and uneven-aged stands. Some of these disparities or characteristics affect decisions on whether to manage for even-aged or uneven-aged stand structures. They also influence the silvicultural treatments chosen to obtain a more balanced size class structure, to improve efficiency of cutting operations, to obtain or maintain nontimber values, and so forth.

Even-aged vs Uneven-aged Stands

Many areas within the southwestern ponderosa pine type can be managed as either even-aged or uneven-aged. If conversion from one to the other is practical and advisable, the conversion should be made without destroying the growing stock. This conversion can be done by combining adjacent groups or stands of similar condition classes, or subdividing large stands into smaller ones. Therefore, conversion may necessitate holding some size class beyond its normal rotation, or stimulating the growth rate of a smaller size class to speed up its entry into the larger size class.

Conversion to Uneven-aged Stands

Pearson (1950) described southwestern ponderosa pine forests as being composed primarily of irregular uneven-aged stands. However, many even-aged stands may be found in a sustained yield unit. These forests are best managed by a combination of even-aged and uneven-aged systems. The stand structure would indicate the form of management.

The manager may want to manage his forest in its entirety as uneven-aged, or specific areas as uneven-aged while others are even-aged to meet multiple use objectives. To convert an even-aged stand to an uneven-aged stand, the stand is subdivided to create groups of about 2 acres or less in area. In previously unmanaged or extensively managed forests, even-aged stands will have different stand condition classes for which different silvicultural treatments can be prescribed.

Stands of any tree size may be treated to create two or more size classes depending on the stand area. Stands of small and intermediate size trees may be cut to different stocking levels. Trees in the most heavily cut groups would grow more rapidly and advance more quickly into a larger size class, whereas trees in the lightly cut and uncut groups would grow more slowly and remain in the smaller size group. Cuts of intermediate intensity would create other size class groups.

Even-aged stands composed of the larger diameter classes may also be treated to develop into a series of different size class groups. Those portions of the stand with the largest or more defective trees could be cut first to create a new small size class. Other groups may be retained until the next cut or given an intermediate cut to create new size classes. The variation in existing stand conditions would be the basis for silvicultural treatment.

Once uneven ages or sizes have been created in a stand, they can be further differentiated and maintained by the selection method. The time required for conversion would vary by stand condition. Uniform even-aged stands would required a longer period than those with greater diversity.

Conversion to Even-aged Stands

Continued harvest of large saw-log trees may eventually convert many irregular uneven-aged stands to an even-aged structure. Many stands have a light saw-log overstory and a relatively heavy understory of regeneration that started in a few favorable years. Where the understory matrix covers large areas, overstory removal could create an even-aged stand in one cut. Within these stands, open areas wider than the height of the understory trees should be planted. Where the openings are smaller, adjacent trees would hinder establishment of younger trees.

Irregular uneven-aged stands may also be converted to even-aged stands by combining groups that differ by only a few size classes or where the adjacent groups represent the extremes in size classes. Stands with uneven-aged groups that differ only moderately in diameter could be cut to achieve a greater uniformity of size by altering the stand density to change the growth rate. Or these same uneven-aged stands could be thinned to the desired growing stock level and the regeneration cut made when the groups with the smallest trees reach rotation size.

As when converting even-aged to uneven-aged structure, stands should be converted with the least adverse impact on growing stock. The time needed for conversion depends on stand condition; in most stands, however, it may require the remainder of the present rotation period. Subsequent management would be by one of the even-aged methods, with shelterwood as the first choice (Schubert 1973).

Intermediate Cuts

Intermediate cuts include all the cutting treatments made following establishment of the new stand until the time to replace it. Cuttings are made when needed, but normally at specific intervals, to increase the quantity and quality of timber produced, and to salvage material which would be lost. Common intermediate cuts in the Southwest include: (1) thinnings, (2) release cuttings, (3) improvement cuttings, (4) sanitation cuttings, and (5) salvage cuttings. These cuttings apply to all stands regardless of the reproduction method.

Thinnings

Thinnings, either precommercial or commercial, may be made up to the time of the regeneration cut. Early thinnings, which followed the concept of uniform spacing, gave way in 1934 to "crop-tree" thinning, which involved cutting trees within a short radius around the crop tree (Pearson 1940c). Thinning was too light under both of these methods, and failed to produce the desired release.

Since 1962, growing stock levels have been under joint study by the western experiment stations of the USDA Forest Service (Myers 1967). Young even-aged ponderosa pine stands are being studied over a wide range of tree sizes, stand densities, and site qualities. The Taylor Woods plots on the Fort Valley Experimental Forest in north-central Arizona are the only ones in the Southwest.

The treatment in the regionwide study is primarily a low thinning; the smallest trees and rough dominants were removed. The wide range of conditions under investigation should provide data needed to answer questions that arise on quantity and quality of timber products, growth prediction, and application of multiple use management of ponderosa pine forests.

Early results of the Taylor Woods study were reported in the Journal of Forestry (Schubert 1971). These and later results are also summarized in the section on "Growth, Yields, and Quality."

The effect of stand basal area on stem taper and branch diameter will also be evaluated in the growing stock level studies. Early reports have indicated that young southwestern ponderosa pine must be grown in fairly dense stands to obtain low taper and small branches (Pearson 1950). However, earlier studies did not establish what stand density resulted in the best tree form and highest stand volume.

Release Treatments

Release of young trees, below the sapling stage, from the competition of grass, brush, or trees is often necessary to provide adequate growing space, light, and moisture for early rapid development. Young trees competing with dense grass or overtopped by brush and trees are retarded or killed unless they are released, particularly in the dry Southwest (Johnsen et al. 1973).

Timely overstory removal is essential for development of natural reproduction under the shelterwood method. The intense competition for moisture affects growth of both the young stand as well as the overstory trees. Ring counts indicate no significant difference in growth rates of overstory and understory trees.

Herbicides may be used to eliminate grass and brush. Bulldozers and axes may be used to reduce stand density of young seedlings, while power saws are best for removal of larger trees. Poisoning of deformed of wolf trees (Herman 1949, Pearson 1950) has not always been effective or esthetically acceptable. Although many poisoned trees on the Fort Valley Experimental Forest died and eventually disintegrated, others are still alive 40 years after treatment.

Improvement Cuttings

Improvement cuttings, particularly Pearson's "Improvement selection cutting" (Pearson 1942, 1943, 1950), have been effective in Arizona and New Mexico. The primary aim was to build up an effective growing stock. The method involves: (1) removal of trees not expected to live 20 years, (2) removal of low-quality wolf trees and those deformed by lightning, dwarf mistletoe, porcupines, or squirrels, (3) removal of coarse dominants where this will open up groups of yellow pines and blackjacks, (4) regeneration of nonstocked areas, and (5) thinning in groups below saw-log size. In actual practice, the method resembles a sanitation-salvage cutting since items 4 and 5 are seldom done. On the Fort Valley Experimental Forest, the treatment has improved the quality of the residual stand and reduced mortality.

Sanitation and Salvage Cuttings

Salvage cutting was the primary intermediate cut on the National Forests during the first 40 to 50 years of management. The primary objective was to cover the forests as rapidly as possible to reduce heavy losses common in old virgin stands. This objective has generally been fulfilled on most forests.

Sanitation cutting eliminates trees that have been attacked or are likely candidates for attack by insects or disease to prevent the spread of these pests to other trees. Sanitation and salvage cutting are usually combined, and may also be combined with improvement cuttings to improve the stand condition class.

Regeneration Cuttings

The two best regeneration cutting methods for southwestern ponderosa pine are the selection and shelterwood methods. The seed-tree and clearcutting methods are suitable under certain conditions. Because the methods are described in all silviculture textbooks, they will be covered only briefly here, with special reference to the Southwest.

Shelterwood Method

The shelterwood method is designed to produce even-aged stands; it involves removing the entire overstory in one or more cuttings near the end of the rotation. The method can also be used to treat even-aged groups within the group selection method.

The classical three-cut shelterwood includes: (1) a preparatory cut, (2) a seed cut, and (3) a removal cut. The preparatory cut is sometimes omitted.

Even-aged stands of ponderosa pine in the Southwest are managed most effectively by a two-cut shelterwood. The first is a seed cut to establish a stand of seedlings. The second removes the remaining overstory after the seedlings are well established (Schubert 1973). Some stands may require one or more light preparatory cuts, prior to the seed cut, to develop windfirmness and good seed tree characteristics. Stands most likely to require preparatory cuts are those on sites with shallow soils or high water tables, and where stand density exceeds 200 ft^2 basal area per acre.

The preparatory cut, where needed, removes about 20 to 30 percent of the volume, primarily in trees of lower crown classes and from among the least desirable trees of all crown classes.

The seed cut leaves about 20 to 40 ft^2 of basal area per acre, to provide shelter as well as an adequate seed supply. The seed cut opens up enough growing space for establishment of sufficient reproduction. The trees left should be the best available, preferably about 20 to 24 inches in diameter, and should show evidence of being good seed producers. Beyond the minimum 20 ft^2 of basal area, the stocking left should depend on the need for shelter on the particular site. The seed cut may be made at any time, but the site should be prepared during the fall of a good seed year, and harvesting completed prior to germination the following year.

In the removal cut, all overstory trees should be removed after adequate regeneration is established. This cut should be made while the seedlings are about 1 to 2 ft high and still flexible enough to bend without breaking. Further delay in removing the shelter results in low seedling vigor due to suppression and heavy losses due to breakage. Logs should be removed with the least possible ground disturbance and seedling damage.

Seed-Tree Method

The seed-tree method is designed for even-aged stands of species that produce abundant light seed, and for situations that do not require shelter for seed germination and seedling establishment. It differs from the two-step shelterwood primarily in the number of seed trees retained. In the seed cutting, all trees are removed except for two to four seed trees per acre (Pearson 1923, 1950). The method is not particularly suited for the southwestern ponderosa pine type. It was used successfully during the heavy seed year of 1913 (Pearson 1950), but no other success has been reported.

Clearcutting Method

The clearcutting method is designed for even-aged stands where, for some ecological reason, all trees should be cut. This method has been used sparingly in the southwestern ponderosa pine type in recent years, in stands of 2 to 20 acres where all trees are defective and are unsuitable for seed production.

Clearcutting has been recommended in areas heavily infected with dwarf mistletoe (Andrews 1957, Hawksworth et al. 1968, Korstian and Long 1922, Pearson 1950). Where large areas have been clearcut during a nonseed year, the areas have failed to restock and are now occupied by grass or brush (Pearson 1910, 1950; Pearson and Marsh 1935; Woolsey 1911). Therefore, stands with heavy dwarf mistletoe infection should be carefully examined to determine whether some other regeneration method, such as the shelterwood, could be used. Although dwarf mistletoe reduces cone production (Korstian and Long 1922), extra trees could be retained to make up the needed seed supply. Young seedlings are normally not infected with dwarf mistletoe for up to 10 years.[15] After overstory removal, the young trees could be examined for dwarf mistletoe and all infected trees cut or pruned.

Where clearcutting is used, the area should be planted immediately afterward.

Selection Method

The selection method, designed for uneven-aged stands, is the best way to manage many stands of southwestern ponderosa pine (Schubert 1973). Either single trees or groups may be removed, depending on stand condition and management objectives. Under group selection, the cuttings are most frequently made in groups occupying an area up to 1 acre.

Many of the earlier cuttings by group selection were referred to as "light cuttings" (Pearson 1910). Excellent reproduction followed these light cuttings on the Coconino, Kaibab, Prescott, and Sitgreaves National Forests. Similar results probably were attained on other forests, though not specifically mentioned in the literature or office reports.

A Model for Forest Management

A frequent objective of forest management is to produce the highest possible sustained yield of high-quality trees. This objective can be modified to produce greater volume with reduced quality or higher quality with some reduction of volume. The manager may change the tree size set for final harvest, the growing stock level, management intensity, or any combination of those to accomplish specific objec-

[15] *Personal communication from Frank Hawksworth, Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.*

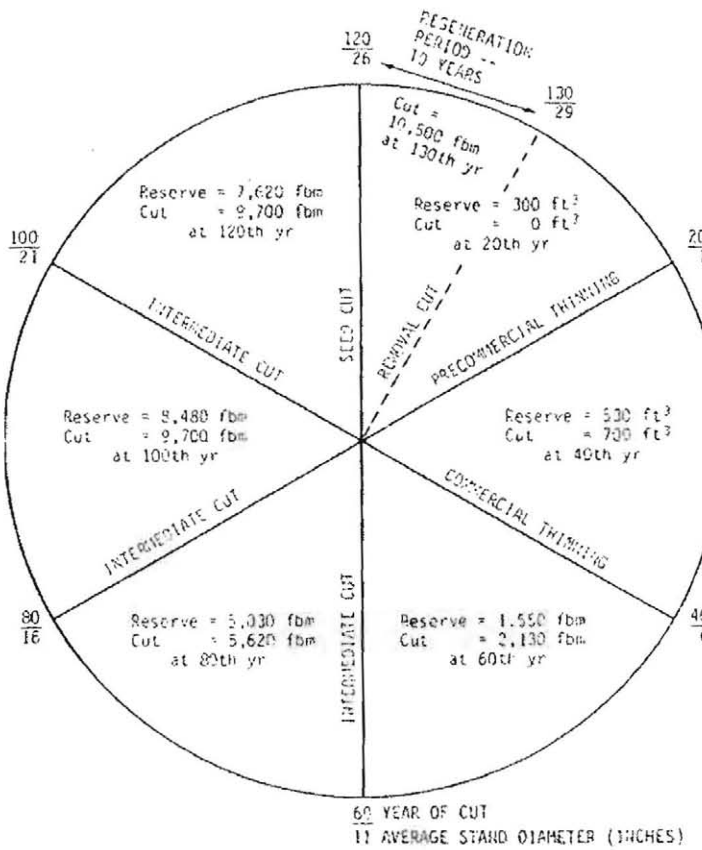

Figure 31.—Schematic diagram for harvesting cutting schedule for management under the shelterwood system at a growing stock level of 60 ft² basal area per acre under a rotation of 120 years and a 20-year reentry period for Site Index 1 land (per-acre basis for volumes).

tives. Within limits, he may convert from one management system to another.

The manager should focus his attention on at least one full rotation, rather than just the segment represented by a 10-year management plan. What he does today was conditioned by past treatments, and will set the stage for the future. He should manage the forest through the application of properly selected and administered silvicultural systems. Under most silvicultural systems, there is sufficient flexibility to revise objectives and adjust prescriptions to meet changing needs.

A schematic diagram (fig. 31) illustrates the series of cuts at 20-year intervals for a 120-year rotation under the shelterwood system for even-aged management. The shelterwood system differs from the seed-tree or clearcutting systems mainly in the way the stand is reproduced. All intermediate cuts would be the same under all three silvicultural systems for even-aged management. Under uneven-aged management by the group selection system, the manager would apply the treatments to even-aged groups in the uneven-aged stands. The scheduled 20-year reentries would be 20-year cutting cycles, and the rotation period would be the time needed to grow the crop to an average of 24 inches in diameter.

A point of primary importance is the retreatment of stands at regular intervals to maintain the desired growth rate. The diagram indicates average stand diameter and yields at 20-year intervals based on an average growth rate of eight rings per inch for a fully stocked stand on a high-quality site. Future research may show that greater yields are possible with shorter reentry intervals or a different growing stock level. The model makes no allowance for mortality. In a well-tended forest, mortality should be negligible except for rare catastrophic losses (Pearson 1950).

In our example forest, we will start with the seed cut. We will manage each stand at a growing stock level of 60 (GSL-60) ft^2 basal area per acre. At the 120th year (or first year of new rotation) we will have 25 trees averaging 26 inches in diameter with gross volume of 17,320 fbm per acre. We will mark 11 trees per acre to leave for shelter and a seed source for the next crop. These 11 trees (about 40 ft^2 in basal area) will be high quality for timber, shelter, and seed. They must be protected from logging injuries. Our seed cut will remove 14 trees with a gross volume of 9,700 fbm per acre. The soil will be thoroughly scarified during late September in a good seed year.

A regeneration period of 10 years is allowed, based on the average frequency of seed years and time for the new crop of seedlings to become established. Overstory removal will then yield a volume of about 10,500 fbm per acre.

The reproduction stand will average about 1 inch in diameter at the 20th year, at which time we will make a precommercial thinning to GSL-60. This will leave about 500 trees per acre.

Subsequent intermediate cuts, starting with a commercial thinning at age 40, will follow at 20-year intervals with estimated yields and residual tree diameters as indicated in figure 31. Each cut will reduce the stand to GSL-60. The total yield will be about 34,100 fbm per acre for the rotation period, including the overstory removal cut. This total assumes that cuts are made on schedule to maintain the growth rate. Improvement of tree quality will be a major consideration in all intermediate cuts.

Treatment Control

Every silvicultural treatment follows a set of guidelines or prescriptions. These prescriptions are executed in the field by marking the trees and by administering the cutting operation. Both marking and administration are key points in treatment control. Cutting is the main tool in forest management, whether the objective is timber, water, forage, wildlife, recreation, or some combination of these resources. To achieve the stated silvicultural objective, prescriptions are presented as marking rules based on various tree and stand characteristics.

Marking is essential so that the right trees are marked for cutting or leaving to fulfill the treatment objective. Marking rules must be considered as guidelines rather than as rigid rules to be followed blindly. They are intended primarily for the assistance of the forest officer in charge of marking a timber sale. The marker must know the specified silvicultural treatment and have the necessary experience, otherwise the marking rules may not accomplish the stated objective. He should also reexamine the area after cutting to ascertain whether the marking did indeed accomplish the stated objective. Hawley (1946) stated that marking rules, when properly developed, supply the necessary information in concise form and serve as summarized plans of silvicultural management.

Tree Classification

Tree classifications have been used extensively in developing marking rules. Most of the tree classification parameters have been described for individual trees in the selection forest (Dunning 1928). These same characteristics can also be applied to even-aged stands.

The main tree classification factors for timber marking are: age, size, crown position, ground position, vigor, merchantability, potential growth capacity, and mortality. Many of the factors work in concert.

Keen (1943) developed age-vigor classes based on susceptibility to insect attack to guide tree cutting. Under this system, trees are placed in four age classes with four vigor classes. Thomson (1940) found, however, that Keen's age-vigor classes did not fit southwestern ponderosa pine when used as an index of growth for a marking rule. He found that ponderosa pine in the Southwest matured at an earlier age and had smaller average diameters than in California and Oregon. The lowest vigor classes also differed for the Southwest, where they included some larger trees that had once been dominant or codominant. Therefore, Thomson (1940) redefined Keen's age-vigor classes to fit southwestern trees.

Four age classes and five vigor classes were recognized in Thomson's classification. His four age classes (figs. 32, 33) were: (1) young blackjacks mainly under 12 inches d.b.h., (2) blackjacks 12 inches and over, (3) intermediates or young yellow pines (mature), and (4) old yellow pines (overmature). His five vigor classes (figs. 32, 33, 34) were: (1) AA = extremely large crowns with length of 70 percent or more of the total tree height (wolf-type trees); (2) A = full vigor, crowns 55 to 70 percent; (3) B = good to fair vigor, crowns 35 to 55 percent; (4) C = fair to poor vigor, crowns 20 to 25 percent; and (5) D = very poor vigor, crowns less than 20 percent of tree height.

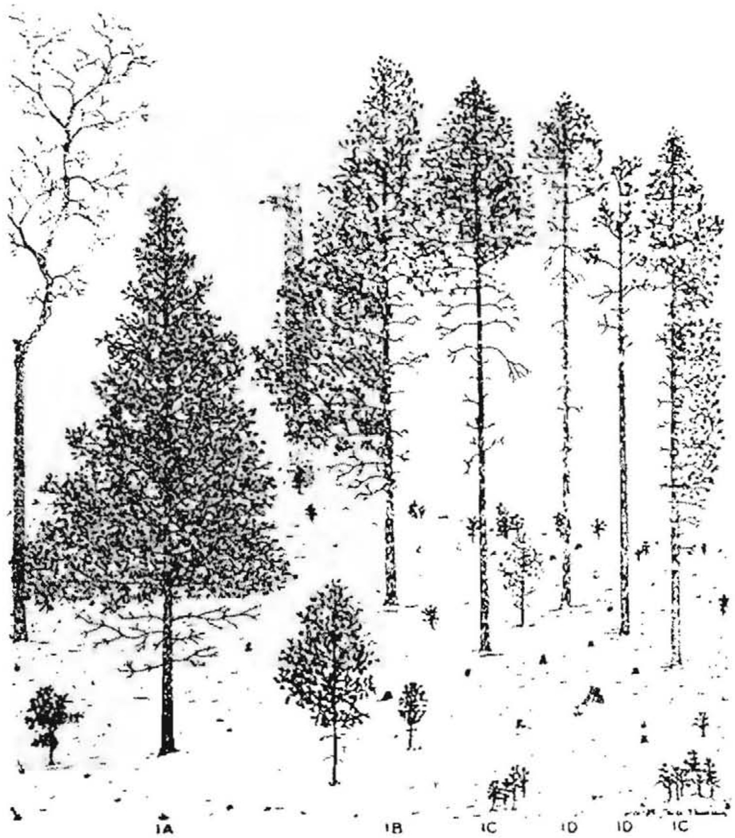

Figure 32.—Age class 1 ponderosa pines. Young blackjacks, usually less than 75 years old and under 12 inches in diameter; growth rates of trees highest for vigor class A and lowest for D (Thomson 1940).

Age-Vigor Marking Rules

When marking is based on age-vigor classes alone, the priority for removal, from highest to lowest, would be: (1) 4D, 3D, 2D, 1D, and all vigor class AA; (2) 4C and 4B; (3) 4A, 3C, and 2C; (4) 3B and 1C; (5) 3A and 2B; (6) 2A and 1B; and (7) 1A.

Other classifications used in marking include the risk rating system (Salman and Bongberg 1942), the Bongberg penalty system for rating high-risk trees (Sowder 1951), and the dwarf mistletoe infection intensity classes (Hawksworth 1961). In the risk rating system, four degrees of susceptibility to bark beetle attack are defined. High risk trees (Risk Class III and IV) should be cut. In the Bongberg penalty system, penalty points are based on needle, twig and branch, and top crown conditions, plus other factors such as vigor classes, lightning strike, beetle attack, and mistletoe. Trees with a penalty score of 9 or more are high risk and should be cut. In the dwarf mistletoe infection rating, 6 classes are set up with zero (no mistletoe), 1 (light mistletoe), and 2 (heavy mistletoe) in each 1/3 of the crown. In a study at the Grand Canyon, 27 percent of the trees with an initial rating of 3 died within 20 years. For trees with a rating of 6, the death rate was 63 percent (Lightle and Hawksworth 1973).

Marking Procedure

Trees should be marked in strips running back and forth over the sale area. The mark should be placed on the back side of the tree so that it is visible to the marker on his return strip. The marker should also indicate the direction of felling where necessary to avoid damage to reproduction and residual trees. Direction of fall can be covered in the sale contract with experienced fallers.

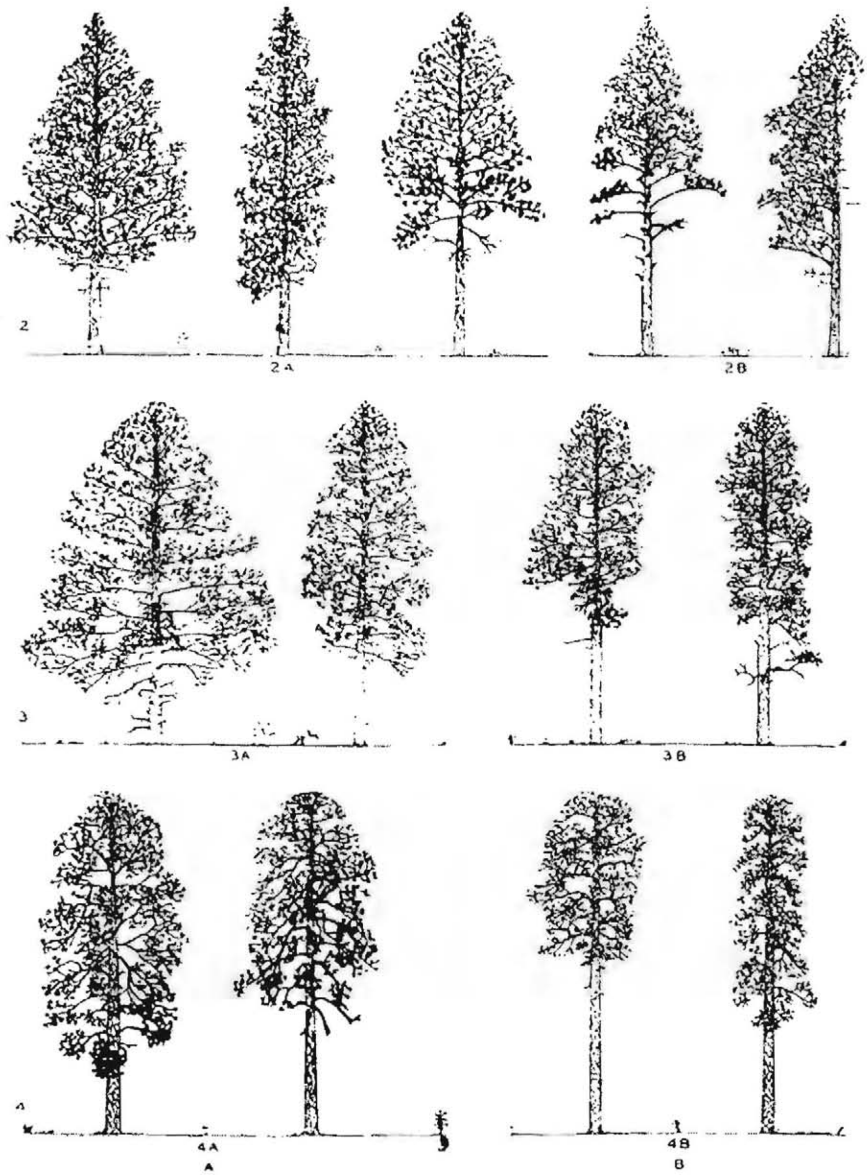

Figure 33.—Age class 2 to 4 ponderosa pines of vigor class A (full) and B (medium). Age class 2 trees are blackjacks, usually less than 150 years and seldom over 24 inches in diameter; age class 3 trees are intermediate-mature, approximately 150 to 225 years old, and usually less than 36 inches. Age class 4 trees are mature-overmature, approximately 225 years old, and usually have large diameter (Thomson 1940).

For the various silvicultural treatments, mark the fewest trees necessary to accomplish the stated objective. For example:

Clearcutting—mark cutting boundary.
Shelterwood—for preparatory cut, mark all trees to be removed. For seed cut, mark all trees to be left. For removal cut, mark boundary.
Seed tree—for seed cut, mark the seed trees. For removal cut, mark boundary.
Selection, Intermediate harvest, Improvement, and Salvage—mark trees to be cut.

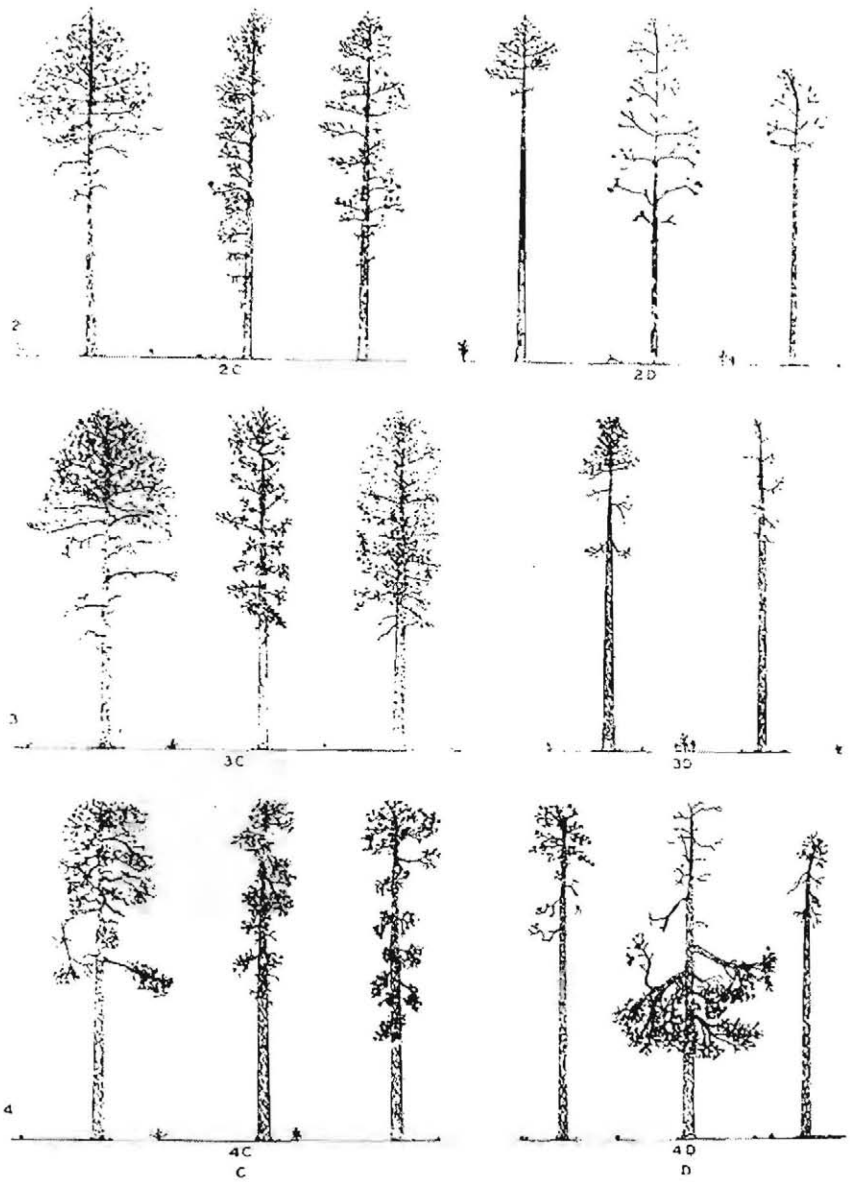

Figure 34.—Age class 2 to 4 ponderosa pines of vigor class C (fair) and D (poor) (Thomson 1940).

Thinning—for precommercial thinning in dense stands use an approximate spacing guide, with instructions on selection of crop trees. For precommercial thinning in less dense stands, and for commercial thinning, mark leave trees.

Multiple-Use Silviculture

Timber management activities in southwestern ponderosa pine have a great impact on all forest values: wood, forage, recreation, water, and wildlife. The standard silvicultural systems discussed will generally provide multiple-use benefits, and commonly can be adapted to emphasize one value or another. For example, by maintaining less basal area and overstory density, and using a shorter cutting interval, both the amount and quality of forage can be increased for wildlife and livestock. Forage production can also be increased by group selection cutting, and by thinning dense thickets.

In travel and water influence zones, recreation sites, and scenic view areas, individual-tree selection can be used to improve natural beauty. Cutting should be light and the number of trees removed varied throughout the stand to develop diversity. Trees retained should range from seedlings to old, yellow-barked veterans. Natural beauty may also be enhanced by planting hardwood species for their fall coloration.

Forested areas in the ponderosa pine type contribute great amounts of water to meet the critical domestic and agricultural needs in the Southwest. Timber cuttings can be geared to increase water production, influence snow accumulation and rate of melt, and regulate streamflow (Brown 1971). Timber production is rather uniform over a fairly broad range of stand densities. Cutting could maintain these stands at a stocking density to increase water yields without a great decrease in timber yields.

Ponderosa pine stands may also be managed to produce other minor woods products. For example, by maintaining less basal area in pine, Christmas trees could be grown as an understory crop during the latter part of the rotation. Christmas trees could be grown also on landings and spur roads that will be reused at the following reentry for intermediate harvest cuttings.

WHAT WE NEED TO KNOW

Until rather recently, the purposes of forest management in the Southwest were relatively simple: (1) to produce logs for local processing from a forest with abundant standing timber; (2) to utilize available forage; and (3) to maintain a substantial degree of forest cover, or at least vegetative cover, to protect and utilize the land. Esthetic and recreational values were largely incidental.

Increasingly, however, the need is to produce a near-optimum mix of goods and other values. We do not yet know how to do that. It requires identifying the potentials and limitations of each site, considering not only the direct effects of site, but also the effects of existing and alternative vegetation, stand structure and condition, and potential problems of pathology and site damage.

We must understand, in some detail, the processes in the ecosystems now on the sites, and in the ecosystems that may result from proposed treatments. Conversely, we must be able to design prescriptions to accomplish specific results with at least fair precision.

Fortunately, ecosystems that are similar in site and in the composition and structure of their biotic communities behave similarly, and the number of combinations is limited. It is therefore possible to classify sites and communities into a limited number of readily recognizable types within which similar treatments will usually produce similar results.

Within these types we need to know how ponderosa pine and other plants and animals reproduce, grow, and interact with each other and with the physical environment. We need to know with considerable reliability what to expect from a treatment, or absence of treatment, in terms of environmental changes and plant succession.

Among specific questions are: (1) How do different stand densities affect the volume and value of timber production in each ecosystem type? (2) Should growing stock levels (GSL's) be changed when the trees reach different ages or sizes? One aspect of this question is at what age or stocking level should a stand first be thinned. (3) How frequently should stands be treated? Twenty-year intervals have been used in examples here, but the best intervals may vary by site, GSL, and so forth.

It is important that field and computer simulation procedures for predicting growth and yield be tied to habitat types, and be expanded to include uneven-aged stands and key uses besides timber production.

Can the timber quality or growth of southwestern ponderosa pine be increased through provenance selection, genetic improvement programs, or fertilization?

Evaluation of fire is needed. How much can prescribed burning reduce disastrous wildfires? What are its side effects? Its multiple use impacts?

Available artificial reforestation methods are reasonably reliable if carried out correctly. Natural regeneration methods, though commonly much cheaper, are unreliable. The general requirements for successful natural regeneration are known, but the factors that are critical in different habitat types must be identified and reliable methods developed. A critical need is to determine suitable stand densities and necessary site preparation in the shelterwood method, and suitable sizes for openings in the group selection method, for different habitat types and stand conditions.

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APPENDIX

COMMON AND SCIENTIFIC NAMES OF PLANTS, ANIMALS, DISEASES, AND INSECTS ASSOCIATED WITH SOUTHWESTERN PONDEROSA PINE

Common Name	Scientific Name
Large and Medium-Sized Trees	
Aspen, quaking	*Populus tremuloides* Michx.
Boxelder, inland	*Acer negundo* var. *interius* (Britton) Sarg.
Douglas-fir, Rocky Mountain	*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco
Fir, white	*Abies concolor* (Gord. and Glend.) Lindl.
Juniper, alligator	*Juniperus deppeana* Steud.
Juniper, Rocky Mountain	*J. scopulorum* Sarg.
Maple, bigtooth	*Acer grandidentatum* Nutt.
Oak, Gambel	*Quercus gambelii* Nutt.
Pine, Apache	*Pinus engelmannii* Carr.
Pine, Arizona	*P. ponderosa* var. *arizonica* (Engelm.) Shaw
Pine, Chihuahua	*P. leiphylla* var. *chihuahuana* (Engelm.) Shaw
Pine, limber	*P. flexilis* James
Pine, ponderosa	*P. ponderosa* Laws.
Pine, southwestern white	*P. strobiformis* Engelm.
Walnut, Arizona	*Juglans major* (Torr.) Heller
Small Trees and Shrubs	
Bitterbrush, antelope	*Purshia tridentata* (Pursh) DC.
Buckthorns	*Rhamnus* spp.
Ceanothus, Fendler	*Ceanothus fendleri* A. Gray
Cherry, bitter	*Prunus emarginata* (Dougl.) D. Dietr.
Chokecherry, common	*P. virginiana* L.
Cliffrose	*Cowania mexicana* D. Don
Currant, wax	*Ribes cereum* Dougl.
Deerbrush	*Ceanothus integerrimus* Hook. & Arn.
Dogwood, red-osier	*Cornus stolonifera* Michx.
Elder, blueberry	*Sambucus glauca* Nutt.
Gooseberry, orange	*Ribes pinetorum* Greene
Juniper, common	*Juniperus communis* L.
Juniper, one-seed	*J. monosperma* (Engelm.) Sarg.
Juniper, Utah	*J. osteosperma* (Torr.) Little
Locust, New-Mexican	*Robinia neomexicana* A. Gray
Manzanita	*Arctostaphylos* spp.
Mountainmahogany, curlleaf	*Cercocarpus ledifolius* Nutt.
Ninebark, mountain	*Physocarpus monogynus* (Torr.) Coult.
Oak, shrub live	*Quercus turbinella* Greene
Pinyon	*Pinus edulis* Engelm.
Poison-ivy, western	*Toxicodendron radicans* var. *rydbergii* (Small) Rehder
Rabbitbrushes	*Chrysothamnus* spp.
Raspberry, American red	*Rubus strigosus* Michx.
Roses	*Rosa* spp.
Serviceberry, Utah	*Amelanchier utahensis* Koehne
Snowberry	*Symphoricarpos oreophilus* A. Gray
Sumacs	*Rhus* spp.
Thimbleberry, western	*Rubus parviflorus* Nutt.
Willows	*Salix* spp.

Common Name	Scientific Name
Forbs, Grasses, and Grasslike Plants	
Bluegrasses	*Poa* spp.
Bluestem, little	*Andropogon scoparius* Michx.
Bracken	*Pteridium aquilinum* (L.) Kuhn
Bromes	*Bromus* spp.
Cheatgrass	*Bromus tectorum* L.
Dropseed, black	*Sporobolus interruptus* Vasey
Dropseed, pine	*Blepharoneuron tricholepis* (Torr.) Nash
Fescue, Arizona	*Festuca arizonica* Vasey
Fescue, Idaho	*F. idahoensis* Elmer
Grama, blue	*Bouteloua gracilis* (H.B.K.) Lag.
Groundsel, broom	*Senecio spartioides* Torr. & Gray
Irises	*Iris* spp.
Johnsongrass	*Sorghum halepense* (L.) Pers.
Junegrasses	*Koeleria* spp.
Larkspurs	*Delphinium* spp.
Lupines	*Lupinus* spp.
Milkweeds	*Asclepias* spp.
Muhly, mountain	*Muhlenbergia montana* (Nutt.) Hitchc.
Muhly, ring	*M. torreyi* (Kunth) Hitchc.
Muhly, spike	*M. wrightii* Vasey
Mullein, purple-stamen	*Verbascum virgatum* Stokes
Needlegrasses	*Stipa* spp.
Orchardgrass	*Dactylis glomerata* L.
Redtop	*Agrostis alba* L.
Ryegrass, perennial	*Lolium perenne* L.
Squirreltail, bottlebrush	*Sitanion hystrix* (Nutt.) J.G. Smith
Sunflower, common	*Helianthus annuus* L.
Thistles	*Cirsium* spp.
Three-awns	*Aristida* spp.
Wheatgrasses	*Agropyron* spp.
Yarrow, western	*Achillea lanulosa* Nutt.
Mammals	
Chipmunks	*Eutamias* spp.
Cottontails	*Sylvilagus* spp.
Coyote	*Canis latrans* Say
Deer, mule	*Odocoileus hemionus hemionus* Rafinesque
Deer, white-tailed	*O. virginianus* (Zimmermann)
Elk, Rocky Mountain	*Cervus elaphus* (Linneaus)
Ground squirrel, golden-mantled	*Spermophilus lateralis* (Say)
Ground squirrel, spotted	*S. spilosoma* Bennett
Jack rabbit, black-tailed	*Lepus californicus* Gray
Myotises	*Myotis* spp.
Pocket gophers	*Thomomys* spp.
Porcupine	*Erethizon dorsatum* (Linnaeus)
Prairie dog, Gunnison's	*Cynomys gunnisoni* (Baird)
Pronghorn	*Antilocapra americana* Ord
Shrew	*Sorex* spp.
Skunk	*Mephitis* spp.
Squirrel, Abert's	*Sciurus aberti* Woodhouse

Common Name	Scientific Name
Squirrel, Arizona gray	*S. arizonensis* Coues
Squirrel, Kaibab	*S. kaibabensis* Merriam
Squirrel, red	*Tamiasciurus hudsonicus* (Erxleben)
Voles	*Microtus* spp.
Woodrats	*Neotoma* spp.

Birds

Chickadee, mountain	*Parus gambeli* Ridgway
Crow, common	*Corvus brachyrhynchos* Brehm
Dove, mourning	*Zenaida macroura* Linneaus
Flicker, common	*Colaptes auratus* (Linnaeus)
Grosbeak, black-headed	*Pheucticus melanocephalus* Swainson
Grosbeak, evening	*Hesperiphona vespertina* Cooper
Jay, pinon	*Gymnorhinus cyanocephalus* Wied
Jay, Steller's	*Cyanocitta stelleri* Gmelin
Juncos	*Junco* spp.
Nutcracker, Clark's	*Nucifraga columbiana* Wilson
Nuthatches	*Sitta* spp.
Pigeon, band-tailed	*Columba fasciata* Say
Raven, American	*Corvus corax* Linnaeus
Robin	*Turdus migratorius* Linnaeus
Sapsuckers	*Sphyrapicus* spp.
Starling	*Sturnus vulgaris* Linnaeus
Turkey, Merriam's	*Meleagris gallopavo merriami* Nelson
Woodpecker, acorn	*Melanerpes formicivorus* Swainson
Woodpecker, downy	*Dendrocopos pubescens* Linnaeus
Wookpecker, hairy	*D. villosus* Linnaeus
Woodpecker, Lewis	*Asyndesmus lewis* Gray

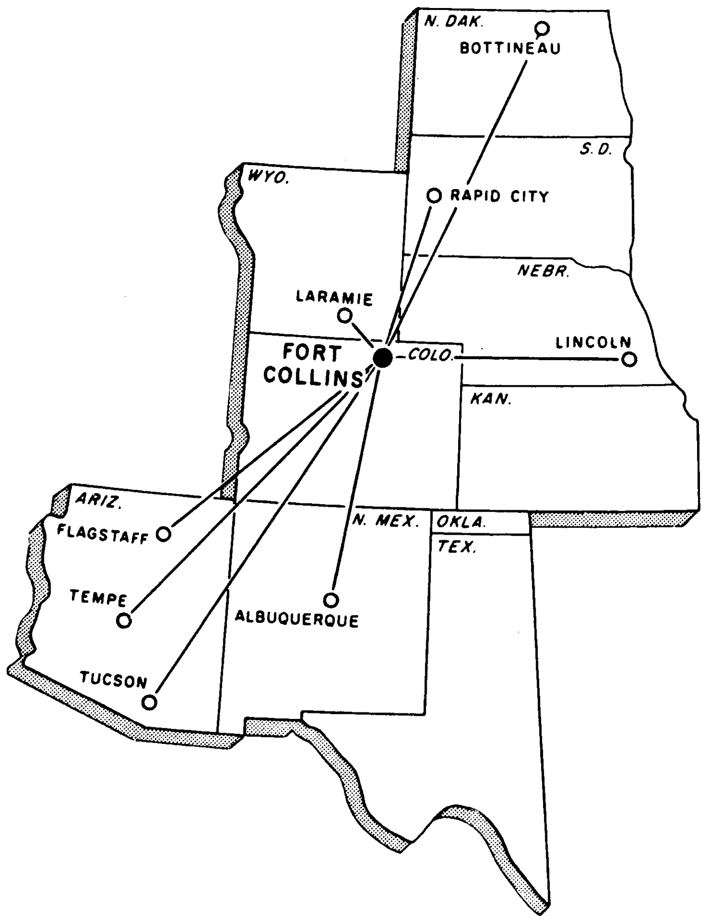
Diseases

Seedling diseases	
Fusarium damping-off	*Fusarium* spp.
Pythium damping-off	*Pythium* spp.
Rhizina root rot	*Rhizina undulata* Fr.
Rhizoctonia damping-off	*Rhizoctonia solani* Kuehn
Sclerotium damping-off	*Sclerotium bataticola* Taub.
Stem diseases	
Dwarf mistletoe	*Arceuthobium vaginatum* subsp. *cryptopodum* (Engelm.) Hawks. & Wiens
Atropellis canker	*Atropellis arizonica* Lohm. & Cash
Pine canker	*A. piniphila* (Weir) Lohm. & Cash
Comandra rust	*Cronartium comandrae* Pk.
Limb rust	*Peridermium filamentosum* Pk.
Western gall rust	*P. harknessii* J.P. Moore
Needle diseases	
Dothistroma needle blight	*Dothistroma pini* Hulb.
Elytroderma needle blight	*Elytroderma deformans* (Weir) Dark.
Hypodermella needle blight	*Davisomycella medusa* (Dear.) Dark.
Prescott needle cast	*Lophodermella cerina* (Dark.) Dark.

Common Name	Scientific Name
Root rots	
Armillaria root rot	*Armillaria mellea* Vahl.
Fomes root rot	*Fomes annosus* (Fr.) Cke.
Stem rots	
Brown trunk rot	*Fomes officinalis* (Vill. ex Fr.) Faull
Red ring rot	*F. pini* (Thore) Lloyd
Western red rot	*Polyporus anceps* Pk.
Red-brown butt rot	*P. schweinitzii* Fr.

Insects

Common Name	Scientific Name
Cone and seed insects	
Pine cone beetle	*Conophthorus scopulorum* Hopk.
Fir coneworm	*Dioryctria abietella* D. & S.
Pine coneworm	*D. auranticella* Grote
Pine seed moth	*Laspeyresia piperana* Kearf.
Root feeders	
White grubs	*Phyllophaga* spp.
Wireworms	Elateridae
Cutworms	Noctudae
Bark beetles	
Colorado pine beetle	*Dendroctonus parallelocollis* Chap.
Mountain pine beetle	*D. ponderosae* Hopk.
Red turpentine beetle	*D. valens* Lec.
Roundheaded pine beetle	*D. adjunctus* Bland.
Southern pine beetle	*D. frontalis* Zimm.
Western pine beetle	*D. brevicomis* Lec.
Arizona five-spine ips	*Ips lecontei* Sw.
California pine engraver	*I. plastographus* Lec.
No common name; locally known as Cloudcroft ips	*I. cribicollis* (Eichh.)
Knaus ips	*Ips knausi* Sw.
Pine engraver	*Ips pini* Say
Butterfly, moths, and scale	
Pine butterfly	*Neophasia menapia* Feld.
Pine shoot moth	*Eucosma sonomana* Kearf.
Ponderosa twig moth	*Dioryctria ponderosae* Dyar.
Ponderosa pine sawfly	*Neodiprion fulviceps* Cress.
Colorado pine sawfly	*Neodiprion gillettei* Roh.
Pine tiger moth	*Halisidota ingens* Hy. Edws.
Southwestern pine tip moth	*Rhyacionia neomexicana* (Dyar)
Prescott scale	*Matsucoccus vexillorum* Morrison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