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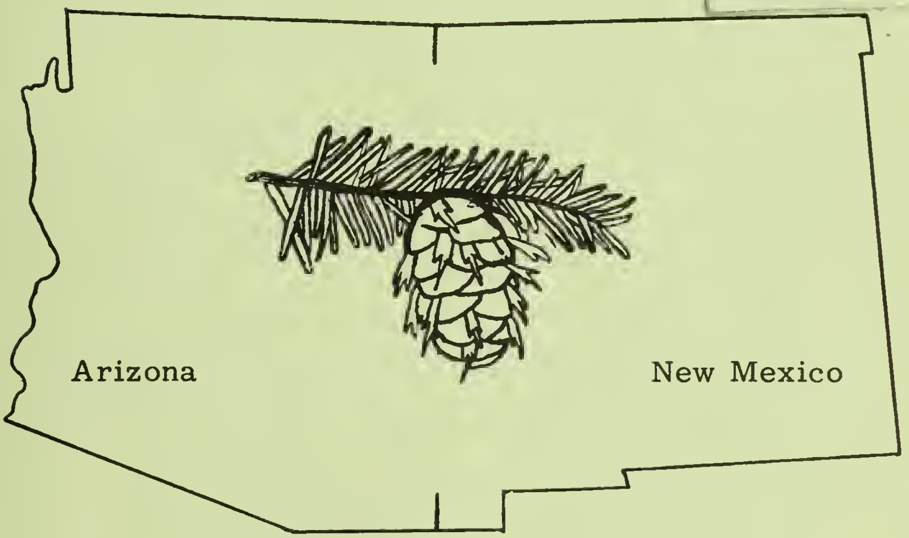
MANAGEMENT OF DOUGLAS-FIR TIMBERLAND IN THE SOUTHWEST

By

HERMANN KRAUCH



ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Raymond Price, Director Fort Collins, Colorado

FOREST SERVICE U. S. DEPARTMENT OF AGRICULTURE

MANAGEMENT OF DOUGLAS-FIR TIMBERLAND IN THE SOUTHWEST

by

Hermann Krauch, Silviculturist

FOREWORD

Hermann Krauch was engaged in forest management studies in New Mexico and Arizona from 1922 until his retirement from the Forest Service in 1948. Much of that time he studied the Douglas-fir type in this region. He is a keen observer, and his conclusions, based on careful and repeated attention to details, are valid, even though, because of early day limitations on experimental design, their statistical significance cannot be calculated.

In 1949, following his retirement, Krauch completed a report covering his research in the Douglas-fir type. It is being made available now, as a record of that research, and to serve land managers and research workers in the southwestern Douglas-fir type.

The Southwestern Forest and Range Experiment Station, of which Krauch was a member, was combined in 1953 with the Rocky Mountain Forest and Range Experiment Station, with central headquarters in cooperation with Colorado A & M College, Fort Collins, Colorado.

CONTENTS

INTRODUCTION

In the southwestern region, comprising the States of Arizona and New Mexico, there are approximately 6,280,000 acres of commercial timberland. Although this is not a large area compared with the amount of timberland in other parts of the United States, it nevertheless constitutes one of the Southwest's most valuable natural resources.

With the cutting of the virgin stands of timber in other States gradually coming to an end, the timberlands of Arizona and New Mexico will tend to become more and more important as a source of part of our Nation's future timber needs. But aside from their value for timber production, some of the southwestern timberlands are even more valuable as watersheds and places of recreation. This is particularly true of the timberlands of the higher mountain ranges. These lands are occupied by a number of different forest types, one of the most important of which is Douglas-fir.

To obtain information that would show how to manage the lands represented by this forest type, research studies were conducted for several years by the Southwestern Forest and Range Experiment Station. This report presents a digest of the knowledge gained from these studies and offers suggestions for the silvicultural treatment of Douglas-fir timberlands in the Southwest.

THE DOUGLAS-FIR TYPE IN ARIZONA AND NEW MEXICO

DISTRIBUTION

The Douglas-fir type occurs in all southwestern mountain ranges, at elevations ranging from about 8,000 to 9,500 feet. Its altitudinal limits are not sharply defined. At the upper limits it merges with the Engelmann spruce type, and at the lower, with the ponderosa pine type. Although the Douglas-fir type occurs on various kinds of soil, it is found chiefly on soils of limestone and granitic origin. Reconnaissance estimates indicate the total area of Douglas-fir timberland in the Southwest to be about 664,000 acres. Most of this is in national forests and Indian reservations, but there is also some on State and privately owned land (table 1).

Figure 1 shows where the Douglas-fir type occurs and its relation to other forest types in the Southwest.

Table 1.--Land status* of Douglas-fir type in Arizona and New Mexico (based on reconnaissance estimates)

Status	Arizona	New Mexico	Region
	Acres	Acres	Acres
National Forest	144,000	335,000	479,000
Indian Reservation	23,000	70,000	93,000
State		30,000	30,000
Private		62,000	62,000
Total	167,000	497,000	664,000

[* Land-area statistics are those available in 1949.]

The climate in which the Douglas-fir type occurs is, relatively speaking, very favorable for tree growth, mainly because of the fairly high precipitation and warm daytime temperatures during the growing season. According to Pearson (34)1/ who has reported climatological data for the various vegetation zones in the Southwest, the mean annual precipitation in the Douglas-fir zone averages a little more than 26 inches. About 49 percent of this comes during the months of June, July, August, and September. Average air temperatures for these months are: mean 57.0° F., mean maximum 70.3° F., and mean minimum 43.7° F. These data are based on records from three localities in New Mexico and one in Arizona.

COMPOSITION

The Douglas-fir type is not a pure type but rather a mixed type, comprised of several different species* of trees. Although Douglas-fir (Pseudotsuga taxifolia var. glauca (Mayr) Sudw.) is one of the predominating species, white fir (Abies concolor (Gord. and Glend.) Hoopes) commonly occurs with it and frequently constitutes the larger portion of the volume of the stands, especially on slopes with northerly and easterly aspects. Other conifers found in this forest type are: Engelmann spruce (Picea engelmannii Parry), blue spruce (P. pungens Engelm.), alpine fir (Abies lasiocarpa (Hook.) Nutt.), limber pine (Pinus flexilis James), and ponderosa pine (P. ponderosa var. scopulorum Engelm.). The spruces grow at the higher elevations, chiefly on north slopes; Engelmann spruce usually near the tops of slopes and blue spruce at the bases, near watercourses.

1/ Numbers in parentheses refer to Bibliography, page 55.

[*Plant names are those acceptable in 1949.]

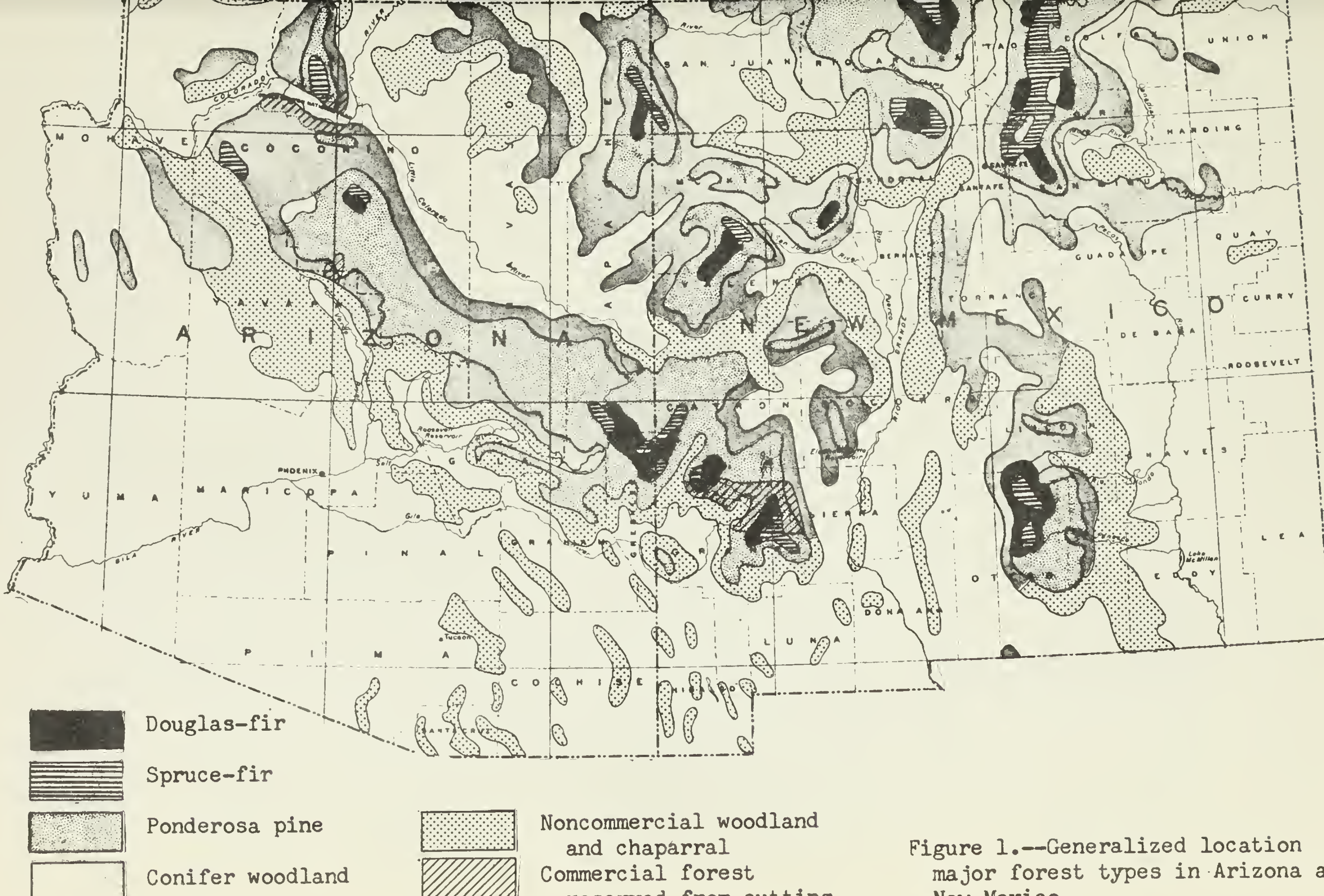


Figure 1.--Generalized location of major forest types in Arizona and New Mexico.

Alpine fir occurs only at the higher elevations and only very sparsely. The pines are usually intermixed with Douglas-fir and white fir; limber pine occurring chiefly on the cooler sites and ponderosa pine on the warmer sites. Interspersed with the conifers are several different species of broadleaf trees such as aspen (Populus tremuloides Michx.), oak (Quercus gambelii Nutt.), locust (Robinia neomexicana A. Gray), and maple (Acer glabrum Torr. and A. grandidentatum Nutt.). These, however, are temporary species which are ultimately displaced by the conifers. There is also an understory of several different species of broadleaf shrubs, oceanspray (Holodiscus ariaefolius) being the most common.

IMPORTANCE

The Douglas-fir type plays an important role in the economic and social welfare of the Southwest. Considerable Douglas-fir timber is used by farmers and ranchers to construct corrals, fences, and buildings, and to line irrigation ditches. In local mines it is extensively used for stulls, props, and ties. Appreciable quantities of low-grade and defective Douglas-fir timber are used in connection with the refining of copper ore. The crude oil industry, located in the midst of the semiarid low country of southern New Mexico, Oklahoma, and Texas, uses Douglas-fir timber in the construction of derricks, and local highway departments use it for bridge construction. A large amount of Douglas-fir is sawed into board lumber, framing, sheathing, flooring, dimension stock, and railroad ties, for all of which there is not only a local but also an outside demand. Douglas-fir is highly favored as a Christmas tree and each year many young Douglas-firs are cut for this purpose.

White fir is sawed into building lumber and is fairly extensively used where high tensile strength is not a prime requirement. White fir lumber is also good box and crating material, the latter being used chiefly by fruit and vegetable growers. Although white fir is used to some extent for mine timbers, it is not very desirable for this purpose because it decays readily under the moist conditions commonly found in mines. Young white firs are also used for Christmas trees but are for this purpose less favored than Douglas-fir.

Ponderosa pine is an "all purpose" species. Among the various products made of it are framing, sheathing, siding, flooring, venetian blinds, finishing, sash, door, form and box lumber, and railroad ties. Ponderosa pine, however, constitutes a relatively small portion of the timber obtained from the Douglas-fir type.

Limber pine is used for many of the same purposes as ponderosa pine, but the amount of limber pine obtained from the Douglas-fir type is also small, being even less than that of ponderosa pine.

Of the two spruces, only Engelmann is important as a timber tree. It is used for mine timbers and to some extent for building purposes.

However, because of its limited occurrence it constitutes very little of the timber supply coming from the Douglas-fir type. Both Engelmann and blue spruce make good Christmas trees, but are only occasionally used as such.

Alpine fir probably is suitable for the same uses as white fir. However, since there are so few trees of this species in the Douglas-fir type, its commercial uses need not be considered here.

Broadleaf trees that grow in the Douglas-fir type also have utility. Shredded aspen makes excellent water-cooler pad material and excelsior for packing fruits and melons for shipment. The stems of aspens are to some extent used as "converter" poles by smelters in refining copper ore. Locust, because of its resistance to decay, makes excellent fence-post material. Oak, although not as decay resistant, is also used for this purpose.

Only in the Sacramento Mountains of southern New Mexico does the Douglas-fir type cover an area large enough to produce the amount of timber required for large-scale sawmill operations. Here, the Douglas-fir type not only occupies a large and continuous area, but is also readily accessible. Its commercial importance in this locality is attested by the fact that large-scale logging of virgin Douglas-fir stands was begun here more than 50 years ago. Some cutting has been done in other localities but only on a limited scale. Table 2 shows the average annual cut of Douglas-fir and white fir timber in Arizona and New Mexico by decades from 1906 to 1945. The cut in Douglas-fir type in New Mexico exceeds that of Arizona because of readier accessibility and more extensive acreage. The much greater cut of Douglas-fir over that of white fir is indicative of the extent to which it is valued as a timber tree.

Because the water supply of the semiarid territory of the Southwest originates largely in the surrounding mountain ranges, the Douglas-fir type is of great importance as a protective cover of the watersheds. It has been estimated that from watersheds where the Douglas-fir type constitutes the major portion of the vegetation cover, the annual water yield is 120 to 200 acre-feet per section. Much of this is water that comes from the melting of accumulated winter snows. Because of the tree cover, this water, instead of being lost through evaporation and surface runoff, enters the soil mantle. The presence of the tree cover also prevents soil erosion. This is important because much of the terrain is steep.

The mountain ranges on which the Douglas-fir type occurs are extensively used for recreation. Many persons select places within the Douglas-fir type for summer homes. Some of the best hunting and winter sports areas are in this forest type.

Table 2.—Average annual production of Douglas-fir and white fir lumber, in Arizona and New Mexico, by decades (1906-45)[1]

Period	Arizona		New Mexico		Region		
	Douglas-fir	White fir	Douglas-fir	White fir	Douglas-fir	White fir	Total
	- - - - - - - - thousand feet board measure - - - - - - - -						
1906-15	922	73	4,761	124	5,683	197	5,880
1916-25	480	60	11,816	3,292	12,296	3,352	15,648
1926-35	197	44	19,233	3,574	19,430	3,618	23,048
1936-45	4,849	122	19,655	4,453	24,504	4,575	29,079

1/ Compiled from: Steer, Henry B., Lumber Production in the United States, 1799-1946. U. S. Dept. Agr. Misc. Pub. 669, October 1948. 233 pp., illus.

The Douglas-fir type also provides feed for grazing animals. It constitutes much of the summer range used by ranchers and farmers for the grazing of their cattle and horses.

FOREST CONDITIONS ON DOUGLAS-FIR TYPE TIMBERLANDS

Forest conditions on the Douglas-fir timberlands of the Southwest vary greatly. In most localities the lands are still occupied largely by virgin stands. These stands are mostly many aged, the age classes varying from large, overmature veterans to trees of pole size and smaller. The different age classes are intermingled, with trees of each age class mostly in groups and each group, as a rule, containing dominant, codominant, intermediate, and suppressed trees. On cool sites (chiefly sites on slopes with northerly aspect), there is frequently considerable advance reproduction of white fir, but usually very little advance reproduction of Douglas-fir. Openings in the stands on cool sites created by fire or other agencies, are usually occupied by broadleaf trees under which good stands of both white fir and Douglas-fir reproduction commonly occur. Under limber pine trees, considerable numbers of which grow on cool sites, both white fir and Douglas-fir seedlings are also usually present.

On warm sites (chiefly slopes with southerly and westerly aspects) where, because of high evaporation, there is not sufficient soil moisture to permit as close spacing of tree groups as on cool sites, the intervening spaces are frequently occupied by ponderosa pine and to some extent also by limber pine. Advance reproduction, especially of Douglas-fir, is usually abundant under these trees and it is also usually thrifty. The larger openings are frequently occupied by oak trees under which thrifty stands of Douglas-fir seedlings are commonly present.

The volume of virgin stands varies greatly but probably averages about 15,000 board-feet per acre. Some fully stocked stands consist chiefly of large mature trees where the per-acre volume is as high as 60,000 board-feet. Diameters of dominant, mature Douglas-fir and white fir trees run as high as 60 inches but are more commonly around 30 to 40 inches. Heights of mature trees on good sites average approximately 100 to 120 feet, but sometimes are as high as 160 feet.

In some localities there are extensive areas on which the virgin stands were completely destroyed by fires many years ago. Following these fires, cool slopes normally restocked to aspen and warm slopes to ponderosa pine, limber pine, and oak. Where such old burns border on patches of virgin timber, they are again gradually restocking to conifers (fig. 2). Occasionally one finds burns that have become fully restocked to almost pure stands of Douglas-fir. In such instances the new stands consist of even-aged trees of fairly uniform size and spacing (fig. 3).

Figure 2.--Typical aspen-stocked burn on slope with northerly exposure, Sacramento Mountain Division, Lincoln National Forest, New Mexico. This area was logged and broadcast burned about 50 years ago. It is gradually, but very slowly, restocking again to conifers from seed carried by wind from nearby patches of unburned timber.

Figure 3.--Stand of 75-year-old Douglas-fir poles on a north-facing slope in Taos Canyon, Carson National Forest, New Mexico. These trees became established after a fire had completely destroyed the old stand. First restocking to aspen, the area subsequently became stocked to Douglas-fir from seed carried by the wind from an adjoining stand of unburned timber. Most of the aspen is now dead, having gradually been crowded out by the Douglas-fir.

Over extensive areas that have been heavily cut in commercial logging operations, the reserved stands consist of merchantable-size trees together with trees of pole size. There is also considerable advance reproduction which, on cool sites, is largely white fir and on warm sites Douglas-fir and ponderosa pine. Very little restocking has taken place on these areas since they were logged.

MANAGEMENT PROBLEMS

The Douglas-fir type presents several problems which, in the order of their importance, are as follows:2/

2/ Inasmuch as the management problems are mostly problems that pertain to Douglas-fir, a word of explanation is necessary. It is assumed that Douglas-fir is the most valuable tree. It is, on the other hand, not assumed that because of this the presence of other species is to be discouraged, but rather that their numbers should be controlled on those sites that are most favorable for growing Douglas-fir. On sites that are unfavorable for the growing or establishment of Douglas-fir it obviously will be desirable to have other species predominate.

1. How to manage virgin stands, particularly those in which watershed and recreational values are of prime importance. The principal problem is how to cut these stands without impairing watershed and recreational values yet at the same time to create conditions that will favor natural regeneration, particularly Douglas-fir. In the best sites this species is frequently superseded by the less valuable white fir. It is also important to know what yields may be expected following partial cutting of the stands.

2. What to do to promote the natural regeneration of Douglas-fir in localities where extensive areas were heavily cut in the past 25 to 50 years. Few of these cutover lands have restocked satisfactorily even where several large Douglas-fir seed trees per acre were left.

3. What to do about extensive burned areas in high-mountain territory that are at present stocked to aspen and other broadleaf trees. While these broadleaf trees provide adequate watershed protection, they have little commercial value. Many of these burned areas represent Douglas-fir sites of high productive capacity.

STUDIES CONDUCTED

To secure clues to the kinds of measures that should be applied under the different conditions obtaining on Douglas-fir timberlands in the Southwest, a number of studies were conducted. Some of these studies, particularly those dealing with the determination of factors influencing natural and artificial regeneration of Douglas-fir, were largely experimental (figs. 4 and 5). Others were mainly of an observational nature, as, for example, noting the conditions under which reproduction of Douglas-fir and other coniferous species becomes established and thrives best and also the conditions under which it occurs only sparsely or not at all.

To determine what influence partial cutting of virgin stands might have on reproduction establishment and increment of the residual stands, a number of permanent sample plots, representing different methods (or degrees) of cutting, were established and periodically remeasured. Studies which sought to determine the efficacy of poisoning cutover areas to control rodents were conducted in cooperation with the U. S. Fish and Wildlife Service.

Most of the studies were conducted on the Cloudcroft Experimental Forest. This forest is in the Sacramento Mountains of southern New Mexico, where the Douglas-fir type is not only extensive but also commercially important.

Figure 4.--View of experimental area, established in 1932 for intensive study of factors influencing Douglas-fir reproduction. Part enclosed with rodent-proof fence (right), part open to rodents but closed to grazing (center), and part accessible to both rodents and grazing (left).

Figure 5.--Hardware-cloth screens placed over seed spots for protection against rodents and birds.

FACTORS INFLUENCING NATURAL REGENERATION OF DOUGLAS-FIR

Natural regeneration of Douglas-fir is influenced by a number of factors. Some of these have a favorable influence, while others do not. In the following discussions of influencing factors, deductions are based largely on observation rather than on the results of the experimental studies. The latter, however, yielded considerable supporting evidence of the influence of some factors. Wherever that has been the case, the results of the studies are cited.

CLIMATE

The climate of the Douglas-fir type is in some respects favorable and in other respects unfavorable for natural regeneration. A favorable feature is the dry weather that usually prevails from about the middle of April to the middle of June (fig. 6), thus assuring that seed will not begin to germinate until after the summer rainy season has commenced. It is during the rainy season (from about July 1 to mid-September) that most of the seeds germinate. There are, however, as a rule periods of a week or more when there is no rain. Seedlings that have come up in exposed situations may then die because of the topsoil drying out. In some years moisture conditions are favorable from early spring on until fall. When this is the case, seeds not only begin to germinate early but seedlings also survive. The occurrences of such conditions are, however, exceedingly rare.

A feature of the climate which often has an unfavorable influence on natural regeneration is the time and amount of winter snow. Not only are snows often late in beginning, but the first good snowfall also frequently does not come before the middle of December or even later. Early snows are usually too light to cover the ground adequately and frequently melt shortly after they have fallen. Until the ground becomes blanketed with a heavy fall of snow, seedlings that have come up during the preceding summer may be killed, either directly by freezing or by frost-heaving of the soil, especially where the soil is clayey. Also, if the ground is not covered with snow soon after seed has fallen, much seed is likely to be destroyed by rodents and birds.

SOIL

Natural regeneration of Douglas-fir is greatly influenced by the character of the soil, especially of the topsoil. A loose granular soil is more favorable than a tight clay soil in that it enables seed to become more easily embedded and permits better root development. Granular soil is also less subject to frost-heaving and puddling. A light-colored soil is more favorable than one that is dark colored because the surface is not so subject to attaining high temperatures. In exposed situations, where the

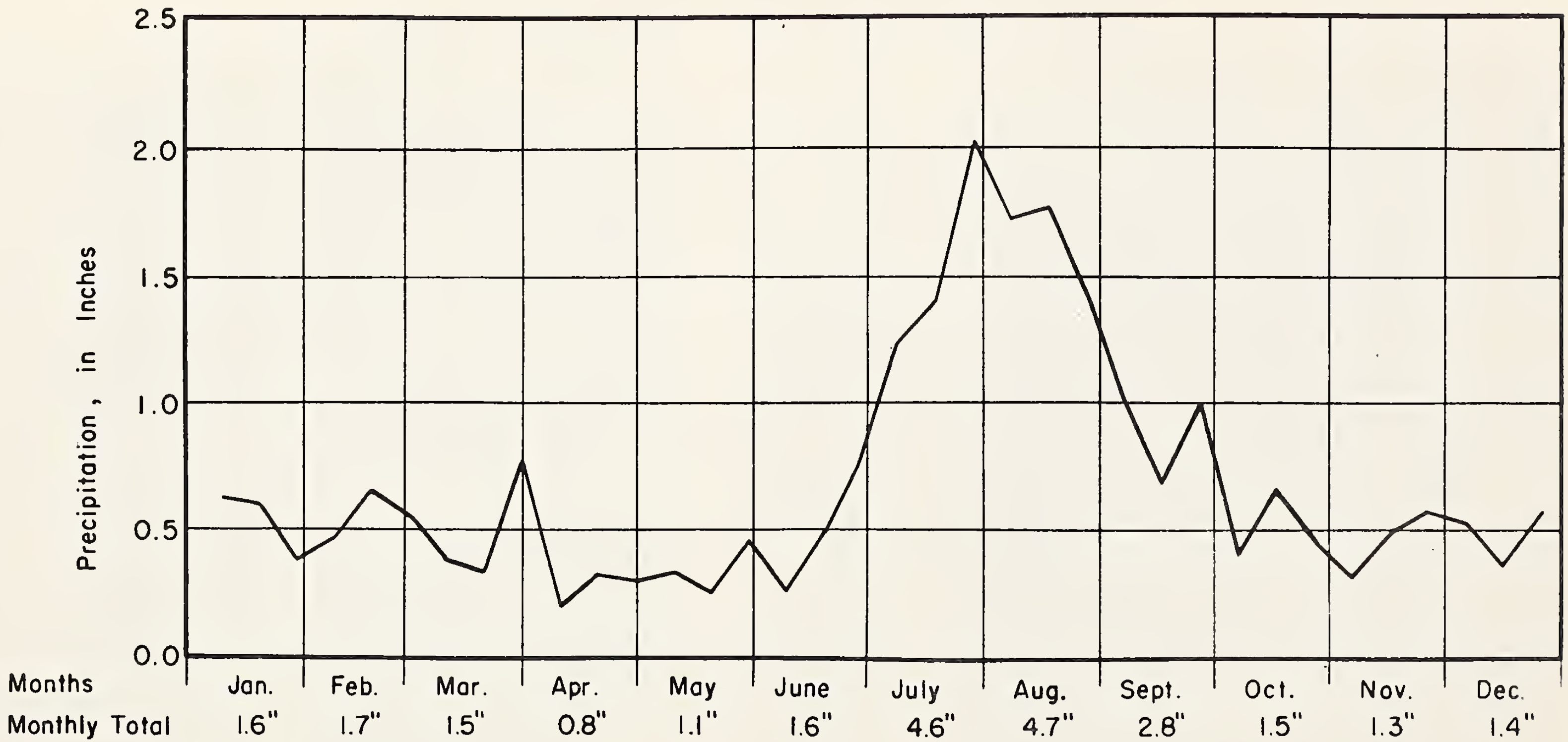


Figure 6.--Distribution of precipitation at Cloudcroft, Otero County, New Mexico, by 10-day periods. Elevation 8,650 feet. (Based on U. S. Weather Bureau records for years 1903 to 1938, inclusive.

surface of black soil becomes dry, the temperature frequently becomes hot enough to kill new seedlings. Isaac (9) has reported similar results in his studies of Douglas-fir reproduction in the Pacific Northwest.

LITTER

The success of natural regeneration of Douglas-fir is largely dependent upon the presence of litter. Litter is especially important where the soil is clayey, because without it, the topsoil is likely to be rendered impermeable by the pore-sealing action of falling rain (29), thus creating a condition inimical to both seed germination and seedling development. Litter not only conserves soil moisture but also prevents rodents and birds from having ready access to seed. A thick layer of litter is not desirable, for it may prevent water from light summer showers from reaching the soil. It may also prevent seed from making contact with mineral soil and prevent the soil from attaining the degree of temperature required for seed germination.

The nature of the litter also has an important bearing on natural regeneration of Douglas-fir. Pine-needle litter is more effective than the needle litter of Douglas-fir or white fir. Being fairly long, the needles of pine produce an open, lattice-like litter which not only permits ready percolation of precipitation and warming up of the soil, but also keeps the soil in a friable condition. The short needles of Douglas-fir and white fir do not provide these favorable conditions. Douglas-fir and white fir litter is, moreover, usually comparatively thin and on areas that are grazed by livestock it frequently is very sparse because of having been dissipated by these animals while moving about in search of feed (fig. 7). The fact that Douglas-fir seedlings are usually found growing under pines (figs. 8 and 9) indicates the favorable nature of the litter. That it is primarily because of this, and not because the shade of pines is more favorable for the development of Douglas-fir seedlings, is indicated by the fact that Douglas-fir seedlings become established under Douglas-fir if pine-needle litter is present under these trees (fig. 10).

Litter from broadleaf trees also favors the establishment of Douglas-fir seedlings (figs. 11 and 12). However, if it becomes too thick it may hinder or even altogether prevent their establishment. A merit of broadleaf-tree litter over pine litter is that it decays more rapidly and hence is more effective in maintaining soil fertility.

Figure 7.--In middle background, dense group of thrifty Douglas-fir seedlings under mature ponderosa pine and aspen. There are very few Douglas-fir seedlings under the Douglas-fir trees in the foreground. Livestock have compacted the soil and dissipated most of the litter here. Douglas-fir does not reproduce well under the canopy of parent trees unless litter from other trees is present (see fig. 10).

Figure 8.--Douglas-fir reproduction under mature ponderosa pine trees. Seedlings growing under mature pines commonly occur in dense groups and close to the tree boles. Presumably this is because here the soil is very friable and most favorable for seed germination and seedling development.

Figure 9.--Douglas-fir seedlings growing beneath a large limber pine. The comparatively open crown, together with the finely textured litter it produces, makes limber pine an ideal nurse tree for Douglas-fir seedlings.

Figure 10.--Fine stand of Douglas-fir seedlings under mixed stand of ponderosa pine and Douglas-fir. Of the two trees shown at left side of photograph, one is ponderosa pine and the other (right) is Douglas-fir.

Figure 11.--Thrifty stand of Douglas-fir seedlings growing in clump of Gambel oak. Seedlings are practically all confined to zone covered by oak canopy. Immediately outside of shaded zone in open foreground are several ponderosa pine seedlings.

Figure 12.--Stand of Douglas-fir and white fir seedlings under aspen stand on old cutover and burned-over area. In aspen thickets such as shown here, the reproduction usually consists of a mixture of Douglas-fir and white fir, rather than Douglas-fir alone.

SHADE

Shade influences natural regeneration of Douglas-fir in several ways. It ameliorates both air and soil temperatures and like litter is instrumental in conserving soil moisture and preventing frost-heaving of the soil. Together with litter, it is also instrumental in preventing herbaceous vegetation from becoming too dense. Probably its most beneficial effect is that by regulating transpiration, it prevents young seedlings from wilting. Unless they are shaded they may wilt despite favorable soil moisture. Isaac, in studying factors that influence Douglas-fir reproduction in the Pacific Northwest found that seedlings sometimes wilt even when soil moisture is above the wilting point (9).

It appears to be primarily because the seedlings require shade during the early stages of development that Douglas-fir reproduction is found mostly under the canopies of trees. It, in other words, occurs here not because it requires shade always but rather because the seedlings need it to survive while they are very young as shown in figure 13. This figure shows a long-crowned limber pine sapling under which numerous young seedlings were growing. Although there is pine-needle litter on the surrounding exposed area, no new seedlings whatsoever were found here. The seedlings under the crown of the limber pine sapling were examined over a period of years and were always found to be doing nicely.

Figure 13.—Young seedlings of Douglas-fir in the shade of a long-crowned limber pine sapling.

Douglas-fir seedlings are occasionally found growing in exposed situations but this, too, is attributed to their having been shaded while young. The necessary shade may have been furnished by some live plant that has since disappeared or by some inert material or object, such as logging slash, a piece of bark, or even a boulder. In the course of conducting studies in which Douglas-fir seed had been sown in north and south running furrows that were marked with grade stakes, it was observed that on warm exposures seedlings that had come up close to the stakes survived when on the north side of the stakes, but died when on the south side. This is a good example of how even the shade supplied by small objects can account for the successful establishment of Douglas-fir seedlings.

After Douglas-fir seedlings have become well rooted, shade may prove to be detrimental, as for instance on slopes with northerly exposure where air and soil temperatures are even in openings often too cool for optimum development of the seedlings. On the other hand, on slopes with southerly or westerly exposures where air and soil temperatures are comparatively high, not only in the open but also in shade, seedlings usually thrive best where they are constantly shaded.

In timber stands, trees constitute the principal source of shade. Trees with high crowns are more desirable than trees with long crowns because while yielding some shade, they also permit considerable light to reach the forest floor.

One of the chief merits of aspen and other broadleaf trees as sources of shade is that they shed their leaves in the fall. It has been observed that when these trees are bare, snow becomes deposited close to the boles. New seedlings that have come up under the trees during the preceding summer are thus protected during the winter months. Older Douglas-fir seedlings under deciduous trees are exposed in the early spring to favorable light and temperature conditions. It appears to be largely because of this that, on cool sites, Douglas-fir reproduces well under broadleaf trees; whereas under the canopy of Douglas-fir and white fir trees it does not. It has been observed that when Douglas-fir seedlings occur under the latter species they are usually spindling. Although such seedlings may, while shaded, continue to live for some time, they make very little growth. Seldom do any of them develop into thrifty seedlings after the overwood is removed. Most of them either remain stunted or die.

COMPETITION

The development of Douglas-fir seedlings is hindered by trees, shrubs, and herbaceous vegetation competing with the seedlings for soil moisture. The effect that competition from trees and shrubs has on the height growth of Douglas-fir seedlings is shown by the results presented in table 3. The table shows the heights attained in 13 years by the surviving seedlings in meter-square plots that had been artificially sown to equal amounts of seed (14). As the results show, the best height growth was made by the seedlings in plots located in the open. The next best growth was made by seedlings in plots located near or directly beneath the canopies of broadleaf trees and shrubs and under limber pine saplings. The poorest growth was made by seedlings in plots located near or directly beneath mature Douglas-fir and white fir trees.

Table 3.--Height growth of Douglas-fir seedlings under different conditions (based on data from artificially sown meter-square plots inside rodent exclosure on slope with northerly exposure -- sowing of October 1932)

Plot	Original no. of seedlings starting	No. of seedlings alive in October 1945	Average height as of Oct. 1945: All seedlings	Average height as of Oct. 1945: Tallest seedlings
			Feet	Feet
Near or directly beneath mature Douglas-fir and white fir trees				
1	124	1	0.80	0.80
2	159	1	.50	.50
3	135	4	.58	.80
4	111	12	.78	1.00
5	107	4	.60	.70
Total and average	636	22	1/ .70	2/ .76
Near or directly beneath broadleaf trees and shrubs and under tall limber pine saplings				
1	40	10	1.94	2.50
2	42	3	1.23	1.60
3	125	41	1.34	2.00
4	55	4	1.55	1.90
5	47	9	1.58	2.50
Total and average	309	67	1/1.47	2/ 2.10
In open (beds originally shaded with lath frames which were subsequently removed)				
1	72	23	1.66	2.60
2	93	34	1.79	2.70
3	120	43	2.10	3.20
4	62	15	2.00	3.30
5	99	17	1.87	2.20
Total and average	446	132	1/1.90	2/ 2.80

1/ Weighted average. 2/ Simple average.

The seedlings in the two series of shaded plots had a healthy green color, indicating that they had been getting sufficient light. Soil and litter conditions were similar on all three series of plots. The lesser height growth of the seedlings in the shaded plots was therefore attributed primarily to root competition. It is evident that root competition from large mature trees is much more severe than it is from smaller trees and shrubs.

The growth of Douglas-fir seedlings is also hindered by the competition from herbaceous vegetation, especially grass. In localities where the soil is of limestone origin, there is usually considerable bluegrass (Poa spp.). This grass thrives wherever there are openings and, because it forms a dense sod, it is particularly effective in preventing the establishment of seedlings. There are also several kinds of weeds that compete with Douglas-fir seedlings for soil moisture. One of the worst competitors is orange sneezeweed (Helenium hoopesi). This plant grows chiefly on the deep black and gravelly bottoms where, because of its fibrous roots, it propagates readily and often becomes the dominating vegetation.

Herbaceous vegetation is as a rule much more abundant on cool sites than it is on warm sites. It is apparently for this reason that on cool sites it is frequently more of a hindrance to both the establishment and development of Douglas-fir seedlings than it is on warm sites.

RODENTS

Most rodents have an adverse influence on the natural regeneration of Douglas-fir, this being especially true of the smaller rodents such as chipmunks, shrews, and mice. Results of studies conducted in the Sacramento Mountain region of southern New Mexico indicated that the failure of cutover stands in this region to restock satisfactorily to Douglas-fir might be largely due to the destructive work of mice (14). The results of trapping studies indicated mice to be much more abundant in cutover stands than in uncut stands.[3] This is attributed to the following conditions that obtain on cutover areas: (1) The presence of logging slash that provides nesting places for mice; (2) the presence of gopher tunnels that after they are abandoned by gophers are used by mice for protection against predatory animals and birds; (3) the presence of a greater amount of herbaceous vegetation than on uncut stands. This vegetation constitutes a considerable portion of the food supply of mice.

Among the larger rodents that have an influence on the natural regeneration of Douglas-fir are porcupines, rabbits, squirrels, and gophers. The influence of the last two may be either beneficial or

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3/ Welch, Jack F. The control of rodents in relation to reforestation in the vicinity of Cloudcroft, New Mexico. Prog. Repts., Proj. 20, U. S. Fish and Wildlife Serv. 1938-1939.

detrimental. Squirrels cut and store large numbers of cones before the seeds are shed, thus causing a reduction in the amount of seed that would otherwise be dispersed over the forest. However, individual cones are sometimes buried in the ground without being reclaimed. Seedlings often become established from the seeds of these cones.

Gophers sometimes kill established seedlings by cutting the roots. However, they also destroy many succulent weeds that might seriously compete with tree seedlings for soil moisture. New seedlings are also sometimes killed by being covered with soil excavated by gophers when constructing underground tunnels. A seemingly beneficial influence of gophers relates to their tunnels that often serve as catchment basins for storm waters, thus increasing the water supply for established seedlings. Gophers are most numerous on cutover areas. This is true not only because such areas contain the succulent vegetation they feed on, but also because these animals like to inhabit areas where air and soil temperatures are comparatively warm.

Porcupines and rabbits both have an adverse influence for they either girdle or cut off the stems of larger seedlings. In no respect can the activities of these animals be said to be beneficial.

SEED SUPPLY

As has been pointed out, the establishment of Douglas-fir reproduction is dependent upon environmental conditions being favorable for both seed germination and seedling survival. It is, however, essential that seed be deposited where such conditions obtain. Obviously, the greater the amount of seed the greater will be the chances that this will happen. The importance of having a large supply of seed is indicated by the results of a study that sought to determine the relationship between the amount of seed deposited and the numbers of seedlings that came up (26). This study showed that out of 290,836 Douglas-fir seeds per acre, only 3,360 seedlings per acre appeared. Since mice had been effectively controlled on this area by poisoning, it may be assumed that the small number of seedlings that came up was primarily due to most of the seed not falling where conditions were favorable for germination. Much of the seed also apparently fell in places that were unfavorable for seedling survival. That this was the case is indicated by the fact that many of the seedlings that came up subsequently died. After 5 years there were only 740 seedlings per acre left.

FIRE

Fire can have both an unfavorable and a favorable influence on the natural regeneration of Douglas-fir. Where fires kill entire stands over extensive areas, natural restocking of the areas is, of course, precluded since there is no longer a source of seed. On the other hand, when fires are not sufficiently intensive to kill all seed trees or the burned areas are so small that seed will blow into the areas from surrounding unburned stands of timber, fire may serve as an aid to regeneration. Fire, for instance, promotes the establishment of a cover of broadleaf trees and shrubs, which serves as a nurse crop to Douglas-fir seedlings. There are numerous examples of burned areas that, after first restocking to aspen and other broadleaf trees and shrubs, are again becoming restocked to Douglas-fir and other conifers. The fact that fire in cutover stands consumes rodent-harboring materials, such as down trees, cull logs, and logging slash, may also be regarded as beneficial. Trappings made by Dr. Walter P. Taylor, Biologist, indicated that there were only one-tenth as many mice on an aspen-covered burn as on a nearby unburned cutover area containing large amounts of logging slash.

LIVESTOCK

Livestock have both a beneficial and detrimental influence on natural regeneration of Douglas-fir. A beneficial influence is that they keep down competing herbaceous vegetation. This beneficial influence is, on the other hand, largely offset by the unfavorable conditions brought about through trampling. In moving about in search of feed, livestock not only compact the soil but also dissipate the litter (see fig. 7).

BIRDS

Seed-eating birds, particularly juncos, have an adverse influence on the natural regeneration of Douglas-fir for they devour the seed or bite off the cotyledons shortly after the seedlings have emerged from the soil. Flocks of juncos have in several instances been observed picking up Douglas-fir seed shortly after it had fallen. Since the seed does not usually become embedded immediately, much of it is picked up before the advent of winter snow. Immediately following the emergence of seedlings in a nursery that had been established within the Cloudcroft Experimental Forest, juncos began to bite off the cotyledons. The birds became so active that someone had to be assigned to drive them away while the seedlings were shedding their cotyledons, otherwise the sowings would have resulted in complete failure.

Juncos vary in numbers from year to year and when their numbers are small their detrimental influence on the natural regeneration of Douglas-fir is not great. However, when there is a large population in a year when there is a good Douglas-fir seed crop, their work becomes a serious matter, especially if there is also a good seed crop of white fir.[4]

4/ Mr. Al W. Moore of the U. S. Fish and Wildlife Service, Portland, Oregon, says that the Crown Zellerbach Company, in their studies of spot seeding of true firs at Molalla, Oregon, found birds to confine their activities chiefly to the plucking of seed caps after seedlings had emerged from the soil.

Since juncos do not have so great a liking for white fir seed as for Douglas-fir seed, restocking to white fir rather than to Douglas-fir is then favored.

INSECTS

In some localities, particularly in northern New Mexico, the spruce budworm (Choristoneura fumiferana) is prevalent. Because the larvae of this moth feeds on the flowers and terminal shoots of conifers, especially Douglas-fir and white fir, they may prevent the production of seed-bearing cones. Obviously, without a seed supply no restocking of stands is possible, even though environmental conditions may be favorable for the establishment of seedlings.

The tent caterpillar (Malacosoma fragilis) attacks aspen stands and in some localities these attacks have been so severe that many trees have been killed. Where there are nearby sources of Douglas-fir seed, killing of some of the aspen trees may be regarded as beneficial in that it provides for more light to enter the stands, thereby rendering conditions more favorable for the development of seedlings.

FUNGUS DISEASES

While Douglas-fir seedlings are subject to attack by a number of fungus disease, little evidence of these were found under natural conditions. However, in a small nursery that was established in a clearing within a virgin forest, damping off (Pythium) and root rot (Rhizoctonia) caused considerable losses of seedlings in certain years. It is possible, therefore, that occasionally these diseases may be responsible for the death of some natural seedlings.

Natural seedlings of Douglas-fir are attacked by a needle blight fungus (Rhabdacline pseudotsugae), which causes the needles to be cast, thereby retarding the growth of the seedlings. Seedlings, however, are seldom killed by this fungus.

ASSOCIATED SPECIES AND FACTORS INFLUENCING THEIR NATURAL REGENERATION

Inasmuch as in the management of southwestern Douglas-fir timberlands the coniferous species associated with Douglas-fir also need to be taken into consideration, it seems desirable to briefly point out the principal factors that influence regeneration of these species. Very little experimental work was done to determine the factors that influence regeneration of the associated species. The following deductions are, therefore, almost entirely based on observations of the conditions under which reproduction of the associated species becomes established.

WHITE FIR

White fir reproduces on both cool and warm sites, but more abundantly on the former. On cool sites it reproduces both in the open and in shade, whereas on warm sites it usually reproduces only under the canopies of trees. White fir seed germinates at a comparatively low temperature. Young seedlings of this species have been observed coming up early in the spring near snowbanks. It is probably because young white fir seedlings become well rooted before the surface soil becomes dry that white fir reproduces in the open as well as in shade. White fir seedlings are, however, very tolerant of shade. This would seem to be largely the reason why much white fir reproduction becomes established in virgin stands and in dense stands of aspen. Thick duff does not appear to hinder the establishment of white fir reproduction so much as it does the establishment of Douglas-fir reproduction. Another factor that probably partly accounts for the abundant reproduction of white fir is that the seed is relatively unattractive to mice and birds.

LIMBER PINE

Like white fir, limber pine also reproduces on both cool and warm sites. It also reproduces in both shade and in the open. It becomes abundantly established on lands that have been denuded (fig. 14). Why this happens is not clear, but presumably it is mainly because of the large size of the seed, which provides ample food for the seedlings, thereby enabling them to become well rooted before soil moisture becomes deficient. Mice apparently are not much of a hindrance to the establishment of limber pine reproduction on denuded lands. Perhaps this is because on such lands there is usually very little material to serve as harbors for these rodents.

Litter is apparently not essential to insure seedling establishment since on denuded land where, as shown, limber pine reproduces well, there usually is very little litter present. Herbaceous vegetation retards the growth of limber pine seedlings but is not as inimical to the development of seedlings as it is to the development of ponderosa pine seedlings.

PONDEROSA PINE

Abundant light and heat are prime requisites for the natural regeneration of ponderosa pine. It is presumably for this reason that ponderosa pine grows chiefly on warm slopes with southerly and westerly aspects and at the lower limits of the Douglas-fir type. Ponderosa pine seldom occurs on slopes with northerly and easterly exposures. Results of artificial sowings of ponderosa pine seed indicate that this may be largely due to the fact that on these sites new seedlings usually do not harden off sufficiently in the fall to withstand freezing temperatures. However, when seedlings do succeed in becoming established on these sites they usually make good growth and develop into fine timber trees.

Figure 14.--View of denuded Douglas-fir timberland area on which limber pines have become established.

Ponderosa pine reproduces better on gravelly and stony soils than on stone-free loam or clay soils. Germination of the seed is favored by the presence of a light layer of litter but this is apparently not so essential as for Douglas-fir. Grasses and other kinds of herbaceous vegetation are decidedly inimical to the establishment and growth of ponderosa pine seedlings (36).

ENGELMANN SPRUCE

Engelmann spruce does not reproduce well in heavy shade. The probable reason for this is that soil temperatures are there too cool for effective seed germination. The seeds of Engelmann spruce are small, and do not germinate well where appreciable amounts of duff or litter are present. Germination is best where duff and litter have been removed. While Engelmann spruce seedlings commonly become established in openings within conifer stands, they also occasionally become established in aspen stands that are sufficiently open to permit the soil to attain temperatures required for seed germination. Engelmann spruce seedlings withstand a long period of suppression but, after they are released, they make good growth.

BLUE SPRUCE

Blue spruce commonly reproduces under the parent trees where herbaceous vegetation is either very sparse or entirely lacking.

Seedlings also often become established under the canopies of isolated trees of other coniferous species, including Douglas-fir, white fir, ponderosa pine, and limber pine. Seedlings also occasionally become established under isolated aspen trees.

ALPINE FIR

The conditions required for the natural regeneration of alpine fir do not appear to be very exacting. This species reproduces readily and abundantly, both in virgin and in cutover stands, the seedlings usually greatly exceeding those of Engelmann spruce, the species with which it is most commonly associated.

PRODUCTIVE CAPACITY OF DOUGLAS-FIR TIMBERLANDS

The productive capacity of Douglas-fir type timberlands is probably greater than that of any of the other commercial timber types of the Southwest. Not only is this indicated by the comparatively high yields of the virgin stands, but even more so by the increment produced by these stands after they have been partially cut. Data pertaining to both the yield of virgin stands and increment of partially cut stands are presented and discussed in the following pages.

YIELD OF VIRGIN STANDS

The per-acre yield of virgin Douglas-fir type stands varies, depending on quality of site, species composition, the extent to which different age classes are represented, and difference in degree of stocking.

Most of the virgin Douglas-fir stands in the Southwest are understocked. A stand survey of a section of virgin timber on the Cloudcroft Experimental Forest, subdivided into 10-acre units, showed a range of 2,681 to 22,407 board-feet (gross) per acre in trees 12 inches d.b.h. and larger (fig. 15), the average volume per acre for the entire section being about 13,000 board-feet. This section is fairly representative of both variation in stocking and board-foot volume per acre for average sites on the Sacramento Mountain region of southern New Mexico. On the best sites in this region, the per-acre volume is considerably greater, occasionally running as high as 60,000 board-feet per acre, for stands that are fully stocked and which consist chiefly of mature trees.

The per-acre yield of virgin Douglas-fir type stands in relation to their ages has not been determined.5/ Some information regarding the

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5/ For stands that are many aged — as most of the virgin Douglas-fir stands in the Southwest are — it is not possible to determine yield in relation to age, except that it may be done on the basis of the average ages of the stands. Such information, however, has little practical value.

22,407	6,490	12,246	15,792	15,332	7,745	13,418	14,758
19,928	13,759	14,121	14,340	18,326	15,643	9,255	13,920
18,854	12,366	12,598	11,035	10,184	14,668	13,789	14,563
17,333	9,529	12,581	17,406	18,606	11,120	11,975	10,770
6,385	6,611	18,064	8,125	13,581	17,483	14,422	10,669
11,760	13,239	10,264	21,452	8,597	14,437	16,753	5,285
11,943	18,816	13,803	10,777	6,244	17,110	16,314	12,179
15,141	20,599	16,567	3,851	2,681	12,431	11,258	12,853

Figure 15.--Variation in board-foot volume per acre in a 640-acre tract of virgin timber in the Cloudcroft Experimental Forest, New Mexico. (Each square represents 10 acres; numerals represent average volume per acre.)

average number of years it takes for Douglas-fir trees to attain different diameters has, however, been obtained (table 4). The data in this table are based on trees that were measured for the construction of a Douglas-fir volume table (27).

The potential yield of virgin Douglas-fir stands is reduced because of mortality. Although the amount of mortality in virgin stands is not known, observations indicate that it is considerable. Most of the virgin stands have been overrun by fires at one time or another, leaving many trees fire scarred. These scars have provided ready access for several types of wood-decaying fungi. Decay in the

Table 4.--Average age of Douglas-fir trees of different diameters in virgin stands. (Data based on 221 Douglas-fir trees selected on Mescalero Indian Reservation timber-sale area, as basis for Douglas-fir board-foot volume table.)

Diameter class (Diameter at breast height, outside bark)	Average age (As determined by regression of age on diameter)
Inches	Years
12	130
14	136
16	143
18	150
20	158
22	166
24	174
26	183
28	192
30	201
32	210
34	221
36	232
38	244
40	257
42	270
44	284
46	298
48	312
50	327

lower part of the stem causes many trees to be readily broken off by wind. Considerable numbers of large trees, especially Douglas-fir and ponderosa pine, are killed by mistletoe. Some mortality is caused by insects, chiefly bark beetles and some also by lightning.

GROWTH FOLLOWING PARTIAL CUTTING OF VIRGIN STANDS

The following record of increment of stands after partial cutting is based on the periodic remeasurements of two series of permanent sample plots within the Lincoln National Forest. One of these series consists of 5 plots that were established in 1925 in stands cut under different methods, primarily to determine what influence method of cutting might have on the establishment of Douglas fir reproduction. The other series, consisting of 4 plots, was established in 1937 on land which at that time was privately owned but cut under cooperative agreement with the Forest Service.

Table 5 shows how the plots differ with respect to total board-foot volume per acre, distribution of volume by species before cutting, and the percent of volume of each species that was cut. On all of the plots, Douglas-fir constituted a greater part of the total volume of the stand before cutting than did white fir. On most of the plots the percentage of white fir cut was considerably greater than that of Douglas-fir. "Other" species (chiefly ponderosa pine and limber pine) were, because of defect, mostly heavily cut. Although most of these plots represent a much greater degree of cutting than is now being made or will in future be made in remaining virgin stands, they nevertheless have furnished some valuable information on the factors that influence the increment of partially cut stands.

Average Annual Increment and Mortality

Table 6 shows how the respective sample plots differ with respect to average annual increment and mortality, as based on the number of years for which records are thus far available. Net increment is shown separately for the "original" trees -- those that were 12 inches d.b.h. or larger when the plots were established -- and for "ingrowth," which is the volume of trees attaining merchantable size during a given period, divided by the number of years in the period. As will be noted, ingrowth accounts for a substantial part of the total increment on all of the plots, particularly so on plots S1, S3, and S9 of the "Method of Cutting" series, and plots A, C, and D of the "Cloudcroft Reserve" plots. The large contribution of ingrowth in increment shows why, in managing stands for sustained yield, it is so important to protect and release advance growth. The rate at which stands of this nature are putting on increment indicates that sufficient volume for an economic cut will be available every 10 or 20 years.

Mortality on these plots has varied greatly, ranging from 1 to 77 board-feet per acre annually on the methods-of-cutting plots and from 0 to 84 board-feet per acre annually on the Cloudcroft Reserve plots (column 8, table 6). On the methods-of-cutting plots, the mortality was largely caused by wind; 49 percent of it because of trees being uprooted and an additional 18 percent because of trees being broken off. Other causes included lightning, 9 percent; mistletoe, 7 percent; and insects, 4 percent. Bark beetles caused only minor losses on these plots. Most of the mortality on these plots occurred 5 to 10 years after cutting.

On the Cloudcroft Reserve plots, the mortality was largely caused by wind (67 percent). Other causes were fire, 16 percent; insects, 4 percent; lightning, 3 percent; and unclassified, 10 percent.

Table 5.--Stand and volume before cutting, and volume removed for nine Douglas-fir growth plots, Lincoln National Forest, New Mexico. (Stand statistics are on a per-acre basis and include all trees 12 inches d.b.h. or larger.)

Plot symbol	Plot size	Name of cutting	Original stand[1]					Volume removed			
			Number of trees	Volume, board measure							
				Total	Douglas-fir	White fir	Other	Douglas-fir	White fir	Other	Total
	Acres			M b.m.	Percent	Percent	Percent	Percent	Percent	Percent	Percent
					Method-of-cutting plots						
S1	10.0	Seed tree	45	24	58	41	1	60	90	26	72
S2	1.6	Shelterwood	69	31	78	19	3	13	79	100	28
S3	8.0	Diameter limit	59	17	45	41	14	68	81	44	70
S6	2.0	Selection (south slope)	58	12	44	8	48	37	98	93	69
S9	2.0	Selection (north slope)	80	44	90	8	2	62	82	92	64
					Cloudcroft Reserve plots						
A	5.0	Heavy selection (east slope)	78	30	54	44	2	86	84	57	84
B	10.0	Heavy selection (west slope)	74	27	58	32	10	71	97	87	81
C	2.5	Heavy selection (north slope)	72	26	79	19	2	74	97	47	78
D	2.5	Heavy selection (south slope)	70	36	74	18	8	73	74	63	72

1/ Just prior to logging and plot establishment.

Table 6.--Reserve stand and average annual gross and net increment and mortality on nine Douglas-fir growth plots, Lincoln National Forest, New Mexico. (On a per-acre basis for all trees 12 inches d.b.h. and larger.)

Plot symbol	Name of cutting	Reserve stand: Number of trees	Reserve stand: Average diameter per tree	Reserve stand: Volume per acre	Average annual net increment: Original trees	Average annual net increment: Ingrowth	Average annual net increment: All trees	Average annual mortality	Average annual gross increment: Original trees	Average annual gross increment: All trees	Increment percent all trees: Net	Increment percent all trees: Gross
			Inches	M b.m.	Ft. b.m.	Ft. b.m.	Ft. b.m.	Ft. b.m.	Ft. b.m.	Ft. b.m.	Percent	Percent
	Method-of-cutting plots (20-year record)											
S1	Seed tree	14	22	6.6	74	72	146	64	138	210	2.2	3.2
S2	Shelterwood	43	24	22.1	112	21	133	24	136	157	0.6	0.7
S3	Diameter limit	29	17	5.0	120	70	190	12	132	202	3.8	4.0
S6	Selection (south slope)	32	16	3.7	132	31	163	1	133	164	4.4	4.5
S9	Selection (north slope)	33	22	15.6	117	89	206	77	194	283	1.3	1.8
	Cloudcroft Reserve plots (10-year record)											
A	Heavy selection (east slope)	26	17	4.7	165	58	223	24	189	247	4.7	5.2
B	Heavy selection (west slope)	22	18	5.1	112	22	134	6	118	140	2.6	2.7
C	Heavy selection (north slope)	28	18	5.8	126	43	169	0	126	169	2.9	2.9
D	Heavy selection (south slope)	31	20	10.1	91	54	145	84	175	229	1.4	2.3

It is probable that over extensive areas the amount of mortality would be found to be quite different from what it was found to be on these plots. Under intensive management it might also be possible to salvage many of the trees that die. It therefore seems more logical to evaluate results on the basis of gross increment (net increment plus mortality), rather than on the basis of net increment. It will be noted that on this basis, on four of the five methods-of-cutting plots the increment of the original trees is almost the same, despite great variation in the amount of volume reserved. Comparison of the gross increment of the various plots with their corresponding reserve stands indicates that a reserve stand consisting of relatively small trees not only may produce as much increment per acre as a stand consisting of larger trees, but also that from the standpoint of return on wood capital (increment percent) it is also more desirable. The trouble is that as a rule there are not sufficient numbers of small trees present in virgin stands. Consequently, if some large trees were not left, a considerable portion of the land would remain unproductive until a new crop of young trees become established.

Periodic Change in Volume

Figure 16 depicts how the per-acre board-foot volume on the five methods-of-cutting plots has periodically changed during the 20 years for which data are thus far available. The solid lines represent net volume of all trees and the broken lines, net volume of original trees only. Obviously, the changes in the trends of these lines are indicative of changes in rate of increment also. Figure 16 brings out two important points, namely (1) that regardless of the amount of reserve volume, increment remains fairly well sustained; and (2) that it remains sustained largely because of the increasing extent to which ingrowth contributes to the increment.

Influence of Releasing Trees on Basal-area Growth

Many of the reserved trees in cutover stands are released as a result of partial cutting of the stands. Because of the additional growing space, light, and soil moisture that is provided, these trees grow at a faster rate than those that are not released. A study of the growth made by released and nonreleased Douglas-fir and white fir trees on one of the methods-of-cutting sample plots indicated that the effect of release on the basal-area growth is relatively greater in old trees than in younger trees, and also that it is relatively greater in the smaller crowned trees that it is in trees with large crowns (25). That the beneficial effects of release continue for many years is indicated by the results of an analysis of the growth of released Douglas-fir trees on a 30-year-old cutting (fig. 17). As this figure shows, basal-area growth continued to be fairly well sustained for all age classes. Even on the largest trees (age class 4), there was a marked increase in rate of growth during the last 5 years.

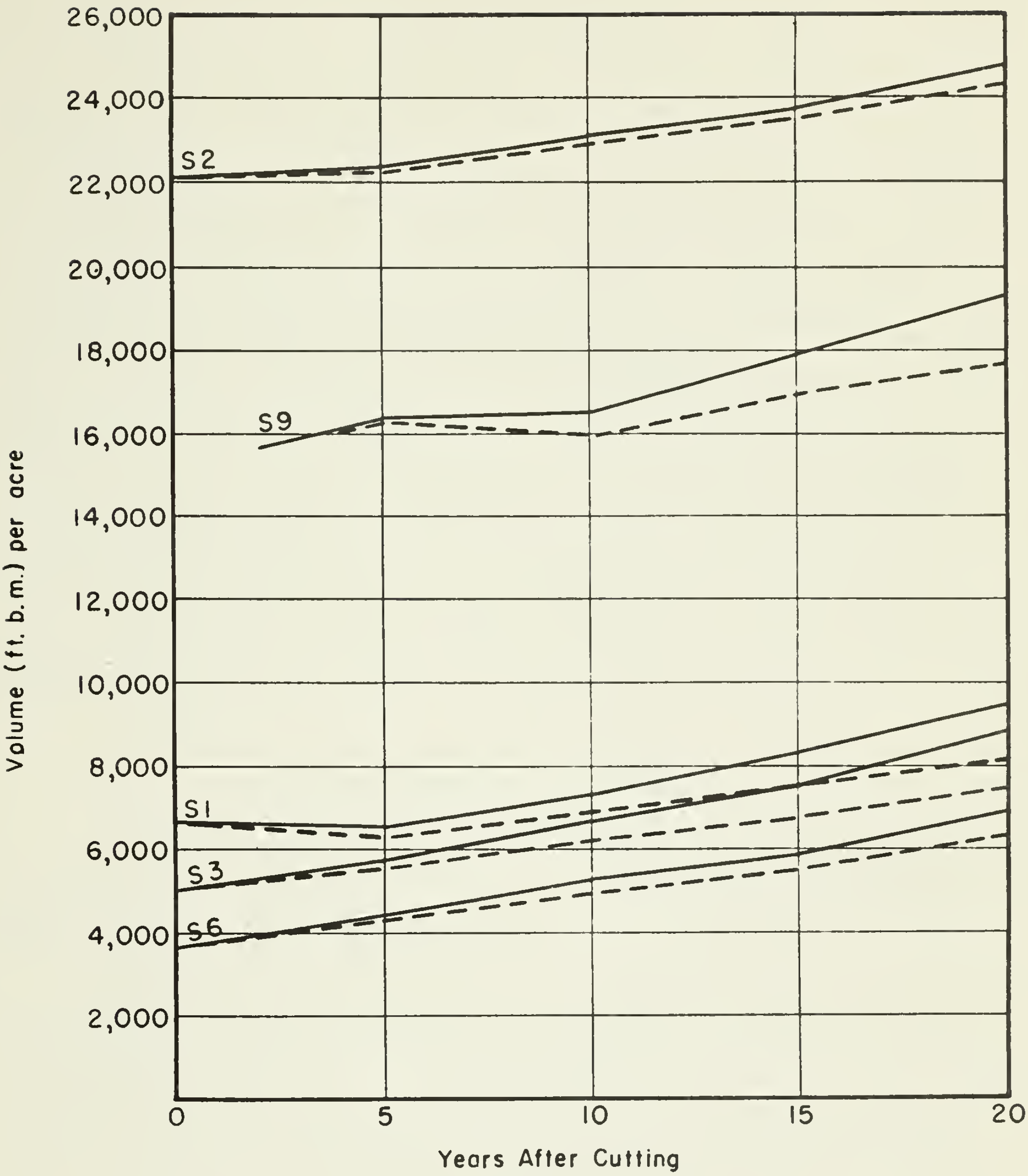

Figure 16.--Periodic change in net board-foot volume per acre of trees 11.6 inches d.b.h. and larger on 5 permanent sample plots established in 1925. (Solid lines represent volume of original trees plus ingrowth; broken lines represent volume of original trees only; the vertical distances between the broken and the solid lines represent increase in volume due to ingrowth; S1 - scattered seed-tree cutting; S2 - shelter-wood cutting; S3 - diameter-limit cutting; S6 - selection cutting, south slope; S9 - selection cutting, north slope.)

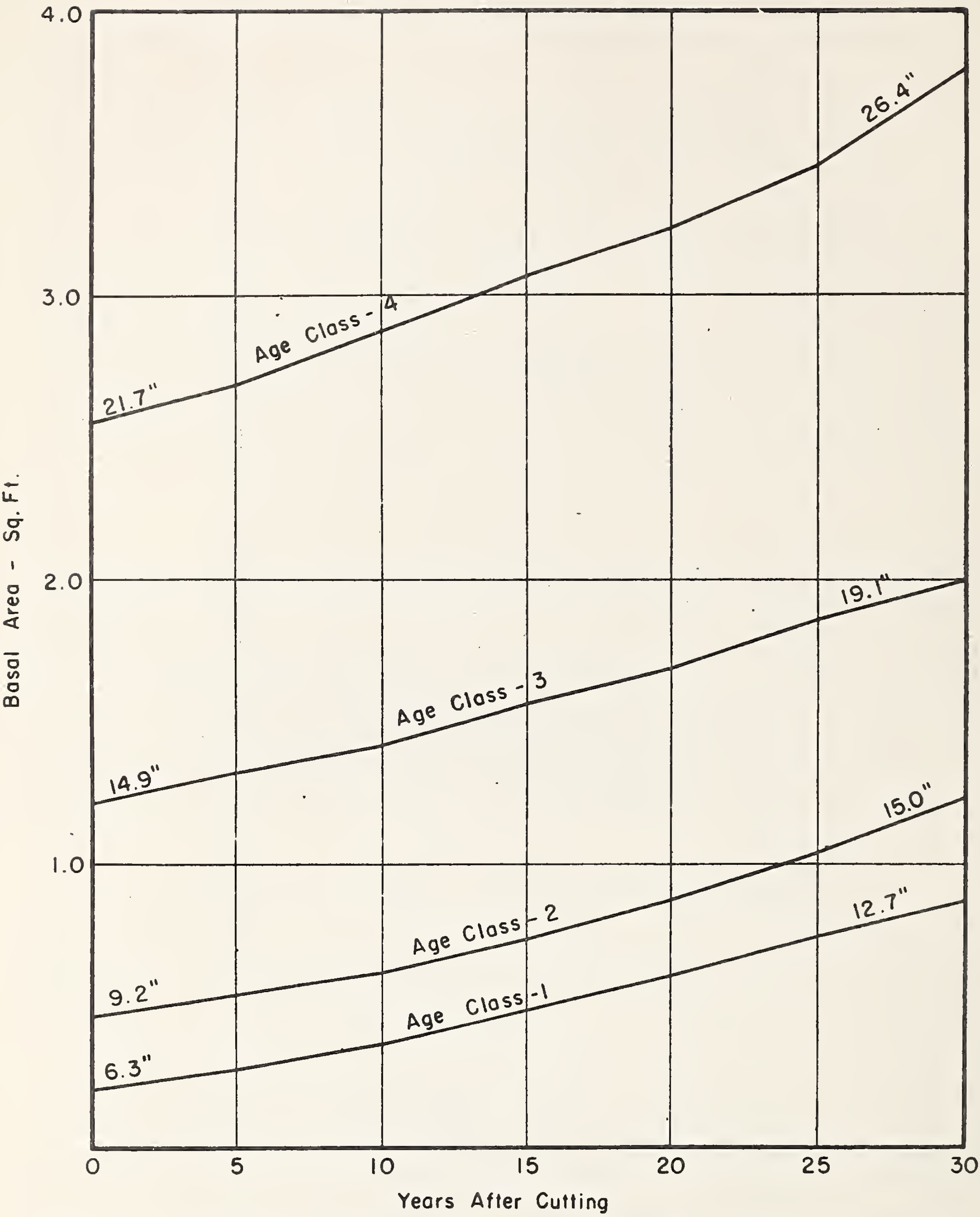

Figure 17.--Periodic basal-area growth of released Douglas-fir trees in a stand that was partially cut in 1916. Sacramento Mountain region, Lincoln National Forest, New Mexico. (The numerals shown at the extremities of the plotted lines represent the average diameters, inside bark, of the trees in the respective age classes at time of cutting and 30 years later.)

Influence of Stand Composition on Increment

The increment of cutover stands is greatly influenced by the extent to which different species are represented. This is illustrated in table 7, which shows the annual increment per acre, by species, for the five methods-of-cutting plots. It will be noted that on all plots white fir constitutes a much smaller portion of the reserve volume than does Douglas-fir. Nevertheless, on three of the plots (S1, S3, and S9) the net increment produced by this volume (i.e., average annual net increment of original trees) is greater than that produced by Douglas-fir. This, as is indicated by percent of increment of the respective species (column 13) is due to the much faster growth rate of white fir. It will also be noted that on most of the plots white fir contributes by far the greatest amount of increment from ingrowth. This is partly attributable to the faster growth rate of white fir and also partly to the larger numbers of young trees of this species that were present when the plots were established. Because of the large amount of advance reproduction of white fir, the amount of increment contributed by this species in the future on many cutover areas will undoubtedly continue to be greater than that of Douglas-fir. Since white fir ranks comparatively low as a timber species, this may not be desirable from an economic standpoint.

ARTIFICIAL REFORESTATION STUDIES

The studies dealing with artificial reforestation included both planting and direct seeding. The planting studies were confined entirely to Douglas-fir. Although the direct-seeding studies were also confined primarily to this species, a little seeding of ponderosa pine and limber pine was also done.

The Douglas-fir planting stock used was raised in a small nursery within the Cloudcroft Experimental Forest (fig. 18) from locally collected seed. All of the planting was done on land within or near the experimental forest. Planting was done in five different years on different sites and under different kinds and degrees of overhead cover. To determine what bearing quality of stock might have on survival, two grades of stock designated as #1 and #2 were planted side by side. In some of the plantings, only 3-year-old seedlings were used and in others, 3-1 transplants.[6] The chief differences between the two grades of stock was that grade #1 had both longer and better roots and also a better root-top ratio than grade #2. Grade #1 stock was also for the most part somewhat taller than grade #2. To determine the influence of time of planting, planting was done in the spring (April-May), early summer (June), and fall (October). The plantings were periodically examined, the condition of each tree being noted and recorded.

6/ Three years in seedbeds and 1 year in transplant beds.

Table 7.—Reserve stand and increment, by species, on five different permanent sample plots, Lincoln National Forest, New Mexico, (20-year record; trees 11.6 inches d.b.h. and larger).

Species	Reserve stand: Average diameter	Reserve stand: Vol. per acre	Average annual gross increment: Orig. trees	Gross: New trees	Gross: Total	Gross increment percent: Orig. trees	Gross increment percent: New trees	Gross increment percent: All trees	Average annual net increment: Orig. trees	Net: New trees	Net: Total	Net increment percent: Orig. trees	Net increment percent: New trees	Net increment percent: All trees
	Inches	Ft. b.m.	Ft. b.m.	Ft. b.m.	Ft. b.m.	Percent	Percent	Percent	Ft. b.m.	Ft. b.m.	Ft. b.m.	Percent	Percent	Percent
S1 - SCATTERED SEED-TREE CUTTING PLOT														
Douglas-fir	25.2	5,551	85	16	101	1.53	0.29	1.82	31	16	47	0.56	0.29	0.85
White fir	16.9	959	50	52	102	5.22	5.42	10.64	41	52	93	4.28	5.42	9.70
Other	16.2	135	3	4	7	2.22	2.96	5.18	2	4	6	1.48	2.96	4.44
All species	22.2	6,645	138	72	210	2.08	1.08	3.16	74	72	146	1.11	1.08	2.19
S2 - SHELTERWOOD CUTTING PLOT														
Douglas-fir	25.4	20,831	88	5	93	0.42	0.02	0.44	64	5	69	0.31	0.02	0.33
White fir	16.4	1,275	48	16	64	3.76	1.26	5.02	48	16	64	3.76	1.26	5.02
Other	--	--	--	--	--	--	--	--	--	--	--	--	--	--
All species	23.9	22,106	136	21	157	0.62	0.09	0.71	112	21	133	0.51	0.09	0.60
S3 - DIAMETER-LIMIT CUTTING PLOT														
Douglas-fir	17.6	2,416	46	22	68	1.90	0.91	2.81	40	22	62	1.65	0.91	2.56
White fir	16.0	1,310	68	40	108	5.19	3.05	8.24	63	40	103	4.81	3.05	7.86
Other	18.1	1,283	18	8	26	1.40	0.63	2.03	17	8	25	1.32	0.63	1.95
All species	17.2	5,009	132	70	202	2.63	1.40	4.03	120	70	190	2.39	1.40	3.79
S6 - SELECTION-CUTTING PLOT (SOUTH SLOPE)														
Douglas-fir	15.6	3,272	106	21	127	3.24	0.64	3.88	106	21	127	3.24	0.64	3.88
White fir	12.4	15	5	4	9	33.33	26.67	60.00	5	4	9	33.33	26.67	60.00
Other	13.7	387	22	6	28	5.68	1.55	7.23	21	6	27	5.43	1.55	6.98
All species	15.5	3,674	133	31	164	3.62	0.84	4.46	132	31	163	3.59	0.84	4.43
S9 - SELECTION -CUTTING PLOT (NORTH SLOPE)														
Douglas-fir	24.9	14,924	123	14	137	0.83	0.09	0.92	50	14	64	0.34	0.09	0.43
White fir	14.4	654	69	75	144	10.55	11.47	22.02	65	75	140	9.94	11.47	21.41
Other	15.1	68	2	--	2	2.94	--	2.94	2	--	2	2.94	--	2.94
All species	22.5	15,646	194	89	283	1.24	0.57	1.81	117	89	206	0.75	0.57	1.32

Figure 18.--View of a part of the Cloudcroft nursery. Shows method of suspending lath-roll fencing material above seedbeds, namely, on telephone wires fastened to supporting wooden stakes.

As in planting, direct seeding was also done on various sites and under different conditions of overhead cover. Seed was sown in both prepared and unprepared spots with equal numbers of seeds per spot. In the prepared spots, the seed was covered with soil and a thin layer of litter; whereas in the unprepared spot it was merely dropped on the undisturbed forest floor. To determine to what extent the success of direct seeding depended upon protection against rodents and birds, some of the seed spots were covered with hardware-cloth screens. Sowings were made in summer (June-July) and in the fall (October).

Quantitatively, the results of these studies varied materially. However, with respect to the various influencing factors the results were fairly consistent. Following are some of the more important findings.

PLANTINGS

Survival was in direct relation to the grade of stock used. In practically all instances the percentage of survival was considerably greater for grade #1 stock than for grade #2. This was true of both seedlings and transplant stock. Survival, however, was somewhat better for transplants than for seedlings, especially on sites having a broadleaf-tree cover. On such sites, some of the smaller plants were smothered by fallen leaves. On all sites, the surviving plants of #1 grade stock made considerably better height growth than those of #2 grade.

Site had mostly an indirect influence on survival in that mortality due to rodents was greater on some sites than on others. Mortality, for instance, was especially heavy on open sites, because gophers cut the roots of the planted trees. Considerable mortality also was caused by rabbits, especially on old burns that are at present stocked to broadleaf trees and shrubs. Cover of this kind is inviting to rabbits because it affords a source of both food and protection against predators.

Season of planting was also found to have an important bearing on survival. Spring plantings were much more successful than plantings made in the summer. Summer plantings, in fact, were almost complete failures. This was attributed not to deficient soil moisture -- for this was not the case. Rather, the relatively warm weather then prevailing caused the planted trees to die before they could reëstablish root connection with soil moisture to replace the moisture lost through transpiration from the tops.

Fall planting, which was tried only twice, was in one instance fully as successful as spring planting. A planting made the following year, however, failed completely because rabbits cut the trees. Had this not been the case, this second planting would probably have done as well as the first one. An important precaution to take in fall planting is not to start planting until after the soil has been well wetted. This precaution is necessary because of the uncertainty of when winter snows will come. If, as is sometimes the case, snows are late in beginning, the soil may not remain sufficiently moist for the planted trees to survive.

DIRECT SEEDING

The Douglas-fir sowings in which seed spots were not protected with wire screens resulted in almost total failure. This was found to be largely due to the destructive work of mice and birds. Some seedlings also died from lack of shade. On spots covered with wire screens, results were fairly good, for the screens warded off birds and mice and provided additional shade (18). To determine how long Douglas-fir seed spots need to be protected, an experiment was conducted in which screens were removed at various intervals after seed germination. The results of this experiment indicated that the spots need to be protected for at least 1 year (17). Better results were obtained in sowings in which spots were prepared than in those in which the spots were not prepared.

Table 8 shows the results of sowings of Douglas-fir in which screens were retained for a year or more. These results indicate that if environmental conditions are favorable and mice and birds are effectively controlled, fair success from direct seeding of Douglas-fir may be expected.7/

Table 8 also shows the results of sowings of limber pine and ponderosa pine seed. It will be noted that the results of the limber pine sowings are much better than those of the Douglas-fir sowings. This is largely attributed to the capacity of limber pine seedlings to withstand adverse conditions better than Douglas-fir. Because they have much thicker stems than Douglas-fir seedlings, limber pine seedlings are also not as much molested by mice. This accounts for the relatively good showing of the sowing of June 22, 1936, in which the protective screens were removed on August 17 of the same year.

The results of the ponderosa pine sowings were, for the most part, poor. This is attributed partly to the poor germination and partly to the heavy shade. The small percentage (16.0) of spots with one or more seedlings in the sowing of June 22, 1936, is attributed to the cutting of seedlings by mice after the screens were removed. The extremely poor results obtained on the selectively cut virgin Douglas-fir area are attributed to air and soil temperatures being too low for seed germination. Only a few seedlings came up on this site.

THE SILVICULTURAL TREATMENT OF DOUGLAS-FIR TYPE TIMBERLANDS

From the studies that were conducted, considerable information was obtained that can be used as a guide to the silvicultural treatment of Douglas-fir timberlands. Although the following silvicultural measures take this information into consideration, they are necessarily based largely on conjecture in that many of them have not as yet been adequately tested in forest practice. It is, nevertheless, believed that these measures will be effective in bringing about the indicated results.

TREATMENT OF VIRGIN STANDS

Method of Cutting

In making cuttings in virgin stands, the important thing to be considered is the effect that cutting will have on watershed conditions (26a). For this reason, cutting should usually be light. Making light cuts at intervals of, say, 5 years or more, avoids impairment of both watershed and recreational values, yet accomplishes

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7/ Attention is called to the poor results (only 9-percent survival) obtained on the denuded area. Many seedlings on this area died shortly after emerging from the soil because the topsoil dried out.

Table 8.--Results of direct seeding of Douglas-fir, limber pine, and ponderosa pine in spots on which protective screens were retained for different lengths of time. (Counts and measurements made November 1945.)

Description of area	Number of spots sown	Date of sowing	Date screens removed	Percent of spots with 1 or more seedlings	Range in height of seedlings	Average height of tallest seedlings	Average height growth per year of tallest seedlings
				Percent	Feet	Feet	Feet
			Douglas-fir				
Old burn on flat area with fairly dense stand of oak and locust poles	25	11/ 7/36	9/11/38	36.0	0.4 - 1.5	0.89	0.099
Old burn; moderate east slope; dense stand of oak poles	100	7/ 2/38	7/ 9/40	42.0	0.3 - 1.1	0.53	.067
Denuded area; moderate west slope; very light shade of oak sprouts	100	7/ 2/38	7/10/40	9.0	0.4 - 1.4	0.89	.111
Selectively cut virgin stand; steep north slope; moderate to heavy shade	100	7/13/38	8/ 4/41	42.0	0.3 - 1.0	0.53	.670
Heavily cut virgin stand; moderate west slope; light shade	25	7/23/38	7/ 9/40	44.0	0.3 - 1.9	1.18	.148
			Limber pine				
Old burn on flat area with	25	6/22/36	8/17/36	52.0	0.3 - 2.0	0.96	.096
light stand of locust,	25	6/22/36	7/ 5/37	64.0	0.4 - 2.7	1.43	.143
Holodiscus and willow bushes	50			58.0	0.3 - 2.7	1.22	.122

Table 8 (continued)

			Limber pine (continued)				
Old burn on flat area with fairly dense stand of oak and locust poles	25	11/ 7/36	9/11/38	52.0	0.3 - 1.9	0.91	.100
Selectively cut virgin stand; steep north slope; moderate to heavy shade	100	7/13/38	8/ 4/41	30.0	0.3 - 1.1	0.55	.069
Heavily cut virgin stand; moderate west slope; light shade	25	7/23/38	7/ 9/40	76.0	0.3 - 1.7	1.00	.125
			Ponderosa pine				
Old burn on flat area with light stand of locust, Holodiscus and willow bushes	25	6/22/36	8/17/36	16.0	0.6 - 2.1	1.30	.130
	25	6/22/36	7/ 5/37	36.0	0.6 - 1.9	1.22	.122
	50			26.0	0.6 - 2.1	1.24	.124
Old burn on flat area with fairly dense stand of oak and locust poles	25	11/ 7/36	9/11/38	12.0	0.5 - 1.0	1.10	.110
Selectively cut virgin Douglas-fir stand; steep north slope; moderate to heavy shade	100	7/13/38	8/ 4/41	2.0	0.9 - 1.0	0.95	.106
Heavily cut virgin stand; moderate west slope; light shade	25	7/23/38	7/ 9/40	24.0	0.8 - 1.6	1.37	.171

the same silvicultural objectives as would a single heavier cutting. One of the main objectives of making cuttings is to create favorable conditions for the establishment and development of reproduction. Several light cuts will probably have to be made before the stands will have been opened up sufficiently to produce such conditions. The character and degree of cutting will depend upon the species desired for restocking. An understanding of what are climax species for different sites will be found helpful in this respect. For example, on cool sites, white fir and spruce are climax species. Therefore, if it is desired to have these sites restock primarily to Douglas-fir rather than to white fir and spruce, cutting should at first be mostly confined to trees of these species. Douglas-fir trees should on the other hand, be mostly reserved until the openings created as a result of cutting the other species, have restocked to Douglas-fir seedlings. The limber pine trees on cool sites should also be mostly reserved because they serve as excellent nurse trees to Douglas-fir seedlings. Large aspen trees interspersed with the coniferous trees should be cut since doing so will cause numerous sprouts to spring from the roots. Sprouts often come up in the openings created by the removal of coniferous trees (fig. 19). Should Douglas-fir seedlings start in these openings, the aspen sprouts will supply the shade that these seedlings require during the early stages of development.

Figure 19.--Following partial cutting of virgin Douglas-fir stands, numerous aspen sprouts frequently spring up from the roots of older trees. Here, sprouts grow beneath tall standards in a selectively cut stand on a slope with northwesterly exposure.

On warm sites where Douglas-fir is the climax species, considerable advance Douglas-fir reproduction is usually present under the associated ponderosa pine and limber pine trees. Here, the cutting policy should be to cut the older pine trees to release the Douglas-fir seedlings. The younger pines, however, should be left. Since on warm sites Douglas-fir reproduces well in advance of cutting, mature trees of this species can on these sites be cut to a greater extent than on cool sites. The occasional white fir trees occurring on thes sites should probably, as a rule, be cut. If it is desired to have warm sites restock more to ponderosa pine than to Douglas-fir, care should be taken to retain ample numbers of ponderosa pine trees for seed.

In actual practice it may be necessary to depart considerably from the above suggested methods of cutting. Thus, on cool sites where it has been suggested that cutting be at first confined primarily to white fir and spruce, it may, because of economic consideration, be necessary to cut some Douglas-fir trees as well. This may from a silvicultural standpoint also be desirable. It will, for instance, be well to cut large mature Douglas-fir trees where they are dominating smaller and younger trees. Decadent Douglas-fir trees that do not contain sufficient sound wood to pay their way through the mill might, on the other hand, be left for seed, especially in locations where advance reproduction is lacking. After reproduction has become established, decadent trees should be cut or poisoned. In some localities there may be a market for such trees in the form of firewood or converter pole material. On warm sites, there probably will be little need of departing from the advocated cutting practice. Here, cutting will be done primarily to release Douglas-fir reproduction that is already present.

Aside from releasing advance growth and creating conditions that will favor the establishment of Douglas-fir reproduction where it is lacking, cutting should also be done with the view of releasing thrifty trees for further growth. Cutting the kinds of trees that should be removed to improve the condition of the stands will, of course, contribute much to that end. These include malformed trees, such as forked, crooked, and leaning trees; trees that are badly fire scarred; trees that are heavily mistletoed; trees that have been attacked by insects; and especially trees that contain rot. Unless there are fruiting bodies on the bole, it may be difficult to judge whether a tree does contain rot. Rot may, however, be suspected to be present in trees that have large fire scars, dead tops, or large dead branches. Appearance of the crown is not indicative; trees may have perfectly normal looking crowns yet not be sound.

Where, as is usually the case, trees occur in groups, it will be well to cut some of them to provide for more growing space for those retained. Before doing so, however, the danger of the retained trees being windthrown should be considered. If it is suspected that this danger exists, care should be taken not to thin the groups too heavily. If over half of the trees of a given group are unthrifty and it, therefore, seems advisable to remove these trees, it will probably be better to cut the entire group. Because trees that have grown up in relatively isolated locations are least likely to be windthrown, such trees should always be retained so far as possible, provided they are not unthrifty.

Slash Disposal

Because of the light cutting that is recommended, the resulting slash should not be much of a fire hazard. The slash should, therefore, so far as possible, be disposed of in a manner that will be silviculturally beneficial. Scattering slash in the openings created by the cutting of trees will not only help to conserve soil moisture but should also be helpful in promoting the establishment of Douglas-fir reproduction because of the needle litter and shade it provides. Slash also repels grazing animals, thus preventing dissipation of litter and compacting of soil and browsing of seedlings. Where trees have been felled into openings entirely devoid of advance reproduction, it may be desirable simply to leave the unutilized tops lie with branches attached. Skid trails should be covered with branch slash. In doing this, the slash should be placed across and not parallel to the trails. Care should also be taken to place the slash close to the ground so that it will effectively check water flow and soil movement. It is especially important to do this on slopes with steep gradients. Where skidding is done with Caterpillar tractors, it may be well to run the tractors over slash when proceeding from log landings to get logs.[8] Because, by so doing, slash becomes embedded in the soil, not only is the fire hazard reduced but soil erosion is also more effectively prevented.

As has been pointed out, the presence of logging slash encourages mouse habitation. Hence, if slash is decreased, mice are likely to be less abundant.

Stand Improvement

It is unquestionably silviculturally desirable to do stand-improvement work in forest stands. However, because of the financial investment involved and the uncertainty of whether the results of such work will be commensurate with the cost thereof, it is difficult to say what should be done. The following recommendations are made with the above considerations in mind:

8/ Recommending that slash be disposed of in this manner is promoted by the observance of its effectiveness on an area on which that had been done.

Thinning of pole stands

Since there will probably be little, if any, market for the trees removed, it is recommended that thinning operations be confined to the release of crop trees. In selecting the crop trees, good stem form rather than vigor alone should be considered. Since the number of desirable crop trees varies with site and condition of the stands, no definite recommendations for reserving a specified number per acre can be made. The main thing is that every crop tree be well released. Crop trees should be selected from a fairly wide range of diameters, so that not all will attain merchantable size at the same time. Doing so will thus permit a selection system of management to be practiced. Where the pole stands consist primarily of a mixture of white fir and Douglas-fir, it would seem desirable to remove more white fir than Douglas-fir, assuming, of course, that Douglas-fir is the more desirable species to grow to merchantable size. Where there are other coniferous species in mixture, some of these should also be selected for crop trees, particularly where there are ponderosa pines. A mixture of species is usually desirable as a safeguard, since there is always the possibility that one of them may be attacked by some insects or fungus disease that would cause heavy mortality.

Pruning

Since pruning results in improved quality of wood produced, this operation would appear to promise returns that may be more commensurate with cost than thinning. Trees should be pruned before the branches die, because doing so assures the formation of tight knots. Investigations of pine by Paul (33) have shown that the tight, intergrown knots from pruned live branches cause much less degrade in lumber than the loose, black, and decayed knots from dead branches. While pruning should be chiefly confined to trees of small diameter (4 to 8 inches d.b.h.), it may also be desirable to prune larger trees (up to 12 inches d.b.h.) where these have live branches on the lower part of the bole. Ordinarily, trees should be pruned only to a distance of 17 feet above ground line. While pruning to a greater height would be desirable, it is doubtful whether the gain in quality and wood produced would be commensurate with the additional cost of such pruning.

Wood from trees that have made slow diameter growth in youth has much better structural qualities than that from trees that have made fast growth during this period. Therefore, since young, open-grown trees make fast diameter growth such trees should be pruned rather severely and at as early an age as possible as this may tend to slow up the rate of diameter growth. Because Douglas-fir lumber is largely used for structural purposes, the pruning of open-grown trees of this species would seem to be especially desirable.

TREATMENT OF STANDS ALREADY PARTIALLY CUT

There is a considerable amount of Douglas-fir timberland on which cutting was done in the past. This cutting was largely confined to large, mature, and overmature trees. Also, because there was then little market for white fir lumber, comparatively few trees of this species were cut. There is considerable advance reproduction present but most of it is white fir. Although some restocking has taken place since cutting, it has for the most part been meager, especially with respect to restocking to Douglas-fir. This may be largely due to the fact that the first cutting left considerable numbers of cull logs and unutilized tops which, as has been pointed out, favor mouse habitation.

It would be highly desirable to make a second cutting in the previously cut stands now, and there should be sufficient numbers of merchantable trees per acre available to justify doing so. The second cut should and probably will be largely confined to the thinning of the younger tree groups, which for the most part were not touched when the first cut was made. In doing this, white fir trees should mostly be cut and Douglas-fir trees mostly retained. When the first cut was made there were some mature white fir trees left. These also should be removed, especially if they are competing with Douglas-fir trees or retarding the development of reproduction of this species. Mature Douglas-fir trees that were left for seed should also be cut if reproduction has since become established near them; otherwise, they should be left, even though they may no longer be thrifty.

Subsequent cuttings should be similar to those of the second cut. That is, they should continue to be made with the view of releasing advance growth of Douglas-fir and creating conditions that will favor further establishment of Douglas-fir reproduction.

The same stand-improvement measures as were previously advocated in the discussion pertaining to the treatment of virgin stands can also well be applied here. It would, in fact, seem more urgent to do so because of the fact that removal of the older trees has resulted in rapid development of the young trees. It would seem especially desirable to prune Douglas-fir crop trees, many of which may be making too rapid diameter growth to produce good structural timber.

Because the presence of cull logs and unutilized tops that were left when the first cut was made, some cutover areas are heavily infested with mice. Therefore, if it is found that satisfactory restocking to Douglas-fir is being prevented because of the destructive work of mice, it may be advisable to poison the areas.9/ Poisoning should be done just prior to the advent of a good Douglas-fir seed crop. Furthermore, in order to discourage too much restocking to white fir, it will also

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9/ Detailed information on methods of poisoning and materials to use for this purpose can be obtained by writing to the Control Methods Research Laboratory, U. S. Fish and Wildlife Service, Denver, Colorado.

be well to defer poisoning the areas until there is a good seed crop of Douglas-fir alone and not of both Douglas-fir and white fir.

Under some conditions satisfactory restocking to Douglas-fir may not be obtainable through natural seeding. In such cases, it may be desirable to supplement the natural reproduction with artificial seeding or planting of nursery-grown stock.

TREATMENT OF DEVASTATED LANDS

There is a considerable amount of devastated Douglas-fir timberland which, because of its high potential productive capacity it would be desirable to have stocked with coniferous trees again. To bring this about will require artificial reforestation. Since artificial reforestation is costly, however, it is suggested that it be employed primarily with the view of getting some seed trees established so that these lands may eventually again become restocked naturally. If any intensive reforesting is to be done, it is suggested that it be restricted, at least for the present, to lands located near settled communities, thereby assuring a readily available future supply of timber and fuelwood for local use. Some of these lands might also well be reforested for the production of Christmas trees.

Methods

It is believed that the artificial reforestation of devastated lands should, for the most part, be done by planting rather than by direct seeding. There are several reasons why direct seeding is not recommended, among these being (1) the need of placing protective screens over seed spots and subsequently removing them; (2) the uncertainty of climatic conditions being favorable for seed germination and seedling survival; (3) the possible need of thinning seedlings to a single seedling per spot. Another disadvantage of direct seeding is that for species like Douglas-fir, which require shade during the early stages of development, this shade, especially if it is supplied by live plants, may later on hinder the development of the seedlings. On the other hand, when reforesting is done by planting it is not so important to provide for shade and because of this the trees can be set where conditions for their development are the most favorable. However, despite the disadvantages of direct seeding, it may be the most feasible method to use on stony sites where the digging of planting holes would be both difficult and costly.10/

10/ Should it be found possible to poison devastated land successfully and economically, it would seem that reforesting stony sites by direct seeding would be practical. Since in that case the use of screens would not be required, seed could be sown broadcast in the most favorable places, so that fairly large groups of trees would become established. It might then also be well to sow a mixture of seeds rather than seed of only one species.

Where to Plant

Assuming that the primary objective is to get some seed trees established, plants should be set where they are most likely to survive and thrive well. A good place to plant is in the vicinity of tree stumps. Not only is the soil near tree stumps usually fairly deep, but it is also usually very fertile because of the organic material that has accumulated and become incorporated with the soil. Another condition that makes planting favorable here is the good soil aeration provided by the presence of the roots of the cut trees, especially so if the roots have decayed.

Where planting is done on sites that have a cover of broadleaf trees or shrubs, care should be taken to avoid planting where such cover is dense. The most favorable condition for planting here is where the cover is either naturally sparse or where due to competition, disease, or insect attacks it has become thinned. Old aspen stands that contain only a few large trees per acre are favorable places to plant. Other places favorable for planting are those under large oak and also under large locust trees.

Species to Plant

Even though the primary objective is to get devastated lands eventually restocked from the seed supplied by planted trees, planting should not be confined solely to Douglas-fir but should include ponderosa and limber pines,[11] so that trees of these two species may be present to serve as nurse trees to natural Douglas-fir reproduction. The extent to which Douglas-fir and pines are to be planted on a given site will depend largely upon the extent to which conditions are favorable for the establishment and development of the respective species. For example, although on cool sites planting chiefly to Douglas-fir is indicated, there will be places where because of unfavorable soil or other conditions it will be best to plant ponderosa pine or limber pine. Warm sites should be planted chiefly to ponderosa pine but there will here also be places where Douglas-fir can be successfully planted, as for instance, under oaks and locust trees. For Christmas trees, it will probably be best to plant chiefly Douglas-fir, although it might be desirable to plant some white fir also.

When to Plant

Early spring is the best time to plant, not only because moisture conditions are then likely to be favorable but also because the cool air

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11/ If there is objection to planting limber pine because of the danger of this species being attacked and killed by blister rust, it should not be planted. However, no evidence of the disease has been observed on trees in natural stands in the Southwest.

temperature at this time of the year prevents the trees from beginning top growth too soon. Prevention of top growth is especially essential where conifers are planted, because if the trees commence to make top growth before the roots have begun to absorb moisture they are likely to die. It is chiefly because of top growth having commenced that summer plantings have been found to fail despite the presence of ample soil moisture. Fall is also a good time to plant, provided there is reasonable assurance that the soil will not dry out before the advent of winter snows. Planting in the fall should not be done until after a good rain, and also not until after top growth of the planting stock has stopped, i.e., not until after the plants have produced winter buds.

Nature of Planting Stock

Only well-developed stock should be used for planting. It is especially essential that the trees have well-developed roots. Roots must be long enough to enable them to obtain moisture from lower soil levels; otherwise they may die during periods of deficient precipitation. A proper balance should obtain between the tops and roots of planting stock, i.e., top development should not be excessive, particularly not better than root development. Tops should, however, be fairly long (6 to 8 inches) with a number of lateral branchlets. Since transplants come nearest to meeting the indicated requirements, it is suggested that these rather than seedlings be chiefly used for planting.

Control of Rodents and Other Animals

Planted trees are subject to attack by various forms of animal life. The worst offenders are rodents, particularly mice, gophers, rabbits, and porcupines. Mice and gophers kill trees by girdling the stems and rabbits by biting the stems off. Porcupines kill small trees and ruin larger trees by girdling the tops. Cattle and deer inflict serious injury through browsing and rubbing. It may, therefore, be necessary to resort to control measures. Rodents can probably be effectively controlled by poisoning. Protection against cattle can be accomplished by fencing. To protect plantings against deer will, however, probably be difficult.

SUMMARY

About 10½ percent of the commercial timberland in Arizona and New Mexico is land representing the Douglas-fir forest type. Because it occurs largely on mountain ranges that border on vast stretches of semiarid lowland, this forest type, besides being important for timber production, is equally important as a watershed

cover and as a recreation area. The management of Douglas-fir type timberlands, therefore, should not be a kind that would cause the last two values to be impaired. There are three different forest conditions to be dealt with in the management of southwestern Douglas-fir timberlands, namely, virgin stands, cutover stands, and devastated lands. To obtain information that would help solve some of these management problems, several kinds of studies were conducted. These studies involved (1) the determination of factors influencing natural regeneration of Douglas-fir and associated species; (2) the determination of growth and yield of partially cut stands; and (3) methods of artificially reforesting devastated lands. Because Douglas-fir is the most valuable species in the Douglas-fir type, it was studied more intensively than the associated species. Following are some of the more significant facts learned through these studies.

NATURAL REGENERATION OF DOUGLAS-FIR

Among the various factors that influence natural regeneration of Douglas-fir, those that favor it are: (a) shade, (b) litter, (c) friable soil, and (d) a plentiful supply of seed. Douglas-fir seedlings require shade, especially during the first season. Young seedlings that are not shaded frequently die by wilting. Some are also killed through heat injury to the stems, this being particularly true of seedlings on dark-colored soils that are devoid of litter. Litter helps to keep the surface soil moist and in a friable condition. It also prevents rodents from having ready access to seed. Together with shade, litter is also instrumental in preventing herbaceous vegetation from becoming too dense. Douglas-fir reproduces well under the canopies of ponderosa and limber pine trees and also under broadleaf trees such as aspen, oak, and locust. It does not reproduce well under the canopies of Douglas-fir or white fir trees unless there is pine or broadleaf litter present. A plentiful supply of seed is essential because only a relatively small percentage becomes deposited in places that are favorable for both seed germination and seedling survival.

Factors inimical to natural regeneration of Douglas-fir are (a) various forms of animal life and (b) competition from trees, shrubs, and herbaceous vegetation. Small rodents, particularly mice, are a great hindrance to reproduction establishment in that they not only eat seed but also kill young seedlings by biting them off. Because the logging slash that is left on cutover areas affords both protection and breeding places for mice, such areas are likely to have a large mouse population. Mice are largely responsible for some cutover stands failing to restock satisfactorily. Birds, particularly juncos, to some extent also hinder the establishment of Douglas-fir reproduction in that, like mice, they also not only eat seed but also kill seedlings by biting off the cotyledons shortly after the seedlings have emerged from the soil. Gophers hinder reproduction establishment both directly and indirectly. They destroy new seedlings through their diggings and older seedlings by cutting the roots or girdling the stems.

The development of Douglas-fir seedlings is hindered by trees and shrubs competing with the seedlings for soil moisture. Large trees, especially of Douglas-fir and white fir, hinder the development of seedlings most. Herbaceous vegetation is also a hindrance. Because herbaceous vegetation is usually much more abundant on cool sites than on "warm sites" it is more of a hindrance to the establishment and development to Douglas-fir reproduction on warm sites.

NATURAL REGENERATION OF ASSOCIATED SPECIES

White fir seedlings are very tolerant of shade, but they do not actually require it. This largely explains why white fir reproduction occurs both more abundantly and also under a greater variety of conditions than does Douglas-fir reproduction. On cool sites, white fir reproduces both in the open and in shade, whereas on warm sites it usually reproduces only under the canopies of trees. White fir seed germinates at a comparatively low temperature. The presence of thick duff does not hinder seedling establishment. White fir seed is comparatively unattractive to mice and birds. This probably is another reason why it reproduces more abundantly than Douglas-fir.

Limber pine reproduces both in shade and in the open. It becomes abundantly established on denuded lands representative of cool sites. A factor that favors its establishment on such lands is the large size of the seed, thus providing ample food for the seedlings so that they will become well rooted before soil moisture becomes deficient.

Ponderosa pine does not reproduce well in shade. This species requires both abundant light and heat. It is probably largely for this reason that denuded warm sites become restocked to ponderosa pine first.

Engelmann spruce does not reproduce well in heavy shade, nor where there is a heavy layer of duff. It reproduces best in openings where the mineral soil has been exposed. Engelmann spruce seedlings withstand a long period of suppression, but after they are released they make good growth.

Blue spruce reproduction commonly becomes established under parent trees, but it also becomes established, to some extent, under isolated trees of other conifers and under isolated broadleaf aspen trees.

Alpine fir is an associate of Engelmann spruce. It, however, reproduces more abundantly than the Engelmann spruce, both in virgin and in partially cut stands.

YIELD OF VIRGIN STANDS

The gross per-acre yield of virgin Douglas-fir stands varies greatly. Factors influencing the yield are: site quality, species composition, the extent to which different age classes are represented and degree of stocking. Most of the virgin stands in the Southwest are understocked. The per-acre board-foot volume probably does not average more than 15,000 feet. On the best sites the per-acre volume occasionally runs as high as 60,000 board-feet per acre for stands that are fully stocked and which consist chiefly of mature trees. There is considerable mortality in virgin stands. Most virgin stands have at some time been overrun by fires, leaving many trees fire scarred. These scars have provided ready access for several types of wood-decaying fungi. Decay in the lower part of the stem causes many trees to be readily broken off by wind. Mistletoe kills considerable numbers of mature trees, especially Douglas-fir and ponderosa pine.

GROWTH FOLLOWING PARTIAL CUTTING OF VIRGIN STANDS

Data on growth following partial cutting of virgin stands were obtained by establishing and periodically remeasuring a number of permanent sample plots. On five plots having an average reserve volume of about 10,600 board-feet per acre, the average annual per-acre increment -- as based on a 20-year record of growth -- was 203 board-feet gross and 168 board-feet net. On four other plots having an average reserve volume of about 6,425 board-feet per acre, the average annual per-acre increment -- as based on a 10-year record of growth -- was 196 board-feet gross and 168 board-feet net. On both series of plots a part of the increment was contributed by ingrowth. On the first series, ingrowth amounted to 34 percent of the net increment, and on the second series it amounted to slightly more than 26 percent. Most of the mortality on these plots was caused by wind, amounting to 67 percent of the total on each series. An increment record of the first series of plots by 5-year periods shows that total net increment, due to the increasing contribution of ingrowth, has remained well sustained and even increased during the last 5 years of the 20-year period.

A study of the basal-area growth made by released trees showed that the effect of release is relatively greater in old trees than in younger trees and also that it is relatively greater in the smaller crowned trees than it is in trees with large crowns. Analysis of the periodic growth of released Douglas-fir trees on a 30-year-old cutting showed that basal-area growth was still well sustained in all age classes.

SILVICULTURAL TREATMENT OF DOUGLAS-FIR TYPE TIMBERLANDS

Following is the gist of the silvicultural measures recommended for application under the three forest conditions obtaining on Douglas-fir timberlands in the Southwest.

Virgin Stands

To avoid impairment of watershed and recreational values, cutting in virgin stands should always be light. The nature of the cutting will depend upon what species it is desired to favor. If Douglas-fir is to be favored, cutting should be confined chiefly to the other species. The objectives of cutting should be (a) to release advance growth, (b) to create favorable conditions for the establishment of Douglas-fir reproduction where it is lacking, and (c) to release thrifty Douglas-fir trees for further growth. Several light cuts, at intervals of 5 years or more, may be required before favorable conditions for the establishment of new crops of Douglas-fir seedlings will have been created. Decadent Douglas-fir trees that do not contain sufficient sound wood to warrant logging might well be left for seed, especially in locations where advance reproduction is lacking. In leaving thrifty trees for seed, care should be taken to select trees that are least likely to be windthrown. Also, because of the danger of windthrow, care should be taken not to thin tree groups too heavily. If over half of the trees in a given group are unthrifty it will probably be best to cut the entire group. Slash should be disposed of in a manner that will be silviculturally beneficial. Skid trails should be plugged to prevent erosion. Where skidding of logs is done with Caterpillar tractors, it will be possible to dispose of much of the slash by running the tractors over it. Doing so will not only reduce the fire hazard but also help to prevent soil erosion.

Stand-improvement work in virgin stands should probably be chiefly confined to pruning of young trees. Open-grown trees especially should be pruned since they are the ones that require it most. Thinning of pole stands should probably be confined to release of crop trees, especially crop trees of Douglas-fir.

Partially Cut Stands

It would be highly desirable to make a second cutting in stands that have already been partially cut. This cutting should be largely confined to the thinning of the younger tree groups, which, for the most part, were not touched when the first cut was made. Since some mature white fir trees were left in the first cut, these should be cut now, especially if they are competing with Douglas-fir trees in retarding the development of Douglas-fir reproduction. Mature Douglas-fir trees that were left for seed should also be cut if reproduction has since become established near them; otherwise, they should be left, even though they may no longer be thrifty. Because the removal of older trees has resulted in rapid development of young trees, there is probably greater need of doing stand-improvement work in cutover stands than in virgin stands. The presence of undisposed cull logs and unutilized tops in some previously cut areas is likely to increase mouse populations. Therefore, it may be found necessary to poison these areas to insure satisfactory restocking to Douglas-fir. If poisoning seems necessary, it should be done just before the advent of a good Douglas-fir seed crop. In order to discourage too much restocking to white fir, poisoning should be deferred until there is a good seed crop of Douglas-fir alone and not of both Douglas-fir and white fir. Under some conditions it may be necessary to supplement natural reseeding with artificial reseeding or planting.

Devastated Lands

To get devastated lands restocked to conifers will require artificial reforestation. Since artificial reforestation is costly, it should be employed primarily with the view of getting seed trees established so that devastated lands may eventually again become restocked naturally. Intensive planting, if done, should be confined to lands near settled communities. Some lands might well be reforested for production of Christmas trees. Reforestation by planting nursery stock rather than sowing seed is in most cases recommended. Trees should be planted where they are most likely to survive and thrive. A good place to plant is in the vicinity of tree stumps. Where planting is done on sites that have a cover of broadleaf trees or shrubs, care should be taken to avoid planting where such cover is dense. Planting should not be confined solely to Douglas-fir but should also include pines so that these may eventually serve as nurse trees to natural Douglas-fir reproduction. Early spring is the best time to plant. Only well-developed stock should be used. It is especially essential that the trees have well-developed roots and also roots that are sufficiently long to enable them to obtain moisture from lower soil levels. Top development should not be excessive, particularly not better than root development. Since transplants come nearest to meeting the indicated requirements, it is suggested that these rather than seedlings be planted.

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BIBLIOGRAPHY

Many of the listed publications deal with studies conducted in other regions. They, nevertheless, contain much information that is applicable to conditions in the Southwest. The reader's attention is called particularly to references 1, 9, 28, 32, 34, 35, 36, 37, 38, and 39 which deal largely with the influence of physical factors on the natural regeneration of conifers. Many of the writer's findings with respect to the influence of these factors are in agreement with those reported in these publications. Attention is also called to references 4, 7, 8, 11, 31, and 40 which deal with the influence of rodents, birds, and other animals. The writer's findings with respect to the influence of these agencies are also largely in agreement with those reported in these publications. Verification of many of the writer's views regarding the management of stands for sustained production will be found in references 12 and 13.

(1) Bates, Carlos G.
1924. Forest types in the Central Rocky Mountains as Affected by Climate and Soil. U. S. Dept. Agr. Bul. 1233, 152 pp., illus.

(2) Chapman, Herman H.
1931. Forest Management. 544 pp., illus. New York.

(3) Frothingham, E. H.
1909. Douglas fir: A Study of the Pacific Coast and Rocky Mountain Forms. U. S. Forest Serv. Circ. 150, 38 pp., illus.

(4) Garlough, F. E., and Spencer, Donald A.
1944. Control of Destructive Mice. U. S. Fish and Wildlife Serv. Conserv. Bul. 36, 37 pp., illus.

(5) Hawley, Ralph C.
1946. The Practice of Silviculture. 5th ed. 354 pp., illus. New York and London.

(6) Hofmann, Julius V.
1924. The Natural Regeneration of Douglas fir in the Pacific Northwest. U. S. Dept. Agr. Dept. Bul. 1200, 63 pp., illus.

(7) Horn, E. E.
1937. Report of Biological Survey for District Investigative Committee, Region 5, U. S. Forest Serv. (Unpub. Rpt.)

(8) ____________
1939. Some California Wildlife-forest Relationships. U. S. Bur. Biol. Survey, Wildlife Res. and Mangt. Leaflet BS-132, 5 pp., mimeo.

(9) Isaac, Leo A.
1943. Reproductive Habits of Douglas-fir. Chas. Lathrop Pack Forestry Found. pub. for U. S. Forest Serv. 107 pp., illus.

(10) Keen, F. P.
1936. Susceptibility of Ponderosa Pines to Bark Beetle Attack. Jour. Forestry 34: 919-927, illus.

(11) Keyes, Joseph, and Smith, Clarence F.
1943. Pine Seed-spot Protection with Screens in California. Jour. Forestry 41: 259-264, illus.

(12) Kirkland, Burt P., and Brandstrom, Axel J. F.
1936. Selective Timber Management in the Douglas fir Region. Chas. Lathrop Pack Forestry Found. pub. for U. S. Forest Serv. 122 pp., illus.

(13) Knuchel, H.
1946. Management Control in Selection Forest. Imp. Forestry Bur. Tech. Commun. 5. 32 pp., illus. Oxford, England.

(14) Krauch, Hermann
1936. Some Factors Influencing Douglas-fir Reproduction in the Southwest. Jour. Forestry 34: 601-608, illus.

(15) ____________
1937. Use of Protective Screens in Seed-spot Sowing Found to Serve Two-fold Purpose. Southwest. Forest and Range Expt. Sta. Res. Note 22, 3 pp., mimeo., illus.

(16) ____________
1938. Covering Seed Spots with Screens Still Remains the Only Effective Method of Deflecting Rodents. Southwest. Forest and Range Expt. Sta. Res. Note 29, 2 pp., mimeo., illus.

(17) ____________
1938. Seedlings Safe from Rodent Destruction After a Year's Protection. Southwest. Forest and Range Expt. Sta. Res. Note 43, 5 pp., mimeo., illus.

(18) ____________
1938. Does Screening of Seed Spots do More than Protect the Spots Against Rodents and Birds? Southwest. Forest and Range Expt. Sta. Res. Note 49, 4 pp., mimeo., illus.

(19) ____________
1939. Douglas fir Seedlings Successfully Transplanted Without Artificial Watering. Planting Quart. 8(2): 7-8.

(20) ____________
1939. Analysis of a 36-year Record of Precipitation at Cloudcroft, New Mexico. Southwest. Forest and Range Expt. Sta. Res. Note 60, 5 pp., mimeo., illus.

(21) ____________
1940. Tests show Douglas-fir Seed Stored in Sealed Containers Retains its Viability. Planting Quart. 9(2): 10-12.

(22) ____________
1940. Vigor, Release, and Tree Form as Guides to Marking. Jour. Forestry 38: 595.

(23) ____________
1940. Merchantable Length of White Fir and Limber Pine in Relation to Total Height of Trees. Southwest. Forest and Range Expt. Sta. Res. Note 83, 3 pp., mimeo., illus.

(24) ____________
1942. Control of Rodents in Douglas-fir Cut-over Stands Relatively More Important than Seed Supply. Southwest. Forest and Range Expt. Sta. Res. Note 100, 2 pp., mimeo., illus.

(25) ____________
1945. The Influence of Release on the Diameter Growth of Trees in Douglas-fir Cut-over Stands in the Southwest. Southwest. Forest and Range Expt. Sta. Res. Note 111, 3 pp., mimeo., illus.

(26) ____________
1945. The Influence of Rodents on the Natural Regeneration of Douglas-fir in the Southwest. Jour. Forestry 43: 585-589.

(26a) ____________
1949. Silvicultural Treatment of Virgin Douglas-fir Stands in the Southwest. Jour. Forestry 47: 200-203.

(27) ____________, and Peterson, Geraldine
1943. Two New Board-foot Volume Tables for Douglas-fir. Southwest. Forest and Range Expt. Sta. Res. Note 107, 7 pp., mimeo., illus.

(28) Lowdermilk, W. C.
1928. Forest Litter Aids in Conserving Water for California Farms. U. S. Dept. Agr. Yearbook 1928: 326-327.

(29) McGeorge, W. T., and Breazeale, J. F.
1938. Studies of Soil Structure: Effect of Puddled Soils on Plant Growth. Ariz. Agr. Expt. Sta. Tech. Bul. 72, pp. 413-447, illus.

(30) Maximov, N. A.
1928. The Plant in Relation to Water, a Study of the Physiological Basis of Drought Resistance. Trans. by R. H. Yapp. 451 pp., illus. London.

(31) Moore, A. W.
1940. Wild Animal Damage to Seed and Seedlings on Cut-over Douglas-fir Lands of Oregon and Washington. U. S. Dept. Agr. Tech. Bul. 706, 28 pp., illus.

(32) Munger, Thornton T.
1927. Timber Growing and Logging Practice in the Douglas fir Region. U. S. Dept. Agr. Bul. 1493, 42 pp., illus.

(33) Paul, B. H.
1938. Knots in Second-growth Pine and the Desirability of Pruning. U. S. Dept. Agr. Misc. Pub. 307, 35 pp., illus.

(34) Pearson, G. A.
1931. Forest Types in the Southwest as Determined by Climate and Soil. U. S. Dept. Agr. Tech. Bul. 247, 144 pp., illus.

(35) ____________
1940. Reforestation in the Southwest by CCC Camps. CCC Forestry Pub. 7, 14 pp., illus.

(36) ____________, and Marsh, R. E.
1935. Timber Growing and Logging Practice in the Southwest and in the Black Hills Region. U. S. Dept. Agr. Tech. Bul. 480, 80 pp., illus.

(37) Roeser, Jacob, Jr.
1924. A Study of Douglas fir Reproduction under Various Cutting Methods. Jour. Agr. Res. 28: 1233-1242, illus.

(38) Shirley, Hardy L.
1941. Restoring Conifers to Aspen Lands in the Lake States. U. S. Dept. Agr. Tech. Bul. 763, 36 pp., illus.

(39) ____________
1945. Reproduction of Upland Conifers in the Lake States as Affected by Root Competition and Light. Amer. Midland Nat. 33: 537-612, illus.

(40) Smith, Clarence F., and Aldous, Shaler E.
1947. The Influence of Mammals and Birds in Retarding Artificial and Natural Reseeding of Coniferous Forests in the United States. Jour. Forestry 45: 361-369, illus.

(41) Sudworth, George B.
1916. The Spruce and Balsam fir Trees of the Rocky Mountain Region. U. S. Dept. Agr. Bul. 327, 43 pp., illus.

(42) ______________
1917. The Pine Trees of the Rocky Mountain Region. U. S. Dept. Agr. Bul. 460, 47 pp., illus.

(43) ______________
1918. Miscellaneous Conifers of the Rocky Mountain Region. U. S. Dept. Agr. Bul. 680, 45 pp., illus.

(44) U. S. Forest Service and Soil Conservation Service
1940. Influence of Vegetation and Watershed Treatments on Runoff, Silting, and Stream Flow. U. S. Dept. Agr. 80 pp., illus.

(45) Wahlenberg, W. G.
1941. Methods of Forecasting Timber Growth in Irregular Stands. U. S. Dept. Agr. Tech. Bul. 796, 56 pp., illus.

(46) Woolsey, T. S., Jr.
1920. Studies in French Forestry. 550 pp., illus. New York.

Agriculture—Colo. A&M, Ft. Collins.