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REPRODUCTION OF WESTERN YELLOW PINE IN THE SOUTHWEST.

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Western yellow pine (*Pinus ponderosa*) has by far the greatest commercial importance of any tree in the Southwest. In 1908 it constituted 96.5 per cent of the lumber cut of Arizona and 87.7 per cent of the cut in New Mexico. The extensive pure stands of it in this region are now being heavily logged, and this exploitation will undoubtedly increase. Therefore the perpetuation of the trees becomes a problem of vital importance. Reproduction has not been satisfactory, either in the virgin forest or after lumbering operations, and large areas once covered with good stands of yellow pine are now practically bare. The artificial reforestation of denuded areas is impracticable at present, yet a study made in 1908 indicates that proper methods of management will insure a satisfactory second growth.

FACTORS THAT INFLUENCE REPRODUCTION.

Temperature, soil, and air and soil moisture are the natural factors; and methods of cutting, brush disposal, grazing, and fire the artificial factors which influence reproduction. Usually several or all of these work together, and the presence or absence of reproduction on any particular area seldom can be attributed to one factor alone. Thus poor reproduction may be due partly to adverse climatic conditions, such as exposure to wind and frost, partly to excessive cutting, partly to grazing, and partly to fires.

CLIMATIC CONDITIONS.

For the Southwest as a whole, even though general conditions may favor advanced growth, the average year is unfavorable to the estab-

lishment of seedlings. This is especially true in the southern, more arid portion of the region and toward the lower altitudinal limit of the western yellow pine type.

Moisture conditions probably exercise the greatest influence on reproduction, and the quantity and character of the precipitation are primarily responsible for success or failure. Within most of the western yellow pine type the annual precipitation averages about 20 inches, which is sufficient for trees that are already established. The greater part of this, however, comes in winter and summer, with corresponding dry periods in spring and fall. The spring season from about April to July is especially trying, for then the drought is accompanied by severe winds, which blow continuously for many days at a time. The surface soil becomes exceedingly dry, and most of the seeds therefore fail to germinate, and of those which do, only a small proportion succeed in establishing themselves. Practically all of the seedlings start in July and August, after the beginning of the rainy season, and seedlings starting this late are still very tender when the fall frosts come. As a result, they are very susceptible to injury. Of the seedlings which sprang up on the Coconino National Forest during August, 1908, at least three-fourths were killed by frost in October. There may not be such heavy loss every fall, but the climatic conditions indicate that it is common.

Drought and frost, therefore, work together to prevent reproduction. The influence of both can be controlled to some degree, however, by such means as brush scattering and regulating the density of the stand, and any measures that will help to reduce evaporation and prevent injury from early fall and late spring frosts are of great silvicultural importance.

On the heavier soils much damage is done to seedlings during the winter and early spring by "heaving." The alternate freezing and thawing of the top layers of soil not infrequently raises the surface as much as 6 inches and throws the young seedlings completely out of the ground. In summer sand storms are sometimes severe, and the fine sand driven over the surface of the ground will bury the seedlings or cut off their stems.

CUTTING.

Cutting methods in any forest type should aim to secure the best reproduction. By regulating the density of the stand, the physical factors upon which seedling growth is most dependent—temperature, soil and air moisture, and light—can be controlled in large measure.

Typical western yellow-pine stands are open, and in such stands reproduction seems to be best when the natural conditions of the virgin forest are but little modified. This is particularly true toward

the lower limits of the type and in the drier part of the region. When climatic conditions are especially favorable and precipitation abundant, there may be exceptions to this rule. Thus, on the Pecos National Forest excellent reproduction has followed heavy lumbering, and in places the yellow pine is even encroaching on the oak-brush type. In general, however, heavy cutting has proved disastrous. A conspicuous illustration of this is on the large cut-over area covering several townships south and west of Flagstaff. There are apparent exceptions where areas stripped of all commercial timber have a vigorous second growth. In such cases, however, reproduction started either before the cutting or after a preliminary light cutting, and in all cases before the final logging.

On the other hand, there are many examples of good reproduction after light cutting. On the Sitgreaves National Forest, near Pinetop, counts in typical sample plots showed from 3,000 to 43,000 seedlings per acre, following light cuttings extending back to twenty years ago. These cuttings have usually removed from one-third to one-half of the stand. The seedlings were vigorous and healthy, were most abundant in small openings, and in many places stood so dense as to cause a stagnation in growth.

The entire Prescott National Forest has been culled very severely to supply the mines in its neighborhood. Individual cuttings have been light, but they have been repeated until nearly all of the merchantable timber has been removed. But reproduction throughout the forest is good, and in places the young growth is so dense that it is almost impossible to walk through it. Nearly all is more than 5 years old, and most of it is from 10 to 20 years. This shows that most of the seedlings came in either before or immediately after the first cutting, and practically none since the final cutting. Climatic conditions in this Forest, especially as regards precipitation, are not particularly favorable, and yet the system of light cutting has secured a dense young stand, which should form the basis of ample timber supplies for all future local needs.

Similarly, the Coconino National Forest shows examples of good reproduction after light logging, with practically none after heavy logging. For example, a pasture belonging to the Arizona Lumber and Timber Company was logged in 1883 and again in 1895, when practically all of the merchantable timber was removed. The greater part of the young growth started from twenty to twenty-five years ago, shortly after the first logging, with practically none starting less than ten years ago. The region north and northwest of Flagstaff has been less severely logged than that to the south and southwest; the logging took place from twelve to twenty years ago, and has been followed by a much more satisfactory reproduction than that in

the region to the south. It is true that the soil to the north is mainly of volcanic origin, while that to the south is mainly of limestone origin, but the difference in reproduction is due primarily to differences in degree of cutting, and not to differences in soil, shown by the fact that equally good reproduction is found on both types of soil where the cutting has been light. Of course there are areas which were cut lightly at first and are now denuded, but in almost all the lack of young growth is due to other causes, such as fire, grazing, lack of seed, or very unfavorable climatic conditions.

The explanation of the more satisfactory reproduction after light than heavy cuttings undoubtedly lies in the difference in seed supply and in physical conditions. Light cuttings leave a much more abundant supply of seed available to restock the area—of course, a great advantage. This alone, however, does not furnish an adequate explanation, because even a few trees are capable of reseeding a large area, and severely cut-over lands which show an entire absence of reproduction usually contain some seed trees. It is therefore evident that there is a direct and potent influence of physical conditions on reproduction.

Meteorological observations at the Coconino Forest Experiment Station, at Fort Valley, 8 miles northwest of Flagstaff, show an interesting relation between conditions in a virgin forest and in an open park. The forest and park stations are about one-half mile apart, with respective elevations of about 7,300 and 7,250 feet. Both stations have good air drainage. In January, 1909, the average daily wind movement in the forest was 56.66 miles, as compared to 110.17 miles in the park—a ratio of almost 1 to 2; and the difference in wind velocity is undoubtedly much greater during the season of high winds, from April to July, when tender forest growths particularly need protection from evaporation. The average minimum temperature for January was 20.8° F. in the forest, against 14.7° F. in the park, while the lowest temperature in the forest was +3.8°, in contrast with −14° in the park, a difference of 17.8°. This great difference in minimum temperature indicates that the crown cover of the forest greatly lessens the frost danger. Additional evidence of this was given directly after the first killing frost in the fall of 1908, when the damage to young seedlings was decidedly less in a virgin forest than on the adjoining cut-over lands. It is interesting that on clear nights the temperature in the park was invariably many degrees lower than in the forest, while on cloudy nights there was practically no difference between the two stations. This indicates that the difference in temperature is due primarily to a lower rate of radiation under the crown cover of the forest, and that a clouded sky exercises a similar retarding influence in the park and forest alike.

As yet, no comparison has been made between atmospheric conditions in heavy and light cuttings, but it is likely that a marked difference will be found to exist.

It is markedly characteristic that young growth in virgin and cut-over stands is in groups rather than uniform throughout the forest. These groups are usually near the parent trees, and on the north and east sides of them. This is characteristic of the drier parts of the forest that do not particularly favor tree growth. On the Coconino Forest this grouping is especially conspicuous in the cinder country east of Elden Mountain, where there is light precipitation and, in addition, the surface soil is not retentive of moisture. These groups are usually no nearer than 5 to 10 feet from the base of the tree and extend out to the north and east about 20 or 30 feet; frequently they are sharply outlined, with scarcely a seedling beyond well-marked, definite limits. There is similar, though less conspicuous, grouping of seedlings around the old trees, also, in other sections of the forest. Even in the region south of Mormon Lake and east of Stonemans Lake, where reproduction is everywhere abundant, there is much evidence to support the opinion that many of the young pine thickets, most of which are now from 20 to 25 years old, originated in this manner. While these thickets usually cover large, contiguous areas, and represent the combined offspring of a number of parent trees, yet where there is a single tree or group of trees, or perhaps only a stump, there will be a dense group of seedlings that extends from 40 to 50 feet to the northeast, with only a scattering growth elsewhere.

These groups are uniformly on that side of the tree opposite the direction the prevailing winds (southwest) are blowing at the time of seed dispersal. The northeast is also the side shielded against the direct rays of the sun during the hottest portion of the day. In nearly all cases, however, where young growth is grouped northeast of the tree it stops abruptly at from 20 to 30 feet from the parent tree; in extreme cases not farther than 50 feet. Yet it is known that seeds are carried much farther than this and that they are present on all sides of the tree. In the late fall of 1908, after practically all of the seeds had fallen, there were seeds present as far as 210 feet northeast of a large, isolated tree, and, on the southeast side, abundant within 60 feet.

Table 1, which shows the number of seeds and seedlings per unit area on the north and south sides of a group of trees, indicates that the absence of reproduction on the south side was not due to lack of seeds, because there is evidently no relation between seed distribution and density of seedlings.

TABLE 1.—*Seeds and seedlings on north and south sides of a parent tree.*[a]

STRIP No. 1.

North side of tree.			South side of tree.		
Distance of plot from tree.	Seeds on plot.	Seedlings on plot (1 and 2 years old).	Distance of plot from tree.	Seeds on plot.	Seedlings on plot (1 and 2 years old).
Feet.	*Number.*	*Number.*	*Feet.*	*Number.*	*Number.*
15	18	9	20	17	0
20	11	18			
40	13	0			

STRIP No. 2.

10	7	26	20	14	0
15	4	9			
40	10	0			

[a] Counts were made on two strips 5 feet wide, 20 feet apart, extending north and south. In each case the plot was 5 by 5 feet.

What is indicated by the fact that the densest growth occurs within the areas shaded by the tree crown during the middle of the day is that the groups of the seedling growth spring up under the shade afforded by the tree crowns and are probably due to the shade's conservation of soil moisture. Yet sometimes there are dense stands of 1-year-old seedlings on the north and east sides of the stump where trees were cut early in the summer before the seedlings appeared. This indicates that there is another factor of importance in addition to the shading effect of the crowns. But in such cases the seedlings were always in a patch of deep, decaying litter, which usually was forming humus at the bottom. Soil samples from beneath the litter near stumps showed an average moisture content of 21.4 per cent in the upper 10 cm. of soil, while samples at the same depth from near-by soil showed a moisture content of only 6 per cent. Samples to determine the moisture content of the soil were taken also in good and in poor groups of young growth at different distances on the north and south sides of an irregular row of large trees extending nearly due east and west. In this case there was a dense stand of seedlings on a strip parallel with the trees on the north side, but practically none outside of this strip. The results are given in Table 2.

TABLE 2.—*Percentage of moisture content in relation to shade.*

Distance and direction of soil samples from trees.	Leaf litter.	Reproduction.	Number of samples.		Average moisture content (per cent).[a]			
					Depth 0 to 2.5 cm. (0 to 1 inch).		Depth 15 to 20 cm. (6 to 8 inches).	
			Sept. 26.	Oct. 14.	Sept. 26.	Oct. 14.	Sept. 26.	Oct 14.
15 feet north...	Deep	Dense ..	9	9	12.7	8.8	7.5	4.3
30 feet north...	Very light.....	None ...	6	6	2.3	1.4	5.5	4.5
75 feet north...	None	None ...	3	.....	2.0	.....	9.8	.....
10 feet south...	Medium to thin.	None ...	6	6	7.2	4.2	8.2	5.2

[a] All soil moisture percentages are based upon the dry weight of the soil. For methods of taking samples and determining moisture content, see Research Methods in Ecology, Clements, pp. 25–30.

NOTE.—About 1 inch of rainfall on September 25. No rainfall between September 25 and October 14.

Table 2 shows a coincidence between best reproduction, highest moisture content for the surface soil, and deepest leaf litter. The moisture content for the deeper samples appears to be about the same in the different areas. All of these measurements, then, point to the moisture content of the surface soil as the most important factor in the establishment of the seedlings. Because of the leaf litter, the shade afforded by the tree crowns, and the decreased evaporation due to lower wind velocity, the surface moisture is likely to be greater in the forest than in the open; in addition, the forest, by reducing minimum temperature, helps to protect the young seedlings from early frosts in the fall and late ones in the spring.

Western yellow pine is decidedly intolerant of shade, and the problem of securing the quantity of light necessary for its reproduction and development is of great importance. Typical yellow-pine forests are so open that about half of the area is exposed to full sunlight for several hours a day. That seedlings are able to establish themselves in these openings under favorable conditions is shown by the dense young growth reproduction in virgin stands throughout the region. On the other hand there is but little advanced growth within 20 feet of the base of full-crowned trees, and except under a very open crown cover there are seldom any saplings or even seedlings over 4 or 5 years old. A number of light readings [b] in different parts of the Coconino Forest showed that there were no thrifty saplings 20 to 25 years old under a light intensity lower than 0.228, while the majority of thrifty saplings and seedlings were in a light intensity of between 0.400 and 0.500. These figures are based upon the intensity of full sunlight at noon—100 per cent. In general, then, while it is evident

[b] The method of measuring light intensities is that known as the photographic method originally invented by Bunsen and Roscoe and improved by Weisner and later by Clements. See Research Methods in Ecology, Clements, pp. 48–64.

that yellow pine reproduces well under the shade of older trees, there must be a light intensity equal to from one-third to one-half of full sunlight for the young trees to thrive after they reach the sapling stage. It follows, therefore, that although light cutting is favorable for the establishment of second growth, further opening of the stand in a few years is necessary for this growth's proper development.

BRUSH DISPOSAL.

In an arid region like the Southwest the method of disposing of the brush left after lumbering has a marked effect upon reproduction. The practices of brush piling and burning, which have been common on the National Forests, while necessary in many cases as a protection from fire, have not always given good results from a silvicultural standpoint. In the more recent cuttings, where brush has been disposed of with greatest care, it is too early to draw definite conclusions, but the results so far obtained are not altogether satisfactory. On the other hand, there are many examples of excellent reproduction after older, unregulated cuttings, in which the brush was allowed to lie where it fell, with no attempt to dispose of it. This is especially noticeable on the Sitgreaves and Prescott National Forests. On both these Forests young growth has come in abundantly amid the brush and other débris left after lumbering. On the Prescott Forest the reproduction is almost uniformly excellent in the old slashings where no planned disposal was made of the brush, and it is better than in virgin forest of equal density.

This favorable influence of brush upon reproduction is undoubtedly due to its effect in retaining soil moisture and ameliorating frost. The dependence of seedlings upon soil moisture is greatest during and immediately after germination, and it is during this period that the surface moisture is of greatest importance. Many of the soils in the yellow-pine type, and especially the light cinder soils, become exceedingly dry at the surface, even though there is abundant moisture at a depth of from 3 to 4 inches. This leaves a dry layer of soil through which the root of the young seedling is unable to penetrate, even if the seed succeeds in germinating. Under a light cover of brush or leaf litter the surface soil remains moist several days longer than where it is directly exposed to the wind and sun, and it is a noteworthy fact that on areas where there is very scant young growth practically the only seedlings are those that have started along old logs, or under tree tops or piles of brush. In parts of the Coconino Forest, especially on the cinder soils, seedlings are likely to grow in bunches of grass. At first thought it would seem that the root competition of the grass would make this impossible, but it is probable that the grass roots occupy the smaller open spaces just as fully as the space immediately below the tuft which is protected from evapo-

ration. Tests made in November, 1908, at the close of the growing season, revealed a higher moisture content in the soil immediately under the tufts than in the open spaces. The average moisture of several samples 1 decimeter below the surface was 9.1 per cent under the tufts against 6.6 per cent for the open spaces.

In order to determine the efficacy of scattered brush as a conserver of soil moisture and as an aid to reproduction, an experiment was started in September, 1908, on the Coconino Forest. Here the brush was scattered on an area of 126 acres on the Greenlaw timber sale immediately after logging, and since there was an abundant crop of seed last year, successful reproduction is promised. Soil-moisture contents on the brush-covered and on adjoining open areas on November 6 were as follows:

	Per cent.
Depth 0 to 2.5 cm. (0 to 1 inch):	
Under brush (average of 12 samples)	13.4
In open area (average of 12 samples)	3.9
Depth 0 to 10 cm. (0 to 4 inches):	
Under brush (average of 12 samples)	14.3
In open area (average of 12 samples)	9.3

The great difference in the surface samples is of especial interest.

Table 3 shows air temperatures after sunset and before sunrise, under the brush and on adjoining open areas, and indicates that the brush is a decided protection against frost.

TABLE 3.—*Air temperatures under brush and in open spaces.*

Date.	Hour.	Character of day.	Average temperature.[a]		
			Brush.	Open.	Difference.
			°C.	°C.	°C.
October 14	9 to 9.30 p. m	Clear; high wind.	11.4	10.4	1.0
October 15	6.30 to 7 a. m	do	9.8	9.8	.0
October 15	6 to 6.30 p. m	do	12.0	11.2	.8
October 27	5.30 to 6.30 p. m	Clear; still	1.0	— 2.8	3.8
October 28	7 a. m	do	—7.8	—11.4	4.4
October 28	5.25 to 6.15 p. m	do	3.2	— .9	4.1
October 29	6.45 to 7.15 a. m	Clear	—4.9	— 8.3	3.4

[a] The figures represent the average of several readings taken in various places 3 or 4 rods apart during periods of from thirty minutes to one hour.

It is interesting that during a high wind the temperature was practically the same in the brush as in the open, but that on still nights it was several degrees warmer under the brush cover.

Another experiment also tended to show the practical value of a brush cover as protection to seedlings against frosts. On September 2, two plots were laid off in groups of dense seedling growth which had started during the preceding August. Each plot was then subdivided into two equal parts and the seedlings counted on each half. One-half of each plot was then covered with fresh pine branches, while the other was left uncovered. On October 14, a week after the

first heavy frosts, practically all of the seedlings on the open portions of both plots had been killed by frost, while on the brush-covered portions there was no evidence of damage. There is little doubt that the seedlings were killed by frost, because they were in good condition on September 26, and there were heavy frosts during the first week of October. It is clear that their death was not due to drought, because heavy rain fell on September 25; and on October 14 there was a moisture content on the plots of from 12 to 30 per cent.

These experiments demonstrate, in connection with general observations, that brush cover is of a decided value in preserving soil moisture and in lessening damage from early frosts.

GRAZING.

After the seedlings have succeeded in establishing themselves, one of the greatest sources of danger to them is from grazing animals, particularly sheep. The difference between young growth on adjacent grazed and ungrazed areas is often striking even to most casual observation; and careful examinations of grazed areas almost invariably show that many of the seedlings which had succeeded in establishing themselves were injured by browsing. This injury from sheep grazing is apparent on the Sitgreaves National Forest. Over most of the region near Lakeside and to the north and west of it, sheep have grazed unrestricted for many years. As a result, there is practically no young growth except a few seedlings of juniper and cedar. Yet conditions otherwise favor reproduction, since fires largely have been kept out, and there have been light cuttings, with brush left as it fell. As added evidence, fenced pastures from which sheep have been excluded show dense stands of young growth. Within a few miles, near Pinetop, sheep have not grazed for many years, and the young growth there is abundant; and, except for the fact that in one locality sheep have been allowed and in the other excluded, conditions in the two localities are practically the same.

Over most of the Prescott National Forest, which is remarkable for the abundance and vigor of its young pine growth, sheep have not been allowed to graze for many years. On nearby areas where they grazed there is little or no young growth, and it seems fair to attribute the difference to the absence or presence of sheep. The same conditions of good young stands on ungrazed and poor on heavily grazed areas obtain on the Coconino Forest, although cause and effect are there somewhat obscured by other factors, such as fire and methods of cutting.

There is a wide difference of opinion as to the amount of injury to seedlings by sheep grazing. The injury is, of course, most conspicuous on bedding grounds and along driveways; but there is also a great deal in other parts of the forest which is not apparent to one who

merely rides through the forest on horseback. In order to get an exact knowledge of grazing damage, plots were laid off in the fall of 1908 on the Coconino Forest, on representative areas. Actual counts were made of the number of injured and uninjured seedlings, and injuries of the current year were the only ones considered, since the cause of past injuries could not be ascertained with certainty in every case, and since more definite knowledge could be secured from observations on a single season rather than from a period of unknown length. Among the older seedlings, many which were not injured during the current season showed unmistakable evidence of browsing or trampling in the past. While all of the counts were made in the fall, a number were made before the close of the grazing season, November 20; therefore the figures are probably a little low for the actual damage of a summer grazing season, and consequently conservative.

Nine sample plots in good stands of seedlings on the Greenlaw sale area showed an average of slightly over 10 per cent injured in one season. The results from other sample plots in this locality are given in Table 4.

TABLE 4.—*Comparisons of damage from sheep grazing on open range and on protected areas.*

Size of plot.	Date of count.	Seedlings.	Injured.		Age.
			Number.	Per cent.	
Feet.		*Number.*			*Years.*
OPEN RANGE NEAR GREENLAW SALE.					
6 by 15	October 29	16	3	19.9	2
25 by 50	November 11	95	22	23.2	1–2
	Total	111	25	22.5	.....
PASTURE.[a]					
10 by 60	October 15	100	0	0	1–2
3 by 18	October 28	11	2	18.2	2–3
4 by 18	.....do	14	0	0	2–3
	Total	125	2	1.6	.....
OPEN RANGE SOUTHWEST OF FLAGSTAFF.					
50 by 100	October 10	7	3	43.9	1, 2, 3, 5, 10
50 by 50	.....do	64	17	26.6	2 and 3
	Total	71	20	28.2	.....
PASTURE.[b]					
75 by 75	October 8	344	19	5.5	2, 3, 4, 5
50 by 50	October 10	66	3	4.5	1, 2, 3, 4, 5
	Total	410	22	5.4	.....

[a] Pasture fenced in 1907, and since used exclusively for horses.
[b] Pasture inclosed in 1904, and since used for horses, cattle, and burros; the injury from browsing probably due to the last.

The greatest damage to young growth from browsing was in the open range south of Mormon Lake, where a plot typical of driveways and bedding grounds had 63.8 per cent injured, and one typical of the whole grazing area 41.4 per cent.

That sheep grazing seriously injures seedlings is conclusively proved by these figures, especially since the investigation covers only one season; and the cumulative damage would be very much greater during the fifteen or twenty years it would take the seedlings to attain sufficient size to be out of danger. Of course, many of the injured seedlings recover, but even a slight injury will retard growth or deform the tree; severe or repeated grazing almost surely causes a permanent stunted growth or even death. Moreover, these figures are only for damage by browsing and do not include that by trampling. Yet trampling kills many seedlings every year.

The only instance noted in which young pines have been browsed upon by cattle is in a fenced pasture near the Coconino Experiment Station. The reason for this is that a disproportionate number of cattle has been confined within a very limited area, but under ordinary conditions there would be no injury by cattle browsing. Cattle, especially bulls, occasionally injure the larger seedlings and saplings, but the number injured in this manner is comparatively small. No instances of browsing by horses have been noted, although they have been allowed to graze, when hungry, in groups of young seedlings. It is possible that both cattle and horses will browse to a limited extent upon young seedlings during the first year of growth, before the seedlings acquire their characteristic resinous flavor, but it seems certain that the damage from this source is slight. The damage done by horses, and to a less degree by cattle, is by trampling; but this damage is minimized by the fact that they move singly or in small groups, and not like sheep, in dense, compact herds.

FIRES.

Although old western yellow pine is extremely fire resistant, the young growth is susceptible to injury, though it will recover more or less completely from severe burns. This fact is evident from the large number of fire-scarred saplings that are growing thriftily throughout the yellow-pine forest. Before the time of extensive grazing, surface fires, because of the greater accumulation of dry grass and herbage, were much more severe than at present. On the other hand, however, more destructive slash fires have followed logging within the last twenty or twenty-five years. By far the greater part of the western yellow-pine forest has been burned over at least once, and fire scars on young saplings are abundant evidence of recent fires even on those areas that bear dense young stands.

Fire has been a potent enemy of the forest and is largely responsible for denuded areas. The increased efficiency of fire patrol and the other protective measures now in force, together with the cooperation of local residents, have helped to minimize the fire danger. Protection from fire is, of course, absolutely necessary to insure a satisfactory second growth.

MANAGEMENT.

For satisfactory results, forest management in western yellow pine in the Southwest must aim to ameliorate unfavorable climatic conditions. Conservation of soil moisture, particularly in the upper layers, and protection against frost, are the two essentials. For these no system seems better adapted than that known as the "stand system" or "shelterwood compartment system." By this method the stand should be cut over moderately at first in order to stimulate reproduction, and then, as soon as the young growth is well established, the remainder of the stand should be removed. The first cutting is to open up the stand in order to admit sufficient light to stimulate reproduction, yet without destroying the protective influence of the forest. From a silvicultural standpoint the second cutting should be made in from twenty to thirty years after the first. On many of the National Forests, however, there is much overmature timber, and since cut-over areas can not, as a rule, be profitably logged again until the merchantable stand has been considerably increased, generally at least fifty years must elapse before extensive second cuttings are made. While this is not ideal management, it is probably the best that can be applied generally under present circumstances. On some forests, however, where there is not a large supply of virgin timber, and where a steady supply is needed for local use, the period between cuttings can be materially reduced.

Since western yellow pine stands vary so greatly, there can be no hard-and-fast rules as to the amount of timber to be left after the first cutting, and every area marked for cutting should be made the subject of a careful study from the point of view of both the silviculturist and the lumbermen. The first object should be to leave enough trees to insure protection and seed, with the smallest loss of merchantable timber; for it must be borne in mind that if mature trees are left many of them will be lost through windfall or decay before the second cutting can be made.

A matter of first importance is the distribution of the trees left after cutting. The aim should be to leave trees where they are needed, and not simply to leave a certain number of trees per acre. Where there are large natural openings, a number of seed-bearing trees should be left on the borders, especially on the windward side, but where there are good stands of poles beyond danger from fire

no mature trees should be left. Of course, where there is still a fire risk, a sufficient number of old trees should remain to insure reproduction in case of a burn.

The selection of the right kind of trees to leave is no less important than the choice of their number and distribution. No sound "black jacks," or thrifty immature trees, should be cut unless thinning is desirable. Where it is necessary to leave a "yellow pine," or fully developed tree, a thrifty, full-crowned one should be selected. Decadent or overmature trees usually bear only a small amount of seed, and they are sure to die before a second cutting can be made; and slender, thin-crowned trees produce but little seed and afford practically no protection from the wind, and the minimum amount of shade so necessary in the early development of young seedlings.

A study of the comparative vitality of seeds from "black jacks" and overmature "yellow pines" has shown a decided difference in favor of the former. The average germination per cent for 9 "black jacks" from 50 to 145 years old was 83.2 against 68.3 for 11 "yellow pines" from 280 to 425 years old. Trees standing in somewhat isolated positions have the best crowns and are most windfirm. When such are not available it is well to leave several trees in a group. When several members of a group are left, those on the borders should be selected, especially those on the south and west sides, in preference to those inside the stand. Very large, clear-boled, mature "yellow pines" should, as a rule, be cut, even though a large opening is made, because such trees are likely to be windthrown, and this entails financial loss with little or no benefit to reproduction. It would be good economy to utilize the proceeds from the sale of such trees to plant contiguous areas rather than to risk their total loss by allowing them to remain. Defective and insect or fungus affected trees should as a rule be cut, though sometimes it may be advisable to leave defective trees when they are needed to close large openings, provided they do not menace the remaining stand. In short, the timber marker must exercise his own judgment as to whether the influence of a defective tree upon reproduction will justify the sacrifice of its merchantable value.

Ordinarily, there are two general problems in marking timber, that presented by stands which consist largely of young growth and that of stands which are almost entirely of mature trees.

In stands that contain a large proportion of large "black jacks" and poles, marking is comparatively simple. Where the immature growth is sufficient to furnish ample protection and seed, all mature timber should be cut. Enough "yellow pines" should be left to insure an ample seed supply, however, even though they may not be needed for protection. Where there is an average of less than 5 seed-

bearing "black jacks" more than 18 inches in diameter per acre, enough "yellow pines" should be left to make up this number.

Very careful judgment, however, is required of the marker in stands made up almost entirely of mature and overmature timber. Ordinarily, the leaving of enough trees to insure favorable conditions for reproduction will result in a great loss from decay and windfall. This loss can be minimized by leaving the trees in groups, and by selecting the smaller and more thrifty trees for this purpose. To shorten the period between cuttings, the first logging should be made within two or three years after a crop of seedlings has sprung up beneath the old trees, and an effort should be made to return for the second cut in about twenty years in order to save the mature timber.

On sparsely timbered areas, where to leave a sufficient stand to insure the necessary protection and seed supply would render the cost of logging disproportionately excessive, cutting should be deferred from fifteen to twenty years under good protection from fire and sheep, with the hope of securing reproduction before all the timber is cut. The natural reforestation of completely denuded areas can not be depended upon even under relatively favorable conditions; it is therefore likely that such areas eventually will have to be planted.

Since brush favors reproduction by conserving soil moisture and protecting against frost, it should be scattered around the felled trees after logging. The most practical method is to cut branches as large as can be conveniently handled by one man, and have them carried only far enough from the main stem to make room for all the branches in a single layer. Ordinarily, brush scattered in this manner will lie within 2 feet of the surface of the ground; and further lopping to bring the branches nearer the ground has proved too expensive. In typical stands only from one-half to two-thirds of the area will be brush-covered, but this is not only less expensive but is considered better than to have brush scattered uniformly over the whole area, because it helps to prevent the wide spread of fire. In order to facilitate the control of fires, a fire line on which all brush has been piled and burned, from 200 to 400 feet wide, and varying with the topography, should extend around each section. Where the danger from fire is great, additional lines may be necessary.

Sheep should be excluded from areas on which it is desired to secure reproduction, until the seedlings have become firmly established and out of danger from browsing. In order to secure advance growth, it may also prove advisable to exclude sheep for about five years before the cutting takes place from areas which are to be cut. Generally the period of exclusion should be about twenty years; that is, after sheep have been excluded from a certain area twenty years it will be safe to again throw the range open, so that, as far as grazing

is concerned, the forest will be handled upon a twenty-year rotation. Since the exclusion of sheep will practically be limited to cuttings, and only to those cuttings upon which the reproduction is already deficient, no violent disturbance of the sheep industry will result. Moreover, since cattle and horses need not be excluded, the removal of sheep may result simply in a change in the kind of stock grazed and not in an impairment of the use of the range for grazing purposes.

SUMMARY.

The result of the investigations upon which this circular is based may be briefly summarized as follows: Climatic conditions in the Southwest do not favor reproduction, since most of the seedlings die during the first year from drought and frost, but proper cutting and brush disposal, and the control of grazing and fire, will insure good reproduction. Probably the most important of these factors is cutting; heavy cutting retards reproduction, not so much by reducing the seed supply as by introducing unfavorable physical conditions; light cutting stimulates reproduction because it affords favorable light conditions and only slightly disturbs normal forest conditions. The forest protects seedlings against evaporation and frosts. Scattering brush after logging similarly aids natural reproduction by reducing evaporation and moderating the effects of frost.

Sheep severely injure seedlings by browsing and to a less extent by trampling, and they should therefore be excluded from areas on which reproduction is desired. Horses and cattle do but little damage, and their exclusion is unnecessary.

The prevention of fire is absolutely necessary to secure satisfactory natural reproduction.

The ideal management for western yellow pine in the Southwest is by means of the shelterwood system, where relatively light preliminary cuttings will stimulate reproduction and can be followed by removal of the rest of the stand as soon as the second growth has established itself.

Approved:

JAMES WILSON,
Secretary of Agriculture.

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