ditions were frequently severe, limiting growth and reproduction. Sentiment toward the practice of silviculture was generally apathetic or actively antagonistic.

With these conditions prevailing, the forester faced the problem of improving the health of the stand, increasing the rate of growth, and securing more pine reproduction to the limited extent that one cutting permits. In 10 years' time a large amount of valuable data has been accumulated which has served to indicate good silvicultural practice. There is an increasing demand for reliable growth statistics in the preparation of working plans, not only for public forests but for private timber also, as evidenced by recent requests from several private timber owners contemplating management of their tracts on a permanent yield basis. In addition, all possible information should be available for those directly or indirectly concerned with the forests and their products in considering the remedies for forest devastation and the establishment of forest policy for the State and region.

As indicated in the text, some of the conclusions drawn from this study as to the best silvicultural practice are not immediately applicable on the national forests because of management conditions.

DESCRIPTION OF DATA.

The study is based on 25 permanent sample plots, varying in size from 6 to 25 acres, totaling about 300 acres, on which over 13,000 numbered trees have been measured at 5-year intervals from 1911 to 1921. The attempt has been made to bring out the important points rather than to set down in detail the multitude of possible variations represented. For the sake of simplicity the reaction of individual trees is used as a basis for analysis wherever possible. The plots are located in the Sierra timber belt from near Mount Shasta to a point southwest of Mount Whitney. Sites vary from first to third quality (on a scale of five classes based on total height at maturity). The four more important types—pure yellow pine, yellow pine-sugar pine, mixed yellow pine-sugar pine-Douglas fir-white fir-incense cedar, and sugar pine-fir—are represented. Purely experimental cuttings were not feasible. The plots, therefore, do not represent ideal site, type, or other factors. They were established just before or just after logging to represent the results of actual average marking practice of that period on the national forests. The marking was often based on a compromise between economic lumbering and silviculture.

The areas were carefully mapped to show distribution of numbered trees, stumps, cover, brush piles, etc. All trees 4 inches in diameter and larger were numbered with metal tags, diameters were taken in inches and tenths with a steel tape, and total heights and heights to base of crown to the nearest foot with a Klaussner hypsometer. A detailed description was made of each tree, giving its dominance class, width of crown, color and density of foliage, form of top, presence of mechanical injuries or pathogenic agencies, and a rough estimate of age and apparent vigor. Reproduction data were secured from subplots, in the form of permanently marked continuous strips 0.1 chain wide, or a series of mechanically located quadrats varying in size from 5 feet to 1 chain square. In some cases each seedling is mapped or marked with a numbered tag and wire pin. Annual examinations have been possible for only a few of the reproduction plots.

The early methods of cutting represented by the sample plots in this study differ considerably from present methods. All of the earlier cuttings, including those on the plots, were light, leaving a volume of 10,000 to 20,000 board feet per acre, representing 30 to 60 per cent of the original stand, and contemplated a second cut in 30 to 60 years. This method was termed " selection " cutting for lack of a better name. Yellow pine and sugar pine were strongly favored, with the hope that the percentage of these species would be increased in the next stand. In reality, many of these cuttings resembled somewhat the second stage of a shelterwood system. The virgin stands were characterized by even-aged groups of uniformly over-mature trees with advance reproduction in openings due to the action of fires and insects. They might be compared to the first stage of a shelterwood method after the cutting to secure reproduction had been completed. The original cutting done at the time of the sale was designed to release advance growth, secure further restocking, and enhance the rate of increment on reserved trees. The method differed from the true shelterwood system in that only two cuttings were contemplated and the final removal of the overwood was deferred for a long period.

Since these early sales, when very light cutting was the practice, the tendency has swung to the opposite extreme, very heavy cutting, especially on poorer sites, leaving only thrifty seed trees for insurance against destruction of advance growth by fire. At present there seems to be a logical reversion to an intermediate course, in which a considerable nucleus of thrifty standards and sound, thrifty, mature trees are reserved, especially on the better sites, for increased volume and value increment in a second cut and to insure adequate seed. It seems likely, therefore, that future cuttings may not differ greatly from some of those on which this study is based.

GROWTH OF REMAINING STAND.

Considering first the rate of growth of reserved trees without regard to quality increment, there are several factors which have proved to be of prime importance. Of these, site will be considered first.

SITE.

The importance of site as affecting method of cutting can not be overestimated. Criteria for site differentiations had not been developed at the time of the earlier sales, and in consequence as heavy stands were sometimes reserved on poor as on good sites. The results of this study indicate that no method of cutting on Site III or poorer will result in a rate of growth which, in itself, will be sufficient to justify reserving a considerable volume of trees approaching maturity for increased wood production.

This is to be demonstrated if some of the plots are arranged in order of site from the poorest to the best, using only trees between 12 and 30 inches in diameter, which furnish most of the reserves. Yellow pine, because of its presence on all of the plots, is used as an indicator to express the relation in annual basal area growth per cent maintained between sites during the 10 years since cutting. The same individual trees have been followed throughout the period. The effects of accidental death and the entrance of new trees into the lower diameter classes have been eliminated in order to bring out merely site potentialities.

There are, of course, age differences within 6-inch diameter groups between such extremes of site, and some variations in stand density which tend to enhance the apparent differences, but, in the main, site variation is the controlling factor in the figures given in Table 1.

TABLE 1.—*Periodic annual growth, per cent, in basal area of western yellow pine.*

Site.	Plot.	Number of trees.[1]	Diameter classes (inches).		
			12–17	18–23	24–29
III−	Shasta, 6	288	0.78	0.62	0.45
III	Tahoe	261	1.35	.90	.67
II−	Plumas, 1	306	1.52	.98	.70
II+	Stanislaus, 3	160	2.69	1.61	1.29
I	Sierra	33	3.27	3.00	.78
I	Sequoia, 6	76	4.72	4.21	2.75

[1] The numbers of trees in this and the following tables include all those of the given site, plot, species, and size class.

Examination of many cut-over areas leads to the belief that these figures represent a fair average of what can be expected from reserved trees. The best silviculture, therefore, on Site III or poorer, would be designed to secure reproduction and release advance growth, and only on Sites I and II would a reserve volume be left for increased growth. Management considerations, however, may justify the reservation of a considerable volume for a second cut.

SPECIES.

On Site II or poorer the species under consideration may be arranged in order of rapidity of growth as follows, the most rapid first: White fir, sugar pine, Douglas fir, yellow pine, incense cedar. Averaging the rates for 18 to 24 inch trees for 15 plots on which all species except Douglas fir occur, there is given in Table 2 the relation between annual basal area growth percentages, which reliably reflect volume growth also.

TABLE 2.—*Rate of growth, per cent, in basal area by species.*

	Annual.	Basis.
	Per cent.	*Trees.*
White fir	2.22	463
Sugar pine	2.07	81
Yellow pine	1.50	156
Incense cedar	1.21	321

Douglas fir is omitted because it is present in only a few cases. Comparison under similar conditions indicates that it grows rather more rapidly than yellow pine in this region.

On poorer sites incense cedar is usually conspicuously behind the others in rate of growth, but it is remarkably adaptive to site differences and under the most favorable conditions, up to about 24 inches in diameter, may exceed all species except white fir.

It is evident that, from the standpoint of growth, sugar pine is a better tree to leave than yellow pine. It also furnishes the most valuable wood of all the species in this region. White fir, because of its rapid growth and, as will be seen later, high reproductive capacity, will doubtless receive more consideration under management as the market for pulpwood and box and low-grade lumber improves. Sugar pine and white fir likewise exceed the other species in rate of height growth for a given age class, as well as in total height at maturity, and consequently maintain their superiority in volume growth to an even more striking degree than in basal area.

Plainly, therefore, the sugar pine-fir type, which is closely limited to first-quality sites and is composed principally of the two most rapid growing species, promises the highest yields under management.

SIZE AND AGE LIMITS.

After site, age is probably the most important factor affecting the rate of growth. But the timber marker can seldom determine age accurately and must depend on size as expressed by diameter and other external features in estimating degree of maturity.

Of the four species considered here, sugar pine maintains a good rate of growth to a higher diameter than any of the others and on Site II or better will maintain a rate of 2.5 per cent annually up to 30 inches. On the best sites well-formed, well-located sugar pines make good growth up to 36 inches in diameter, but as a rule about 30 inches should be the upper limit in marking trees of this species to be reserved.

On the best sites selected yellow pines maintain good growth up to 30 inches in diameter, but under average conditions trees over 24 inches seldom exceed a rate of 1 per cent annually, and only under exceptional circumstances should trees above 26 inches be left.

The rate of growth in white fir decreases rapidly above 24 inches in diameter, and larger trees of this species should rarely be reserved in marking, even on Site I.

Incense cedar shows a marked decrease in rate of growth above 18 inches. About 24 inches should be the limit in cutting, since smaller trees are doubtfully merchantable.

Table 3, made of averages of five plots classed as Site I, brings out the relations discussed above.

TABLE 3.—*Site I—Average periodic annual growth, per cent, in basal area, 1910–1920.*

Species.	Diameter classes (inches).							Basis number of trees.
	4 to 11	12 to 17	18 to 23	24 to 29	30 to 35	36 to 41	42 up.	
Yellow pine	6.45	3.30	2.20	1.50	1.15	0.90	0.70	798
Sugar pine	7.10	4.05	3.10	2.70	2.10	1.40	.70	716
White fir	9.70	5.30	3.30	2.00	1.50	1.20	1.00	1,131
Incense cedar	7.10	4.00	2.40	1.70	1.10	.80	.50	535

An expression of growth on an age basis is shown in Table 4, which gives average results from eight plots on the Plumas National Forest. These plots represent Site II, but a heavy stand and light cutting resulted in rather slow growth.

TABLE 4.—*Site II—Relation of age to annual growth, per cent, in basal area. (Eight plots, Massack, Plumas National Forest, curved.)*

Age	50	100	150	200	250	300	350	400	Number of trees.
SPECIES.									
White fir	4.50	2.20	1.25	1.10	0.90	0.80	0.70	0.60	789
Sugar pine	3.30	1.90	1.50	1.20	.80	.50	.40	.40	437
Yellow pine	2.40	1.40	.95	.70	.60	.55	.50	.45	724
Incense cedar	2.40	1.50	.90	.65	.55	50	.45	.40	1,249

After 200 years, which roughly corresponds to the 24 to 29 inch size class, the rate of growth for all species under these conditions falls below 1 per cent annually. Probably 150 years, which corresponds to the 18 to 23 inch size class, should be the limit in cutting for all but sugar pine, in which value increment as well as better sustained growth has an influence, taking into consideration, of course, site and other factors.

On some of the earlier sales many large, obviously mature pines were left, primarily to increase the proportion of pine reproduction, and their presence results in a material decrease in the average rate of growth maintained. Such trees represent a high risk of loss by fire or insects and, as will be seen later, have resulted in very little reproduction. How far leaving such trees is justified on the ground of improved quality of second cut will be discussed below.

In selecting trees to be reserved it is of the greatest importance that the marker be able to estimate accurately degree of maturity, vigor, and probable effect of cutting, as well as soundness and seed-producing capacity, in order to utilize completely the potentialities of species and sites. Results may be neutralized by accidental losses or unproductive trees. Certain external features have been found most reliable as reflecting vigor, such as color and texture of bark, form of top, color and density of foliage, size of crown, and freedom from disease.

CROWN SIZE AND FORM.

The crown furnishes the most reliable index of what may be expected from reserved trees. A dense, rich green, pointed crown gives certain evidence of a thrifty tree. The most significant single factors are crown length and form of top. If yellow pine is again used for demonstration, considering only trees between 12 and 30 inches, on the basis of ratio of crown length to total height, the following relation, shown in Table 5, expressed in annual basal area growth, per cent, is found:

TABLE 5.—*Relation of crown length to rate of growth in basal area.*

[Basis, 434 trees. Curved.]

Crown ratio.	Annual per cent.			Crown ratio.	Annual per cent.		
	Site I.	Site II.	Site III.		Site I.	Site II.	Site III.
30	1.40	0.40	0.40	60	2.40	1.01	0.55
40	1.50	.50	.40	70	3.60	1.70	.80
50	1.75	.65	.45	80	4.90	2.50	1.20

Trees with narrow, long crowns are usually growing more rapidly than the average trees of the same size. For yellow pine, probably 60 per cent of the total height is the most desirable proportion of crown for standards of the size usually reserved. Trees with larger crowns are too limby, and those with shorter ones are apt to be growing slowly. On all the sample plots considered here, the length of crown for all size classes averages 65 to 70 per cent of the total height. On poor sites, density of stocking being the same, trees of a given size carry relatively smaller crowns than on good sites, as is shown by Figure 1.

A significant fact brought out clearly during this study is that the ordinary crown classification based on position of trees in the crown canopy, when applied to irregular mixed stands of this character, is practically valueless as an indication of relative vigor of individual trees. Taking trees of the same size and species representing the ordinary dominant, codominant, intermediate, and suppressed groups as carefully classified in the field, one would expect to find a definite relation between crown class and the crown-height ratio, and between crown class and rate of growth, increasing from the suppressed to dominant trees. This is not found to be true of the present data, although it doubtless is true for even-aged stands.

Taking 318 yellow pines on the Plumas plot classed as dominants and segregating them into two groups, the first composed of trees with crowns of average size or larger and pointed tops, the second with smaller than average crowns and round, flat, or dead tops, it was found that the trees of the first group were growing at a rate of 1.22 per cent annually in basal area, while those of the second group were growing at a rate of only 0.42 per cent annually. On the same area trees of the same size, called intermediate and suppressed, were divided into similar groups. The first of these were growing at the rate of 1.37 per cent and the second 0.96 per cent annually, or considerably faster than dominants of the same character.

The several important observable factors which contributed to an accurate estimate of vigor might be combined into four thrift or tree classes, which would guide in the mental appraisal of each tree according to the following standards:

Class 1.—Dominant, codominant, or isolated trees, with pointed tops, well-shaped crowns forming 60 per cent or more of the total height; sound, symmetrical trunks; bark characteristic of young trees; foliage dense and rich in color.

Class 2.—Similar to the above in all respects except with crowns of smaller than average size.

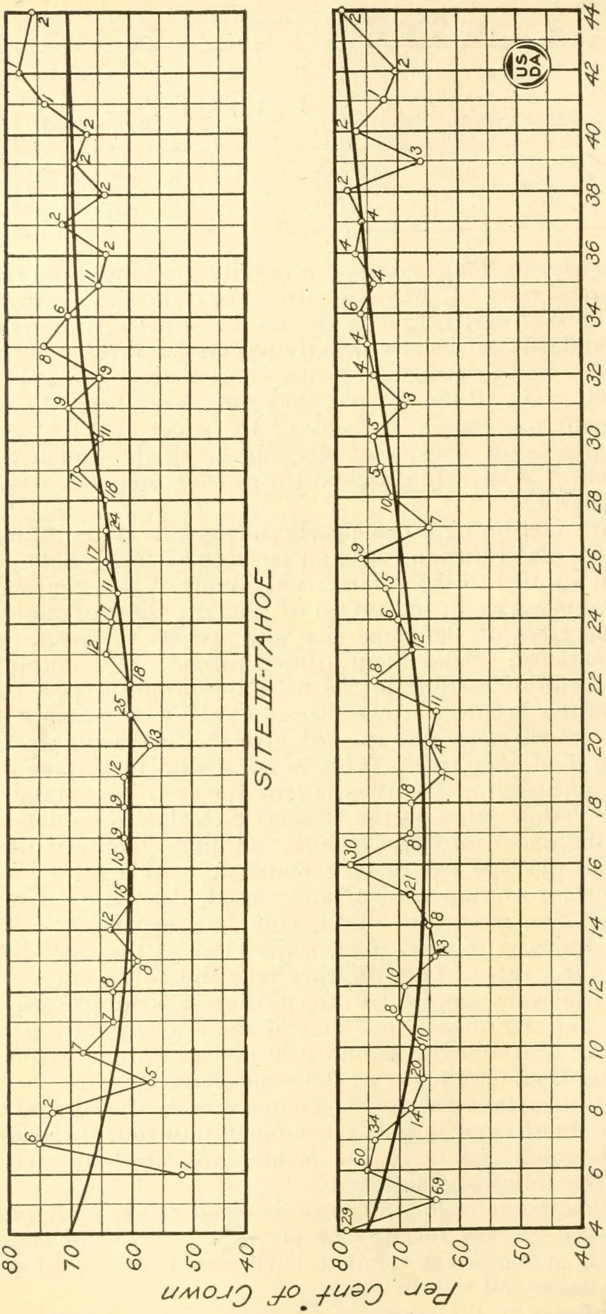

FIG. 1.—Ratio of crown length to total height in relation to size of tree and site. Western yellow pine, all crown classes.

Class 3.—Trees of any crown class having average-size crowns or larger, round or flat tops, thin foliage, bark characteristic of maturity, with sound, well-formed trunks.

Class 4.—Trees of any crown class with smaller than average crowns, pale, thin foliage, flat or dead tops, poorly formed trunks, bark characteristic of poor vigor.

Seriously diseased trees are, of course, considered apart.

The reliability of such groups as indicating relative vigor is shown in Table 6, in which 349 yellow pines over 12 inches in diameter on the Plumas National Forest are arranged according to this plan. Only dominant and codominant trees are included. The inclusion of intermediate and suppressed trees would accentuate the differences shown in Table 6.

TABLE 6.—*Relative vigor of different classes of dominant trees.*

Tree class.	Number of trees.	Annual basal area growth.	Deviation from average.
		Per cent.	*Per cent.*
1.....	209	1.22	+56.3
2.....	39	.95	+21.8
3.....	77	.55	−29.5
4.....	24	.42	−46.1

The relative response of such classes to cutting will be discussed later.

DISTRIBUTION—DEGREE OF CUTTING.

A study of the growth of individual trees on the various sale areas brings out clearly the disadvantages of the so-called group selection cuttings and indicates that trees reserved for increased growth and seed production, particularly yellow pine, should not be left in groups, if this can be avoided. It has been argued that such groups offer greater protection against wind. The data under consideration throw no light on this subject, as windfall has been of slight consequence on the study areas. Smith and Weitknecht, in southern Oregon, found windfall to be heavier in groups of 4 or 5 than for single trees and 13.4 per cent higher for groups of 16 trees or more than for groups of 4 or 5. Frequently in this region the only available reserves occur in groups, and cutting is avoided because damage results to remaining trees from logging.

Many increment borings indicate that trees left in groups seldom respond to cutting. This is illustrated in Table 7 by the growth figures for typical yellow pines on the Stanislaus and Sequoia National Forest timber-sale areas, which give the annual rate by 5-year periods, before and after cutting, for trees between 12 and 24 inches in diameter. The number of trees included has been limited by selecting from several hundred bored only those as nearly similar as possible as regards distance of cutting, age, vigor, and crown character. Trees have been considered released when large trees were cut within 60 feet of them.

TABLE 7.—*Effects of grouping on basal area growth, per cent.*

Plot.	Number of trees.	Before cutting. 10 years.	Before cutting. 5 years.	After cutting. 5 years.	After cutting. 10 years.	After cutting. 15 years.	Average increase or decrease.
							Per cent.
Stanislaus:							
Released	16	2.22	2.26	2.81	2.63	....	+21.4
Left in groups	10	1.71	1.51	1.44	1.43	....	−10.9
Sequoia:							
Released	13	2.78	3.20	3.43	3.32	2.55	+3.7
Left in groups	15	3.30	3.30	3.59	3.06	2.59	−6.7

The Sequoia area before cutting was already quite open, so that the cutting resulted in only slight changes in rate of growth.

In general the trees left in groups declined in rate of growth, while the growth of released trees was accelerated by the cutting. This relation is more clearly illustrated by the accompanying diagrams of typical increment cores. (Fig. 2.)

It has been well established that leaving trees in groups has an adverse influence also on seed production, as the trees, unless they are fully released, build up their crowns only slowly after cutting.

Because of the presence of many variable factors, comparison of these sample plots does not indicate clearly the effects of degree of cutting on rate of growth. At Massack, on the Plumas National Forest, eight plots, originally representing fairly similar stand and site conditions, were subjected to cuttings of various degrees with this object in view, but, unfortunately, the differences in degree of cutting were so slight and all cuttings were so light that the results are obscure.

The slow rate of growth maintained by all of these plots was probably due primarily to the dense stand left, which averaged 73.5 trees over 4 inches in diameter and 20,000 feet board measure per acre. Average heights of the tallest trees indicate that these plots represent a good Site II, in spite of which the annual rate of growth in basal area averaged only 1.02 per cent, whereas the Tahoe plot, a much poorer site, classed as third quality, but with only 23.1 trees and 15,520 feet board measure, maintained practically the same rate, 1.01 per cent. Similarly, another Plumas plot classed as Site III, with 51. 5 trees and 10,065 feet board measure per acre, maintained a rate of 1.22 per cent. Bearing in mind the probable effects of differences in composition and size of remaining trees on these plots, which would tend to favor those at Massack, the lightness of cutting seems to be the only explanation of the slow growth.

Weidman, probably under more uniform conditions in yellow pine stands in southern Oregon, found a very close correlation between the acceleration of growth and degree of cutting as expressed by per cent of volume removed, but arrangement of the present sample plots in order of degree of cutting shows little correlation as to rate of growth, probably because of site and type differences.

Light cutting results in leaving many large mature or overmature trees which greatly reduce the average subsequent rate of growth. Moreover, the loss of one such tree, containing high-quality material,

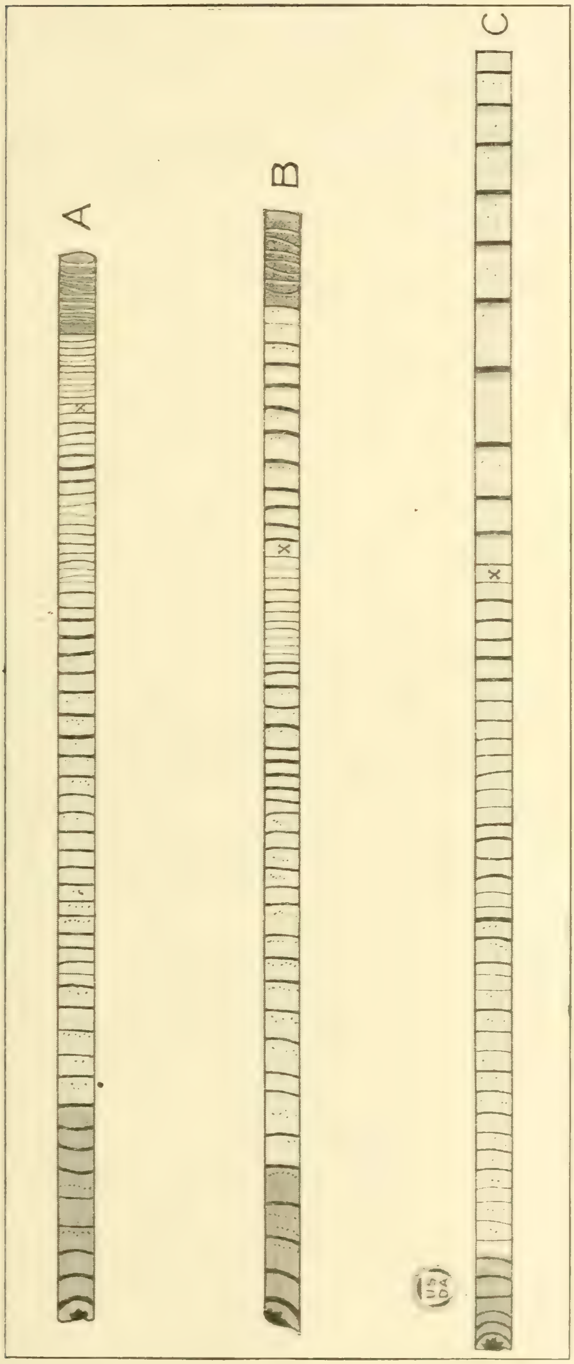

FIG. 2.—Increment cores, western yellow pine, showing response to cutting in year 1909, marked "x."

A—Tree No. 367. Stanislaus—2. Site II. In group.
B—Tree No. 282. Stanislaus—2. Tree cut 60 feet west.
C—Tree No. 661. Stanislaus—1. Tree cut 20 feet north.

may neutralize the volume produced by thriftier trees, so that no net growth appears. For illustration, take the Plumas plot, considering, for the sake of brevity, only yellow pine, which formed 86 per cent of the original and 74 per cent of the present volume. On the basis of the previously discussed tree classes, the remaining merchantable trees were divided by field observation into two groups, the first including trees which would be cut under present marking methods, the second including trees which would be reserved. The comparative annual rates of growth of the two groups during the 10 years since cutting are shown in Table 8, expressed in basal area percentages.

TABLE 8.—*Comparative annual rates of growth.*

Group.	Diameter classes.										Total.	
	12 to 17		18 to 23		24 to 29		30 to 35		36 plus.			
	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.
To cut	32	0.84	33	0.85	36	0.72	27	0.48	12	0.35	140	0.60
To leave	104	1.77	73	1.34	28	.90	18	.59	3	.60	226	1.18
Average		1.305		1.095		.81		.535		.475		.89
Percentage deviation of trees to cut from the average	−35.6		−22.4		−11.1		−10.3		−26.3		−32.6	

Expressed in volume, the trees which would have been cut totaled 118,200 board feet, which produced 40 board feet per acre annually, while the total volume of those which would have been left was 96,840 board feet, which produced 63 board feet per acre annually: that is, 45 per cent of the total volume produced 61 per cent of the total growth. Such a cutting would have reduced the stand left from 57 to 18 per cent of the original volume, would have added 4,930 board feet per acre to the cut, and probably would have resulted in more rapid growth per cent of the trees left than actually occurred on the larger number reserved.

On one 20-acre plot on the Stanislaus a stand per acre was left of 24,100 board feet, containing 16.9 trees over 12 inches in diameter, which formed 46 per cent of the original volume. There were left 14 yellow pines and 12 sugar pines over 42 inches in diameter, the largest tree being an 82-inch sugar pine 215 feet high. Considering the quality of this site, which approached Site I, a rate of growth 2½ to 3 per cent annually might be expected. The average rate maintained by the surviving trees, however, was only 1.44 per cent in basal area, and the net total increment in board feet was only 0.93 per cent annually. The reason for this is clearly the presence of overmature, slow-growing trees, as will be seen from Table 9.

For any given size class, sugar pine maintained, in general, its normal position as to rate of growth, but its aggregate rate was lower than for any of the other species. The high proportion of sugar-pine trees in the larger-size classes gives the explanation. The same condition was true to a lesser extent of the other species.

TABLE 9.—*Periodic annual basal area growth in per cent, Stanislaus National Forest, 1910–1920.*

Species.	Diameter classes.							Total.
	4 to 11 inches.	12 to 17 inches.	18 to 23 inches.	24 to 29 inches.	30 to 35 inches.	36 to 41 inches.	42 up.	
White fir:								
Number	50	9	4	3	1	4	1	72
Per cent	9.11	3.63	3.90	.87	.98	.63	.33	2.33
Sugar pine:								
Number	34	4	8	4	5	8	12	75
Per cent	6.35	3.03	2.51	2.36	1.25	1.03	.51	1.06
Yellow pine:								
Number	273	71	55	44	27	19	14	503
Per cent	4.92	2.74	1.61	1.39	1.37	.69	.38	1.46
Incense cedar:								
Number	53	21	14	6	4	1	6	105
Per cent	5.53	2.75	1.66	1.27	1.23	.42	.18	1.30

ACCELERATION OF GROWTH.

It is to be expected that the degree to which growth is accelerated by cutting will depend upon the proportion of the stand removed, provided age, site, composition, and other factors remain comparable. As stated previously, variations in these factors on the plots here considered have been so great as to mask this relation. There are, however, several other factors more clearly emphasized by the present data than degree of cutting, which must be given consideration if enhancement of the growth of reserved trees is to be secured.

Study of several hundred increment cores has shown that individual trees of all species and all ages seldom fail to respond if the trees removed are near enough so that light and soil-moisture relations are materially improved for those that remain. If, prior to cutting, a given tree was already receiving all the light it could utilize, its response will depend upon the increase in available soil moisture. As a rule, no acceleration is observable unless trees are removed within 50 or 60 feet. If the stand is already quite open before cutting, and the current rate of growth be high, no response may be apparent. An example of this is shown in the Sequoia plot in Table 7. Expressions of acceleration of growth, based on percentage ratios between the average rates before and after cutting, do not, of course, give the total effect of the thinning, which is in reality the difference between the actual rate and that which would have been maintained with advancing age had no cutting been made. This is shown in Table 10 by comparing the growth rates of trees left after a cutting with those in adjacent virgin timber, using only yellow pines as nearly as possible the same in size, crown form, dominant class, and other respects, during the same periods as indicated for trees from the Sierra National Forest. The figures represent the percentage ratios between the rates maintained during one 5-year period and the preceding one. The remarkable decrease in rate during the last period on the cut-over area may be due to the combined effects of rapidly invading bear clover and reproduction, and a series of four exceptionally dry seasons from 1917 to 1920.

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TABLE 10.—*Comparison of basal area growth per cent on virgin and cut-over areas during successive 5-year periods, Sierra National Forest.*

Condition of area.	Number of trees.	Per cent of increase or decrease over preceding period for periods ending—			
		1905	1910	1915	1920
Virgin	13	−3.1	−12.7	−8.5	−13.5
Cut over 1906	28	−3.7	+57.8	+42.0	−58.6

The ability to respond to the stimulus of cutting varies with the species. It has been stated that the amount of acceleration is inversely proportional to the light requirements of the species. If this be true, we might expect white fir, one of our most tolerant species, to show a greater relative response than yellow pine, the least tolerant in this region. The results obtained from increment borings are not in accordance with this expectation. It is difficult to get strictly comparable conditions, and present data are not considered final. To obtain as nearly as possible comparable data for the two species, however, there have been selected from many trees bored on each plot a few as nearly as possible similar in size at time of cutting, character of crown, and position. All the trees were dominants or codominants with large pointed crowns about which some cutting was done within a radius of 60 feet. Trees which stood in stream beds or were otherwise exceptional have been omitted. This limiting of the data gives the appearance of a scanty basis, but it is considered preferable to averaging together a larger number of trees which would introduce variations, the effects of which could not be determined. The results are given in Table 11.

TABLE 11.—*Relative response of yellow pine and white fir.*

Plot.	Yellow pine.					White fir.				
	Number of trees.	Average diameter breast high.	Annual basal area growth.		Acceleration.	Number of trees.	Average diameter breast high.	Annual basal area growth.		Acceleration.
			Before.	After.				Before.	After.	
			P. ct.	P. ct.	P. ct.			P. ct.	P. ct.	P. ct.
Shasta	20	20.6	0.53	0.83	+56.6	9	12.7	1.39	1.48	+6.5
Tahoe	25	18.9	1.15	1.46	27.0	11	17.4	3.67	4.20	14.4
Plumas	32	18.1	1.15	1.34	16.5	6	11.4	2.09	2.48	18.7
Stanislaus–2	31	20.0	1.73	1.87	8.1	11	18.1	3.65	3.87	6.0
Sierra	13	15.8	1.93	3.19	65.3	8	15.8	2.25	4.26	89.3
Stanislaus–1	7	18.5	1.70	3.48	104.7	8	12.3	5.53	7.31	32.2

In every case white fir has grown at a much higher rate than yellow pine, but the relative increase after cutting was greater in only two of the six cases.

With increasing age the percentage of acceleration, as well as the absolute rate attained after cutting, decreases.

Suppressed trees growing at a slow rate show relatively greater response to cutting than those which were always dominant, although the rate attained may be much less.

Trees with large, well-formed crowns and dense foliage respond more promptly (usually during the first season after cutting) and attain a higher rate under the stimulus than trees with small, poorly formed crowns in which response is usually delayed from one to three years. Response is greater and more prompt on good than on poor sites. The maximum rate is attained in 7 to 10 years after cutting, but the stimulation is discernible for many years, depending on the rate of closing of the crown canopy, invasion of brush, etc. A heavy cutting, good distribution, and careful selection of remaining trees are necessary to secure the greatest response.

NET GROWTH.

Statements in the preceding discussion have been largely in terms of potential rather than net growth rates, in order to demonstrate more clearly the effects on growth of the factors mentioned. It may be of interest to consider what the actual net returns have been from the areas under consideration. This may be seen from Table 12. The Feather River, Sequoia-4, and Tahoe plots represent examples of the reduction of net increment by the loss of a few large trees. On the better sites net growth has been excellent, amounting in some cases to over 400 board feet per acre annually, or more than 3 per cent.

TABLE 12.—*Stand, losses, and net increment per acre, 1911 to 1921.*

Site.	Plot.	Type.	Stand.		Annual loss.		Net annual increment.	
			Trees, 4 inches up.	Volume, board feet.	Trees.	Volume.	Board feet.	Per cent.
					Per cent.	*Per cent.*		
III	Shasta-11	Mixed	83.9	6,500	0.33	0.06	60	0.92
III−	Shasta-6	do	54.4	9,880	.53	.36	53	.54
III	Tahoe	JP-WF[1]	23.1	15,520	.80	.68	53	.34
II−	Plumas	Mixed	51.5	10,065	.28	.31	130	1.29
II	Feather River, 1-8	do	73.5	20,000	.83	.55	76±	.38
II+	Stanislaus-2	SP-YP[1]	38.4	18,570	.46	.11	265±	1.43
II+	Stanislaus-3	do	37.7	24,100	.87	.26	225	.93
II	Sequoia-3	YP	53.3	10,870	.83	.85	200	1.84
I	Sierra	do	34.5	11,350	.10	.22	294	2.59
I	Sequoia-1	SP-WF	51.8	12,930	.81	.63	325	2.51
I	Sequoia-4	SP-YP	45.5	21,710	.57	.60	80	.37
I	Sequoia-6	YP	32.7	12,700	.03		440	3.46
I	Stanislaus-1	SP-WF	62.2	20,780	1.46	.12	470	2.26
	Average		49.4	14,998	.61	.39	205	1.37

[1] JP=Jeffrey pine; WF=white fir; SP=sugar pine; YP=yellow pine.

INJURIOUS AGENCIES.

Loss in number of trees, averaging 0.61 per cent annually since cutting, seems rather high, but it is due to the fact that most of the trees were small, occasioning but slight volume loss, and died during the first few years after cutting from injuries received during brush burning and logging. Other causes of loss, principally among small trees, were snow, suppression, and, in white fir, engraver beetles (*Oecoptogaster*). The greatest volume losses were due to wind and bark beetles (*Dendroctonus*) in yellow pine, and to mistletoe in Douglas fir on the Shasta plots, the latter being the only case of serious volume loss. From Table 12 it will be seen that volume losses have never exceeded 1 per cent and have averaged 0.37 per cent annually. Since windfall and deaths from other causes are usually heaviest during the first five years after logging (true, thus far, of practically all the areas included), this rate should decrease in the future. (Pl. I.)

Economic conditions at present do not permit the removal of all defective material, and in consequence there are on these plots a number of trees showing the effects of mechanical injuries, or attacks by pathogenic organisms, some of which reduce growth. Probably the most serious of these is mistletoe. This subject early received rather careful consideration in marking, so that most of the trees seriously attacked were removed. Excepting the above-mentioned case of Douglas fir on the Shasta, mistletoe damage is largely confined to attacks of the lower limbs of white fir and yellow pine by *Razoumofskya* and of the tops of large decadent white firs by a *Phorandendron.* Pearson, in the Southwest, has shown that a considerable infestation of mistletoe reduces growth to a marked degree.

On timber sales made before the advent of the sanitation clause in the contracts there remain considerable numbers of old unmerchantable white firs and incense cedars affected with fungi. These trees are growing slowly, probably due as much to advanced age as to the fungi, most of which attack the heartwood only.

Even large mechanical injuries, such as basal logging and fire scars, have not been found to reduce growth except in smaller trees, which are practically girdled.

Increment borings show that injuries, such as scorching away part of the foliage by brush-burning fires, raking off of green limbs by falling trees, or broken tops, are always evidenced by reduction in the width of the annual rings made during the years immediately following logging, in proportion to the amount of foliage destroyed.

The dense cover of shrubs which, owing to the open character of the stands, frequently grows to the bases of the larger trees, undoubtedly reduces the amount of soil moisture available and consequently their rate of growth. While this fact is usually conceded, the extent to which it is true has not been determined.

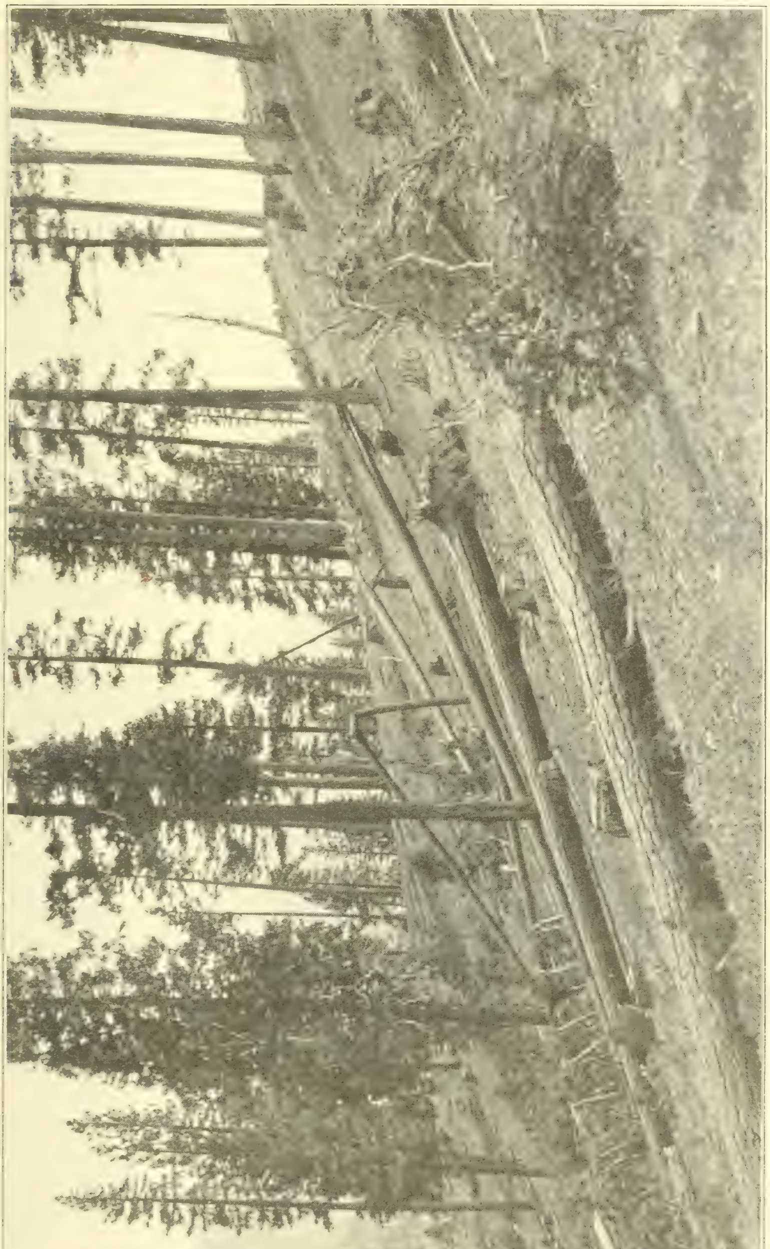
VALUE OF INCREMENT.

So far we have been considering the disadvantages of a heavy stand after cutting as regards volume increment without regard to quality. There is considerable justification for leaving a certain amount of large, high-quality material for value increment, where the stand will be accessible for a second cut in a reasonable time, but great care should be exercised in selecting trees to be reserved for this purpose. The following figures, although they do not represent the method of determining national forest timber-sale policies, indicate that a profit will result from such stand unless unexpected wind or insect damage occurs.

The valuation of the stand left on the Stanislaus plot 3 at the time of cutting, assuming a second cut in 30 years, would be:

Sale value of timber at time of cutting, $45.20 per acre.

Value of timber at end of 30 years, with compound interest at 3 per cent. $109.71.



Windfall resulting from leaving very tall trees and trees weakened by fire scars on the lee side of a wind-swept ridge with their crowns projecting above the crest. Plumas National Forest.

FIG. 1.—Heavy cutting on private land on Site I, effective in releasing the abundant advance growth of sugar pine and white fir. Sierra National Forest.

FIG. 2.—A good stand of yellow pine reproduction present as small seedlings prior to cutting, which grew rapidly and became conspicuous after release. Note condition of slash 11 years after cutting with no disposal, no fires, and moderate sheep grazing. Plumas National Forest.

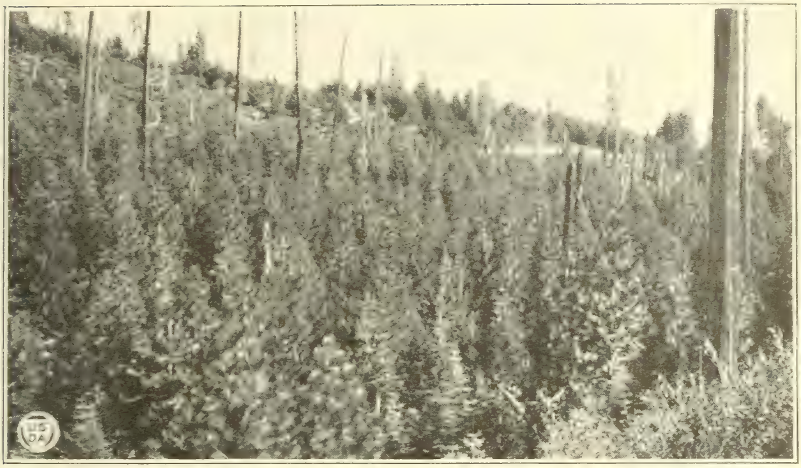


FIG. 1.—An accidental stand of yellow pine reproduction on a north slope due to abundant seed ripened the year of cutting, following a hot slash fire of the same season. The fire was followed by favorable conditions for germination and growth. Private lands within the Sierra National Forest.

FIG. 2.—South slope of same ridge where, with similar treatment, less favorable conditions resulted in a stand of bear clover and manzanita instead of tree seedlings. Private lands within the Sierra National Forest.

FIG. 1.—A group of trees left after cutting. Groups as dense as this do not permit reproduction, growth of the trees is seriously retarded, and they show little or no response to cutting in the form of increased growth. Plumas National Forest.

FIG. 2.—Abundant advance reproduction of western yellow pine on an unfavorable site where the condition of the natural stand resembles that which would be secured by a first cutting under the shelterwood system. The primary object of cutting should be to release and preserve such reproduction. Lassen National Forest.

Cost of brush-disposal at 30 cents per thousand for 28,560 board feet per acre removed, or $8.57 at 3 per cent compounded for 30 years, $20.80 per acre.

Fire pervention and suppression, 30 years at 1½ cents per acre annually, with compound interest at 3 per cent, 71 cents.

Total investment in timber at the end of 30 years, omitting taxes and administrative charges, $131.22.

Since most losses on sale areas occur during the first five years after cutting, we may expect a higher net annual growth rate for the longer period of 30 years than the 0.93 per cent given above, so it seems conservative to use a rate of 1 per cent annually. At this rate the stand per acre at the end of 30 years would be 32,482 board feet. With an investment of $131.22, as determined above, the stand would have to bring an average stumpage price of $4.04 per thousand to earn 3 per cent on the investment.

As present (1922) stumpage rates for similar timber are $5 for sugar pine, $4.50 for yellow pine, and $1.50 for white fir and incense cedar, more than twice what they were at the time of the above sale 10 years ago, it is readily seen that the Government may reasonably expect a profit of over 3 per cent on the 30-year investment from such high quality stands.

REPRODUCTION.

In the forests of California, where expense generally prohibits artificial regeneration, the question of securing natural reproduction is of the first importance. Unfortunately, when this study was begun, the securing of growth data was given first consideration and, except in a few cases, only rather generalized reproduction data were provided for. Since that time more intensive studies have been undertaken, but have not yet yielded conclusive results. Only the more obvious facts developed will be mentioned and no attempt will be made to explain them.

One of the most important results of these studies has been to emphasize the great importance of advance reproduction. It becomes more and more evident that the establishment of reproduction after cutting is a long, tedious process, requiring as high as 20 years or more on poorer sites to secure even a fair stand. In none of the sample plots even on the best sites has more than one-third of the seedlings now present been established since cutting, and in only two cases are the number and distribution of seedlings sufficient to constitute complete stocking 10 years after logging. That this condition is not exceptional is evident from examination of many of the more important cut-over areas in the State. With very rare exceptions the large number of seedlings now found on cut-over areas was present under the original stand, or developed from seed borne by trees during the season of felling.

Investigation of the excellent stands of seedlings often pointed out on clear-cut or heavily-cut areas in support of the argument that this is the proper method of securing good reproduction, practically always discloses the fact that the majority of seedlings were present as very small inconspicuous trees at the time of cutting, and that the removal of the older stand was exactly what was needed to release them. Their sudden advent was apparent, not real. (Pl. II.)

Some remarkably fine stands of yellow-pine reproduction have become established by a rare combination of circumstances, such as an abundant seed crop ripened during the season of felling, stirring up the soil by logging, a series of favorable seasons following germination, and the miraculous escape from slash fires. (Pl. III.) Obviously such stands can not be counted on regularly in practice.

The reasons for the failure to secure at will abundant reproduction of desirable species are not so evident. In most cases at the time of cutting advance growth is present in openings made by fire or insects, and even directly under the more open, older stands. Investigation shows that as a rule there is a great range in age of these seedlings, or that they germinated abundantly during certain widely separated years—that is, advance growth originated either by a long, gradual process or by rare combinations of favorable circumstances.

The slow progress of restocking is brought out in tabulation (Table 13) of selected typical data, which shows the differences between the number of seedlings present at two examinations of the same area made at intervals of from 4 to 10 years. Advance growth or reproduction which had become established before logging is included. Examinations at intermediate periods have shown that some seedlings start practically every year, but deaths due to drought, rodents, and unknown causes almost or more than offset the number of new trees. The conspicuous decrease in number on the Feather River plots is due to the fact that the 1913 examination was made prior to logging and brush burning and included seedlings of the current year's germination, in which mortality is always high, a condition not true of the other plots. Certain changes in methods make comparison with the earlier examinations in most cases rather difficult, and they have been omitted, but the general trend or results would be the same.

TABLE 13.—*Progress of reproduction, all species.*

Plot and date.	Seedlings per acre.	Per cent of original.	Plot and date.	Seedlings per acre.	Per cent of original.
Shasta:			Feather River 1 to 8:		
1915	4,534	100.0	1913	25,366	100.0
1920	4,165	91.9	1919	5,464	21.5
Tahoe:			Sierra:		
1916	540	100.0	1916	9,680	100.0
1920	493	91.3	1920	8,544	88.3
Plumas:			Sequoia-1:		
1910	1,270	100.0	1916	1,690	100.0
1920	1,352	106.5	1920	1,690	100.0

It was stated above that the stand of seedlings on most of the plots was deficient. It might be assumed from Table 13, which shows totals of 4,000 to 10,000 seedlings per acre on some of the plots, that this was not true. It should be explained, however, that from 35 to 67 per cent of the reproduction is incense cedar, over half of which consists of dense patches of small seedlings less than 6 inches high. Only a very small portion of this will ever reach large size.

The reasons for this slow progress in restocking will not be dealt with at length, because lack of sufficient meteorological, seed crop, light intensity, and other data at present restricts the discussion to generalities of slight interest. Briefly, there are several outstanding reasons to which failure is attributed. On the poorer sites it is probably due primarily to drought and infrequent seed crops and on the better sites to infrequent seed crops, abundant brush and ground cover present before cutting, and light cuttings where the original stand was heavy.

In what way could changes in marking affect these factors? On most of the older sales enough, and in some cases too many, seed trees were left on the poorer sites, but what effect a heavier cutting would have on amount of seed borne is unknown. Apparently trees on the sale areas bear more seed than similar trees in adjoining virgin timber, and as on these poorer sites, particularly on the east slope of the Sierras, brush invasion is slow in the absence of fire, a heavier cutting leaving only well-distributed, well-formed, frequent seed trees, as at present, seems justified. Grouping of reserved trees should be avoided. (Pl. IV.) As to modifying the effects of drought, there is doubtless a compromise between some method, such as the shelterwood, designed to prevent soil deterioration and loss of soil moisture by evaporation, and clear cutting, which makes more soil moisture available to seedlings by reducing root competition of the older trees but encourages heavier herbaceous and shrubby undergrowth. This matter is still an open question. On poor sites some cover doubtless favors the establishment of reproduction. On the Plumas plot over 90 per cent of the seedlings are situated in patches of squaw carpet which covers only about 20 per cent of the area. This plant (*Ceanothus prostratus*) forms dense flattened mats which protect seed from rodents, act as fire barriers, probably reduce frost damage, and prevent excessive evaporation during the early season when seed is germinating, thus favoring establishment. Apparently root competition later results in slow growth of the seedlings until sufficient shade is provided to kill the shrub.

On the better sites, in addition to the question of seed supply, the control of brush and ground cover assumes greater importance and offers a particularly difficult problem. Until recent years uncontrolled fires, started by lightning, Indians, miners, stockmen, etc., have favored the spread of many species of *Ceanothus*, manzanita, bear clover (*Chamæbatia foliolosa*), and other shrubs whose vigorous sprouting and seeding capacities enable them to seize openings to the detriment of reproduction. The light requirement of some of these shrubs, notably *Ceanothus cordulatus*, *Prunus emarginata*, *Castanopsis chrysophylla*, and *Chamæbatia foliolosa* is nearly the same, but lower than that necessary for yellow-pine reproduction. In many cases the crown canopy is already sufficiently open to permit the shrubs to gain a foothold before logging, so that no choice is left but to risk their extension by cutting the timber. That the brush does spread appreciably following cutting is evidenced by photographs taken at intervals from the same point. Under intensive management this underbrush might be grubbed out and the space replanted with trees, a course not open at present because of excessive cost. Seedlings gradually become established in even the densest brush (especially is this true of white fir), and, after severe competition for soil moisture for a time, overtop the brush and shade it out. (Pls. V and VI.) Several instances are known where this has happened in less than 30 years. Apparently, for the present, we must depend on this process with fire protection for control of brush already present.

Heavy litter is definitely known to favor fir and cedar at the expense of yellow pine. Heavier cutting in the yellow pine, the sugar pine-yellow pine, and the sugar pine-fir types with better distribution of reserved trees undoubtedly favors pine reproduction and is especially necessary to release advance growth.

In most cases the period required for natural regeneration will range from 10 years on the best to 20 years or more on the poorer sites. Bearing in mind the character of the virgin forests in which the best advance growth is found, an extensive application of the shelterwood system seems to offer the best chance of improving on conditions existing at the time of cutting. It is particularly adapted to the fir and sugar pine-fir types if an increasing proportion of fir is accepted as unavoidable. It was stated previously that most of the early cuttings inadvertently resembled shelterwood cuttings. How, then, are the unsatisfactory results explained? In the first place, sufficient time has not elapsed. Few good stands of reproduction can be found in which all seedlings have been established in less than 10 years, except on the best sites or where a good seed crop has been followed by favorable seasons.

In the second place, the system was not definitely in mind at the time of marking, and improper application of it resulted. Seed cuttings were made where the presence of advance reproduction justified heavier removal cuttings. Even markings intended for seed cuttings were probably too light. On the other hand, some later very heavy cuttings, where advance growth is scanty, and which have left only three or four thrifty standards per acre for seed trees, will probably result in slow regeneration, as such trees bear little seed for a number of years after cutting. (Pl. VII.) In many cases in which the stands are essentially even-aged to start with, a heavy shelterwood cutting would be practically the same as the present system of leaving a greater number of seed trees and at the same time a volume of 4,000 to 10,000 feet board measure per acre for increased growth and improved quality of the second cut. (Pl. IV.) The principal objection to this system is that even two cuttings within a reasonable period are not possible on most areas for economic reasons. Even to-day, however, it would be possible to cut over a second time several sale areas on the Plumas and other national forests.

Fortunately, in nearly all cases considerable advance reproduction is already present and every effort should be made to preserve it and favor its growth. In the early markings not enough attention was given to such advance growth, especially if of small size or composed largely of fir and cedar. The aim was to secure a new crop. The advance growth was given little protection in felling, yarding, and brush burning, with the result that in some cases much of it was destroyed. In others it remained suppressed by trees left for seed. An extreme case of this is represented by the Massack plots above, where the number of seedlings present now represents only 21.5 per cent of the 25,000 or more per acre before logging, and much of what remains is still suppressed. The present policy of heavier cutting and better distribution of reserves is again indicated. (Pl. VIII.)

FIG. 1.—Dense bear clover which hinders the establishment and retards the early growth of reproduction. Nevertheless numerous white fir seedlings may be seen in it. Sierra National Forest.

FIG. 2.—Same location five years later. White fir gradually overtopping the bear clover.

FIG. 1.—Good marking has resulted in excellent reproduction of yellow pine on Site I after cutting. While the seed tree is approaching maturity it is still thrifty and is justified by prompt abundant seed crops which a smaller tree would not produce. Sierra National Forest.

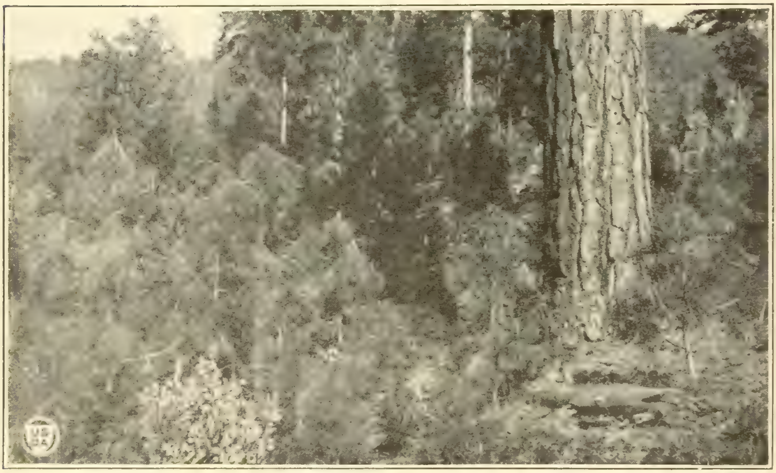


FIG. 2.—Same location five years later, showing rapid growth of seedlings which will soon occupy the soil to the exclusion of bear clover and manzanita.

FIG. 1.—A shelterwood cutting in Jeffrey pine on Site III, where 20 years or more may be required before reproduction becomes established. Tahoe National Forest.

FIG. 2.—A heavy cutting where advance reproduction is absent. It is doubtful if so few reserved seed trees of this size and age can furnish enough seed for regeneration under prevailing unfavorable conditions.

FIG. 1.—Mature stand of western yellow pine. Reproduction and intermediate sized trees practically absent. Some large trees should be reserved from cutting to insure a seed supply. Lassen National Forest.

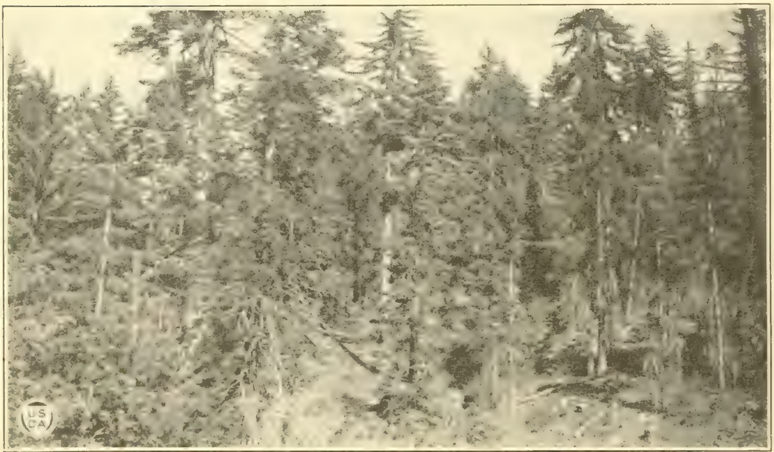


FIG. 2.—A heavy stand of mature trees left on a timber-sale area in the sugar pine-fir type in accordance with the practice of several years ago. A heavier cutting would have been more favorable for reproduction. Sequoia National Forest.

The method of brush disposal practiced has a very important influence on advance growth. Where piling and burning is done the area covered by the piles, even with careful burning under ideal conditions, is considerable. On the 24-acre Plumas plot in the mixed coniferous type, yellow pine predominating, from which a cut of 13,480 board feet per acre was removed, the number of piles per acre was 24 and the percentage of the area covered by closely confined brush-burning fires was 6.7. On a more recent sale area of the Lassen National Forest, pure yellow pine type, from which an average of 17,500 board feet per acre was cut, the number of piles indicated by a strip cruise was 20 per acre, which covered 6.2 per cent of the area before burning and 9.2 per cent after burning. A more extensive airplane photographic survey of the same sale area gave an average of approximately 15 piles per acre, or 6.7 per cent covered by fire. This was with careful burning under favorable conditions. The period during which satisfactory brush burning can be done is usually short, and frequently fires spread much more than indicated above. On the eight Feather River plots, where the average cut was 34,770 board feet per acre, brush-burning fires covered 8 to 17 per cent of the area. With careful supervision piles can be placed away from reproduction, so that the area burned does not necessarily mean proportionate destruction of advance growth. The areas covered by the fires are rendered unfavorable to establishment of seedlings for several years. Formerly practically all piles were burned, regardless of proximity to advance growth, but it is customary now to leave 10 to 20 per cent of the piles where their location close to clumps of seedlings is unavoidable. Careless piling and burning may result in great damage, particularly with donkey logging, where the seedlings which escape yarding are left in narrow sectors between the skidding trails radiating out from the lead block. Slash and other débris is likewise pushed aside into these same sectors by incoming logs. If the brush pilers merely heap the trash up where it is found, burning may easily destroy what reproduction escapes logging.

The piling and burning method of brush disposal was adopted because of the extreme difficulty of controlling slash fires, the uncertainty as to the effect of slash on increasing insect depredations, and the belief that in most cases new reproduction could be secured easily. We have long realized that the most abundant and thriftiest young growth in this region is found in areas where abundant advance growth was fully released by a heavy cutting, no slash disposal was practiced, and the area accidentally escaped fire, rather than on areas where new reproduction was established after cutting. Experience has shown that there is slight danger of the spread of bark beetles due to slash. (This is true at least of *Dendroctonus*, although the less destructive *Ips* may spread under certain conditions.) The expense is a serious factor. There remains, then, only the reduced fire hazard to justify the method. The Forest Service has hesitated to change its method until it is certain of the results or can find a more effective substitute. Modified methods whereby slash is cleared from control lines separating the areas into natural protection units are now being tried out on a large scale, with the hope that, combined with more intensive fire protection, they will give better results at less cost.

The effects of different methods of logging on advance reproduction will not be discussed in detail. Briefly, big-wheel and other types of horse logging are the least destructive. Power logging with a ground lead over extensive chutes, as generally practiced several years ago, caused only moderate damage. With present ground-skidding methods damage can be kept within reasonable bounds. The method of high lead logging, generally used during the last three of four years on private land, where the lead block is placed on a spar tree from 75 to over 100 feet from the ground, as a rule precludes dependence on advance growth for restocking. This method is only justifiable on extremely difficult topography or where subsequent planting can be done.

The effects of grazing upon reproduction on the areas under consideration have been slight. Sheep are excluded from all of the plots and grazing by cattle has been light.

As stated elsewhere, one object in practically all the older markings was to increase the proportion of the more valuable species, yellow and sugar pines, in the next stand. It was hoped that this would be accomplished by leaving abundant pine seed trees and marking white fir and incense cedar as closely as economic conditions would permit. It may be definitely stated, however, that in 10 years' time such markings have failed to show any progress toward the desired result. Repeated counts rarely indicate any great change in the ratio of the species present, and what changes have occurred are generally in favor of the fir and cedar. This relation is best expressed in Table 14.

TABLE 14.—*Changes in composition of reproduction by species.*

[Number of seedlings per acre and per cent of total.]

Plot and date.	Yellow pine.		Sugar pine.		Douglas fir.		White fir.		Incense cedar.		Total.	
	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.
Shasta:												
1915	1,587	35.0	9	0.2	674	14.9	247	5.4	2,017	44.5	4,534	100
1920	1,273	30.5	12	.3	745	17.9	237	5.7	1,898	45.6	4,165	100
Tahoe:												
1916	195	36.1					345	63.9			540	100
1920	170	34.5					323	65.5			493	100
Plumas:												
1910	330	26.0	41	3.2	96	7.6	123	9.7	680	53.5	1,270	100
1920	366	27.1	38	2.8	85	6.3	120	8.9	743	54.9	1,352	100
Feather River 1 to 8:												
1913	2,500	9.9	1,256	5.0	6,392	25.2	5,288	20.8	9,930	39.1	25,366	100
1919	578	10.6	333	6.1	1,161	21.2	1,315	24.1	2,077	38.0	5,464	100
Sierra:												
1916	1,985	20.5	455	4.7			705	7.3	6,535	67.5	9,680	100
1920	2,098	24.5	417	4.9			766	9.0	5,263	61.6	8,544	100
Sequoia:												
1916			490	29.0			600	35.5	600	35.5	1,690	100
1920			520	30.8			580	34.3	590	34.9	1,690	100

From what has been said before in regard to securing reproduction after cutting, this result might be anticipated. The composition of the new stand is predetermined in the advance growth, which in general resembles the original stand. The single cutting possible resulted in only slight modifications in composition. Doubtless heavier cutting than took place on most of these sale areas would have favored the pines in the small amount of reproduction which actually did come in, because both shade and litter may be so heavy as to exclude sugar and yellow pines where incense cedar and white fir come in abundantly.

Another reason for this failure to secure the expected change in composition was that early markers did not give sufficient consideration to the natural succession of tree species. Where natural conditions of site favor white fir, which is generally true of Sites I and II on north and east slopes, this species is destined to succeed yellow pine unless the normal succession is disturbed by fire or other accidents. Fir seeds more abundantly than pine germinate under stands of yellow pine, whose litter and shade exclude their own seedlings, and the young trees endure suppression longer. Moreover, height growth of fir is more rapid, and the total height attained is greater than for yellow pine. In the past occasional fires have been primarily responsible for sustaining yellow pine on fir sites. Fir seedlings and young trees are far more susceptible to fire damage than the pine because of their thinner bark with balsam cysts, more inflammable foliage, and small resinous terminal buds which are far less resistant than those of yellow pine. The fir is more often eliminated by fungi entering through fire scars than is pine. Exposure of mineral soil and openings created by fire favor yellow pine. Striking examples of the succession of white fir with fire exclusion may be seen in many places, notably on the Lassen National Forest, where the mature stand is composed of practically pure yellow pine, while the reproduction beneath it is over 90 per cent white fir.

Although incense cedar reproduces abundantly under the same conditions as white fir and is equally or more tolerant, its slow height growth prevents it from becoming anything but a secondary species in the final stands.

Leaving out of consideration, for the present, the possibility of using fire to maintain pine in the stands as inefficient and wasteful if practicable at all, there remain open only two courses—fir must be accepted on fir sites or planting of other species must be resorted to. The first course is the only one regarded as feasible at present, and from what has been said about growth and the trend of market conditions for possible fir products, it is not at all discouraging.

Under certain conditions, not uncommon, planting may be not only the logical but the most economical method, in the long run, for the Government. On Sites I and II, where rotations would be less than 75 years, planting would result in a yield of 50,000 board feet or more per acre of desirable species. Where advance reproduction is deficient and young trees for reserves are few, clear cutting could be practiced, permitting logging to proceed as cheaply as possible, destroying inferior trees and brush, and concentrating slash in piles and rows, thus obviating expensive brush disposal. Areas treated in this way could be planted successfully for $15 per acre.

Present methods of securing natural reproduction on the national forests involve leaving at least 5 seed trees, averaging 20 inches in diameter, per acre, an investment of about $8. The interest on this amount is chargeable to the final crop, provided the trees themselves survive. Additional cost of logging to protect seed trees and advance growth is roughly 75 cents per thousand for slash piling and burning, snag disposal, and additional blocks, bushing, etc., to protect trees from lines, or, for a cut of 20,000 board feet, about $15 per acre. These costs are really borne by the Government in reduced stumpage rates. Natural reproduction, as compared with planting, will increase the rotation by 10 or more years. Comparing the two methods on a financial basis, disregarding taxes and administrative charges, and using the same rate of interest in each case for the respective rotations, the ultimate costs are much in favor of planting. At present the planting of such areas is inconsistent with the nationwide policy of the Forest Service which gives first consideration to completely denuded areas where lack of seed trees makes even slow natural regeneration impossible and to areas where rapid growth and good markets will insure quickest returns.

SUMMARY.

Site is the most important factor in the growth of stands left after cutting. On Sites I and II a reserve volume of 6,000 to 10,000 feet board measure is justified for increased growth and improved quality of second cut. By proper selection of reserves a net growth of 2½ to 3 per cent annually can be maintained for at least 10 years after cutting. On Site III, or poorer, silvicultural considerations indicate marking aimed to secure reproduction. Other considerations, however, do not permit the uniform application of these principles.

White fir ranks first in rate of growth, followed by sugar pine, Douglas fir, yellow pine, and incense cedar. Sugar pine maintains a high rate of growth to a greater age or diameter limit than the other species. On Site II, or better, indicated diameter limits are roughly 30 inches for sugar pine, 26 inches for yellow pine, and 24 inches for white fir and incense cedar. Corresponding ages range from 150 to 200 years in present stands.

In selecting trees to reserve for increased growth the best results will be obtained from trees free from defects, with the color and texture of bark characteristic of immaturity, pointed tops, dense dark green foliage, and crown length equal to 60 per cent or more of the total height.

Leaving trees in groups neutralizes the effects of cutting and discriminates against pine reproduction.

The greatest response to cutting can only be secured by heavy marking, proper distribution, and careful selection of reserves according to the foregoing statements. Response is greater and more prompt on good sites and where cutting frees both root and crown.

The net rate of volume increment for stands averaging about 15,000 board feet per acre for Sites I to III has been from 53 to 470 board feet per acre annually, or 0.34 to 3.46 per cent. Loss by death has averaged 0.37 per cent annually.

Except on Sites I and II, in 10 years' time there has been no appreciable increase in the amount of reproduction on early sale areas cut over lightly by the group selection and shelterwood methods. A regeneration period of from 5 to 10 years on Site I and of 20 or more years on Site III may be expected.

The favoring of yellow pine and sugar pine by leaving abundant seed trees of these species and marking white fir and incense cedar closely has resulted in no change in composition, because few new seedlings of any kind have come in; there always remain enough unmerchantable firs and cedars to supply abundant seed; light cutting, heavy litter, brush, and ground cover favor fir and cedar; and on certain sites, if fire or heavy cutting are excluded, fir naturally succeeds pine.

Attempts to control brush and ground cover by marking methods without eradication or planting are not successful, because the natural stands are already sufficiently open to permit survival of many shrubs where yellow-pine reproduction is excluded. Cutting of any kind favors extension of the brush. With fire protection, suppression of such shrubs depends, for the present, on the slow process of competition by which the brush is overtopped by the tree seedlings, especially those of white fir.

Marking designed to promote natural regeneration should give primary consideration to existing advance reproduction. Cutting should be as heavy as management restrictions allow in order to release it. Every precaution should be taken in felling, yarding, and brush burning to preserve it. Its presence will shorten the rotation 5 to 20 years or more.

Brush disposal by piling and burning results in covering by fire at least 6 to 10 per cent of the area, on which a considerable number of seedlings and saplings are destroyed, and costs from $8 to $10 per acre. Leaving slash rarely induces insect infestation. Cleared control lines with intensive protection may ultimately supersede piling and burning of slash.

The best advance reproduction in nature has occurred under conditions resembling a shelterwood system. When reproduction is absent and the stand essentially even-aged, a heavy shelterwood, or a seed-tree cutting, leaving numerous well-distributed seed trees preferably larger than 18 inches, will combine the most favorable conditions for improved growth and reproduction. In irregular stands a heavy selection cutting, removing 75 to 80 per cent of the volume, and avoiding grouping of the reserved trees as much as possible, promises to give the best silvicultural results. Each acre is a problem in itself and much depends on the marker's ability to recognize the character of the site, the mature stand and reproduction requirements, and to apply the right silvicultural principles as a part of the broad marking policy by which he is guided.

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