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EFFECTS OF INITIAL STOCKING ON FINANCIAL RETURN FROM YOUNG-GROWTH DOUGLAS-FIR

RUDOLF F. GRAH

UNIVERSITY OF CALIFORNIA · BERKELEY, CALIFORNIA

Understocking of commercial Douglas-fir stands may markedly reduce financial return. The experiment reported herein was designed to study the effects of initial understocking, to analyze them within a financial framework, and to provide guides for the economic management of young-growth Douglas-fir stands. Four model stands at initial stocking rates of 25, 50, 75, and 100 per cent of normal stand values formed the basis of the experiment. Results were as follows:

Difference in total physical output between initially understocked and fully-stocked stands is minor, but quality of output, as measured by sawmill and peeler logs, is much lower in the understocked stands. Maximum reductions in net income and soil expectation values (at 3 per cent interest) were $612 and $44 per acre, respectively, for stands of low initial stocking.

Pruning and planting (at 3 per cent) are feasible means of eliminating or reducing the quality differential on some stands and sites. However, the level of profitability varies between stocking and site, and is highest on fully-stocked, highest-site lands. Thus, where funds for management inputs are limited, they should be allocated first to stands of high initial stocking and best sites.

When the interest rate was figured at 5 per cent, it was found that natural stands of the initial stocking levels and sites studied here can be profitably operated at that rate.

Under the 5 per cent rate, maximum soil expectation values were reduced substantially, and rotation ages were shortened. In addition, there was little difference in soil expectation values between the initially understocked and fully-stocked stands. This indicates that, within biological limits, stocking is not the important factor in economic success of a forest enterprise operating at a 5 per cent rate of return that it is under a 3 per cent rate. These conclusions would indicate that a "do-nothing" policy with respect to fill-in planting and pruning is the most profitable one. However, it is recognized that this is indicated only under conditions where stumpage values do not increase commensurate with interest rates.

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INTRODUCTION

INITIAL STOCKING is a production factor over which the forest manager has a measure of control. This, plus a knowledge of effects of various management practices, enables him to manipulate stocking to meet specific management objectives. Decisions made during this period of initial stocking may affect the ultimate profitability of a forest enterprise. The forest manager must decide what constitutes an adequate stand, and must also plan for the desired amount of new stocking (regeneration) following harvest of the mature stand. The latter may be done by site preparation for natural regeneration, by reseeding or planting, or by a combination of treatments. Each requires substantial investment of resources which, within a framework of even-aged forest management, will not be returned until the first commercial harvest many years hence.

Because understocking of young, even-aged stands is a common problem on the commercial forest lands of the West, much research and field practice have sought means of bringing understocked stands to an optimum or desirable initial stocking level. Unfortunately, what "optimum" or "desirable" stocking levels really are, and what means are economically feasible for achieving such levels, have not been determined for the commercially important Douglas-fir forest type.

The present study was designed to develop a framework within which the stocking levels could be evaluated in quantitative terms, and their effect on the profitability of the enterprise could be analyzed. The objective was to determine desirable density of initial stocking and to evaluate the practices designed to correct deficiencies in initial stocking.

STOCKING IN FOREST MANAGEMENT

The term stocking, as used in forest management, means the amount of growing stock, that is, living trees present on a forest area. Initial stocking

[1] Submitted for publication May 19, 1959.

[2] Lecturer in Forestry and Specialist in Forestry in the Experiment Station, Berkeley.

is the growing stock in the form of seedlings and saplings which have become established on an area following the complete harvesting of the previous stand. Stocking measurements used depend on the product in mind, and include numbers of trees, wood volume, and basal area per acre. Trees in young stands in the initial stages of restocking are too small to be measured in wood volume or basal area terms; thus stocking at this stage of stand development is commonly expressed in terms of numbers of well-distributed trees per acre that have potential for development into crop trees.

Any given forest site provides a certain amount of resource for tree growth. If this resource is to be used fully, the site must contain a certain minimum number of trees per acre. Below this minimum, the site is not fully utilized; above it, the number of trees that can fully occupy the site covers a wide range. Within that range, a relatively few trees may produce the same total volume, at a specific age, as would a larger number.

The key to obtaining full utilization of the site, therefore, is to have sufficient growing stock so that each tree has room to grow but none to waste. Both understocking and overstocking are problems in forest management, but since the former is by far the most common in very young stands, it is the only one considered in this study.

The recognition of initial stocking deficiencies is a critical matter because stocking establishes the quality and quantity output pattern of a stand for a major portion of its life. Furthermore, it is during the period of initial stand development that the forest manager has the best opportunity to correct deficiencies by cultural practices.

GENERAL EFFECTS OF INITIAL UNDERSTOCKING ON WOOD QUALITY

The major physical effects of initial understocking are: (1) a possible reduction in volume output due to incomplete occupancy of the site; and (2) a reduction in the quality of the output due to excessively wide annual rings and large knot size caused by the wide spacing between trees. The first possibility is obvious; the second, less so. Baker (1953)[3] in a study of 30-year-old Ponderosa pine in California, found stands with 130 trees per acre exhibiting essentially the same volume in cubic feet as stands with 2,000 trees per acre. One important difference between the stands was apparent: the mean diameter of trees on the openly-stocked stands was 7.7 inches, while that of the closely-stocked stands was 4.3 inches. Baker concluded: "Growth in a biological sense is not much affected by common densities (number of trees per acre) but in an economic sense it is profoundly so affected."

Since diameter is one measure of quality, it might be concluded that, within limits, openly-stocked stands not only can produce as much volume as heavily-stocked stands, but also have some quality advantages. However, diameter is not the sole measure of quality. Other factors, such as growth rate, and size and distribution of knots, are recognized as equally important determinants of quality, and when these are considered, the relationship between initial understocking and quality is reversed.

[3] See "Literature Cited" for citations referred to in the text by author and date.

The initial density of the stand in which a tree is grown has a direct influence on the size of knots. It is known that openly-grown trees, for example, those grown in stands of low stocking, produce larger limbs than do trees in dense stands. When crown closure takes place in the stand, reduced light causes death of the branch. Thus, knot size does not increase. The earlier crown closure takes place, the smaller will be the knots, and early crown closure is characteristic of densely-stocked stands.

Understocking further affects quality of wood produced by influencing diameter growth rate of individual trees. Openly-stocked trees have a more rapid diameter growth rate than closely-stocked trees. While rapid diameter growth rate is desirable from a volume production viewpoint, it may adversely affect quality by reducing strength of the wood. Brown, Panshin, and Forsaith (1949) indicate that strength properties of wood are related to its specific gravity, and specific gravity is dependent on the density of wood substance. Density, in turn, is closely related to the ratio of summerwood to springwood in the annual rings. Normally, summerwood is two or more times as dense as the springwood portion; thus wood with a high portion of summerwood in the annual ring has a higher specific gravity. Gross correlation between specific gravity and growth rate, expressed as number of rings per inch, has indicated that fast-grown conifers have less summerwood and lower specific gravity than do slow-grown woods (Drow, 1957).

Wood from fast-grown trees tends to shrink and warp excessively during the drying of manufactured products. Such wood is therefore degraded and reduced in value. Paul (1955) has indicated that wide rings adversely affect the general appearance of wood, and that this wood does not hold paint so well as does narrow-ringed stock. Fast-grown wood is not highly suitable for face veneer in plywood, a major use of Douglas-fir. Fleischer (1949) reported that among the problems associated with using fast-growth Douglas-fir for veneer were the coarse grain characteristics and large, dead knots.

Since fast-grown wood tends to have lower density than slower-grown wood, and thus less cellulose content, there are disadvantages in using it for the manufacture of wood pulp. Paul (1947) has shown that, in fast-growing Douglas-firs, the wood density is lower than in the slow-growing ones, and the expected paper yield is less.

Thus, while total resources of a growing site can be fully utilized within a wide range of stocking densities, the total volume output of stands within this range may vary only slightly. On the other hand, differences in wood quality between densely-stocked and openly-stocked stands may be great—a factor responsible for the major effect of initial stocking on the financial yield of young-growth Douglas-fir stands.

MATERIALS AND METHODS

In quantifying the effects of initial understocking, physical production functions were established, reflecting volume and quality differences between initially fully-stocked and understocked stands. Monetary values were placed on these functions, costs of production were deducted, and present net values compared. Differences in values, resulting from differences in initial stocking rate, were used in the economic analysis, and inferences were drawn from this evidence relative to the management of young Douglas-fir (*Psuedotsuga menziesii* [Mirb.] Franco) stands of the Pacific Douglas-fir forest type (Society of American Foresters, 1954). Inputs of pruning and planting were made, and their influence in modifying the effects of initial understocking was studied. The results are expressed in both physical and monetary terms, and the relative effectiveness of the two methods is based on the differences in value.

A series of models of forest stands were developed to reflect conditions and behavior of natural stands, but controlled so that initial stocking was a principal independent input variable. Models represented various levels of initial stocking which could be projected forward in time according to patterns established by studies of natural stands. The management objective of these hypothetical stands was assumed to be the production of sawmill and peeler logs for the lumber and plywood industries. Thus, for each model, volumes of wood produced in each major quality category pertinent to sawmill and peeler log grades were calculated at each significant period of time, and the current value of this wood was derived.

Initial Stocking of Model Stands

Since most initial stocking problems of Douglas-fir are associated with understocking, the models were designed to provide full representation of the lower stocking ranges.

The measure of initial stocking used in establishing the models was the number of well-distributed trees per acre with potential for development into "crop" trees available for harvest at the end of a rotation. This concept is based on the "stocked quadrat" method of measuring regeneration on the ground—a measure directly related to numbers of trees on the ground. The method has been widely used, in sampling and evaluating Douglas-fir regeneration, by Cowlin (1932), Isaac (1943), Bever (1949, 1952, 1954) and by Lavender, Bergman, and Calvin (1956). Barnes (1949) has shown that stocked quadrats, as used in the Oregon State Board of Forestry regeneration survey system (Bever, 1949), can be reliably converted to numbers of trees per acre.

The numbers of trees included in each initial stocking level model were based on recommendations for regeneration used in planting and reseeding operations in the Douglas-fir region, and on standards set up by state governments for determining adequacy of regeneration in compliance with state forest laws.

Initial stocking values from 300 to 2,700 trees per acre have been considered as the over-all range pertinent to the growing of Douglas-fir timber crops (Douglas-fir Second-growth Management Committee, 1947; Oregon State Board of Forestry, 1946; Eversole, 1955). In constructing the models, stocking of 2,700 trees per acre was rejected since this is obviously more than any currently accepted goal. Furthermore, 300 trees per acre was considered too high to provide good representation of very low initial stocking conditions such as encountered in field surveys of regenerating stands (Bever, 1949). Reasonable coverage of pertinent ranges of initial stocking can be obtained by confining the ranges to between 100 and 600 trees per acre, judged at 20 years, the beginning age for the model stands.

Four models were established to represent: (1) a fully-stocked stand (normal yield table standards); (2) an understocked stand with minimum stocking within the range considered significant; (3) and (4) two intermediate levels to cover the range in relatively small, discrete steps. For consistency, ranges of initial stocking levels were established by setting each as a rounded percentage of the Douglas-fir normal yield table value (McArdle and Meyer, 1949) for 20-year-old stands. On this basis, the number of trees per acre in the fully-stocked model at age 20 was established at 100 per cent of the yield table value at that age, or 571 trees per acre. The next level lower was established at 75 per cent of the yield table value, 428 trees per acre. The next two steps were set at 50 and 25 per cent, 286 and 143 trees per acre, respectively.

The following designations were given the models:

MODEL	INITIAL STOCKING	RELATIONSHIP TO NORMAL YIELD TABLE VALUE*	NUMBER OF TREES PER ACRE
		per cent	
A	full	100	571
B	good	75	426
C	fair	50	286
D	poor	25	143

The above values for numbers of trees per acre were established using site 200 in the yield tables as the fully-stocked base for the models since this compares favorably with generally accepted, satisfactory stocking levels at this age. Three sites (140, 170, and 200) were used in the analysis, and the basic initial stocking pattern was applied to each. While this is at variance with the number of trees per acre shown in the normal yield tables for sites 140 and 170, the use of the above-mentioned numbers is more in keeping with currently acceptable stocking levels for recently regenerated stands.

VOLUME PRODUCTIVITY OF MODEL STANDS

Financial analysis of the effect of initial stocking on yields of Douglas-fir is based on determination of volume output from the model stands. In the subsequent analysis, relationships were obtained between basal area and number of trees per acre for each model. These data were projected forward in time according to established patterns of approach toward normality, and then converted to average stand diameter which, in turn, was used as the basis for construction of stand tables. Height and form factors were combined with the stand table data to obtain volumes by model and site class.

Basal Area-Numbers of Trees Relationships. To provide the essential relationships between basal area and number of trees at the initial age for each stocking model, field studies were undertaken in Humboldt County, California. The stands studied were natural Douglas-fir, 18 to 23 years of age, occurring on the eastern edge of the redwood belt. The young stands

*Normal yield table value for number of trees per acre, site 200.

and the surrounding areas of virgin timber were judged to be typically Pacific Douglas-fir type (Society of American Foresters, 1954).

Stands measured covered a wide range of stocking values as expressed by numbers of trees per acre. The stands of low stocking were invaded to a limited extent by tanbark oak and madrone, which are common hardwood associates of Douglas-fir in the southern part of its range. The Douglas-firs, however, were dominant over the hardwoods, and had developed full crowns over the latter species. It was assumed that volume production of the Douglas-fir was unaffected by the hardwoods present.

Field measurements were taken on 19 circular plots varying from 1/10 to 1/40 acre in size and covering a range of stocking levels from 20 to over 100 per cent of normal, based on numbers of trees at age 20.

Since the ages of these stands varied from the 20 years used in this analysis, current age was converted to 20 years by adjustment according to the diameter growth rate prevailing during the five years before measurement. These values were added to or subtracted from the current diameter measurement as appropriate.

The scope and amount of data collected for this analysis were restricted to a minimum considered necessary to indicate the relationship between numbers of trees and basal area. The relationships obtained were not considered definitive for the Douglas-fir type as a whole. However, they compared reasonably well with other limited data available, and were used in development of the models.

Diameter measurements were converted to square feet of basal area per tree at breast height, and were summed to obtain total basal area per plot. This, in turn, was expanded to basal area per acre by applying the plot multiplier. Values obtained were plotted on cross-section paper against number of trees per acre as determined from the individual plots. Curves were fitted through the points, and balanced. Figure 1 shows the relationships obtained.

Average total basal area values (in square feet) for each stocking model and site class used in subsequent calculations were read directly from the curves, and are arranged in table 1.

Approach Toward Normality. The foregoing constituted the basic stand data on basal area and numbers of trees for models at the initial age of analysis. These had to be projected forward in time so that stand characteristics could be summarized by 10-year time increments to the ultimate rotation age selected. This was achieved by applying approach-toward-normality data obtained from studies of natural Douglas-fir stands by Briegleb (1942). Briegleb's studies consisted of analyses of measurements taken at five-year intervals on stands 24 to 93 years old and ranging in stocking normality from 24 to 131 per cent of normal yield table standards. He derived regression equations for approach toward normality for several measures of stocking, and statistical measures of reliability showed equations for numbers of trees and basal area to be significant at the 0.01 level. The correlation between change in stocking in board feet, Scribner Rule, was not significant at an acceptable level. None of the coefficients relating age, site index, and normality percentage to change in stocking was significant.

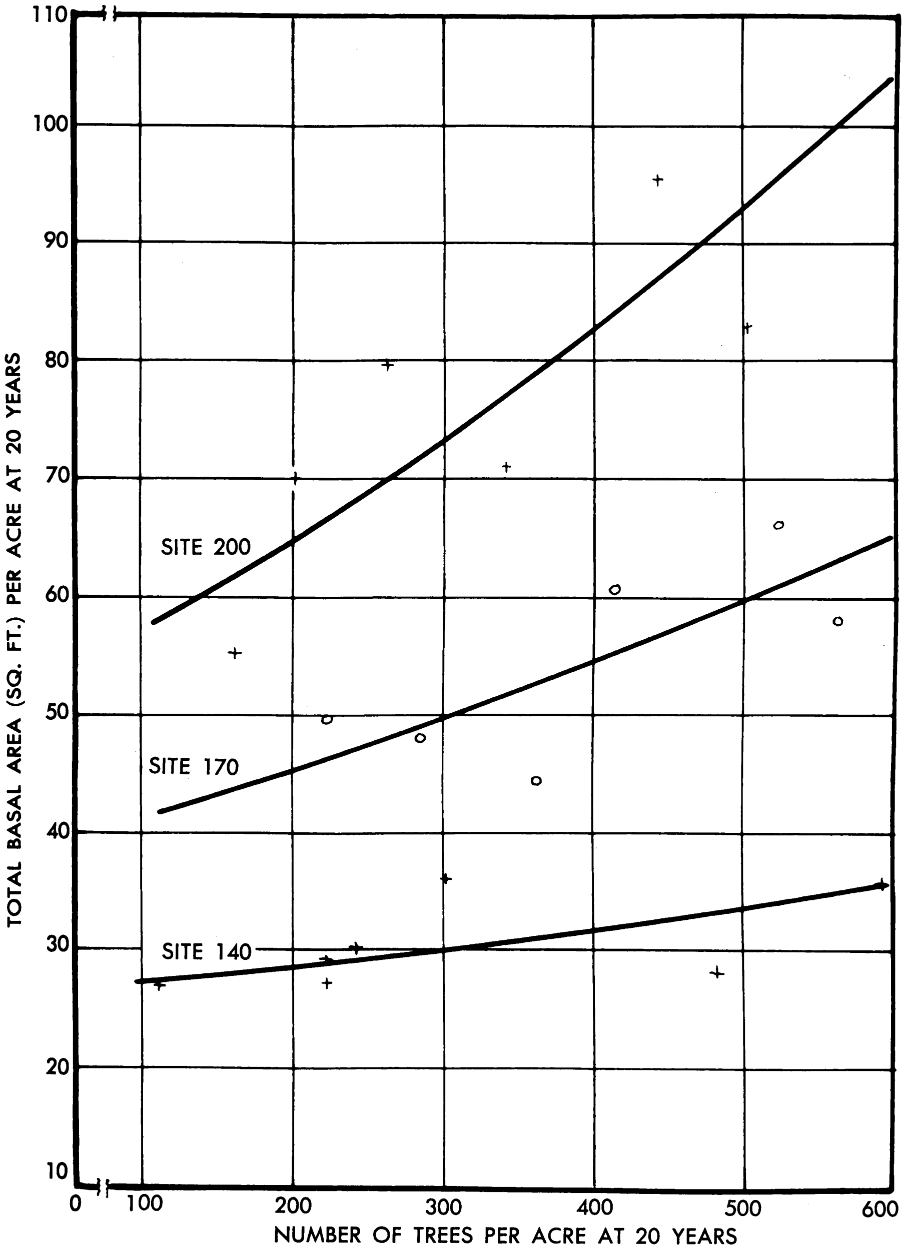

Fig. 1. Relationship between basal area and number of trees per acre.

TABLE 1

BASAL AREA AND NUMBER OF TREES PER ACRE AT AGE 20 YEARS BY SITE AND STOCKING MODEL

Stocking model	Basal area per acre (sq. ft.)	Number of trees per acre
Site 200		
A	101	571
B	87	428
C	72	286
D	61	143
Site 170		
A	63	571
B	56	428
C	50	286
D	43	143
Site 140		
A	36	571
B	32	428
C	30	286
D	28	143

Briegleb's equations for numbers of trees and basal area are directly applicable for the estimation of normality change in the models. They are as follows:

Numbers of trees: $Y = 15.94 - 0.121x_1 - 0.091x_2$

Where: Y = five-year change in normality percentage with respect to numbers of trees per acre;

x_1 = age of stand at beginning of five-year period; and

x_2 = normality percentage of stand at beginning of five-year period.

Basal area: $Y = 23.45 - 0.146x_1 - 0.145x_2$

Where: Y = five-year change in normality percentage with respect to total basal area per acre;

x_1 = age of stand at beginning of five-year period; and

x_2 = normality percentage of stand at beginning of five-year period.

The basal area and numbers of trees data in table 2 were converted to normality percentage using values in the normal yield tables as the percentage base. These initial percentages were then fitted into the equations, and the change for the ensuing five-year period was calculated. Initial normality was then corrected by the amount of this change, and the latter value was fitted back into the equation for the calculation of change during the next period. Values were obtained in this manner for successive five-year periods up to 100 years, and normality percentage values at the end of each period were converted directly to absolute values of numbers of trees and basal

TABLE 2

TOTAL NUMBER OF TREES AND BASAL AREA (SQUARE FEET) PER ACRE IN MODEL STANDS AT VARIOUS AGES

Age (years)	Model A		Model B		Model C		Model D	
	Total trees	Basal area	Total trees	Basal area	Total trees	Basal area	Total trees	Basal area
Site 200								
20	571	101	428	87	286	72	143	61
30	378	169	308	154	234	142	161	125
40	269	224	228	211	187	199	146	183
50	199	260	174	249	150	237	125	226
60	155	283	138	273	123	265	106	253
70	122	292	112	287	101	281	89	273
80	100	296	92	291	84	285	77	279
90	81	290	76	287	71	284	65	278
100	68	278	62	275	59	271	56	268
Site 170								
20	571	63	428	56	286	50	143	43
30	378	128	308	119	234	113	161	105
40	269	183	228	174	187	168	146	161
50	199	224	174	215	150	210	125	204
60	155	251	138	246	123	241	106	236
70	122	268	112	263	101	260	89	255
80	100	273	92	276	84	268	77	265
90	81	270	76	270	71	267	65	264
100	68	263	62	260	59	260	56	257
Site 140								
20	571	36	428	32	286	30	143	28
30	378	92	308	88	234	85	161	83
40	269	147	228	143	187	142	146	138
50	199	190	174	186	150	184	125	181
60	155	219	138	217	123	215	106	212
70	122	237	112	234	101	234	89	234
80	100	246	92	243	84	243	77	243
90	81	248	76	245	71	245	65	242
100	68	241	62	238	59	238	56	235

area at the desired ages by applying these percentage values to the normal yield table values at the corresponding age. The values obtained are shown in table 2.

Average Stand Diameter. Average stand diameter was calculated using the numbers of trees and total basal area data previously obtained. Total basal area at successive 10-year periods, for each model, was divided by the number of trees in the stand at the particular age to obtain average basal area per tree. These values were converted to average stand diameter. Values obtained for all models are summarized in table 3.

As expected, average stand diameters showed an increase with a decrease in stocking level. This was the result of smaller numbers of trees occupying the site on the understocked models. Since trees tend to occupy the site as fully as possible regardless of numbers, those on the understocked models obtained a larger share of the available site resources, and thus attained larger diameter at an earlier age. The principal effect of site is a decrease of average stand diameter with lowering of site.

TABLE 3

AVERAGE STAND DIAMETER, OUTSIDE BARK, BREAST HEIGHT, TOTAL STAND

Age of stand (years)	Stocking model			
	A (inches)	B (inches)	C (inches)	D (inches)
	Site 200			
20	5.7	6.1	7.0	8.9
30	9.0	9.6	10.6	11.9
40	12.4	13.0	14.0	15.2
50	15.5	16.2	17.0	18.2
60	18.3	19.0	19.9	20.9
70	20.9	21.7	22.6	23.7
80	23.3	24.1	24.9	25.8
90	25.6	26.2	27.0	27.9
100	27.1	28.1	29.0	29.6
	Site 170			
20	4.5	4.9	5.7	7.5
30	7.9	8.4	9.4	10.9
40	11.2	11.8	12.9	14.2
50	14.3	15.1	16.0	17.3
60	17.2	18.1	19.0	20.2
70	20.1	20.7	22.4	22.9
80	22.4	23.5	24.2	25.1
90	24.6	25.5	26.3	27.3
100	26.6	27.7	28.4	29.0
	Site 140			
20	3.4	3.7	4.4	6.0
30	6.7	7.2	8.2	9.7
40	10.0	10.7	11.8	13.2
50	13.2	14.0	15.0	16.3
60	16.1	17.0	17.9	19.1
70	18.9	19.5	20.6	22.0
80	21.2	22.0	23.0	24.1
90	23.7	24.3	25.2	26.1
100	25.5	26.5	27.2	27.7

Stand Tables. Stand tables were constructed, employing alignment chart methods. The values obtained provided the information on diameter and number of trees needed for final calculation of volume. (Stand tables are equally important in the analysis of quality characteristics of model stands which are related to the distribution of diameters within the stands.)

The alignment chart developed by L. H. Reinecke and reported by McArdle and Meyer (1949) in the Douglas-fir yield tables was used for stand table construction.

The application of Reinecke's alignment chart in stand table construction involves the use of average stand diameter (from basal area) and the lower diameter limit of the particular diameter group employed. Average diameter by basal area in 2-inch diameter classes was obtained directly from the calculations in the preceding section (table 3). The alignment chart provided percentage distribution of the total number of trees at the particular age and stocking model in each diameter class. This distribution was converted to absolute numbers by applying the percentage to the total number of trees in the stand.

TABLE 4

DISTRIBUTION OF TREES PER ACRE BY DIAMETER GROUP AND STOCKING MODEL, AGE 80

Diameter group (inches)	Stocking model							
	A		B		C		D	
	Number trees	Per cent	Number trees	Per cent	Number trees	Per cent	Number trees	Per cent
				Site 200				
10-20	34	34.0	28	30.4	24	28.6	20	26.0
20-30	50	50.0	46	50.0	42	50.0	36	46.7
30-40	16	16.0	18	19.6	18	21.4	19	24.7
40 plus	..	....	..	....	..	....	2	2.6
				Site 170				
10-20	38	38.0	31	33.6	25	29.8	22	28.6
20-30	51	51.0	45	49.0	42	50.0	37	48.0
30-40	11	11.0	16	17.4	17	20.2	18	23.4
40 plus	..	....	..	....	..	....	..	....
				Site 140				
10-20	45	45.0	38	41.4	29	34.5	23	29.9
20-30	47	47.0	44	47.8	43	51.2	40	51.9
30-40	8	8.0	10	10.8	12	14.3	14	18.2
40 plus	..	....	..	....	..	....	..	....

A summary of the stand tables is presented in table 4 in the form of a comparison of distribution of trees by diameter classes for each model and site class at age 80. A pattern of the characteristic effects of understocking on diameter distribution is apparent from this comparison. For example, in the 10- to 20-inch class, the percentage of trees in the class decreases with decrease of initial stocking levels, while in the 30-inch and over class, the percentage increases with the decrease in initial stocking. The intermediate diameter group represented by the 20- to 30-inch diameter classes shows no marked change with initial stocking level.

Volume Yield Tables. Elements necessary for final determination of volume yield are numbers of trees, diameters, tree height, and form class. Values for numbers of trees and diameters were derived as described in the previous section. Tree heights were obtained from Meyer's (1936) height curves for even-aged Douglas-fir stands.

A difference in bole form of trees developing in understocked stands as compared with those in fully-stocked stands is generally well recognized. Open-grown trees taper more than do closely-grown trees. Tree form also changes with age, as shown by Smith (1956*a*) who reported form changes over a 40- to 50-year period in Douglas-fir in British Columbia. The changes were variable in amount, but, with one exception, the trend was from lower to higher form class with increasing age.

Girard form class for 16-foot logs (Girard and Bruce, no date) is a common measure of tree form employed in the Douglas-fir region, and applicable to volume determination for the model stands. The figures below are based on unpublished information from the Forest Survey of the California Forest and Range Experiment Station and a general range of volumes reported by Girard and Bruce. These values were used in subsequent volume determinations.

DBH OUTSIDE BARK	GIRARD FORM CLASS	
	MODELS A AND B	MODELS C AND D
inches		
12	0.75	0.68
14	0.77	0.70
16	0.78	0.71
18	0.79	0.72
20	0.79	0.72
22	0.79	0.72
24	0.79	0.72
26	0.79	0.72
28	0.79	0.72
30	0.79	0.72
32	0.80	0.73
34	0.80	0.73
36	0.80	0.73
38	0.80	0.73
40	0.80	0.73
42	0.80	0.73
44	0.80	0.73

The figures above allow for variation in form class with changes in initial stocking as well as changes associated with diameter class. The latter also accounts for variation in form class with stand age by reason of the close relationship between age and diameter in any stocking class group. Values in the table increase with both stocking and age (as expressed by diameter). This change is expected as the stands of low initial stocking approach the fully-stocked condition, and mechanical stresses, which account for increased

TABLE 5

YIELD PER ACRE OF TREES 12 INCHES IN DIAMETER (BREAST HEIGHT) AND LARGER, BY STOCKING MODEL AND SITE

Age (years)	Volume (board feet, Scribner Rule)			
	Stocking model			
	A	B	C	D
Site 200				
20	0	0	0	1,100
30	6,700	9,400	11,700	15,500
40	34,300	35,000	35,400	36,500
50	59,000	58,400	56,600	55,500
60	79,800	78,200	75,700	72,700
70	94,000	92,500	90,000	86,800
80	102,400	101,000	99,200	96,700
90	107,000	105,800	104,500	102,700
100	109,200	108,200	107,300	105,800
Site 170				
20	0	0	0	200
30	2,000	4,000	6,400	8,400
40	19,200	21,000	22,700	25,000
50	41,600	42,600	43,600	44,500
60	57,700	58,800	59,700	60,300
70	71,800	71,500	71,300	71,100
80	81,500	80,500	79,800	79,200
90	85,600	85,000	84,500	84,000
100	88,500	87,200	86,300	85,500
Site 140				
20	0	0	0	0
30	0	600	2,100	4,100
40	9,400	11,000	14,000	17,000
50	24,800	26,300	29,000	30,600
60	40,000	40,500	41,200	41,700
70	50,100	50,000	50,800	50,700
80	58,400	58,100	57,900	57,700
90	61,700	61,400	61,000	60,700
100	62,700	62,100	61,600	61,000

taper in lower logs, are spread more evenly over the bole. The possible variation of form class with site was assumed to be unimportant over the sites considered.

Board-foot volumes (Scribner Rule) for trees 12 inches in diameter and larger were calculated by arranging the stand table information for each 10-year period, from 20 to 100 years, alongside information on merchantable heights in logs, Girard form class for the particular stocking level and diameter class, and numbers of trees in the diameter class. Volumes were obtained for each 2-inch diameter class from form class volume tables (Bruce and Girard, no date). These were multiplied by the number of trees in the

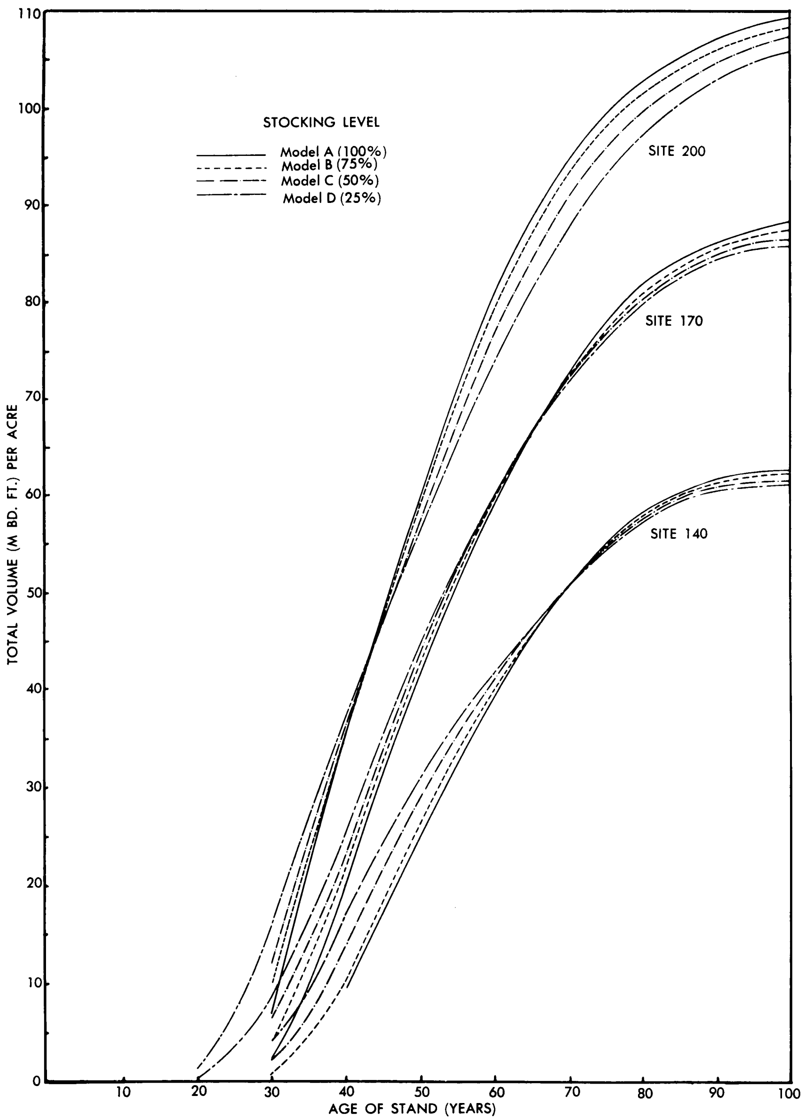

Fig. 2. Yield (thousand board feet per acre, Scribner Rule) as a function of age of stand. Trees 12 inches and larger.

class and summed by 10-year stand-age periods for each site and stocking level model.

The total volumes at each age were plotted on cross-section paper, and freehand average curves were fitted through the points. Average volume yield at each age, stocking model, and site class was read directly from these average curves to the nearest 100 board feet. Volumes derived are arranged in table 5; the resulting average curves are shown in figure 2.

The yield curves describe a typical growth function. They appear in site class groups, with the better sites showing higher volumes at all ages. With respect to stocking level, the stands of low initial stocking show the highest volume at early ages and a reversal of position at later ages.

Stands of low initial stocking show a volume advantage in the early years principally because the Scribner Log Rule is used for volume determination of trees 12 inches or more in diameter, breast height (dbh), and it employs board feet as the unit of measure. As indicated previously, the stands of low initial stocking reach merchantable diameter (12 inches dbh) sooner than the fully-stocked ones, and thus show board-foot volume sooner. This apparent anomaly of higher volume in the stands of low initial stocking is reversed between the ages of 40 and 70 years, depending on site, and thereafter, stands of high initial stocking show higher volumes. This reversal of position shows a relationship to site, with the better sites having an earlier age of reversal than the poorer ones. This, of course, is related to diameter growth rate which is most rapid on the better sites, where a larger portion of the trees reaches measurable size at a young age.

While a difference in total volume exists between stocking levels, the matter of primary interest is the virtual equality of yield between the stands of full initial stocking and those of low initial stocking. This situation indicates that low initial stocking within the limits considered here has very little, if any, effect on board-foot volume yields beyond the fortieth and sixty-fifth years, depending on site, and agrees with preliminary findings of Baker (1953) in ponderosa pine as well as with statements by others, such as Hawley and Smith (1954), that stand density, within reasonable limits, does not affect total net yield.

Evaluation of Volume Yields from Model Stands. The shape of the yield curves and the volume yields obtained were compared, for evaluation purposes, with curves and values for similar sites in the normal yield tables. It is recognized that yields obtained from understocked stands do not necessarily bear any close relationship to the normal yield table values. However, since normal yield table values constitute the only widely recognized and available data of this nature, they serve in a general way as a base for comparison.

While shapes of the yield curves derived here (fig. 2) are similar to those of the normal yield curves for Douglas-fir, a difference exists in the level of the yields for model stands between ages of 30 and 70 years, where they exceed the normal yield table curves. Additional differences are evident in the 90- to 100-year period, where model-stand curves fall below values of the normal curves. These variations from the normal curves are due primarily to the characteristics of the stands as measured by Briegleb and reflected in the regression equations used to derive the basic data upon which model-stand curves are based.

In the paper presenting the regression equations, Briegleb (1942) referred to the variance to be expected when using his equations instead of the yield-table values in predicting yield. In this regard, he cited Meyer's (1933) observations that the Douglas-fir yield tables tend to underestimate full stocking. Although calculations were not reported, Briegleb anticipated such a departure in the following:

> . . . . it now appears that for younger age classes (younger than 60 years) the published tables represent an even smaller proportion of full stocking, while for stands 70 years and older they represent overstocking. . . . Forty to 60 year old Douglas-fir is commonly found fully stocked or overstocked on areas of several thousand acres, or more, but at 100 years of age the chances are these areas will be, on the average, less than fully stocked. However, they will in all probability then contain numerous fully stocked acres such as are selected for sample plots in normal yield studies. . . . In the younger age classes, however, the trend of density is quite the reverse. When Douglas-fir stands attain full stocking at 20 to 40 years, as they frequently do, the chances are their average normality percentage will move substantially above 100 during the next two to four decades.

These comments point to recognized shortcomings in the use of normal yield tables for predicting the behavior of natural stands. The basis for the objections raised here is that normal yield tables do not, in fact, represent changes that take place in any one stand. The Douglas-fir tables are based on temporary plots considered to be fully stocked on the basis of the investigator's judgment. No remeasurements of the plots used were included in the values to reflect changes that normally take place in a stand; the assumption is that a fully-stocked stand at one age will remain fully stocked at all subsequent ages. Briegleb, on the other hand, has shown by remeasurement of permanent plots that substantial changes in normality do take place with time, and these values are reflected in the regression equations he derived.

These observations partially account for the lower volumes in the model stands between ages 90 and 100. However, they do not provide reasonable answers to the distinct leveling off of the volume curves in the last decade. If the trends of the volume curves were extended, an actual decrease in volume at ages 130 to 140 would appear. This trend does not appear realistic when compared with studies which show continued volume increase beyond these ages.

Briegleb's data do not cover these advanced ages and, since original data are lacking, it is meaningless to carry the volume projections into these ages. It is assumed, however, that the leveling-off trend of the model curves after age 90 is part of the fluctuation in volumes which Briegleb and others have described, and that yield curves would again have turned upward at some point beyond 100 if adequate data had been collected to reflect changes during those decades.

By and large, the model curves appeared to represent reasonable volume values over the period concerned in this investigation, and they were therefore used as the basic values for physical productivity in the remaining portions of the analysis.

EFFECT OF INITIAL STOCKING ON QUALITY OF OUTPUT

The results indicated in the previous section show that, if stocking standards such as those established in the models are achieved on the ground, practically full volume production capacity of the sites will be realized before such stands reach 100 years. However, it is expected that differences in quality of yield exist between stands of high initial stocking and those of low initial stocking.

The quality aspects of production related to stocking are important to Douglas-fir management especially in the light of varying recommendations or accepted standards of desirable initial stocking. What concrete differences in quality might be expected between a stand starting with 300 seedlings per acre and one starting with 600? What effect will such differences have on financial yield? And, if a substantial difference in financial yield can be expected from stocking differences of this magnitude, what are the measures to be taken, and what charges can be incurred profitably to bring stocking up to some defined level that will assure maximum financial yield? These are questions currently asked by forest managers in making decisions regarding the adequacy of regeneration goals.

Since financial yield is so closely tied to quality, as well as to the amount of physical output, detailed information is needed to evaluate the effects of stocking on quality. Current literature does not provide details as to which stand densities yield maximum volume with optimum quality for either lumber, plywood, or paper manufacture. This portion of the investigation was designed to quantify the effects of initial stocking level on quality aspects of volume production from the stands in question.

Measurable Quality Factors

The end point at which produce from the model stands will be evaluated is the log dump where a fully competitive market is assumed to exist. Thus quality factors which influence financial return from logs to be used here are those recognized in standard log grading rules. The Puget Sound Log Grading and Scaling Rules were used in applying grades to the logs from the stands under consideration here.

The principal bases for grading logs are: (1) diameter (small end); (2) length; (3) knot size, location, and soundness; (4) growth rate; (5) mechanical defects, such as checks, splits, brooming, fire scars, et cetera; and (6) such "biological" defects as rot, insect holes, off-center heart, amount of heartwood, pitch, stain, and the like. Only a limited number of these factors are directly related to the level of stocking under which the model stands were grown. Those of most importance are diameter, growth rate, and knot size. Other factors, more closely related to other biological conditions of the stand, may be distantly related to stocking, but the relationship cannot be defined nor measured with the same degree of precision as the three listed above.

In the following sections, the quality characteristics of each of the model stands are defined in numerical terms. Differences in characteristics between the initially fully-stocked and understocked stands were assumed attributable to differences in initial stocking level, and were used as the basis for economic analysis. Quality characteristics of the stands were determined by applying the three major grade determinants mentioned above: log diameter; growth rate, in terms of number of rings per inch; and knot characteristics.

Diameter. This is an important determinant of log grade because of its close relationship to the grades of lumber recovered from a given log. Most lumber grade recovery studies show that the larger the log (in diameter), the greater the percentage of valuable grades of lumber that can be cut from it. This is also true of plywood—the amount of wood turned from the log before reaching the minimum-sized core (as determined by the lathe chuck diameter) is related to log diameter. The larger the log, the greater the percentage of its total volume which can be recovered as usable veneer.

These relationships are reflected in currently used log grades which are based on lumber or veneer grade recovery from logs of various sizes and surface characteristics.

Growth Rate. An important determinant of wood quality, growth rate affects the strength and character of wood products. It is of primary concern in the manufacture of Douglas-fir for lumber, plywood veneer, and pulp. For example, standard lumber grading rules published by the West Coast Lumber Inspection Bureau (1956) classify growth rate according to "grain," and specify for dense structural material that: "There shall be an average of more than 6 annual rings per inch of which more than one-third of each ring shall consist of summerwood." Fleischer (1949) indicated that unsuitable grain resulting from too rapid growth rate, and large, dead knots, made most young-growth Douglas-fir unsuitable for face veneer. He stated: ". . . . there seems to be a fairly sharp dividing line at a growth rate of about ten to twelve rings per inch between satisfactory and unsatisfactory veneer from the standpoint of coarseness of texture." Dimock (1956), in further studies of peeler logs from pruned, young-growth Douglas-fir, indicated that such material would grade out as grade "A" while unpruned material would not rate higher than grade "C" because of the large knots and rapid growth rate. In regard to growth rate, Dimock indicated that some of the pruned trees studied that were suitable for grade "A" classification grew at the rate of seven to 10 rings per inch.

Snodgrass (1955) studied the warping of lumber cut from young-growth Douglas-fir and found a direct relationship between fast growth rate and predisposition to warp in drying when the boards (2 by 4's) were cut in portions of the log close to the pith where growth rate was five rings or less per inch.

Douglas-fir log grades reflect findings that fast-grown wood is generally of poorer quality. The higher quality log grade categories do not admit rates faster than eight rings per inch. Six rings per inch is the minimum for the lower grades. Logs with fewer than six rings per inch are classified as "fast-growth" logs (Puget Sound Log Scaling and Grading Bureau, 1954). Since many of the model stands showed very rapid diameter growth rates, it is apparent that rapid growth rate is a quality factor which must be taken into account in this analysis.

Knot Characteristics. Knots affect the strength, appearance, and other properties of lumber and plywood products. Therefore, most log grading rules take into account size, number, distribution, and soundness of knots. Logs that fail to meet the requirements with respect to these characteristics may be downgraded. The primary effects on usability are the weakening of structure through distortion of grain around live knots, and the loss of wood substance when dead knots fall out. Strength is most affected by knots when the wood is under bending stress. At that point, the effect is in proportion to the size of knot in relation to the width of the lumber piece. In lumber for millwork, such as the manufacture of doors and windows, and for interior finish, knots are undesirable both from the standpoint of the manufacturing process and the appearance of the finished product (Brown, Panshin, and Forsaith, 1949; U. S. Forest Service, 1955).

The size, number, and distribution of knots are directly related to the size, number, and spacing of the limbs on the trees from which the log is cut. The appearance of knots on the surface of the logs (the basis on which log grading is done) is dependent on the length of time the limbs remain alive, the length of time dead limbs remain on the tree, and the diameter growth rate of the tree.

In young-growth Douglas-fir plantations, Munger (1946) observed the diameter of limbs in the lower part of the bole to be progressively larger with increased width of spacing between trees. Eversole's (1955) report on 26-year-old plantations of various densities in Washington showed the average diameter of the two largest limbs on the whorl above and below breast height to be 0.36 inch on the 4 by 4-foot planting and 0.73 inch on 12 by 12-foot spacings. Data in the same study indicate the relationship between stand density and height of the live crown. On the 4 by 4-foot planting, height to the live crown was 20 feet, while on the 12 by 12-foot, it was 7 feet. This is of direct significance to log quality in that it reflects the length of life and size of limbs as related to density.

The Douglas-fir log grading rules recognize fully the effect of knot size on log quality. In general, the higher the quality of log, the smaller the knot size allowed within the grade.

Adaptation of Log Grades to Model-Stand Volumes

The assumed objective in the management of model stands was the production of sawmill and peeler logs. Specifications for these logs are found in the Puget Sound Grading Rules for log diameter, growth rate, and knot size and distribution. The specifications used in this study were adapted from these Rules (table 6) and were applied to the volumes in the model stands as discussed below.

Log Diameter. Diameters of logs in each representative tree diameter-height class were determined. Information in tables 2 and 3 provided tree diameter, and trees were classified by height according to stand age and site data previously assigned to the models. Diameters (inside bark, small end) of each log from trees of each diameter and form class were obtained from Douglas-fir taper tables (Girard and Bruce, no date). Data were tabulated for the logs from each tree in each diameter, age, site, and stocking class.

Volumes for each log were obtained by using Girard's and Bruce's tables of percentage distribution of volume within the logs of a tree. These data were tabulated with those of log diameter. Preliminary log grades were assigned on the basis of the diameter standards adopted in column 2, table 6. These grades were later adjusted according to specifications of growth rate and knot size. Using diameter grade specifications, all logs smaller than 12 inches top diameter were graded as Number 3 sawmill logs; those larger than 12 but smaller than 24 inches, as Number 2. Logs 24 inches or larger were classified as Number 3 peeler logs. Number 1 sawmill logs and Number 1 and 2 peeler log categories were not used because these apply to virgin, old-growth logs, none of which was included in the model stands.

Distribution of volume by log grades was obtained by accumulating the percentage of volume in each grade for each diameter class, age, and stocking class and converting to total volume by multiplying by the number of trees in each diameter class.

TABLE 6

SPECIFICATIONS FOR DOUGLAS-FIR LOG GRADES

Log grade	Minimum diameter (inside bark at small end of log)	Minimum no. of rings per inch*	Maximum knot diameter
	inches		
Peeler:			
Number 1	30	8	None allowed†
Number 2	30	8	None allowed†
Number 3	24	6	1½ inches
Sawmill:			
Number 1	30	8	None allowed‡
Number 2	12	6	2½ inches
Number 3	6	6	3 inches
Fast-growth	6	Less than 6	Allowed as in grades 2 and 3

* Measured in outer portion of log equal to 50 per cent of the gross scaled contents.
† Knot clusters or burls allowed if a 6-foot or longer peeler block can be obtained on either side of defect.
‡ Knots allowed, but must be deducted from scale.

While the analysis of log-grade volumes based on diameter alone is of theoretical significance only, the data do indicate several interesting things about the diameter characteristics of stands. The general pattern shows that all measurable volume is initially in the Number 3 sawmill log class because of small diameter. As the stands increase in age and diameter, they move increasingly into the Number 2 classification. The rate of increase of Number 2 sawmill log volume is proportional to the decrease in Number 3 volume since logs formerly classed as Number 3 increase in diameter and qualify as Number 2. The proportion of Number 2 volume increases until a component reaches diameters qualifying it as Number 3 peeler volume. At that point, Number 2 sawmill log volume reaches its maximum, and thereafter declines as the Number 3 peeler volume increases. Figure 3 shows a comparison of the distribution of volume, by per cent, in stands of full initial stocking (Model A) and in stands of low initial stocking (Model D) on site 200.

Initial stocking level influences distribution of volumes in the various grade categories, as indicated in figure 3. Trees in stands of low initial stocking (Model D) reached merchantable and other size limits which admit

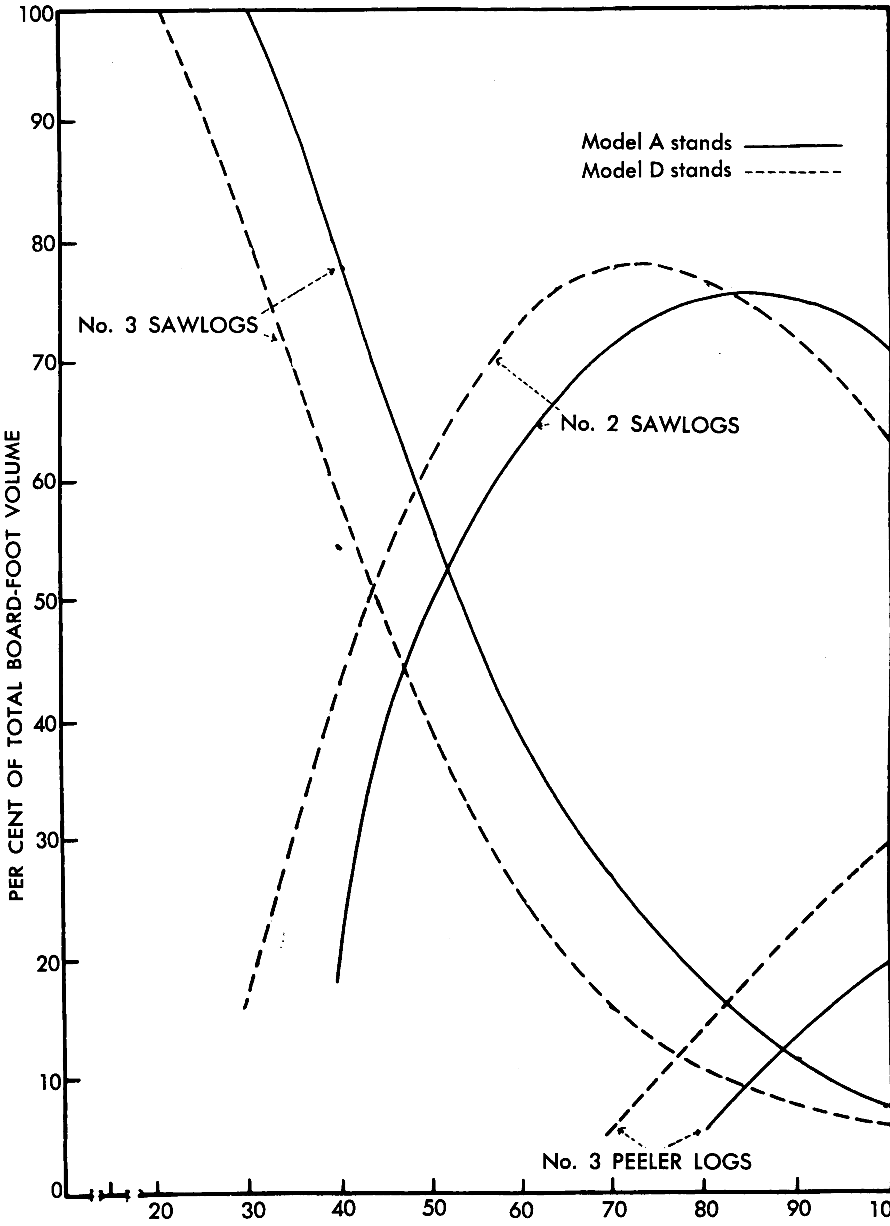

Fig. 3. Distribution of board-foot volume by log grade as determined by diameter specifications (Site 200).

them to higher log grades about one decade before stands of full initial stocking (Model A). Because of their smaller average diameter, the Model A stands contained a higher percentage of low-grade logs than did the Model D stand throughout the period considered.

The effect of site, although not illustrated in figure 3, is to shift the curves of distribution of volume to right or left depending on change of site. For example, the curves for site 170 lie to the right of site 200, indicating a delay of one decade in the appearance of the upper log grades of Number 2 sawmill and Number 3 peeler logs.

Growth Rate. Application of growth rate determinants of log grade to the volumes requires first a knowledge of the diameter growth rate, in terms of rings per inch, for each log in representative tree diameter classes in each model stand. Since growth rate in these terms is a function of diameter attained at specified ages, it is possible to calculate the average growth rate by dividing the age (or number of annual rings on the radius) at the top end of the log by one-half the diameter at that point.

Top diameters inside bark of the logs were determined as discussed in the previous section. Average number of annual rings per inch at the top ends of the logs was calculated as follows:

1. Total age at stump height was obtained by subtracting the number of years required by the trees to reach stump height, as determined by McArdle and Meyer (1949) from the stand age.
2. Average number of years required for trees in each site class to grow 16.3 feet (the standard length of a 16-foot log plus trim allowance) was determined by dividing total height of the tree at the age under consideration by its present age, to give the average annual height growth rate. The annual height growth rate (in feet) was divided into 16.3 feet to obtain the average number of years required to grow a log length.
3. The number of years required to grow 16.3 feet in height was subtracted from age of tree at stump height, to give the age (or number of rings) at the top end of the first log. Ages at the top of successive logs were calculated in a similar manner by subtracting the number of years required to grow a log length from the age of the preceding log.
4. Growth rate, in rings per inch, was obtained by dividing age at the top of the log by one-half the diameter (inside bark).

It is recognized that diameter growth rates determined in this manner are not directly comparable to growth-rate specifications in the log grading rules, since the values used here are indirectly determined and are average rates over the radius of the log while those in the standard rules are actual rates in the outer portion of the log. However, the average growth-rate values determined are indicative of actual growth rate, and are used in the subsequent analyses.

The growth-rate values derived were entered on the tabular form used previously in determining log grade by diameter specifications. Log-grade growth-rate standards were applied to the logs, and the percentage of volume in each grade was accumulated. Logs with a growth rate of less than six rings per inch were automatically thrown into the fast-growth category. Volumes were then summed by log-grade categories.

Figure 4 shows the distribution of volume by log grade as determined by both growth rate and diameter specifications in Models A and D stands, site 200. The principal effect of adding growth-rate specifications to diameter specifications as log-grade determinants is to bring into play the fast-growth log-grade category. In comparison with log grade as determined by diameter alone, the addition of growth rate caused a shift of volume from the Number 2 sawmill and Number 3 peeler log categories to the fast-growth category since the logs in the former groups were both the largest and fastest growing. The curves show a high proportion of volume in the fast-growth log-grade category for both models A and D. These proportions decrease with increasing age as the rate of diameter growth on individual trees declines. From age 70 to 100, the curve of fast-growth grade tends to level off as a result of the shift of the fast diameter-growth zone to the upper logs of the dominant trees.

A reduction in initial stocking level affected growth-rate characteristics of logs by increasing the fast-growth volume and reducing numbers 2 and 3 sawlog volumes. The relationships among these grades appeared to be direct, i.e., the amount of fast-growth grade in the Model D stands was of about the same magnitude as the difference in the amount of numbers 2 and 3 sawmill log volume between A and D stocking levels. The relatively high volume of fast-growth logs in the Model D stands was presumably achieved at the expense of sawmill log grades 2 and 3.

The volume of Number 3 peeler logs increased slightly with decrease in stocking level as a result of the larger diameters in stands of lower initial stocking level. But the full effect of larger diameter of understocked stands is not reflected in peeler log volumes because the amount of fast-growth volume also increased with decrease in stocking level. A large portion of the logs that would ordinarily qualify for the peeler grades was excluded on the basis of growth rate. This effect was greater in the Model D than in the Model A stands.

A comparison of the fully-stocked Model A with the understocked Model D indicates that exercise of silvicultural control on stocking level will have a marked influence on the value and final log grade out-turn of the forest products. On the basis of price, the fast-growth is of lower value than other grades considered, and Model D stands contained 8 to 14 per cent more fast-growth than the Model A stands. Although the total volume difference in yield between the various stocking levels may not be great, the effect of growth rate alone on quality becomes apparent with substantial differences in ultimate financial returns.

Knot Size and Distribution. Knots, a common characteristic of all coniferous timber, are undesirable for most uses of wood. In order to characterize the model stands with respect to size, number, and distribution of knots, it was necessary to make field studies of actual stands and apply the findings to the models.

Field studies were made in 38- to 40-year-old stands in Humboldt County, California, to determine the relationship between size and number of knots and initial stocking. The trees studied were in young, natural stands which exhibited a wide range of stocking values.

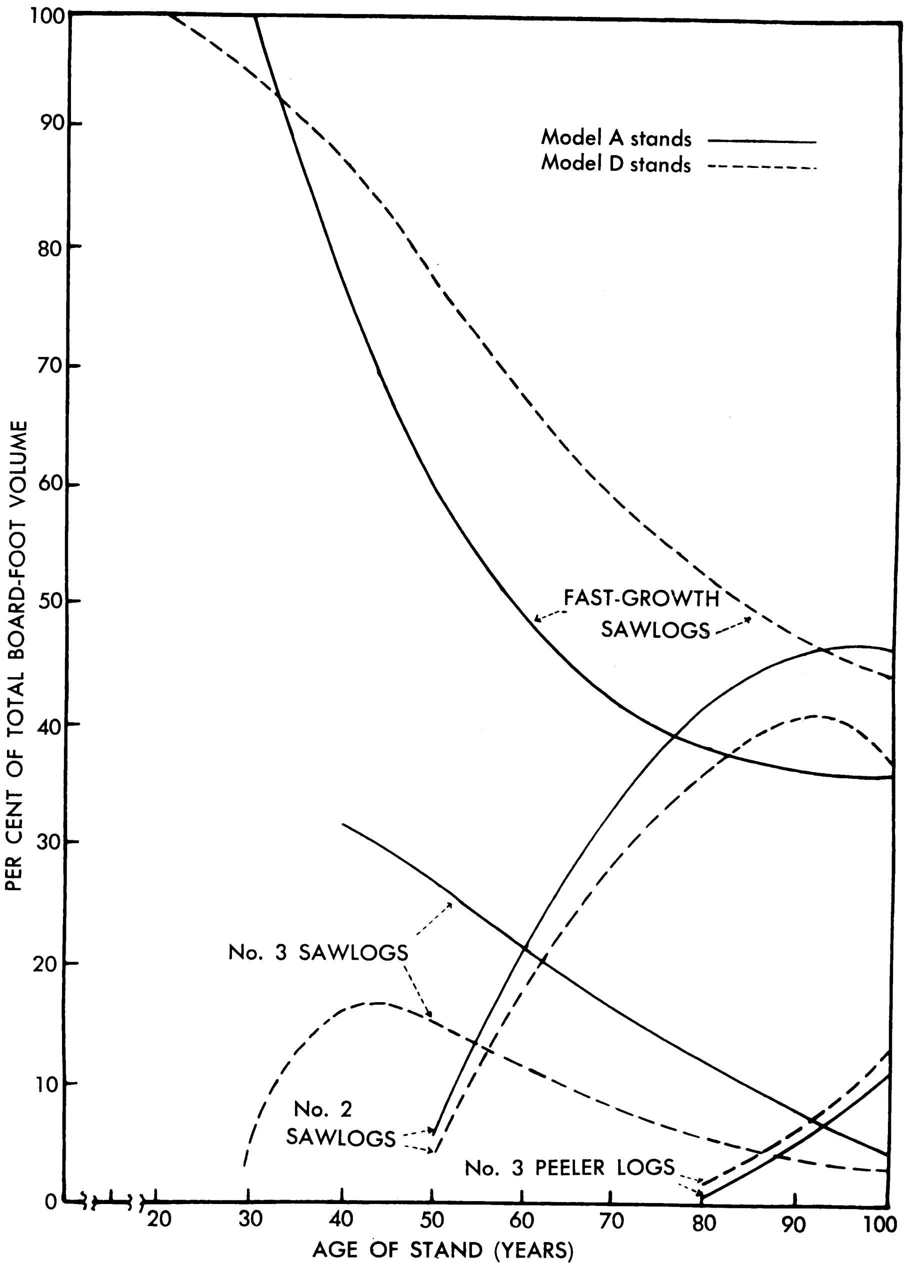

Fig. 4. Distribution of board-foot volume by log grade as determined by diameter and growth-rate specifications (Site 200).

Plots of one-fifth acre were laid out in stands of uniform density. Site was determined on the basis of average height of dominant and codominant trees, and the stands studied were judged to be high site III (equivalent of 150 feet at 100 years). Current stand density was determined by counting the number of trees on the plots and converting to number of trees per acre. Since the stands had been undisturbed by cutting since their establishment, current stocking was related back to stocking at 20 years on the basis of number of live and dead trees in the stands.

Diameter (breast high), radius of the crown, and height to the lowest live branch were recorded for each live tree. The diameter of each knot in the lower 16-foot log was measured with fixed-slot calipers graduated at 1/4-inch intervals at the limb base. These measurements were recorded on diagrams arranged by cardinal quarters around the tree so that distribution patterns could be studied. In addition, radius of the crown, diameter (breast high), and distance from the tree being measured were recorded for the nearest tree in each cardinal quarter.

Knot size in relation to stocking was determined by summarizing the total number of knots over 1½ inches in diameter, and the number over 2½ inches on each quarter face according to average spacing between trees as based on distance measurements for each tree. These particular knot-diameter categories were established to correspond with critical knot sizes set up as grade determinants in the log grading rules. Logs with knots larger than 2½ inches on three or more quarter faces are disqualified for grades above Number 3 sawmill. Those with knots of similar placement larger than 1½ inches in diameter are admissible only to grades lower than Number 3 peeler. Results are summarized in table 7.

Important values in table 7, from the viewpoint of relating knot size to stocking level, appear in columns 4 and 6, where a basis is provided for assigning log grades based on knot size to the volumes in each of the stocking models. These data were plotted against numbers of trees per acre. Freehand curves were fitted through the data, resulting in the relationships shown in figure 5. After superimposing the average spacing equivalents of the four model stands over the curves, and assuming that evidence of knot size will remain until harvest age, the following conclusions were drawn:

1. Ninety-seven per cent of the trees grown at stocking level D (143 trees per acre, or an average spacing of about 17 feet) will have one or more knots larger than 2½ inches in diameter on three or more quarter faces in the first 16-foot log. Because the remaining 3 per cent of the logs that might not have such knots appeared to be an insignificant number, all such logs grown at the Model D initial stocking level were assumed to be ineligible, because of knots, for inclusion in the Number 3 peeler or Number 2 sawmill log classes.

2. Forty-two per cent of butt logs grown at the Model C initial stocking (286 trees per acre, or an average spacing of 12½ feet) will have one or more knots larger than 1½ inches in diameter, and thus will not qualify as Number 3 peeler logs.

3. An insignificant number of the logs grown at stocking levels A and B will have knots larger than 1½ inches in diameter in the first log, and therefore will not be reduced in grade because of knot diameter.

These conclusions were applied directly to the models affected. The tabular form on which volumes had been previously classified according to log grade, using diameter and growth-rate specifications, was employed in this step. All butt log volumes in Model D stands that were not already classified as fast-growth were thrown into the Number 3 sawmill log class because of the

TABLE 7

SIZE AND NUMBER OF KNOTS IN THE BUTT LOG IN RELATION TO TREE SPACING IN 40-YEAR-OLD DOUGLAS-FIR STANDS

(Humboldt County, California)

Average distance between tree centers	No. trees measured	Knots with diameter greater than:				Av. knot diameter
		1½ inches		2½ inches		
		Av. no. per butt log†	Trees with knots	Av. no. per butt log†	Trees with knots	
feet			*per cent*		*per cent*	*inches*
4	3	0	0	0	0	0.25
5	5	0	0	0	0	0.25
6	5	0	0	0	0	0.50
7	5	0	0	0	0	0.50
8	7	0	0	0	0	0.50
9	4	0	0	0	0	0.50
10	9	0	0	0	0	0.75
11	4	0	0	0	0	1.00
12	6	4	20	0	0	1.00
13	5	12	60	3	20	1.25
14	9	8	67	5	33	1.25
15	5	14	80	13	40	1.25
16	7	25	100	14	71	1.50
17	8	32	100	13	75	1.50
18	6	18	100	3	100	1.25
19	3	26	100	9	100	1.75
20	2	28	100	33	100	2.00
21	5	38	100	21	100	2.00
22	4	31	100	13	100	1.50
23	1	48	100	39	100	2.50
24	..	..	..	..	..	..
25	..	..	..	..	..	..
26	3	48	100	40	100	2.00
Open*	5	60	100	59	100	3.50

* Average spacing greater than tree height.
† Distributed over three or more quarter faces of butt log.

presence of knots larger than 2½ inches in diameter. No change was made in the graded volumes of the Model C stands because, on all sites, more than 42 per cent of all the butt logs was already in grades which accept knots larger than 1½ inches in diameter.

Major changes in the distribution of log-graded volumes brought about by addition of knot characteristics as a grade determinant occur primarily in the stands of low initial stocking (Model D stands). These are most openly stocked during early years of stand development, and tend to produce larger limbs and knots. There was a shift of graded volumes from the Number 2 sawmill log and Number 3 peeler log classes to the Number 3 sawmill log

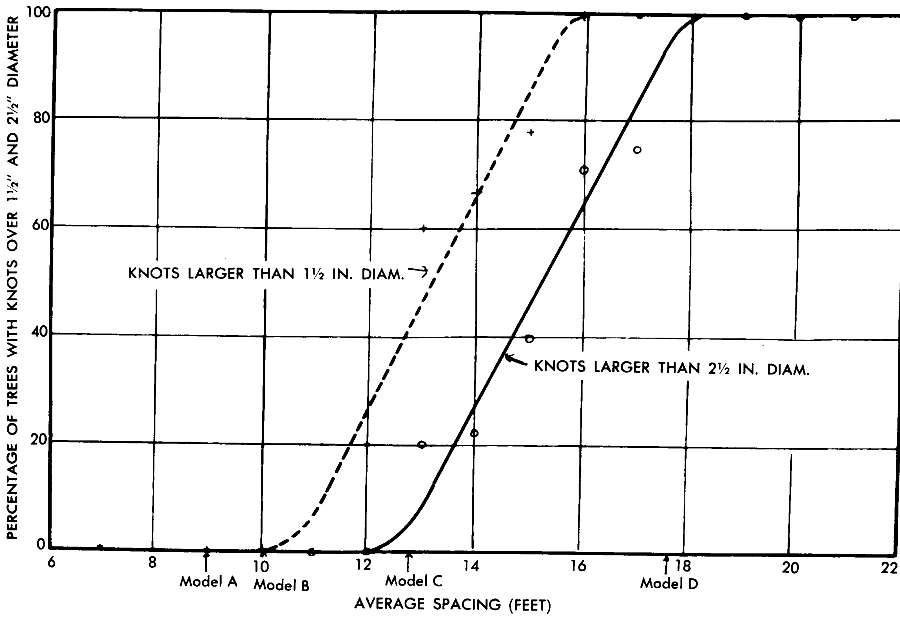

Fig. 5. Relationship between average tree spacing and occurrence of knots larger than 1½ and 2½ inches in diameter.

class. The shift of Number 2 sawmill logs varied in amount with age; in the 70- to 80-year-old stands, the change amounted to over 25 per cent of the volume in the grade. The shift in Number 3 peeler logs occurred at ages beyond 80 years, since the logs in this grade were the largest ones in the stand and occurred in dominant trees—those likely to have the most growing space and develop the largest limbs.

Relationship Between Quality and Stocking Level as Determined by the Combined Influence of Log Diameter, Growth Rate, and Knot Characteristics

The over-all effects of initial stocking on quality were determined by the joint application of the grade determinants as described above. The resulting distributions of volume by log grade are given in table 8 and illustrated in figure 6, using models A and D on site 200 as contrasting examples. The values in table 8 represent the final results of the effect of initial stocking on physical quality in the model stands, and constitute the basic data used subsequently for economic analysis.

Fast-growth Sawmill Log Volume. Site 200 was used for purposes of comparison. From age 50, when 75 per cent or more of all trees in the model stands are larger than 11½ inches in diameter, and thus measurable in board-feet, the Model D stands contain 12 to 14 per cent more fast-growth volume than the Model A stands. This difference shows a slight tendency to

TABLE 8

DISTRIBUTION OF VOLUME AMONG LOG GRADES AT VARIOUS STAND AGES, AS DETERMINED BY DIAMETER, GROWTH RATE, AND KNOT SIZE

SITE 200

Stand age (years)	Total volume (bd. ft. per acre)	Fast-growth		No. 3 sawlogs		No. 2 sawlogs		No. 3 peeler logs	
		Per cent of total volume	Volume (bd. ft. per acre)	Per cent of total volume	Volume (bd. ft. per acre)	Per cent of total volume	Volume (bd. ft. per acre)	Per cent of total volume	Volume (bd. ft. per acre)
Model A									
20	..	..	..	..	..	..	..	..	..
30	6,700	100.0	6,700	..	..	..	..	..	..
40	34,300	68.1	23,362	31.9	10,938	..	..	..	..
50	59,000	66.7	39,365	27.5	16,213	5.8	3,422	..	..
60	79,800	56.6	45,167	20.0	15,960	23.4	18,673	..	..
70	94,000	41.8	38,245	21.9	20,558	36.3	34,197	..	..
80	102,400	48.3	49,494	9.6	9,783	41.0	41,993	1.1	1,130
90	107,000	38.7	41,372	8.0	8,536	47.4	50,745	5.9	6,347
100	109,000	37.4	40,777	4.6	5,027	46.7	50,874	11.3	12,322
Model B									
20	..	..	..	..	..	..	..	..	..
30	9,400	94.2	8,878	5.8	522	..	..	..	..
40	35,000	68.5	23,987	31.5	11,013	..	..	..	..
50	58,400	72.6	42,507	21.5	12,455	5.9	3,438	..	..
60	78,200	62.6	48,832	20.6	16,119	16.8	13,249	..	..
70	92,500	50.0	46,299	12.8	11,847	37.2	34,354	..	..
80	101,000	46.9	47,460	9.0	9,100	43.3	43,632	0.8	808
90	105,800	40.6	42,800	5.0	5,453	48.5	51,199	5.9	6,348
100	108,200	42.2	45,727	4.2	4,502	40.0	43,299	13.6	14,672
Model C									
20	..	..	..	..	..	..	..	..	..
30	11,700	95.1	11,122	4.9	578	..	..	..	..
40	35,400	81.0	28,664	19.0	6,736	..	..	..	..
50	56,600	76.7	43,392	19.3	10.902	4.0	2,306	..	..
60	75,700	66.6	50,382	13.7	10,397	19.7	14,921	..	..
70	90,000	54.4	38,928	10.3	9,453	35.1	31,619	..	..
80	99,200	50.4	49,983	7.8	7,752	42.8	41,465	..	..
90	104,500	43.4	45,319	5.7	6,008	48.2	50,349	2.7	2,823
100	107,300	44.5	47,769	3.3	3,581	45.8	49,120	6.4	6,830
Model D									
20	1,100	100.0	1,100	..	..	..	..	..	..
30	15,500	97.1	15,054	2.9	446	..	..	..	..
40	36,500	83.2	30,352	16.8	6,148	..	..	..	..
50	55,500	80.7	44,797	19.3	10,703	..	..	..	..
60	72,700	71.8	52,215	25.1	18,239	3.1	2,246	..	..
70	86,800	59.5	51,667	35.1	30,445	5.4	4,688	..	..
80	96,700	54.6	52,818	34.1	32,976	11.3	10,908	..	..
90	102,700	47.5	48,792	30.6	31,445	21.9	22,463	..	..
100	105,800	45.3	47,850	31.7	33,531	19.8	20,932	3.2	3,487

TABLE 8—(*Continued*)

SITE 170

Stand age (years)	Total volume (bd. ft. per acre)	Fast-growth		No. 3 sawlogs		No. 2 sawlogs		No. 3 peeler logs	
		Per cent of total volume	Volume (bd. ft. per acre)	Per cent of total volume	Volume (bd. ft. per acre)	Per cent of total volume	Volume (bd. ft. per acre)	Per cent of total volume	Volume (bd. ft. per acre)
Model A									
20	..	..	..	..	..	..	..	..	..
30	2,000	100.0	2,000	..	..	..	..	..	..
40	19,200	68.9	13,229	31.1	5,971	..	..	..	..
50	41,600	59.4	24,715	40.6	16,885	..	..	..	..
60	47,700	53.2	30,715	26.1	15,042	20.7	11,943	..	..
70	71,800	53.9	38,716	18.1	12,993	28.0	20,091	..	..
80	81,500	49.4	40,298	11.7	9,538	38.9	31,664	..	..
90	85,600	45.0	38,574	8.1	6,910	44.5	38,103	2.4	2,013
100	88,500	42.2	37,304	6.3	5,575	45.7	40,495	5.8	5,126
Model B									
20	..	..	..	..	..	..	..	..	..
30	4,000	100.0	4,000	..	..	..	..	..	..
40	21,000	74.1	15,566	25.9	5,434	..	..	..	..
50	42,600	64.9	27,641	35.1	14,959	..	..	..	..
60	58,800	58.0	34,085	21.9	12,896	20.1	11,819	..	..
70	71,500	55.2	39,429	16.6	11,868	28.2	20,203	..	..
80	80,500	55.9	44,999	9.5	7,648	34.7	27,853	..	..
90	84,000	47.3	40,180	6.7	5,712	43.6	37,094	2.4	2,014
100	87,200	45.6	39,789	5.1	4,479	42.3	36,789	7.0	6,143
Model C									
20	..	..	..	..	..	..	..	..	..
30	6,400	100.0	6,400	..	..	..	..	..	..
40	22,700	82.8	18,802	17.2	3,898	..	..	..	..
50	43,600	70.9	30,906	29.1	12,694	..	..	..	..
60	59,700	64.0	38,206	18.8	11,198	17.2	10,296	..	..
70	71,300	65.6	46,773	11.0	7,843	23.4	16,684	..	..
80	79,800	59.7	47,641	8.0	6,384	32.3	25,775	..	..
90	84,500	50.9	42,980	5.6	4,720	43.5	36,800	..	..
100	86,300	48.6	41,852	4.3	3,714	43.0	37,199	4.1	3,535
Model D									
20	200	100.0	200	..	..	..	..	..	..
30	8,400	100.0	8,400	..	..	..	..	..	..
40	25,000	87.9	21,973	12.1	3,027	..	..	..	..
50	44,500	77.8	34,608	22.2	9,892	..	..	..	..
60	60,300	71.5	43,099	28.5	17,201	..	..	..	..
70	71,100	67.9	48,298	32.1	22,811	..	..	..	..
80	79,200	62.5	49,518	33.1	26,169	4.4	3,513	..	..
90	84,000	56.5	47,423	32.3	27,178	11.2	9,399	..	..

TABLE 8—(*Continued*)

SITE 140

Stand age (years)	Total volume (bd. ft. per acre)	Fast-growth		No. 3 sawlogs		No. 2 sawlogs		No. 3 peeler logs	
		Per cent of total volume	Volume (bd. ft. per acre)	Per cent of total volume	Volume (bd. ft. per acre)	Per cent of total volume	Volume (bd. ft. per acre)	Per cent of total volume	Volume (bd. ft. per acre)
Model A									
20	..	..	..	..	..	..	..	..	..
30	..	..	..	..	..	..	..	..	..
40	9,400	58.1	5,462	41.9	3,938	..	..	..	..
50	24,800	49.7	12,326	50.3	12,474	..	..	..	..
60	40,000	51.2	20,468	31.8	12,731	17.0	6,801	..	..
70	50,100	44.0	22,064	21.7	10,850	34.3	17,186	..	..
80	58,400	43.9	25,654	16.8	9,812	39.3	22,934	..	..
90	61,700	41.0	25,317	12.0	7,379	47.0	28,986	..	..
100	62,700	34.6	21,672	8.4	5,252	57.0	35,776	..	..
Model B									
20	..	..	..	..	..	..	..	..	..
30	600	100.0	600	..	..	..	..	..	..
40	11,000	100.0	11,000	..	..	..	..	..	..
50	26,300	56.6	14,875	43.4	11,425	..	..	..	..
60	40,500	53.8	21,845	27.1	10,963	19.0	7,692	..	..
70	50,000	48.2	24,081	19.2	9,609	32.6	16,310	..	..
80	58,100	46.3	26,889	14.0	8,144	39.7	23,067	..	..
90	61,400	44.3	27,193	10.3	6,295	45.4	27,912	..	..
100	62,100	38.9	24,144	7.2	4,510	53.9	33,446	..	..
Model C									
20	..	..	..	..	..	..	..	..	..
30	2,100	100.0	2,100	..	..	..	..	..	..
40	14,000	70.0	9,803	30.0	4,179	..	..	..	..
50	29,000	67.3	19,505	32.7	9,495	..	..	..	..
60	41,200	61.5	25,350	24.2	9,980	14.3	5,870	..	..
70	50,800	54.5	27,665	14.7	7,473	30.8	15,662	..	..
80	57,900	51.2	29,672	11.2	6,469	37.6	21,759	..	..
90	61,000	47.7	29,107	9.8	5,949	42.5	25,944	..	..
100	61,600	41.9	25,799	6.0	3,704	52.1	32,097	..	..
Model D									
20	..	..	..	..	..	..	..	..	..
30	4,100	100.0	4,100	..	..	..	..	..	..
40	17,000	83.5	14,196	16.5	..	..	..	..	..
50	30,600	76.7	23,470	23.3	7,130	..	..	..	..
60	41,700	69.9	19,160	30.1	12,540	..	..	..	..
70	50,700	62.3	31,600	37.7	19,100	..	..	..	..
80	57,700	54.4	31,388	43.1	24,859	2.5	1,453	..	..
90	60,700	53.3	32,375	38.5	23,327	8.2	4,998	..	..
100	61,000	43.8	26,743	40.7	24,807	15.5	9,450	..	..

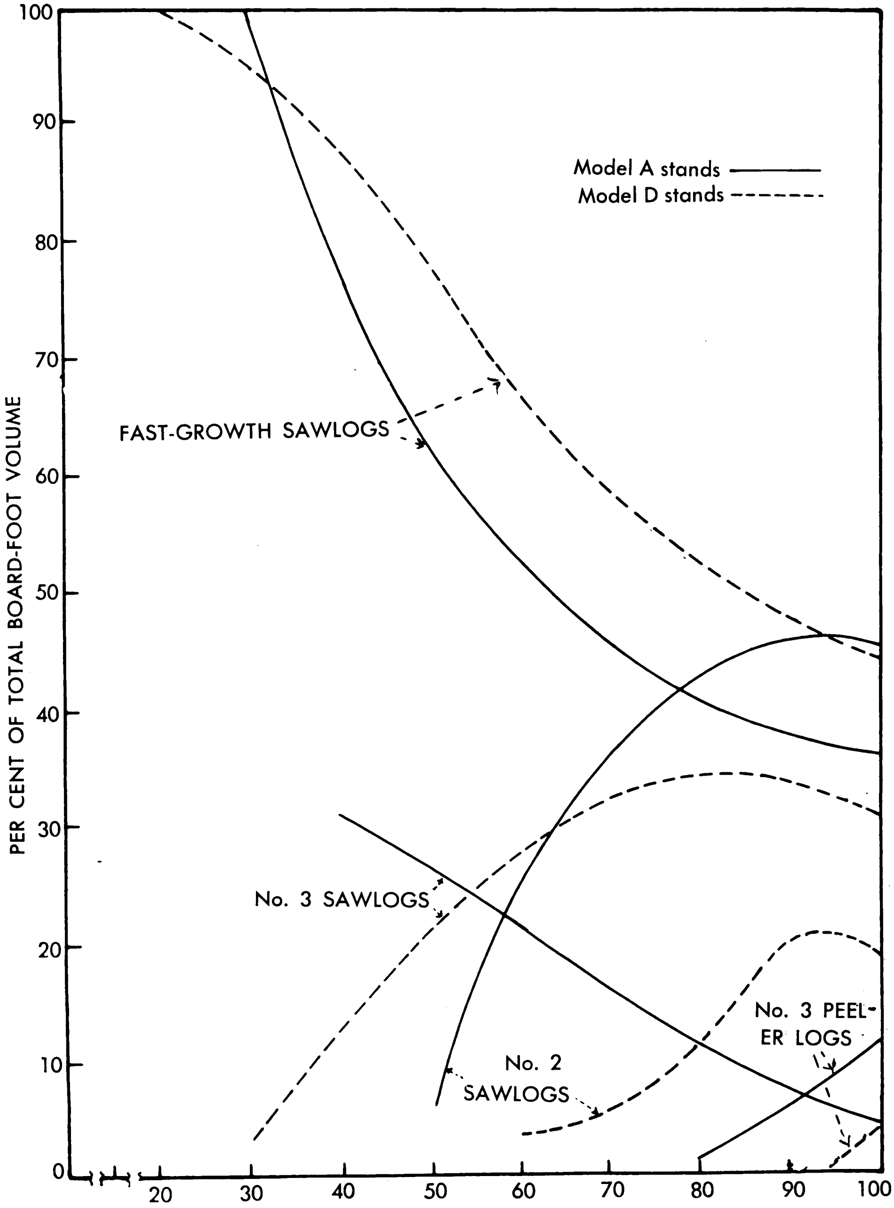

Fig. 6. Distribution of board-foot volume by log grade as determined by diameter, growth-rate, and knot specifications (Site 200).

decrease as age approaches 100, and it is likely that this trend continues as the stands grow older and the rate of diameter increase slows down.

Number 3 Sawmill Log Volume. Values for the two stocking models show a marked divergence in trend with age. Beyond age 50, the Model A stands show a consistent decrease in percentage of Number 3 sawmill log volume. This is due to increasing diameters and consequent transfer from Number 3 to Number 2 sawmill log classification on the basis of diameter alone. The Model D stands show an increase in Number 3 sawmill log volume between ages 50 and 80, and a decline from 80 to 100. The increase is due primarily to a transfer of logs out of the fast-growth category, and is related to the decline in diameter growth rate with increasing age. Because of the large knots in the Model D stands, volume transferred from the fast-growth grade because of reduced diameter growth rate does not qualify as Number 2 sawmill logs. The decline in Number 3 sawmill logs from age 80 on appears to be associated with an increase in diameter of logs above the butt log that qualifies them for the Number 2 grade. This effect may be unrealistic, since it is assumed that knot size will not be a limiting factor in logs above the butt logs. Knot sizes were not measured above the butt logs in this study.

Number 2 Sawmill Log Volume. Number 2 sawmill log values show similar trends, that is, an increase to about age 90, and then decline. The Model A stands maintain 25 to 28 per cent more volume in this category than the Model D stands. The principal reason for this difference is the large portion of the volume in the Model D stands retained in the Number 3 class because of knot size. The decline from age 90 to 100 appears to be associated with the increase in Number 3 peeler log grade resulting from transfer of volume from Number 2 sawmill log grade. In Model A, this transfer may also take place from the fast-growth category since many of these logs are of sufficient size to qualify as Number 3 peelers once average growth rate has slowed down. In Model D stands, the shift from Number 2 to the peeler grade can take place only in logs above the butt log; thus less volume of sufficient diameter is eligible to make the shift.

Number 3 Peeler Log Volume. Values for models A and D show a consistent increase with age. Volumes in the Model A stands qualify for number 3 peeler category at an earlier age than those in Model D stands, and maintain values 7 to 8 per cent higher than the stand of lower initial stocking. The reasons for this are indicated in the previous paragraph.

The effect on quality of initial stocking values intermediate to models A and D can be evaluated from table 8. In general, the trends discussed above hold for models B and C, wherein Model C performs in a manner closely allied with that of Model D, and Model B is similar to Model A. In each case, the values are intermediate to the models on each side.

Site, over the range considered here, had some influence on the relationships indicated above. Table 8 shows a delay in the appearance of measurable logs in all log-grade categories in the lower sites and a complete absence of peeler logs in lower stocking models on such sites. This is a reflection of retarded growth rates and lower diameters of trees growing on lower sites. Furthermore, there is a minor but consistent depression of volume in categories in lower sites, again a reflection of slower growth rate.

The effect of knot size as influenced by site cannot be separated from the data used in this study because the field data collected do not reflect the influence of site. However, it is apparent that reduced growth rate would also affect knot size in a manner similar to that indicated above. The growth rate of knots would be reduced in proportion to that of the tree.

PRUNING TO IMPROVE QUALITY OF INITIALLY UNDERSTOCKED STANDS

Stands of low initial stocking produce a large volume of lower-grade logs, principally because of rapid growth rate and numerous large knots. For example, on the basis of knot characteristics alone, Model D stands from age 60 to 100 contain at least 25 per cent more volume in Number 3 sawmill log class than do Model A stands, and correspondingly lower amounts of upper grades. Because knots are the principal factor in this lowering of quality, pruning of stands was considered as a possible means of improving log grades.

Smith (1954, 1956*b*), and Shaw and Staebler (1950) have indicated conditions under which pruning appears to be economically feasible. The consensus is that properly managed pruning in young, vigorous stands is a sound economic investment and should be encouraged.

Fleischer (1949) and Dimock (1956) indicate the feasibility of producing commercially acceptable Douglas-fir plywood face veneer by pruning and by controlling growth rate. On the other hand, they indicate that only a small portion of logs from unpruned stands less than 100 years old will be suitable for more than the lowest quality plywood core material.

In summarizing pruning techniques, the Douglas-fir Second-Growth Management Committee (1947) recommends that pruning be done between the twentieth and fortieth years on stands growing on site III or better, in which the trees to be pruned are at least 4 but not over 12 inches in diameter (breast high). About 100 vigorous, straight, and well-formed trees per acre should be selected from among those most likely to be carried forward to maturity.

With regard to stocking, the Committee indicates that overstocked stands should not be pruned, but that understocked stands will profit greatly because of their normal tendency to produce large limbs, and because the growth potential of the area will be concentrated on the pruned stems of high quality. Branches should be removed to at least 10 feet from the ground and preferably to 18 feet so that a full 16-foot log is cleared of knots. The height to which pruning is done depends on the amount of live crown that will remain after the operation. Not more than one third of the live crown should be removed.

Pruning Model Stands

Stand tables for the model stands indicate that each has over 150 trees 4 or more inches dbh at age 20, and fewer than 100 trees at age 100. These stands were therefore suitable for application of the pruning techniques suggested by the Committee, and basic assumptions for such pruning were therefore established. Log-grade specifications, set up to cover type of log expected from pruning, were applied to the model stands. Effects of pruning on quality were determined by comparing distribution of volume by log grade for unpruned stands with that for pruned stands.

The number of trees to be pruned at age 20 to assure that all trees in the stand at age 100 will be pruned trees was obtained by comparing the number of live trees in each stand at age 100 (from stand tables) with the number of live trees at the same age in columns 3, 4, and 5 of table 9. The

TABLE 9

PROBABLE NUMBER OF PRUNED TREES ALIVE AT VARIOUS PERIODS AFTER PRUNING AT AGE 20 YEARS*

Stand age (years)	Years after pruning	Number of live trees at various stand ages when number of trees pruned at age 20 is:		
		100	90	80
30	10	97	87	77
40	20	93	84	74
50	30	89	80	72
60	40	86	77	69
70	50	82	74	66
80	60	79	71	63
90	70	75	68	60
100	80	72	64	57

* Based on mortality estimates for pruned trees by Shaw and Staebler (1950).

Model D stands contain 56 trees at age 100, thus 80 trees should be pruned at age 20 (56 trees compares most closely with the 100-year value of 57 in column 5). On the same basis, 100 trees must be pruned in Model A stands, and 90 trees in models B and C.

Establishing Specifications for Pruned Logs

Because conventional log-grade categories for surface-clear logs, such as established for Number 1 sawmill logs and Number 1 and 2 peeler logs, do not adequately cover the characteristics of pruned logs, a special grade for such logs is needed. Conventional grades, requiring minimum diameters of 30 inches for logs in any of these surface-clear categories (see table 6), were developed for logs cut from natural stands. In these, surface-clear logs that will produce the required amount of clear, uniformly-colored face veneer or grade B-and-better lumber are necessarily large.

In contrast, logs from trees pruned when 4 to 12 inches dbh will yield more than the 50 and 35 per cent clear veneer required for Number 1 and 2 peeler grades, respectively, and more than 50 per cent B-and-better lumber for the Number 1 sawmill log grade. Huey (1950), and Shaw and Staebler (1950) have demonstrated this for western white pine, ponderosa pine, and Douglas-fir.

The current log market does not provide for pruned logs. However, in light of values indicated above, such categories probably will be established in the future to recognize the inherent values in pruned material. In anticipation of this, a pruned log category was established for purposes of this analysis.

The primary consideration in establishing such a grade was to set diameter limits in which such high-quality logs could be realistically included. The current lower diameter limit of 30 inches appeared to be too high. Establishment of a lower diameter limit is affected by (1) amount of clear veneer or B-and-better lumber that can be cut, and (2) the minimum diameter at which the log can be held efficiently in the chucks of a veneer lathe or on the carriage blocks of a sawmill. Dickinson, Hess, and Wangaard (1950) have indicated that such a limit is 14 inches for southern pine peeler logs. The Douglas-fir log market currently admits so-called "peewee" peeler logs, usable primarily for core veneer, at a diameter limit of 16 inches (Grah, 1955). On the basis of these requirements, minimum diameter of pruned log grade to be used here was set conservatively at 18 inches inside bark at the small end.

One factor unaccounted for in establishment of a pruned-log grade is the uniform color requirement set up for Number 1 and 2 peeler logs. Color is related to the heartwood content of the log and, because of the relatively small proportion of heartwood in young-growth logs, it is doubtful whether the category established here will adequately cover this requirement. It is assumed, however, that this deficiency will be ignored in the future, since color has only a minor effect on many use properties of wood.

Growth rate, on the other hand, is an important factor affecting grade, and should be included in the specifications for a pruned log-grade classification. Present growth-rate restrictions for highest quality peeler and sawmill logs are a minimum of 8 rings per inch. On the other hand, Dimock (1956) indicates that a growth rate as fast as 7 rings per inch is satisfactory for grade A veneer. The West Coast Lumber Inspection Bureau (1956), which publishes the standard Douglas-fir lumber grading rules, designates wood grown at an average of 6 rings per inch or more as "close grain" and "dense material," depending on the proportion of summerwood in the annual ring. B-and-better lumber can be sawed from material of this growth rate according to these rules.

The outlook for log supply suitable for veneer and high-quality lumber production is such that young-growth material will undoubtedly be used to a greater extent. Once the portion of old-growth material is further reduced and the relative portion of young-growth increased, it is likely that growth-rate specifications will be lowered to accommodate faster-grown, young material. On this basis, it appeared reasonable to establish growth-rate restrictions for pruned logs at a lower standard than now exists for Number 1 and 2 peeler and Number 1 sawmill logs. Thus growth-rate standards for this pruned log grade were set at a minimum of 6 rings per inch.

The following are the specifications established for Douglas-fir pruned logs:

Product grade recovery: Logs shall be Douglas-fir suitable for rotary cutting production of clear veneer or B-and-better lumber in an amount of not less than 50 per cent of the net scaled content.

Diameter: Not less than 18 inches inside bark at small end.

Length: 16 feet, plus trim.

Growth rate: Not less than an average of 6 rings per inch measured at the top end of the log in the portion of the radius outside of the 8-inch center core. (Assumes plywood lathe chuck plates 8 inches in diameter.)

These specifications were applied in assigning log-grade values to volumes in various model stands. The effect of pruning on distribution of volume among the various grades was assessed by separating volumes in butt logs of pruned trees from total volume in various grade categories. At ages less than 100 years, stands will contain both pruned and unpruned trees. In such cases, separation of volumes in the two categories was accomplished by assigning pruned-log grades to butt logs of those trees that met diameter and growth-rate requirements, and that were the largest trees in the stands. These grades were assigned to each tree in order of descending size until the number of live pruned trees, as indicated in table 9, was accounted for. The volume in remaining unpruned trees was assigned log-grade values based on conventional classification of volumes according to diameter, growth rate, and knot-size specifications.

Results of Pruning Model Stands

The distribution of volumes by log grade after pruning is shown in table 10 and illustrated in figures 7 and 8, for stocking models A and D on site 200. Each figure compares distribution of volume, by age, for pruned and unpruned stands. The figures show no difference in percentage of total volume, in the fast-growth category, between pruned and nonpruned stands because none of the volume in this grade is admissible in the pruned log grade. In Model A stands (fig. 7), no change is associated with pruning in the Number 3 sawmill log category, because these logs are too small to be admitted to any other grade. Principal changes in volume distribution occur in Number 2 sawmill log and Number 3 peeler log classes, which are reduced by the amount of increase in the pruned log grade at a particular age. Thus pruning in well-stocked stands affects the volume in higher log-grade categories and not that in the lower.

The nature of change brought about by pruning in stands of low initial stocking is a different matter. Here (fig. 8), pruned log volume comes primarily from Number 3 sawmill log and, to a lesser extent, from Number 3 peeler log grade. For reasons mentioned above, no change has occurred in the fast-growth category. The principal reason for reduction of Number 3 sawmill log grade and concomitant increase in pruned log grade is that a large portion of total volume is reduced in grade because of knot size; pruning removes the knots, and the logs qualify for the pruned log grade. A substantial portion of the total volume remains, however, in Number 3 sawmill log category because of small diameter.

Study of table 10 reveals the effect of intermediate stocking levels and of site on distribution of volumes by log grade. In general, stocking levels B and C were associated with intermediate shifts of volume from Number 3 sawmill logs and Number 2 sawmill logs. Stocking level C is similar to shifts which occurred in level D, and level B is similar to A. The magnitude of these shifts to pruned logs decreased as stocking level decreased (table 10).

Changes of site have no special effects on results of pruning in the various

TABLE 10

DISTRIBUTION OF VOLUME BY LOG GRADE, IN PRUNED STANDS

SITE 200

Stand age (years)	Total volume (bd. ft. per acre)	Fast-growth		No. 3 sawlogs		No. 2 sawlogs		No. 3 peeler logs		Pruned peeler logs	
		Per cent of total volume	Volume (bd. ft. per acre)	Per cent of total volume	Volume (bd. ft. per acre)	Per cent of total volume	Volume (bd. ft. per acre)	Per cent of total volume	Volume (bd. ft. per acre)	Per cent of total volume	Volume (bd. ft. per acre)
Model A											
20	..	..	..	..	..	..	..	..	..	..	..
30	6,700	100.0	6,700	..	..	..	..	..	..	..	..
40	34,300	68.1	23,362	31.9	10,938	..	..	..	..	..	..
50	59,000	66.7	39,368	27.5	16,213	..	..	..	..	5.8	3,422
60	79,800	56.6	45,167	20.0	15,966	12.8	10,230	..	..	10.6	8,433
70	94,000	41.8	39,245	21.9	20,558	21.1	19,806	..	..	15.2	14,391
80	102,400	48.3	49,494	9.6	9,783	26.2	25,728	..	..	15.9	16,265
90	107,000	38.7	41,372	8.0	8,536	35.2	37,626	2.6	2,838	15.5	16,628
100	109,000	37.4	40,777	4.6	5,027	36.2	39,471	5.8	6,289	16.0	17,436
Model B											
20	..	..	..	..	..	..	..	..	..	..	..
30	9,400	94.2	8,878	5.8	522	..	..	..	..	..	..
40	35,000	68.5	23,987	31.5	11,013	..	..	..	..	..	..
50	58,400	72.6	42,507	21.5	12,455	..	..	..	..	5.9	3,438
60	78,200	62.6	48,832	20.6	16,119	6.5	5,233	..	..	10.3	8,016
70	92,500	50.0	46,299	12.8	11,847	21.2	19,644	..	..	16.0	14,712
80	101,000	46.9	47,460	9.0	9,100	28.6	29,047	..	..	15.5	15,393
90	105,800	40.6	42,800	5.0	5,453	36.6	38,756	1.2	1,322	16.6	17,469
100	108,200	42.2	45,727	4.2	4,502	30.9	33,473	6.8	7,368	15.9	17,130
Model C											
20	..	..	..	..	..	..	..	..	..	..	..
30	11,700	95.1	11,122	4.9	578	..	..	..	..	..	..
40	35,400	81.0	28,664	19.0	6,736	..	..	..	..	..	..
50	56,600	76.7	43,392	19.3	10,902	..	..	..	..	4.0	2,306
60	75,700	66.6	50,382	13.7	10,397	9.8	7,401	..	..	9.9	7,520
70	90,000	54.4	48,928	10.5	9,453	19.7	17,748	..	..	15.4	13,871
80	99,200	50.4	49,983	7.8	7,752	26.8	26,607	..	..	15.0	14,858
90	104,500	43.4	45,319	5.7	6,008	33.4	34,875	2.7	2,823	14.8	15,474
100	107,300	44.5	47,769	3.3	3,581	30.2	32,384	6.4	6,830	15.6	16,736
Model D											
20	1,100	100.0	1,100	..	..	..	..	..	..	..	..
30	15,500	97.1	15,054	2.9	446	..	..	..	..	..	..
40	36,500	83.2	30,352	16.8	6,148	..	..	..	..	..	..
50	55,500	80.7	44,797	15.3	8,498	..	..	..	..	4.0	2,205
60	72,700	71.8	52,215	17.0	12,358	3.2	2,246	..	..	8.0	5,881
70	86,800	59.5	51,667	20.8	18,055	5.4	4,688	..	..	14.3	12,390
80	96,700	54.6	52,818	18.1	17,435	12.8	14,240	..	..	14.5	14,027
90	102,700	47.5	48,792	18.0	18,486	20.2	20,764	..	..	14.3	14,661
100	105,800	45.3	47,850	17.8	18,841	19.8	20,932	1.5	1,563	15.6	16,614

TABLE 10—(*Continued*)

SITE 170

Stand age (years)	Total volume (bd. ft. per acre)	Fast-growth		No. 3 sawlogs		No. 2 sawlogs		No. 3 peeler logs		Pruned peeler logs	
		Per cent of total volume	Volume (bd. ft. per acre)	Per cent of total volume	Volume (bd. ft. per acre)	Per cent of total volume	Volume (bd. ft. per acre)	Per cent of total volume	Volume (bd. ft. per acre)	Per cent of total volume	Volume (bd. ft. per acre)
					Model A						
20	..	..	..	..	..	..	..	..	..	..	..
30	2,000	100.0	2,000	..	..	..	..	..	..	..	..
40	19,200	68.9	13,220	31.1	5,971	..	..	..	..	..	..
50	41,600	59.4	24,715	40.6	16,885	..	..	..	..	..	..
60	57,700	53.2	30,715	26.1	15,042	7.9	4,537	..	..	12.8	7,406
70	71,800	53.9	38,716	18.1	12,993	13.0	9,360	..	..	15.0	10,731
80	81,500	49.4	40,298	11.7	9,538	22.5	18,330	..	..	16.4	13,334
90	85,600	45.0	38,574	8.1	6,910	29.4	25,066	..	..	17.5	15,050
100	88,500	42.2	37,304	6.3	5,575	30.6	27,101	3.5	2,289	18.4	16,251
					Model B						
20	..	..	..	..	..	..	..	..	..	..	..
30	4,000	100.0	4,000	..	..	..	..	..	..	..	..
40	21,000	74.1	15,566	25.9	5,434	..	..	..	..	..	..
50	42,600	64.9	27,641	35.1	14,959	..	..	..	..	..	..
60	58,800	58.0	34,085	21.9	12,896	7.3	4,297	..	..	12.8	7,522
70	71,500	55.2	39,429	16.6	11,868	13.5	9,625	..	..	14.7	10,578
80	80,500	55.9	44,999	9.5	7,648	19.0	15,295	..	..	15.6	12,558
90	85,000	47.3	40,180	6.7	5,712	28.4	24,178	..	..	17.6	14,930
100	87,200	45.6	39,789	5.1	4,479	30.3	26,409	2.8	2,402	16.2	14,121
					Model C						
20	..	..	..	..	..	..	..	..	..	..	..
30	6,400	100.0	6,400	..	..	..	..	..	..	..	..
40	22,700	82.8	18,802	17.2	3,898	..	..	..	..	..	..
50	43,600	70.9	30,906	29.1	12,694	..	..	..	..	..	..
60	59,700	64.0	38,206	18.8	11,198	6.0	3,602	..	..	11.2	6,694
70	71,300	65.6	46,773	11.0	7,843	10.8	7,700	..	..	12.6	8,984
80	79,800	59.7	47,641	8.0	6,384	18.0	14,364	..	..	14.3	11,411
90	84,500	50.9	42,980	5.6	4,720	27.5	23,249	..	..	16.0	13,551
100	86,300	48.6	41,852	4.3	3,714	27.4	23,728	4.1	3,535	15.6	13,471
					Model D						
20	200	100.0	200	..	..	..	..	..	..	..	..
30	8,400	100.0	8,400	..	..	..	..	..	..	..	..
40	25,000	87.9	21,973	12.1	3,027	..	..	..	..	..	..
50	44,500	77.8	34,608	22.2	9,892	..	..	..	..	..	..
60	60,300	71.5	43,099	18.9	11,426	..	..	..	..	9.6	5,775
70	71,100	67.9	48,289	20.5	14,518	..	..	..	..	11.6	8,293
80	79,200	62.5	49,518	19.3	15,197	4.4	3,513	..	..	13.8	10,972
90	84,000	56.5	47,423	16.3	13,772	11.2	9,399	..	..	16.0	13,406
100	85,500	552.0	44,460	16.5	14,139	16.6	14,172	..	..	14.9	12,729

TABLE 10—(*Continued*)

SITE 140

Stand age (years)	Total volume (bd. ft. per acre)	Fast-growth		No. 3 sawlogs		No. 2 sawlogs		No. 3 peeler logs		Pruned peeler logs	
		Per cent of total volume	Volume (bd. ft. per acre)	Per cent of total volume	Volume (bd. ft. per acre)	Per cent of total volume	Volume (bd. ft. per acre)	Per cent of total volume	Volume (bd. ft. per acre)	Per cent of total volume	Volume (bd. ft. per acre)
					Model A						
20	..	..	..	..	..	..	..	..	..	..	..
30	..	..	..	..	..	..	..	..	..	..	..
40	9,400	58.1	5,462	41.9	3,998	..	..	..	..	..	..
50	24,800	49.7	12,326	50.3	12,474	..	..	..	..	..	..
60	40,000	51.2	20,468	31.8	12,731	5.1	2,035	..	..	11.9	4,766
70	50,100	44.0	22,064	21.7	10,850	15.1	7,575	..	..	19.2	9,611
80	58,400	43.9	25,654	16.8	9,812	18.9	11,026	..	..	20.4	11,908
90	61,700	41.0	25,317	12.0	7,397	27.6	17,011	..	..	19.4	11,975
100	62,700	34.6	21,672	8.4	5,252	35.2	22,137	..	..	21.8	13,639
					Model B						
20	..	..	..	..	..	..	..	..	..	..	..
30	600	100.0	600	..	..	..	..	..	..	..	..
40	11,000	100.0	11,000	..	..	..	..	..	..	..	..
50	26,300	56.6	14,875	43.4	11,425	..	..	..	..	..	..
60	40,500	53.9	21,845	27.1	10,963	5.8	2,331	..	..	13.2	5,361
70	50,000	48.2	24,081	19.2	9,609	13.7	6,860	..	..	18.9	9,450
80	58,100	46.3	26,889	14.0	8,144	20.5	11,892	..	..	19.2	11,175
90	61,400	44.3	27,193	10.3	6,295	26.5	16,319	..	..	18.9	11,593
100	62,100	38.9	24,144	7.2	4,510	33.0	20,438	..	..	20.9	13,008
					Model C						
20	..	..	..	..	..	..	..	..	..	..	..
30	2,100	100.0	2,100	..	..	..	..	..	..	..	..
40	14,000	70.0	9,803	30.0	4,197	..	..	..	..	..	..
50	29,000	67.3	19,505	32.7	9,495	..	..	..	..	..	..
60	41,200	61.5	25,350	24.2	9,980	3.8	1,590	..	..	10.5	4,280
70	50,800	54.5	27,665	14.7	7,473	13.0	6,621	..	..	17.8	9,041
80	57,900	51.2	29,672	11.2	6,469	18.9	20,921	..	..	18.7	10,838
90	61,000	47.7	29,107	9.8	5,949	24.5	14,993	..	..	18.0	10,951
100	61,600	41.9	25,779	6.0	3,704	31.3	19,256	..	..	20.8	12,841
					Model D						
20	..	..	..	..	..	..	..	..	..	..	..
30	4,100	100.0	4,100	..	..	..	..	..	..	..	..
40	17,000	83.5	14,196	16.5	2,804	..	..	..	..	..	..
50	30,600	76.7	23,470	23.3	7,130	..	..	..	..	..	..
60	41,700	69.9	29,160	21.0	8,745	..	..	..	..	9.1	3,795
70	50,700	62.3	31,600	21.8	10,998	..	..	..	..	15.9	8,102
80	57,700	54.4	31,338	25.4	14,669	2.5	1,453	..	..	17.7	10,190
90	60,700	53.3	32,375	21.3	12,910	8.2	4,998	..	..	17.2	10,417
100	61,000	43.8	26,743	20.8	12,657	15.5	9,450	..	..	19.9	12,150

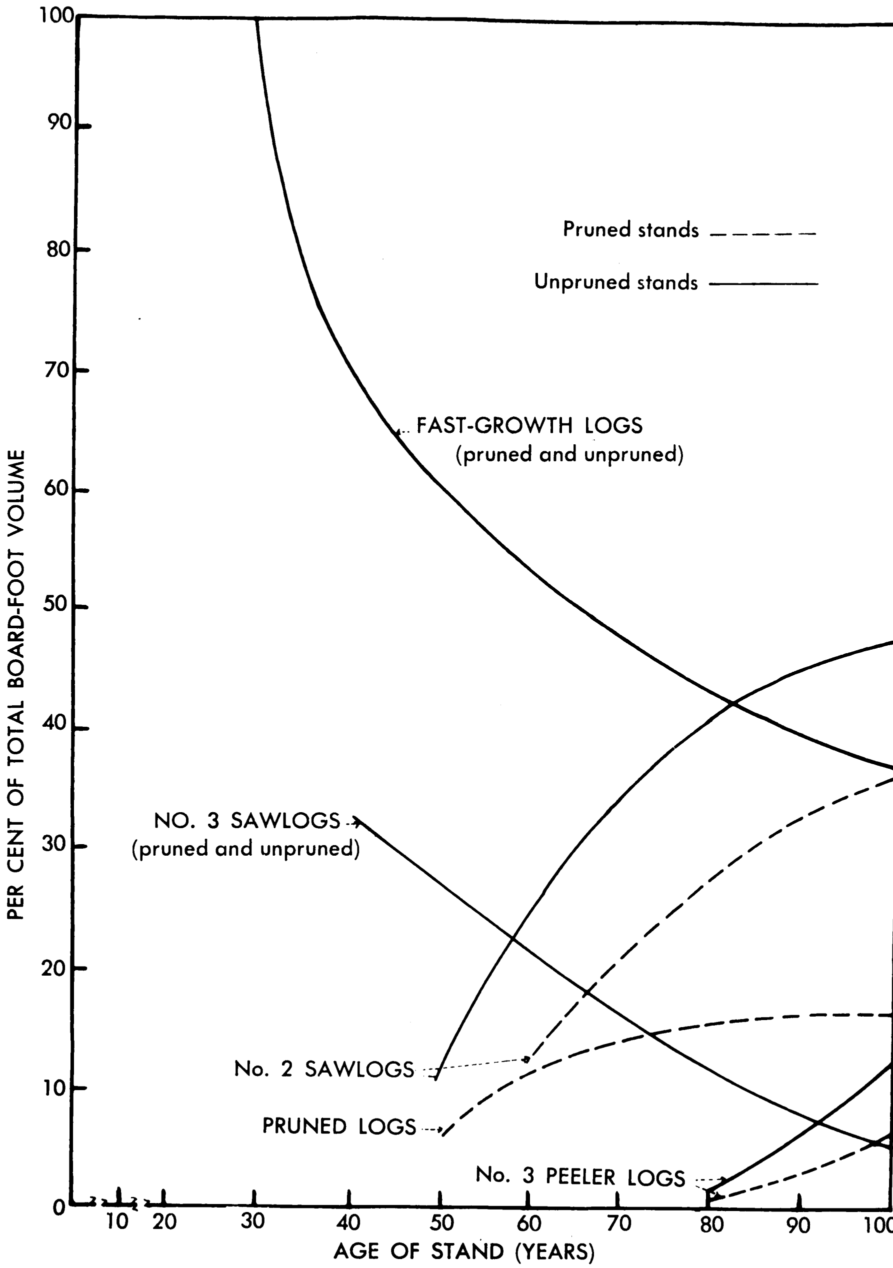

Fig. 7. Distribution of board-foot volume by log grade in pruned and unpruned stands (Site 200, stocking model A).

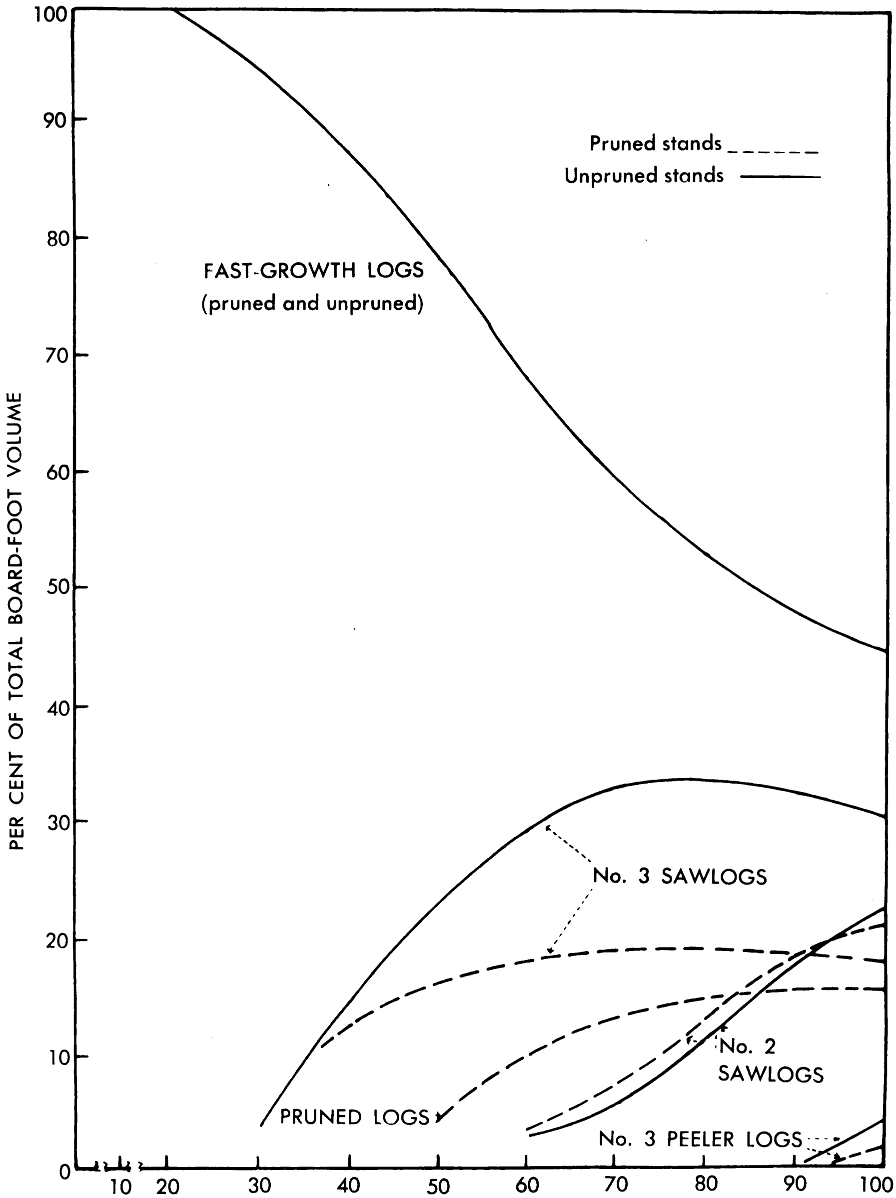

Fig. 8. Distribution of board-foot volume by log grade in pruned and unpruned stands (Site 200, stocking model D).

stocking levels. The primary influence of decreasing site is that of increasing the age at which logs reach sufficient size to be included in higher log-grade categories. A general reduction in amount of fast-growth volume is apparent in the fully-stocked stands.

Associated with the decrease in fast-growth is an increase in Number 2 and 3 sawmill logs. In the stands of low initial stocking, the effect is somewhat different in that there is no substantial change in amount of fast-growth volume; however, there is a tendency for the percentage of Number 3 sawmill logs to increase with lowering of site, with an associated decrease in portion of Number 2 sawmill logs. The volume in Number 3 peeler logs decreases in both levels of stocking with decrease of site.

Over-all Effects of Pruning

Pruning affects quality of logs produced in both fully-stocked and understocked stands. The effect in fully-stocked stands, as evidenced by the amount of pruned log volume resulting, is somewhat greater than that in stands of low initial stocking. However, most of the change in fully-stocked stands is a shift of volume from the Number 2 sawmill log category, while that in understocked stands is from Number 3 sawmill log class to the pruned log grade.

The amount of fast-growth volume in the stands affects the potential benefit from pruning. In fully-stocked, Model A stands between ages 50 and 100, from 37 to 67 per cent of total stand volume is fast-growth. About 20 per cent of this volume is made up of logs originally pruned but not qualifying for the pruned log grade because of overly rapid growth rate. In stands of low initial stocking, at the same ages, the proportion of fast-growth volume is even greater (45 to 80 per cent), with an equally large amount in logs originally pruned which also do not qualify for the higher grade because of growth rate.

Obviously, the effect of growth rate on log grade is a key factor influencing the effectiveness of pruning. Pruning in stands of low initial stocking would appear, on the surface, to have greater potential for improvement than pruning in fully-stocked ones, because pruning eliminates large knots. However, despite this effect, not all the clear wood produced after pruning qualifies as peeler (pruned log) material because of excessive fast diameter growth rate in initially understocked stands. The amount of fast-growth is less in stands of higher initial stocking, thus pruning would probably be more effective in increasing financial value in fully-stocked stands.

So long as present restrictions on growth rate remain in effect, the above observations have important implications as to the kinds of stands that can be most profitably pruned. These findings have not been widely recognized in the literature on pruning of Douglas-fir.

EFFECT OF INITIAL STOCKING ON FINANCIAL RETURN

Framework of Economic Analysis

While a comparison of physical amounts and quality of output indicates the relative favorability of various levels of initial stocking, these values do not in themselves provide a usable measure of financial returns. Physical outputs from each level must be compared within an economic framework. Such a framework was developed for the model stands, and monetary values were placed on both physical outputs and costs associated with management. These monetary values were compared within a consistent framework of time, and conclusions were drawn regarding financial effects of initial stocking on the basis of this comparison.

For purposes of this analysis, output in terms of quantity and quality was evaluated according to an assumed price structure from which the cost inputs carried forward at an assumed interest rate were deducted to determine net income. It was expected that net income would vary with age and, for each model stand, the age at which maximum net income is reached would also vary with initial stocking level and site. With such variation in timing of maximum net return, it was necessary to obtain a consistent base point in time at which to make a comparison of alternatives.

This was done by calculating soil expectation values which are, in essence, the present net worth per acre of land managed in perpetuity, under a consistent framework of stocking and related physical output, costs, prices, and rotation period. These values convert income structure to current value and provide the desired consistent time base for analysis.

The equation for calculating soil expectation values is as follows:

$$Se = \frac{Yr - Ch - e\left[\frac{(1+p)^r - 1}{p}\right]}{(1+p)^r - 1} \qquad \text{Equation 1}$$

Where: Se = soil expectation value
Yr = yield in terms of gross value of logs at any rotation age, r
Ch = costs of harvesting and marketing
e = annual expenses (taxes, fire protection, administration)
r = length of rotation, years
p = rate of interest charged expressed as a decimal

In the second phase of the analysis, fill-in planting and pruning were considered as means of improving quality and, for comparative purposes, were applied to stands of all levels of stocking. For this phase, the equation was expanded as follows:

$$Se = \frac{Yr - Ch - Pa(1+p)^{r-a} - Sb(1+p)^{r-b} - e\left[\frac{(1+p)^r - 1}{p}\right]}{(1+p)^r - 1} \qquad \text{Equation 2}$$

Where: Se = soil expectation value
Yr = yield in terms of gross value of logs at any rotation age, r
Ch = costs of harvesting and marketing
e = annual expenses (taxes, fire protection, administration)
r = length of rotation, years
p = rate of interest charged expressed as a decimal
Pa = cost of fill-in planting at age a
a = age at which fill-in planting is done, years
b = age at which pruning is done, years
Sb = cost of pruning at age a

Markets, Prices, and Costs

Marketing the Output. It was assumed that the forest enterprise responsible for production of logs in the model stands would also market the logs. Within any one corporation with this type of internal organization, the forest production division grows the raw products, delivers them to the manufacturing division, and receives credit at prevailing market prices for logs delivered.

Pricing requires the presence of a fully competitive market such as exists on the Columbia River in and about Portland, Oregon, and on Puget Sound in Washington. Any seller of logs may deliver his product to these markets and expect to find numerous buyers for logs in all quality classes. It was assumed that produce from the model stands would be harvested and delivered to a market of this kind.

Under these assumptions, costs of harvesting logs and delivering them to market are borne by the producers of the logs, and stand as a charge against income to the enterprise from log sales.

Pricing of Products. Since some products from stands developed here presumably would be marketed 50 to 100 years hence, a problem of finding an appropriate price forecasting procedure was encountered. No method has been developed for accurate prediction of future raw forest product prices. However, a reasonable alternative is that of using current price structure and assuming that future prices will bear the same relationship to one another that current prices do.

Since value of the stands was to be determined on the basis of value of logs delivered at a near-by log market (minus costs of growing, harvesting, and delivery), current market prices were needed.

In the following analysis, average prices for Number 2 and 3 sawmill logs and Number 1 and 3 peeler logs were obtained from monthly price summaries published by trade journals for the Columbia River and Puget Sound markets.

Even though fast-growth grade categories are recognized by log grading bureaus, market prices are not generally available for this grade. Prices for "third growth" logs, however, were available, and were used as the base for fast-growth prices in this analysis.

In addition, no price quotations were available for the pruned log category established in connection with the analysis of pruning. For purposes of evaluation, it was assumed that prices prevailing for Number 1 peeler logs would be applicable to this pruned log category. The following assumed prices for delivered Douglas-fir logs were used in the analysis:

LOG GRADE	PRICE PER M
Fast-growth sawlogs	$ 45
#3 sawlogs	47
#2 sawlogs	57
#3 peeler logs	88
Pruned logs (#1 peeler logs)	116

Production Costs. Cost items pertinent to management decisions and to production of logs in model stands are those associated with the establishment of the stands; costs of stand improvement measures taken between stand establishment and harvest; annual expenses, such as fire protection, taxes, and administrative costs; and costs of harvesting and marketing the product.

Costs of improving initial stocking. Initial stocking is usually improved by planting, reseeding, or modification of present ground conditions so that naturally regenerating trees will become established in greater abundance. Of the three alternatives, planting has been most widely practiced, and is the method considered in this analysis.

Planting costs given by McClay (1955) were used to relate total planting cost to the number of trees planted per acre. The following figures, adapted for Douglas-fir from McClay's curves of these relationships, assume the labor used to be equivalent to that classified by McClay as "Experienced F. S. Crews," and include costs of planting stock. Values are rounded to the nearest dollar.

NO. TREES PLANTED PER ACRE	TOTAL PLANTING COST PER ACRE
100	$ 5
200	8
300	12
400	16
500	19
600	23
700	27

These values are used later in applying regeneration costs to model stands (p. 667).

Pruning costs. It was found previously that the number of trees to be pruned per acre at 20 years varied with density of stocking at that age. To apply costs which reflect initial stocking conditions, it is desirable to obtain them on a per tree basis.

Estimates of costs of pruning young-growth Douglas-fir have been made by Shaw and Staebler (1950). Diameters of the trees involved in their study varied between 5 and 14 inches. Pruning time, in hours per tree, was correlated with diameter at breast height. The following figures were adapted from portions of Shaw's and Staebler's table 1.

DIAMETER BREAST HEIGHT *inches*	TOTAL PRUNING TIME *hours*
5	0.0875
6	0.1063
7	0.1225
8	0.1343
9	0.1467
10	0.1575
11	0.1663
12	0.1742
13	0.1793
14	0.1837

Pruning times in various diameter classes were multiplied by current wage rate (hourly gross earnings) for woods laborers to obtain cost per pruned tree. These values in turn were used to calculate pruning costs per acre in model stands by multiplying number of trees to be pruned per acre by cost per tree of the size equal to the average diameter of the stand. Table 11 shows results of these calculations.

Costs in table 11 increase with decrease in stocking in spite of decrease in numbers of trees pruned. This apparently contradictory effect is due primarily to larger diameter of the trees and limbs in the stands of lower initial stocking.

Harvesting and marketing costs. Harvesting and marketing of output from model stands include all steps from felling of trees to dumping of logs in the millpond or water-edge boom where actual sale takes place. Costs of all the following operations, and associated taxes and supervision are included: felling, bucking, yarding, loading, scaling, slash disposal, trucking (including road construction and maintenance), supervision, and social security and vacation benefits.

TABLE 11

ESTIMATED COSTS, PER ACRE, OF PRUNING MODEL STANDS

Stocking model	Number of trees pruned at 20 years	Av. stand diameter (inches)	Total cost per tree	Total cost per acre*
		Site 200		
A	100	5.7	$0.30	$30
B	100	6.1	0.31	31
C	90	7.0	0.34	31
D	80	8.9	0.40	32
		Site 170		
A	100	4.5	0.26	26
B	100	4.9	0.28	28
C	90	5.7	0.30	28
D	80	7.5	0.36	29
		Site 140		
A	100	3.4	0.23	23
B	100	3.7	0.24	24
C	90	4.4	0.26	24
D	80	6.0	0.31	25

* Values rounded to the nearest dollar.

Recent estimates of average regional logging costs obtained by the U. S. Forest Service from studies of 64 coöperating companies in the Pacific Northwest (Carow and Silene, 1957) were used in this analysis. Margin for profit and risk on harvesting and marketing operations is included in this cost, and logging costs are assumed to remain constant over stand age.

Administration, taxes, and fire protection. These costs were grouped and handled as a single item in the subsequent analysis on the basis that they are annual costs and occur simultaneously.

The administrative costs applicable to model stands are those associated with salary items for both direct supervision of the area and overhead items directly chargeable to it. Also included are such items as road maintenance necessary for the general administration of the area and legal fees related to rights-of-way and boundaries. This cost item was established at 25 cents per acre per year.

Tax items considered here were limited to *ad valorem* property taxes based on combined value of land and timber. Taxation practices vary widely over the region, and it is difficult to establish a common level. In view of the variability, an assumption was made that taxes are levied on a constant basis, related to the production capacity of broad site categories. Sites 200, 170, and 140 were included in one category, and the level was arbitrarily set at 90 cents per acre per year.

Forest protection costs are those incurred through maintenance of fire-control crews and equipment or by direct participation in a coöperative fire-protection plan wherein the members pay an annual fee in proportion to the amount of land included. In either case, these costs are variable according to the intensity of protection desired. A unit cost of protection currently maintained in the Douglas-fir region was assumed to be 85 cents per acre per year.

Thus, total annual costs per acre for taxes, fire protection, and administration used in this analysis were: $0.90 + 0.85 + 0.25 = \$2$.

Interest Rate. The rate of interest charged for funds invested in a forest enterprise is related to a number of factors, the most important of which are rate of return available in other investment opportunities, time preference of the organization, risk involved in investment, liquidity of investment, and period of time funds are to be tied up.

From the viewpoint of current markets, it appears that the investment will be liquid by the time the stands reach 30 to 40 years of age. The risk of major loss of investment due to fire or some destructive biological force is considered low in light of the level of fire protection assumed and the fact that stands are young, vigorous, and resistant to insects and disease. These factors tend to favor low interest rates.

The pure risk-free rate of interest, as measured by returns from long-term government securities, is assumed to be between 2 and 2.5 per cent. The hypothetical investor expects higher returns than this on money invested in the forest stands represented by the models. Three per cent has been the ruling rate for long-term forest investments, and is used in the full financial analysis which follows. However, a 5 per cent rate is held by some to be more realistic, and is applied for comparison in later stages of analysis.

Valuation of the Stands

Delivered Log Values. Consistent with the log market price framework adopted, delivered log values were determined. The appropriate price for each log grade category, as shown on page 656, was applied to the volume in each category in table 10. This resulted in dollar values for volumes in each log grade at each age for each stand. These values were summed, resulting in total value of logs delivered at the log market. These values are subsequently called "delivered log values."

Net Income and Soil Expectation Values. Delivered log values reflect

TABLE 12

NET INCOME AND SOIL EXPECTATION VALUES (DOLLARS PER ACRE) FOR MODEL STANDS

Site 200

Stand age (years)	Delivered log value	Total harvesting costs	Stumpage value	Annual cost	Cumulative annual cost with 3 per cent interest	Net income	Soil expectation values
Model A							
20	..	..	..	2	54	−54	−67
30	302	201	101	2	95	6	4
40	1,565	1,029	536	2	151	385	170
50	2,728	1,770	958	2	226	732	216
60	3,847	2,394	1,453	2	326	1,127	230
70	4,681	2,820	1,861	2	461	1,400	202
80	5,180	3,072	2,108	2	643	1,465	152
90	5,714	3,210	2,504	2	887	1,617	122
100	6,055	3,270	2,785	2	1,215	1,570	86
Model B							
20	..	..	..	2	54	−54	−67
30	424	282	142	2	95	47	33
40	1,597	1,050	547	2	151	396	175
50	2,694	1,752	942	2	226	717	212
60	3,710	2,346	1,364	2	326	1,038	212
70	4,598	2,775	1,823	2	461	1,362	197
80	5,121	3,030	2,091	2	643	1,449	150
90	5,659	3,174	2,485	2	887	1,598	120
100	6,028	3,246	2,782	2	1,215	1,568	86
Model C							
20	..	..	..	2	54	−54	−67
30	528	351	177	2	95	82	57
40	1,606	1,062	544	2	151	394	174
50	2,596	1,698	898	2	226	673	199
60	3,606	2,271	1,335	2	326	1,009	206
70	4,448	2,700	1,748	2	461	1,287	186
80	4,977	2,976	2,001	2	643	1,358	141
90	5,440	3,135	3,205	2	887	1,418	107
100	5,719	3,219	2,500	2	1,215	1,285	71
Model D							
20	50	33	17	2	54	−37	−46
30	698	465	233	2	95	138	97
40	1,655	1,095	560	2	151	409	181
50	2,519	1,665	854	2	226	628	186
60	3,335	2,181	1,154	2	326	828	169
70	4,023	2,604	1,419	2	461	958	138
80	4,548	2,901	1,647	2	643	1,005	104
90	4,954	3,081	1,873	2	887	986	74
100	5,229	3,174	2,055	2	1,215	841	46

TABLE 12—(*Continued*)

Site 170

Stand age (years)	Delivered log value	Total harvesting costs	Stumpage value	Annual cost	Cumulative annual cost with 3 per cent interest	Net income	Soil expectation values
Model A							
20	..	..	..	2	54	−54	−67
30	90	60	30	2	95	−65	−92
40	876	576	300	2	151	149	66
50	1,906	1,248	658	2	226	432	128
60	2,780	1,731	1,049	2	326	713	148
70	3,498	2,154	1,344	2	461	883	128
80	4,006	2,445	1,562	2	643	919	95
90	4,410	2,568	1,842	2	887	955	72
100	4,700	2,655	2,045	2	1,215	830	46
Model B							
20	..	..	..	2	54	−54	−67
30	180	120	60	2	95	−35	−146
40	456	630	326	2	151	175	77
50	1,947	1,278	669	2	226	443	131
60	2,814	1,764	1,050	2	326	723	148
70	3,484	2,145	1,339	2	461	877	128
80	3,972	2,415	1,557	2	643	914	95
90	4,368	2,550	1,818	2	887	932	70
100	4,639	2,616	2,023	2	1,215	808	44
Model C							
20	..	..	..	2	54	−54	−67
30	288	192	96	2	95	1	1
40	1,029	681	348	2	151	198	88
50	1,987	1,308	679	2	226	454	134
60	2,832	1,791	1,041	2	326	715	146
70	3,424	2,139	1,285	2	461	824	119
80	3,913	2,393	1,519	2	643	876	91
90	4,253	2,535	1,719	2	887	832	63
100	4,489	2,589	1,900	2	1,215	686	38
Model D							
20	9	6	3	2	54	−51	−63
30	378	252	126	2	95	31	22
40	1,131	750	381	2	151	230	102
50	2,022	1,335	687	2	226	462	137
60	2,748	1,809	939	2	326	613	125
70	3,245	2,133	1,112	2	461	651	94
80	3,658	2,376	1,282	2	643	640	66
90	3,947	2,520	1,427	2	887	640	41
100	4,071	2,565	1,506	2	1,215	292	16

TABLE 12—(*Continued*)

Site 140

Stand age (years)	Delivered log value	Total harvesting costs	Stumpage value	Annual cost	Cumulative annual cost with 3 per cent interest	Net income	Soil expectation values
Model A							
20	..	..	..	2	54	−54	−67
30	..	..	..	2	95	−95	−136
40	431	282	149	2	151	2	1
50	1,141	744	397	2	226	171	51
60	1,927	1,200	727	2	326	391	82
70	2,482	1,503	979	2	461	518	75
80	2,922	1,752	1,170	2	643	528	55
90	3,139	1,851	1,288	2	887	402	30
100	3,261	1,881	1,380	2	1,215	166	9
Model B							
20	..	..	..	2	54	−54	−67
30	27	18	9	2	95	−86	−123
40	495	330	165	2	151	14	6
50	1,206	789	417	2	226	192	58
60	1,937	1,215	722	2	326	396	81
70	2,465	1,500	965	2	461	504	73
80	2,908	1,743	1,165	2	643	522	54
90	3,111	1,842	1,269	2	887	382	29
100	3,205	1,863	1,342	2	1,215	127	7
Model C							
20	..	..	..	2	54	−54	−67
30	95	63	32	2	95	−64	−97
40	638	420	218	2	151	68	30
50	1,324	870	454	2	226	228	67
60	1,944	1,236	708	2	326	382	78
70	2,489	1,524	965	2	461	504	73
80	2,879	1,737	1,143	2	643	500	52
90	3,068	1,830	1,238	2	887	351	26
100	3,165	1,848	1,317	2	1,215	102	6
Model D							
20	..	..	..	2	54	−54	−67
30	185	123	62	2	95	−34	−49
40	771	510	261	2	151	110	49
50	1,391	918	473	2	226	248	73
60	1,902	1,251	651	2	326	324	66
70	2,320	1,521	799	2	461	338	49
80	2,664	1,731	933	2	643	290	30
90	2,838	1,821	1,017	2	887	131	10
100	2,908	1,830	1,078	2	1,215	−137	−250

both quantity and quality of output, and serve as the basis for calculation of net income and soil expectation values.

To obtain net income, stumpage values were first derived from delivered log values by deducting harvesting costs. Harvesting costs were obtained by

TABLE 13

SOIL EXPECTATION VALUES (DOLLARS PER ACRE) FOR MODEL STANDS AS A FUNCTION OF STAND AGE, DENSITY, AND SITE QUALITY

(3 per cent interest)

Stand age (years)	Model A	Model B	Model C	Model D
	Site 200			
20	−67	−67	−67	−46
30	4	33	57	97
40	170	175	174	181
50	216	212	199	186
60	230	212	206	169
70	202	197	186	138
80	152	150	141	104
90	122	120	107	74
100	86	86	71	46
	Site 170			
20	−67	−67	−67	−63
30	−92	−146	1	22
40	66	77	88	102
50	128	131	134	137
60	148	148	146	125
70	128	128	119	94
80	95	95	91	66
90	72	70	63	41
100	46	44	38	16
	Site 140			
20	−67	−67	−67	−67
30	−136	−123	−97	−49
40	1	6	30	49
50	51	58	67	73
60	82	81	78	66
70	75	73	73	49
80	55	54	52	30
90	30	29	26	10
100	9	7	6	−250

applying the unit harvesting cost of $30 per thousand to board-foot volumes in each model stand at each age. Stumpage values represent gross values of standing trees in the model stands.

Net income was then derived from stumpage values by deducting total accumulated costs ($2 per acre) for taxes, fire protection, and administration (p. 659) at 3 per cent interest. These were charged on an annual basis and carried forward, with compound interest, to the end of each 10-year

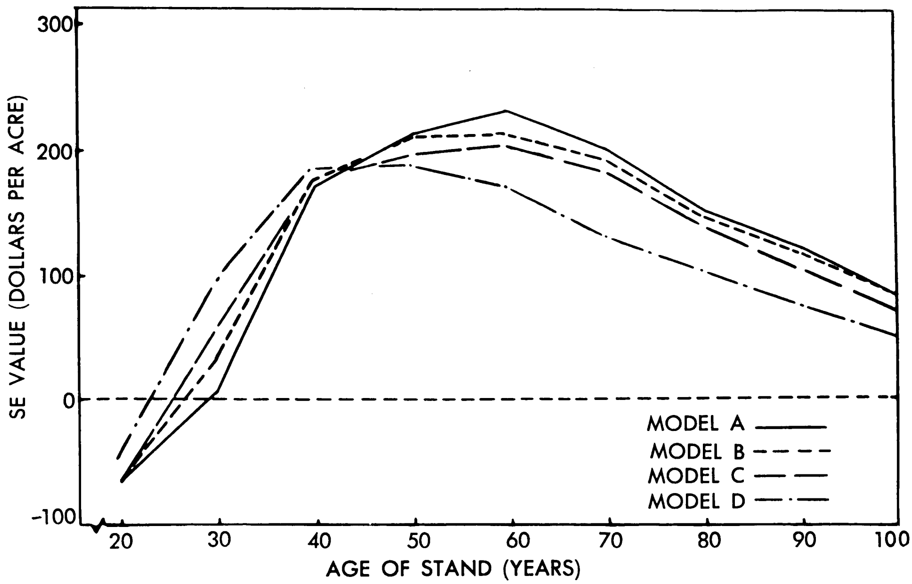

Fig. 9. Soil expectation values for model stands (Site 200).

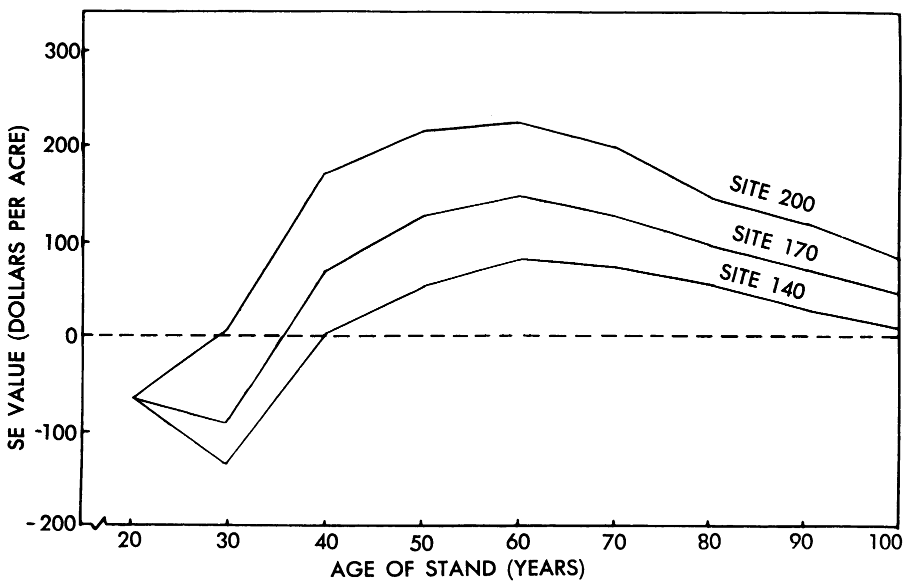

Fig. 10. Soil expectation values for Model A stands, by site classes.

rotation period, at which point they were deducted from stumpage value to give net value of stands at the end of the rotation, over and above all costs. All values obtained in these calculations are given in table 12.

Soil expectation values were determined directly from net income by applying the soil expectation equation (Equation 1, p. 655). These values are entered in table 13, and curves of these values are provided in figures 9 and 10.

Soil Expectation Values

The soil expectation values provide the basis for determining financial rotation age and the effects of initial understocking on financial return. As discussed previously, these values represent present net worth of land that is dedicated perpetually to the production of timber at the level of initial stocking characteristic of the model being analyzed, on a rotation of constant length, and within the framework of costs and revenues assumed for the models.

The values start from a low point at short rotations, increase to a maximum, and then decline. The maximum for each model is the point of greatest profitability, and corresponds to the point at which marginal costs are equal to marginal revenue. These maximums are used in subsequent comparisons between models.

While all model stands show positive soil expectation values at some age, indicating that each will be profitable, there is a substantial difference between the level of profitability in stands of low initial stocking and those of high initial stocking. On each site, the Model D stands have the lowest maximum soil expectation values, and Model A stands the highest. The following figures show the differences in these values, in dollars per acre, as a result of lowering the initial stocking level:

MODEL STAND	SITE 200	SITE 170	SITE 140
A	$ 0	$ 0	$ 0
B	18	0	1
C	24	2	4
D	44	11	9

It will be recalled that the models were established at discrete levels of initial stocking based on numbers of trees per acre present on the site 20 years after logging of the previous stands. The stocking levels were selected in reference to values of numbers of trees per acre on site 200 at 20 years in the normal yield tables. Model A represented full stocking as established in the yield tables with 571 trees, Model B at 75 per cent of this value, or 428 trees, Model C at 50 per cent with 286 trees, and Model D at 25 per cent with 143 trees.

Thus the net effect of managing stands on site 200 with one-fourth as many trees (Model D level) as the fully-stocked stand is to reduce the worth of the enterprise by $44 per acre. The reduction in soil expectation value with reduction of number of trees in initial stocking is not a straight-line relationship. Although the values in the table do not show a consistent decline, it appears that the first increment of reduction in number of trees is associated with less change in value than is the last increment of reduction.

The effect of reduction of initial stocking level on reduction of value appears to decrease with site, indicating that lower sites are less sensitive to changes in stocking level than are higher sites.

For purposes of additional comparison between models, optimum rotation ages, as indicated by maximum soil expectation values, were calculated to the nearest year as follows:

MODEL STAND	SITE 200 *years*	SITE 170 *years*	SITE 140 *years*
A	59	58	59
B	58	58	58
C	57	57	57
D	48	49	51

These values show a decline with initial stocking level between models A and C, and a marked decline between models C and D. This change in rotation age is again a reflection of the low rate of value increase in the understocked models in relation to the rate of cost increase, which is the same on all models. That is, cost increase exceeds the rate of value increase at an earlier age in understocked stands than it does in fully-stocked stands. The disproportionate decline in rotation age between models C and D is due to the very low rate of value increase in Model D stands, and reflects the large and relatively constant amount of fast-growth and Number 3 sawmill log volume in Model D stands.

On the basis of results obtained, it can be stated conclusively that initial stocking does affect financial return and net worth of forest stands. A reduction in initial stocking level reduces both revenue and worth. The most favorable level of initial stocking is obviously the fully-stocked stand (Model A), assuming at this point that stocking level is independent of costs. Even though all levels were profitable on all the sites considered here, the land should be managed at the level of initial stocking that will produce maximum returns, in this case the Model A or full-stocking level.

Financial Effect of Planting to Improve Initial Stocking Level

Since low initial stocking reduces the financial value of stands, consideration was given to measures that the forest manager can take to reduce or eliminate such decreases in value. Fill-in planting as a means of improving initial stocking level is one such alternative.

The purpose of fill-in planting is to supplement natural regeneration and to bring initially understocked stands up to the fully-stocked level (Model A). Its desirability was analyzed by using maximum soil expectation values. These were obtained by deducting fill-in planting costs, with interest, from net income values for Model A stands at each age. Net income values for Model A stands were used as the base for the calculation on the assumption that initially understocked seedling stands that have been fill-in planted to the Model A stocking level will behave in the same manner as Model A stands.

In order to bring models of low initial stocking up to the fully-stocked level, it is necessary to interplant in stands of natural seedlings. Such interplanting requires 143, 286, and 431 trees per acre, respectively, on models B, C, and D to achieve Model A-level stocking. It is assumed planting is done within a year of harvest date and that planted trees will be at same quality as natural stands. Planting costs associated with these numbers of trees were interpolated from the costs shown on page 657, and amount to \$7.20 per acre for Model B, \$11.90 for Model C, and \$17.20 for Model D. These costs were capitalized to the end of each 10-year rotation period, and deducted from the net income values for the Model A stand in each site class and stand age. This resulted in new net income values for model B, C, and D stands. New income values were converted to soil expectation values for each rotation age by applying the divisor in Equation 2, p. 655. The maximum soil expectation values thus obtained are higher than those associated with the "natural" stands (those not planted) on site 200 only, but show a similar pattern in that values decrease as initial stocking is lowered and greater planting inputs are needed. Maximum soil expectation values for stands receiving supplementary planting are compared with those from natural stands in table 14.

TABLE 14

MAXIMUM SOIL EXPECTATION VALUES (DOLLARS PER ACRE) FROM MODEL STANDS WITH AND WITHOUT SUPPLEMENTARY PLANTING

(3 per cent interest)

Model	Site 200			Site 170			Site 140		
	N*	NP†	NP–N‡	N*	NP†	NP–N‡	N*	NP†	NP–N‡
A	230	§	..	148	§	..	82	§	..
B	212	222	10	148	138	−10	81	72	−9
C	206	216	10	146	131	−15	78	66	−12
D	186	210	24	137	125	−12	73	59	−14

* N — Natural.
† NP — Natural plus planting.
‡ NP–N — Natural plus planting minus natural.
§ — Not applicable since Model A stands were not planted.

These values indicate the profitability of fill-in planting on models B, C, and D on site 200. The planting of site 200 Model B stands yields the highest soil expectation value, but the rate of return per dollar invested in planting is highest on the Model D stands. Under the data and assumptions used in this study, it would not be economical to fill-in plant sites 170 and 140. In general terms, it is profitable to fill-in plant the highest site, but on lower sites the value added by planting does not cover planting costs plus interest charges. On high-site lands, the highest rate of return per original dollar invested in planting occurs on Model D stands. Thus, where limited funds are available for planting, Model D stands should receive treatment priority.

In order to apply these findings in field practice, it would be necessary to develop a means of judging initial stocking very early during the regeneration period. Where it is apparent that natural initial stocking of the "A" level will not be reached on site 200, planting should be undertaken at the earliest possible date.

Staebler (1949) has developed an approach to analyzing the reproduction potential of an area and has suggested a method of predicting the amount of regeneration expected on areas of differing aspect and brush

TABLE 15

SOIL EXPECTATION VALUES (DOLLARS PER ACRE) FOR PRUNED STANDS AS A FUNCTION OF STAND AGE, DENSITY, AND SITE QUALITY

(3 per cent interest)

Age (years)	Model A	Model B	Model C	Model D
	Site 200			
20	−67	−67	−67	−118
30	−95	−40	4	43
40	127	130	130	135
50	237	232	199	189
60	296*	271	260	214
70	291	287*	269*	225*
80	208	208	198	171
90	155	153	142	115
100	101	96	92	71
	Site 170			
20	−67	−67	−67	−128
30	−182	−146	−92	−146
40	28	37	48	60
50	94	95	99	99
60	204*	205*	194*	172*
70	189	185	165	145
80	154	141	131	113
90	106	102	94	79
100	66	54	53	34
	Site 140			
20	−67	−67	−67	−67
30	−137	−204	−169	−133
40	−174	−145	−38	−12
50	21	26	39	41
60	108	117	102	90
70	131*	126*	124*	101*
80	102	96	93	75
90	59	54	50	37
100	29	24	23	12

* Indicates maximum soil expectation value.

cover. Lavender, Bergman, and Calvin (1956) have determined additional factors affecting the regeneration chance. While methods of accurately predicting the amount of natural regeneration on an area immediately after cutting are not available at this time, the factors these authors have isolated can serve as a useful guide, in combination with the financial analysis above, in making planting decisions.

Valuation of Pruned Stands

The objective in applying pruning to model stands was to determine the physical and economic effects of pruning in overcoming the quality deficiencies in stands of low initial stocking. Because pruning is a management alternative applicable to all stands, it was applied in this analysis to both fully-stocked and understocked stands. It was previously shown that, in stands of low initial stocking, pruning results in a reduction of Number 3 sawmill logs and an increase in the pruned peeler grade, while in fully-stocked stands, the shift is from the Number 2 log category to the pruned peeler grade. The magnitude of the shift to the pruned peeler log grade is greater in the stands of full initial stocking than in those of low.

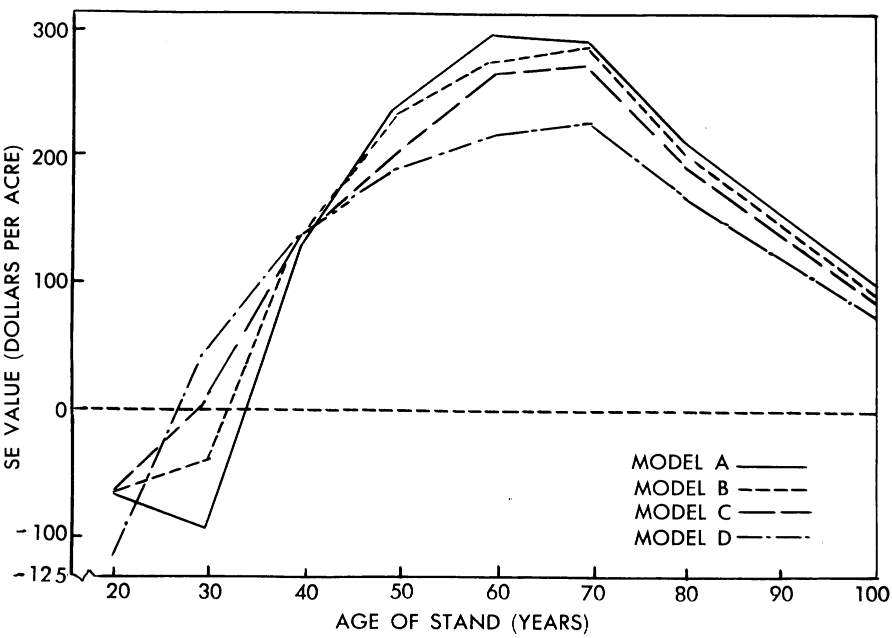

Fig. 11. Soil expectation values for pruned model stands (Site 200).

Financial analysis for the pruned stands was the same as that for the "natural" stands. New income and soil expectation values were calculated from delivered log values in the manner used previously for natural stands with the exception that per acre pruning costs from table 11 were introduced at age 20, and carried forward with interest. Values are summarized in table 15 and presented graphically in figures 11 and 12.

The relationships of stocking level and site to soil expectation values were the same as those obtained for the natural stands. The high initial stocking levels had greater net worth than did low stocking levels. The effect of lowering site quality was to reduce soil expectation values in all models. A striking difference between the pruned and natural stands was the level of the values, which was substantially higher for the pruned stands.

In table 16, maximum soil expectation values for the natural stands (from table 13) are compared with those for the pruned stands (from table 15) to evaluate the effect of pruning. The value added to the stands as a result of pruning is indicated in the last column of table 16.

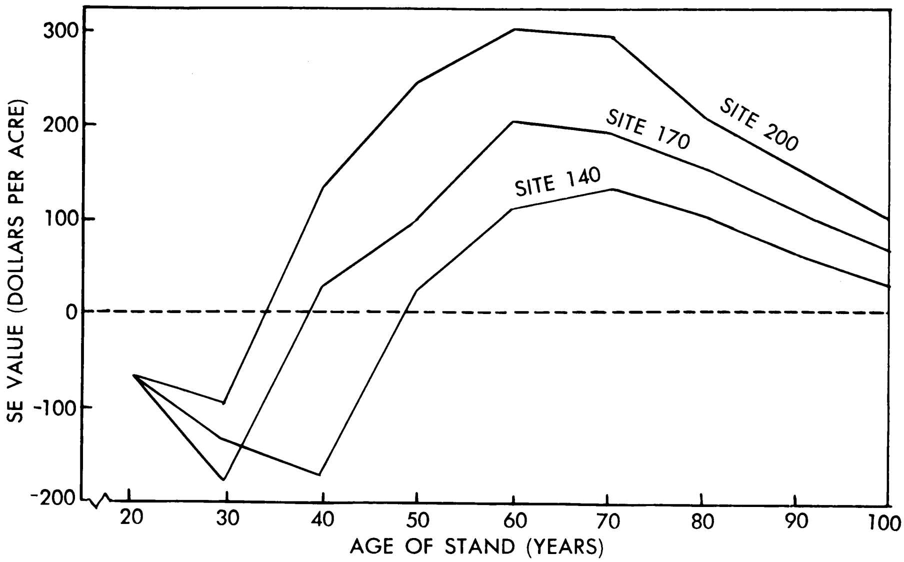

Fig. 12. Soil expectation values for pruned Model A stands, by site classes.

TABLE 16

MAXIMUM SOIL EXPECTATION VALUES (DOLLARS PER ACRE) IN PRUNED AND UNPRUNED (NATURAL) STANDS OF VARIOUS DENSITIES

(3 per cent interest)

Model	Pruned (P)	Natural (NP)	P-NP
Site 200			
A	296	230	66
B	287	212	75
C	269	206	63
D	225	186	39
Site 170			
A	204	148	56
B	205	148	57
C	194	146	48
D	172	137	35
Site 140			
A	131	82	49
B	126	81	45
C	124	78	46
D	101	73	28

The data indicate that pruning is a profitable venture on all initial stocking levels and sites considered here, at rotation ages in excess of 40 years, but the level of profitability varies between stocking level and site. While values in table 16 are not completely consistent, pruning is most profitable on the models of high initial stocking. Profitability decreases with both initial stocking and site.

The effect of pruning in overcoming quality deficiencies in the models of low initial stocking is most apparent on sites 170 and 140. Here the value

TABLE 17

MAXIMUM SOIL EXPECTATION VALUES (DOLLARS PER ACRE) FROM PRUNED, AND PRUNED AND FILL-IN PLANTED STANDS OF VARIOUS DENSITIES

(3 per cent interest)

Model	Pruned (P)	Pruned and fill-in planted (PP)	PP-P
Site 200			
A	296	296	0
B	287	288	1
C	269	282	13
D	225	275	50
Site 170			
A	204	204	0
B	205	196	−9
C	194	190	−4
D	172	183	11
Site 140			
A	131	131	0
B	126	124	−2
C	124	118	−6
D	225	235	10

of the pruned Model D stands exceeds that of the natural Model A stands. On site 200, the values of the pruned D stands fall about $5 short of the values of the natural A stands. There is some question as to the significance of this $5 difference when the increase in values brought about by the addition of pruning on all other sites and levels of initial stocking more than exceeds the decrease in value due to stocking on the natural stands.

Since both planting and pruning improved soil expectation values of some or all of the model stands, it was of interest to determine effects of the two in combination. This was accomplished by adding an input of planting to the pruned stands, which in effect imparted the physical characteristics of fully-stocked, pruned stands. Net income values for pruned, Model A stands were thus used in the analysis, and planting costs plus interest at the level appropriate for the required planting were deducted. Soil expectation values were calculated in the usual manner, using these new net incomes at each age.

Table 17 shows the effects of adding the planting input to the pruned stands.

The values in table 17 indicate that where an established policy of pruning all stands exists (indicated as profitable in the previous section), all annual costs plus pruning and planting costs plus interest would be returned on models B, C, and D, site 200; on models C and D, site 170; and on Model D, site 140. Thus both planting and pruning are financially attractive alternatives on these stands, and should be applied.

It is apparent from a comparison of tables 14 and 17 that a decision to prune affects the breadth of stocking levels over which planting is financially desirable. Without pruning, it is feasible to plant models C and D, site 200, and Model D on sites 170 and 140. Where an input of pruning on all stands is contemplated, it becomes economically desirable to plant Model B, site 200, and Model C, sites 170 and 140, in addition to those mentioned.

Total Effect of Planting and Pruning on Value of Model Stands

The effects of planting and of pruning on "natural" stands, and the effect of planting on pruned stands have been considered. The final choice among these management practices for application to the "natural" stands would obviously be based on which combination produced the highest soil expectation value for each stocking model and site. Final choice is facilitated by comparing maximum soil expectation values for each stocking model, site, and management input combination as shown in table 18. Values marked with a dagger (†) indicate the best management alternative for each model and site. All models yield adequate returns to cover management costs with interest plus a residual for use of the land. Highest returns are associated with the best sites and highest initial stocking in combination with an input of pruning or pruning and planting.

Results from pruning alone are more profitable than those from planting alone, but the combination of both pruning and planting can be most advantageously applied only to model B, C, and D stands on site 200 and to Model D stands on sites 170 and 140. It is also apparent that the decision to invest in one type of input influences the desirability of investing in others. For example, table 18 indicates that pruning alone is a profitable input on all stands considered here, while fill-in planting alone is profitable only on site 200 land. However, once the decision has been made to prune all stands it is apparent that planting then becomes profitable on stands of Model D stocking level on sites 170 and 140. From this it may be concluded that management inputs of the type considered here must be applied selectively and with full recognition of the interplay between inputs. It is likely that similar interplay may be important where precommercial and commercial thinning are considered along with planting and pruning. Further investigation of a wider range of inputs and the relationships among them is indicated.

The forest manager, in deciding what level of initial stocking and what management inputs will achieve highest value, should choose to establish full stocking and to prune the stands at an appropriate age. Within the range of stocking levels considered here, the closer he comes to achieving the full initial stocking level, the better will be the return. Furthermore, under conditions of limited funds for investment in management inputs, available funds should be invested in high site stands first.

The values in table 18 further emphasize the effect of low initial stocking on financial return, and indicate that the best method of partially overcoming this reduced return is by planting and/or pruning. However, while such

TABLE 18

MAXIMUM SOIL EXPECTATION VALUES (DOLLARS PER ACRE) FOR MODEL STANDS WITH VARYING COMBINATIONS OF PRUNING AND FILL-IN PLANTING

(3 per cent interest)

Model	Natural	Fill-in planted	Natural pruned	Pruned and fill-in planted
		Site 200		
A	230	*	296†	*
B	212	222	287	291†
C	206	217	269	282†
D	186	210	225	275†
		Site 170		
A	148	*	204†	*
B	148	138	205†	196
C	146	131	194†	190
D	137	125	172	183†
		Site 140		
A	82	*	131†	*
B	81	72	126†	124
C	78	66	124†	118
D	73	59	101	111†

* Not applicable.
† Indicates the most favorable alternative by site and initial stocking level.

investment in management inputs will improve the level of return, the full effects of very low initial understocking can never be completely overcome. For example, while the fill-in planting of initially understocked stands will do much to improve the level of financial return, the cost of planting will materially reduce the return. Any alternative, but less expensive method of improving initial stocking is highly desirable.

Effect of Interest Rate

Since the prevailing rate of interest has an important influence on the use of capital, its influence on the management of the model stands established in this study and on the inputs of stocking, planting, and pruning is of importance. The 3 per cent interest rate used in the analyses above has been the long-term ruling rate in the past. However, money at 3 per cent interest is currently difficult to obtain for the types of investments involved in this study. A 5 per cent rate, regarded by many as more realistic in current financing, was therefore used in the following analysis to show the effect of a higher rate.

Calculations for this phase of the study were made as previously described (p. 659). The basic physical models remain the same. Stumpage values for the models were taken from table 12, and annual and fixed costs (pruning and fill-in planting) were capitalized at 5 per cent interest rate to the end of each 10-year period, and deducted. The resulting net incomes were then converted to soil expectation values by applying the divisor in Equation 2 (p. 655), using the new interest rate. Maximum soil expectation values and their associated rotation ages are used in the following analyses.

Table 19 summarizes values for the basic "natural" stands. Of immediate

TABLE 19

ROTATION AGES* AND MAXIMUM SOIL EXPECTATION VALUES FOR MODEL STANDS
(5 per cent interest)

Model	Site 200		Site 170		Site 140	
	Rotation age	Soil expectation value	Rotation age	Soil expectation value	Rotation age	Soil expectation value
	years		*years*		*years*	
A	50	$54	50	$23	†	†
B	40	51	50	24	60	$1
C	40	50	50	25	50	2
D	40	52	50	26	50	5

* To the nearest 10 years.
† Soil expectation is a minus value; thus alternative is uneconomic.

interest in the data in table 19 is the fact that the Douglas-fir stands represented by the models can be profitably managed under relatively high prevailing interest rates. The most obvious effect of increasing interest rate is a decrease in soil expectation values; all values at 5 per cent are lower than those calculated at 3 per cent. The relative profitability of the various sites has not changed; site 200 is most profitable and site 140 is the least. Rotation age is lowered significantly in sites 200 and 170, but is not substantially changed in site 140. The latter is mainly the result of fewer fast-growth logs on the lower site, so that the rate of value increase with age remains high with respect to the rate of increase of costs plus interest.

Model A stands on site 140 become uneconomic to operate under this interest rate. This seemingly anomalous finding, that fully-stocked, site 140 lands are uneconomic, follows from the fact that these stands just do not maintain as rapid diameter growth rate as does the stand of lower initial stocking, and thus do not achieve quality and value growth levels sufficient to keep pace with costs built up under the 5 per cent interest rate.

An important change in relationship of soil expectation value to level of initial stocking is apparent under the 5 per cent interest rate. Soil expectation values on sites 170 and 140 now increase with decrease in initial stocking level and, on these sites and with this interest rate, stands of low initial stocking are somewhat more profitable than initially fully-stocked stands. However, a question exists as to the significance of the three- to four-dollar differences in value between the initially fully-stocked and understocked stands. The fact remains, nevertheless, that, within the framework of these models, understocked stands are at no apparent disadvantage and that, where

TABLE 20

MAXIMUM SOIL EXPECTATION VALUES (DOLLARS PER ACRE) FOR "NATURAL," FILL-IN PLANTED, AND PRUNED STANDS

(5 per cent interest)

Model	Natural	Planted	Pruned	Pruned and fill-in planted
		Site 200		
A	54	*	38	38
B	51	44	36	31
C	50	39	25	25
D	52	33	21	19
		Site 170		
A	23	*	15	15
B	24	16	14	3
C	25	10	12	3
D	26	4	5	†
		Site 140		
A	†	†	†	†
B	1	†	†	†
C	2	†	†	†
D	5	†	†	†

* Not applicable since Model A stands had no fill-in planting.
† Soil expectation is a minus value.

higher interest rates prevail, initial understocking, within biological limits, is not the important factor in economic success of an enterprise that is under lower interest rates. Again, the primary reason for this is the higher rate of increase in value of understocked stands during the first 40 to 50 years.

The ultimate choice among the management alternatives considered in this study can be made by comparing maximum expectation values achieved under each alternative, as shown in table 20. The values for the fill-in planted, pruned, and pruned-and-planted stands were calculated in the same manner as previously described except that the 5 per cent interest rate was used.

Considering first the data for the fill-in planted stands (column 3, table 20), it is apparent that the level of values is lower in each case than those calculated using 3 per cent interest (table 14). Furthermore, the values are lower than those for the natural stands (column 2, table 20) where 5 per cent interest is applied to both. This is a reversal of the relationship found under the 3 per cent rate where values for fill-in planted stands on site 200 were higher.

With regard to pruning, similar relationships exist; the level of values achieved under 5 per cent interest is lower than that at 3 per cent. Also, pruned stands do not exceed the value of "natural" stands.

Looking at the over-all comparison of alternatives, it is obvious that a "do-nothing" policy is the most profitable one. The highest soil expectation values are achieved in the "natural" stands and, as was indicated previously, there is a slight, but perhaps insignificant advantage in favoring stands of lower initial stocking.

It would be natural to conclude from these findings that, as interest rate increases, the forest manager can afford to do less and less in the way of stand improvement. This undoubtedly is true under conditions where interest rate is rising and stumpage values remain constant—conditions assumed in this study. However, if stumpage values increase commensurate with interest rates, the basic conclusions drawn from the analysis at the 3 per cent interest rate would probably remain valid. The question of what constitutes a "commensurate" rise in stumpage value to compensate for a rise in interest rate needs further investigation.

SUMMARY

Problems of initial understocking are important in the management of commercial Douglas-fir stands since understocking may markedly reduce financial return. Initial understocking is a production factor over which the forest manager has a large measure of control. With a knowledge of its effects, therefore, he may plan his management to achieve maximum value. This study was designed to quantify the effects of initial understocking, to analyze them within a financial framework, and to provide guides for the economic management of young-growth Douglas-fir stands. Findings are as follows:

1. Initial understocking results in marked physical differences in stands managed for sawmill and peeler log production. Over a rotation of 50 to 70 years, initially understocked stands show larger average stand diameters, fewer trees per acre, and less basal area than fully-stocked stands. However, on a total-volume basis, the magnitude of difference is small.

2. While difference in total physical output is minor, quality with respect to sawmill and peeler logs is much lower in stands starting out initially understocked. The lower quality, and hence value, is due primarily to excessive amounts of "fast-growth" wood and large knots, both characteristic of initially understocked stands.

3. Using four model stands growing at initial stocking rates of 25, 50, 75, and 100 per cent of normal stand values, maximum reductions in net income and soil expectation values (calculated at 3 per cent interest), at financial rotation ages, due to low initial stocking were $612 and $44 per acre, respectively. These differences were at a maximum on the highest site lands, and smallest on the lowest sites.

4. Inputs of pruning and planting carried at 3 per cent interest were

introduced to overcome the quality differences due to low initial stocking. Both inputs proved feasible means of either eliminating or reducing the quality differential on some stands and sites at that interest rate.

5. Productive capacity of the land (site) affects the profitability of planting and the range of stocking conditions over which planting can be profitably applied. Fill-in planting during the regeneration period is a profitable input on high site stands with less than 75 per cent of normal initial stocking, but stands so treated never achieve the value of naturally fully-stocked stands because of planting costs involved. On the lowest site considered (site III), planting is profitable only on stands of less than 50 per cent normal initial stocking.

6. Pruning is a profitable input, if carried at 3 per cent interest, on all stocking levels and sites considered; however, the level of profitability varies between stocking and site, and is highest on fully-stocked and highest-site lands. Thus, where funds for management inputs are limited, they should be allocated first to stands of high initial stocking and best sites.

7. At a 3 per cent interest rate, one or a combination of inputs in every case considered was more profitable than no inputs of pruning or planting. Without exception, soil expectation values calculated at that rate for stands of low initial stocking that had been both pruned and planted were greater than those from fully-stocked stands with no such supplementary treatment. On the highest site it was most profitable to prune stands of 75 per cent or better initial stocking, and to prune and fill-in plant stands of 50 per cent or less stocking. On lower sites, pruning alone is more profitably applied to stands of 50 per cent and better stocking, while the combination of pruning and planting is most profitable on stocking levels of less than 50 per cent.

8. Studies were made of the effect of increasing interest rate on the relationships found above. Five per cent interest was used in recalculating soil expectation values, and it was found that natural stands of the initial stocking levels and sites studied here can be profitably operated at that rate.

9. Under the 5 per cent interest rate, maximum soil expectation values were reduced substantially, and rotation ages were shortened. In addition, there was little difference in soil expectation values between the initially understocked and fully-stocked stands. This indicates that, within biological limits, stocking is not the important factor in economic success of a forest enterprise operating with a 5 per cent alternative rate of return that it is under a 3 per cent rate. It is further indicated that, while fill-in planting and pruning are economical inputs on site 200 and site 170 lands, at 5 per cent, they are uneconomical on lower site lands.

10. The conclusions regarding the effect of the higher interest rate would indicate that a "do-nothing" policy with respect to fill-in planting and pruning is the most profitable one. However, it is recognized that this is indicated only under conditions were stumpage values do not increase commensurate with interest rates.

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