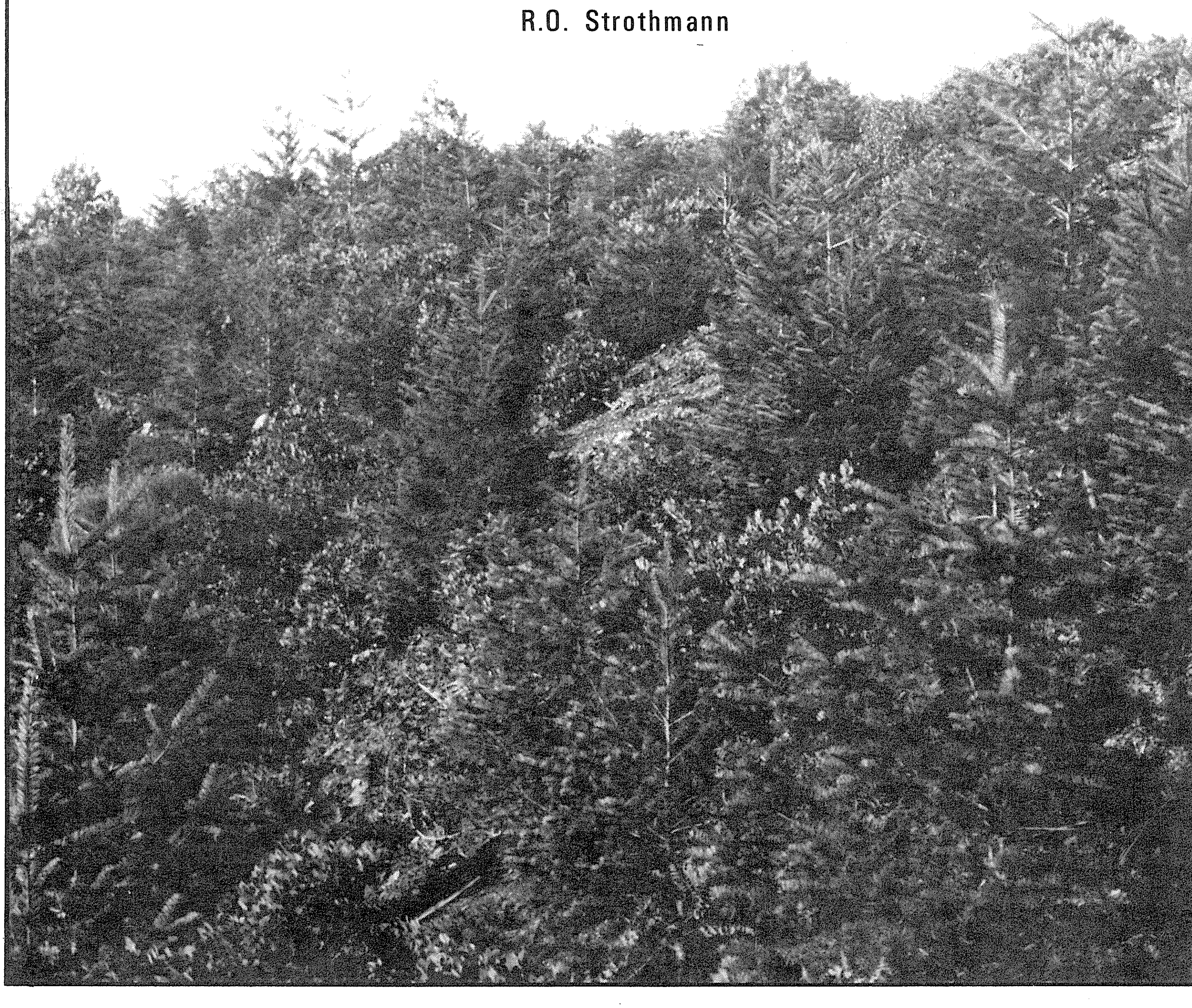
PACIFIC SOUTHWEST
Forest and Range
Experiment Station

FOREST SERVICE
U.S.DEPARTMENT OF AGRICULTURE

Regeneration of Douglas-fir cutblocks on the Six Rivers National Forest in northwestern California

R.O. Strothmann



RESEARCH PAPER PSW-142

The Author

R.O. STROTHMANN is doing research on the silviculture of redwood and Douglas-fir forests, with headquarters in Arcata, California. He earned bachelor's (1950), master's (1951), and Ph.D. (1964) degrees in forestry at the University of Michigan, and has been on the Station's staff since 1964.

Acknowledgment

Special thanks are due William G. O'Regan, formerly Station biometrician, and David A. Sharpnack, Station statistician, for their assistance in developing the quadrat sampling scheme and the analysis technique used in this study.

Regeneration of Douglas-fir cutblocks on the Six Rivers National Forest in northwestern California

R.O. Strothmann

CONTENTS

Pacific Southwest Forest and Range Experiment Station
P.O. Box 245
Berkeley, California 94701

May 1979

IN BRIEF . . .

Strothmann, R.O.
1979. **Regeneration of Douglas-fir cutblocks on the Six Rivers National Forest in northwestern California.** Res. Paper PSW-142, 9 p. illus. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

Retrieval Terms: artificial regeneration; planting; plantations; stocking; Six Rivers National Forest; California; Douglas-fir; *Pseudotsuga menziesii*.

A regeneration survey was conducted on 61 cutblocks on three Ranger Districts of the Six Rivers National Forest. The cutblocks were planted during the period from 1964 through 1975. The purpose was not only to ascertain the current stocking status, but also to determine whether certain characteristics of the cutblocks or plantations were associated with either good or poor stocking. A 2-milacre (8.09 m^2) quadrat was used, on the basis that 500 well-spaced trees per acre (1235/ha) would represent full stocking at age 3 to 5 years.

The cutblocks ranged in size from 6 to 68 acres (2.4 to 27.5 ha) and in elevation from 1300 to 4900 feet (396 to 1494 m). On 51 of the 61 cutblocks, Douglas-fir was the species initially planted; on the remaining 10 it was ponderosa pine. One-third of the cutblocks had been replanted, several as many as three times.

Seven species of conifers were found on the surveyed quadrats, not all of them commercially valuable under present market conditions. Douglas-fir was by far the most abundant species present, occurring on more than 77 percent of all stocked quadrats. Ponderosa pine was second, being present on 22 percent of the quadrats classified as stocked. White fir was present on nearly 6 percent. None of the remaining four species—incense-cedar, sugar pine, Port-Orford-cedar, or Pacific yew—occurred on more than 3 percent of the total number of stocked quadrats. Some quadrats had more than one species present.

For the study as a whole, the average stocking was 42.2 percent, and the average number of trees per acre was 396 (979/ha). The best stocking on any cutblock was 81 percent and the poorest, 15 percent; the corresponding trees-per-acre values were 1246 and 81, (3079 and 200/ha), respectively.

Stocking declined among the three Districts in a north-to-south direction as sites became hotter and drier. The most northerly District (Orleans) had an average stocking of 48 percent, while the most southerly (Mad River) averaged only 37 percent.

For the study as a whole, one-fifth of the cutblocks had a stocking of 60 percent or greater, nearly one-third had a stocking of 50 percent or greater, and more than three-quarters had a stocking of 30 percent or greater. Ten percent of the cutblocks had 800 or more trees per acre (1977/ha), nearly 40 percent had 400 or more (988/ha), 54 percent had 300 or more (741/ha), and 77 percent had 200 or more (494/ha).

Advance reproduction constituted only a small part of the total reproduction in the survey, occurring on only 4.3 percent of the stocked quadrats. All seven coniferous species were present as advance reproduction, with Douglas-fir most abundant, and white fir next in this category.

On eleven cutblocks, no stocked quadrats were overtopped by brush. On the remaining 50, the proportion of stocked quadrats overtopped ranged from 1 to 55 percent. On only four cutblocks, however, were more than 30 percent of stocked quadrats overtopped by brush or hardwoods.

To evaluate the influence of various individual factors on regeneration success, a backwards step-wise regression technique was used, based on data from 36 of the 61 cutblocks. The final model had an R^2 of 0.9136.

For the 36-cutblock sample, statistical analyses indicated that (1) the most favorable aspect for regeneration was about 12° east of north, and conversely, the least favorable about 12° west of south; (2) within the range of plantation ages sampled (1 to 12 years), stocking improved as age increased, probably because of the continuing establishment of natural seedlings among the planted trees; (3) stocking decreased as cutblock size increased; (4) stocking was best on the best sites; (5) cutblocks which were tractor-logged had better stocking than those which were cable-logged; (6) stocking was better at elevations below 3000 feet (914 m) than at higher elevations; and (7) cutblocks planted in December, January, or May were better stocked than those planted in other months.

If the Forest Service's minimum satisfactory stocking standard of "100 thrifty well-scattered trees per acre that are free to grow and have completed one growing season" is applied, only 2 of the 61 cutblocks could be called regeneration failures on the basis of number of trees. Some others, however, would fail to meet the specification that the trees be well scattered.

Prompt and successful regeneration of cutover forest land is a major concern of forest land owners. Prompt regeneration reduces rotation length, minimizes the period of susceptibility to accelerated erosion, and shortens the period of unsightliness that follows logging.

The adverse site or climatic characteristics of some areas challenge the regeneration specialist. Hot, dry summers, steep topography, and unstable soils all increase the difficulty of establishing regeneration after logging. These problems exist on many areas of the Six Rivers National Forest in northwestern California.

In assessing regeneration efforts on some of the cutblocks planted since 1964 on three Ranger Districts on this Forest, my intent was not only to inventory stocking, but also to find out whether regeneration success (or failure) could be associated with particular site characteristics, or with such variables as method of logging, size of cutblock, and years since planting. This paper reports data on percent stocking and numbers of trees per acre for more than 60 cutblocks, and also the results of a regression analysis of a smaller sample of 36 cutblocks to evaluate the influence of specific factors on percent stocking.

STUDY AREA

The Six Rivers National Forest, in extreme northwestern California, is within 6 miles (9.7 km) of the Pacific Ocean near its northern boundary, but nearly 35 miles (56.3 km) from the coast near its southern boundary. It is long and narrow, extending about 140 miles (225 km) in a north-south direction, but generally less than 20 miles (32 km) in an east-west direction.

The topography for the most part is steep and rugged, with elevations exceeding 6000 feet (1829 m) in a few areas. Soil development is influenced by climatic variation and by topographic variations in both the metamorphic and sedimentary rock types commonly occurring on the Forest (Zinke and Colwell 1965). A topographic sequence on schist rock, for example, shows a progression of increasing development from valley bottom to ridgetop, traversing soils in the Sheetiron, Masterson, Orick, and Sites soil series. This sequence illustrates that the most developed soil on this rock type is often found on plateau-like ridge tops, and always on apparently older surfaces.

The reverse pattern also occurs, however, and is the more common sequence found in California mountain forests (Zinke and Colwell 1965). On graywacke sandstone, for example, an elevational transect begins with the better developed Josephine soil series at the lower elevations, then progresses with increasing elevation through the lesser developed Hugo soil series, and finally reaches the least developed Hoover series.

Throughout most of the area included in this study, Douglas-fir *(Pseudotsuga menziesii* [Mirb.] Franco var. *menziesii)* is the predominant tree species. Although it occurs in pure or nearly pure stands in some localities, it is commonly associated with several other species. Chief associates are ponderosa pine *(Pinus ponderosa* Laws.), sugar pine *(P. lambertiana* Dougl.), incense-cedar *(Libocedrus decurrens* Torr.), Port-Orford-cedar *(Chamaecyparis lawsoniana* [A. Murr.] Parl.), white fir (*Abies concolor* [Gord. & Glend.] Lindl.), Pacific madrone *(Arbutus menziesii* Pursh), tanoak (*Lithocarpus densiflorus* [Hook & Arn.] Rehd.), and several true oaks *(Quercus* spp.).

Three forest cover types (Soc. Amer. For. 1975) are probably represented, namely, Pacific Douglas-fir (type 229), Pacific ponderosa pine—Douglas-fir (type 244), and Ponderosa pine—sugar pine—fir (type 243). In limited areas, Port-Orford-cedar—Douglas-fir (type 231) may also be present.

METHODS

Time permitted examination of 61 cutblocks, or approximately 20 on each of the three selected Ranger Districts (Orleans, Lower Trinity, and Mad River). In addition to good geographic distribution of our sample, a reasonably good distribution over the full range of plantation ages (1-12 years) was desirable. Therefore one-third of the sample of cutblocks was taken from those which were planted 1 to 4 years ago, another third, 5 to 8 years ago, and a final third, 9 to 12 years ago. Within these constraints, the sample was randomly chosen from the population of cutblocks planted since 1964 on the three Districts, except for cutblocks for which good records were not available.

For each selected cutblock, certain basic data were taken from the District records: size of cutblock, year of cutting, logging method, month and year of planting, species planted, seed source, dates of any replanting, cutblock elevation, and Douglas-fir site class (as defined by McArdle and others 1961). Aspect and slope were determined in the field.

The selected cutblocks ranged in size from 6 to 68 acres (2.43 to 27.52 ha), and in elevation from 1300 to 4900 feet (396 to 1494 m). On 51 of the 61 cutblocks, Douglas-fir was the species initially planted; on the remaining 10 it was ponderosa pine. One-third (21) of the blocks had been replanted—some of them more than once (12 once, 5 twice, and 4 three times). Douglas-fir and ponderosa pine were used about equally in the replanting (Douglas-fir on 10 cutblocks and ponderosa pine on 11).

Because the Six Rivers National Forest normally plants about 400 to 500 trees per acre (988 to 1235/ha), I chose a quadrat size of 2 milacres (8.09 m^2) as most appropriate, since there would be 500 such quadrats per acre (1235/ha). This choice assumes that 500 well-spaced young conifers per acre represents full stocking—an assumption I considered reasonable for the early establishment phase.

The sampling method was a modification of the two-stage sampling technique described by Cochran (1963). Briefly outlined, the procedure for each cutblock was as follows: (1) establish a convenient base line through the cutblock; (2) divide the block into four approximately equal parts along this base line; (3) randomly select the locations of two sampling lines (at right angles to the base line) within each quarter; (4) determine the total number of quadrats needed on the cutblock to achieve a sampling intensity of four quadrats per acre (9.88/ha); (5) calculate the spacing needed between quadrats along the sampling lines to attain the desired sampling intensity; and (6) randomly select a starting point for the set of quadrats along each of the eight sampling lines.

A quadrat was considered stocked if it had at least one live, healthy conifer 1 foot (0.305 m) tall or taller. Height of the tallest conifer on each quadrat was measured to the nearest foot. Field crews also recorded its species, and whether it was of prelogging or postlogging origin. Other information recorded for each quadrat was the total number of live conifers present, by species, and whether or not the tallest conifer was overtopped by brush or hardwoods.

Data were analyzed by regression techniques to evaluate the influence of various site and other factors on percent stocking. The final model was selected using the backwards stepwise procedure described by Draper and Smith (1966).

RESULTS

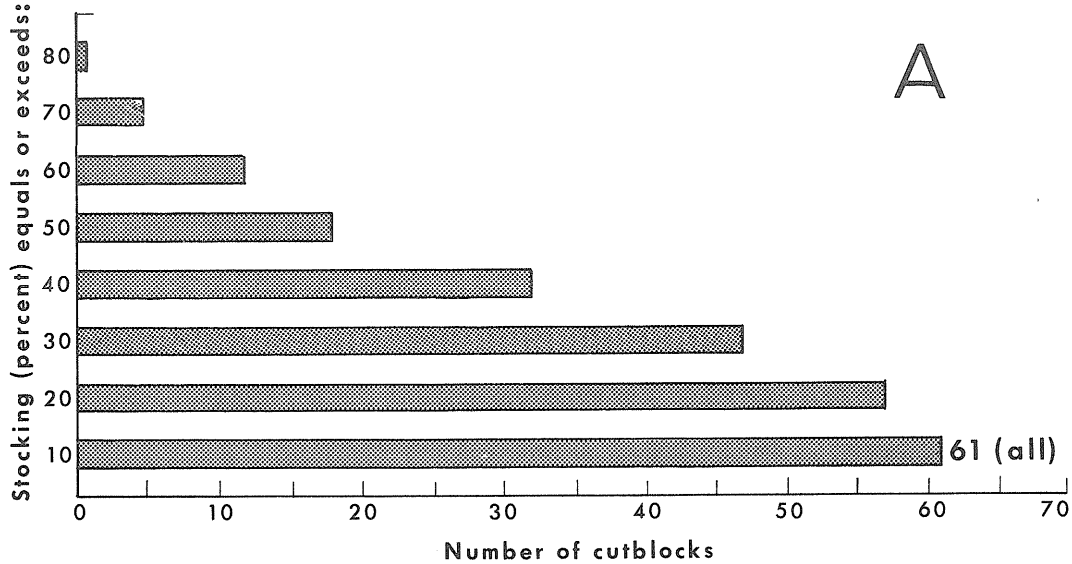
Overall Patterns

During the survey 6032 2-milacre quadrats were examined. For the study as a whole, the average stocking (trees 1 foot or taller) was 42.2 percent, and the average total number of trees per acre was 396 (979/ha).

The heaviest stocking encountered on any cutblock was 81 percent, found in an 11-year-old plantation on a 24-acre (9.71-ha) northeast-facing cutblock on site class 2. The poorest stocking encountered was 15 percent, found in a 4-year-old plantation on a 26-acre (10.52-ha) west-facing cutblock on site class 4. The trees-per-acre figures for these cutblocks were 1246 and 81, (3079 and 200/ha), respectively. Although the Forest does have plantations which fall outside of these extremes (a few plantations reportedly have in excess of 1500 trees per acre, 3705/ha), our sample covered the normal range quite well.

Average stocking by Ranger District revealed an interesting pattern, as follows: Orleans—47.96 percent, Lower Trinity—40.31 percent, Mad River—36.91 percent (see Discussion).

The number of cutblocks on which the percent stocking exceeds specific thresholds is shown in *figure 1A*. Only one cutblock exceeded 80 percent; 18, however, exceeded 50 percent; more than half exceeded 40 percent; and more than three-quarters exceeded 30 percent.



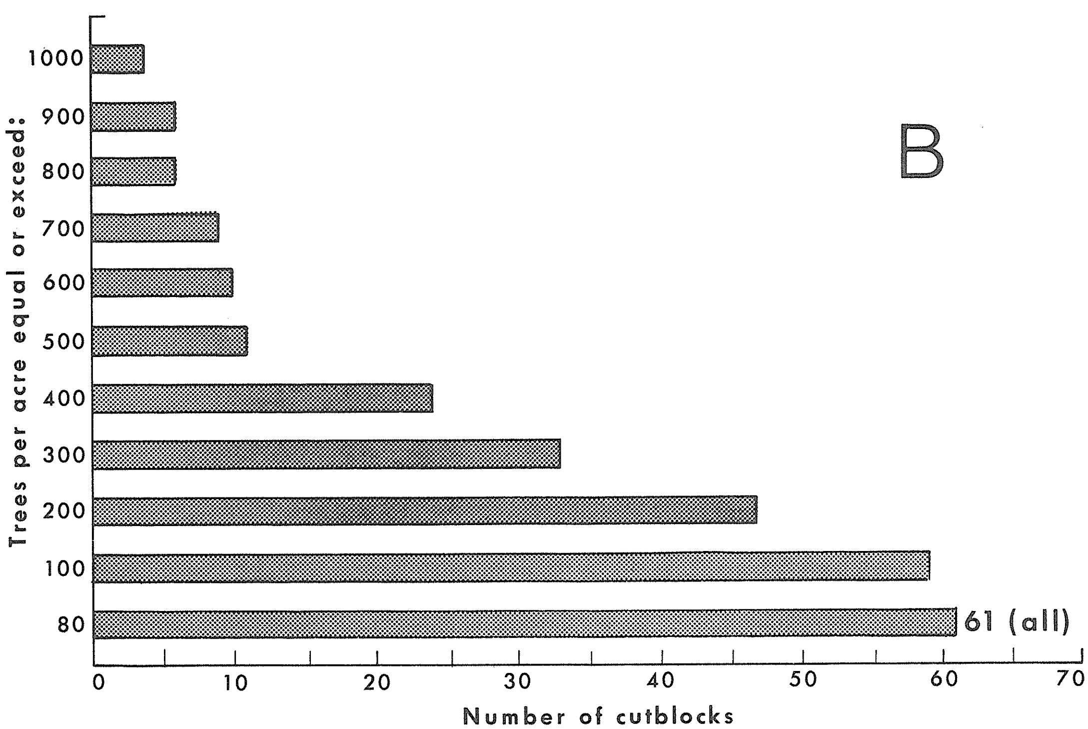


Figure 1—Patterns of stocking are shown as (*A*) number of cutblocks on which percent of quadrats stocked equals or exceeds specific thresholds, and (*B*) number of cutblocks on which the total number of trees per acre equals or exceeds specific thresholds. Data are based on trees at least 1 foot tall.

The number of cutblocks on which the number of trees per acre exceeds specific thresholds is shown in *figure 1B*. Four cutblocks had more than 1000 trees per acre (2471/ha), 10 at least 600 trees per acre (1483/ha), 33 (about 54 percent), at least 300 trees per acre (741/ha), and 47 (77 percent) at least 200 trees per acre (494/ha).

During the course of the survey, seven species of conifers were encountered, some only infrequently. Not all are commercially valuable under present market conditions, but because marketability standards change, all were included as countable stocking if they met the minimum size requirement (at least 1 ft tall). The relative importance of the seven species, as shown by the percentage of all stocked quadrats on which they were present, and the percentage of stocked quadrats on which they were the tallest conifer, is as follows:

	Present	Tallest
Species:	*Percent*	
Douglas-fir	77.1	73.6
Ponderosa pine	22.1	19.8
White fir	5.8	4.2
Incense-cedar	2.7	1.4
Sugar pine	1.2	0.7
Pacific yew	0.2	0.2
Port-Orford-cedar	0.1	0.1
	(109.2)[1]	100.0

White fir was present chiefly on cutblocks at the higher elevations, and Pacific yew *(Taxus brevifolia* Nutt.) and Port-Orford-cedar occurred on only five quadrats and three quadrats, respectively. All seedlings of the four least abundant species were of natural origin.

The tabulation shows that the species pattern for the tallest conifer on each quadrat is much the same as for the frequency of occurrence. On almost 94 percent of all sampled quadrats that were stocked with one or more conifers, the dominant conifer was either a Douglas-fir or a ponderosa pine.

Advance reproduction constituted only a small part of the total, occurring on only 4.3 percent of the stocked quadrats. Douglas-fir was the most abundant species among the advance reproduction, closely followed by white fir. The others, in declining order of occurrence, were ponderosa pine, incense-cedar, sugar pine, Port-Orford-cedar, and Pacific yew.

Overtopping of conifers by brush or hardwoods was not a problem on 11 of the 61 cutblocks, as none of their stocked quadrats were classified as overtopped. On the remaining 50, the proportion of stocked quadrats which was overtopped ranged from 1 to 55 percent. On only 14 cutblocks, however, were more than 20 percent of stocked quadrats overtopped, and on only 4 was the percentage above 30.

[1]More than one species found on some quadrats.

Individual Factors

The influence of individual factors on percent stocking could be summarized as stocking averages for the subclasses of each factor. These would be of limited value, however, and could even be misleading. For this reason, results are best presented in a regression model.

Many preliminary models were tested before the final model was developed. Two topographic variables—aspect and percent slope—were handled jointly because, in various combinations, one can either reinforce or counteract the effect of the other. The approach adopted was suggested by Stage (1976) and is designed to deal with this problem. Stage recommends that "the variables to represent the combined effect of slope and aspect be defined as the tangent of slope (slope percent) times the sine and cosine, respectively, of the azimuth. In this way, plots on flat ground will have a zero value for these two variables, but plots on steep ground will have high weights for the sine and cosine of aspect." Stage's method also identifies the most favorable and least favorable azimuths.

In the preliminary regression models tested, site class was found to be a highly important variable in accounting for stocking differences. Unfortunately, site information was available on only two of the three Ranger Districts studied. Hence, the final regression model was developed using data from 36 cutblocks on these two Districts.

Replanting history was not included as a variable in the model because only 9 of the 36 cutblocks had been replanted. Limiting the model to the 27 cutblocks which had not been replanted would have further reduced the data base. Since a preliminary analysis revealed that the replanted cutblocks were still among the most poorly stocked of the 36-cutblock sample, they were allowed to remain in the model.

Seed source was also excluded as a variable because this information was unavailable for many of the cutblocks, and, on some cutblocks, trees from more than one source had been planted.

The final regression model is as follows:

$Y = f$ (District, $\sin \alpha \tan s$, $\cos \alpha \tan s$, elevation, age, logging method, site, month planted, cutblock size) where

Y = stocking (percent of 2-milacre quadrats stocked with a conifer seedling at least 1 foot tall, either planted or natural)

α = azimuth (degrees measured clockwise from north)

s = slope percent

For this model, $R^2 = 0.9136$

All variables were handled as class variables except plantation age, cutblock size, and the transformed values for slope and aspect, which were handled as continuous variables. In preliminary trials, elevation yielded slightly better results (higher R^2) when treated as a class variable than as a continuous variable; hence it was handled as a class variable in the final regression model.

The analysis revealed that for the cutblocks included in the sample, the most favorable aspect with respect to stocking percent was 11°37′ east of north; conversely, the least favorable was 11°37′ west of south.

The effects of the individual variables in the model are shown by the regression coefficients listed in *table 1*. The reader is cautioned that some of these model "effects" are not fully in agreement with known biological patterns. The probable explanations for this are given in the Discussion.

Table 1—*Variables which exert a significant influence on the percent stocking of 36 cutblocks on two Ranger Districts of the Six Rivers National Forest, California.*

Variable group and/or specific variable	Regression coefficient	Frequency
District:		
Orleans	13.9696	18
Lower Trinity	-13.9696	18
Aspect/slope:		
sin ∝ tan s	2.6590	36
cos ∝ tan s	12.9398	36
Elevation (ft):		
0-2000	7.3063	3
2001-3000	8.0847	12
3001-4000	-4.0001	15
4001-5000	-9.8223	6
Age	2.7399	36
Logging method:		
Tractor	9.7979	11
Cable	-4.3111	25
Site class:		
2	25.7125	7
3	-4.9652	20
4	-8.9648	9
Month planted:		
November	-2.4510	4
December	10.9757	5
January	8.9089	1
February	-7.0212	3
March	-9.1768	10
April	-1.5624	8
May	14.2695	5
Cutblock size	-0.5367	36
Intercept	38.7272	

An examination of the regression coefficients reveals (as noted earlier) that (1) cutblocks on the Orleans Ranger District are better stocked than those on the Lower Trinity District; (2) the positive coefficient for age (2.7399) indicates that as age increases (within the limits of the ages sampled), stocking also tends to increase; (3) the negative coefficient for cutblock size (-0.5367) indicates that stocking tends to decrease somewhat with increasing cutblock size; and (4) the range in coefficients for site class emphasizes the influence of this factor on regeneration success.

Other conclusions are that, in our sample of cutblocks, tractor logging had a more favorable influence on subsequent stocking than did cable logging (regression coefficient of 9.7979 vs. -4.3111). Also, stocking tends to be greater at elevations below 3000 feet (914 m) than at higher elevations.

For month of planting, the coefficients indicate that better stocking has occurred on cutblocks planted in December, January, and May than on cutblocks planted in November, February, March, or April.

Table 1 can be used to predict percent stocking for cutblocks on the two Ranger Districts for which the model is applicable. The coefficients for the appropriate specific variables are simply added (once the coefficients have been multiplied by the value of the variable). *Table 2* is an example.

Table 2—*Example of how the regression coefficients from table 1 can be used to predict percent stocking.* [1]

Variable	Multiplier for value of continuous variables	Regression coefficient	Entry for summation
District: Lower Trinity		-13.9696	-13.9696
Aspect: East (90° azim.)			
Slope: 63 percent			
sin 90 tan 63 =	1.9626	2.6590	5.2186
cos 90 tan 63 =	0.0000	12.9398	0.0000
Elev.: 2500 feet			
(2001-3000)		8.0847	8.0847
Age: 8 years	8	2.7399	21.9192
Logging method: cable		-4.3111	-4.3111
Site class: 4		-8.9648	-8.9648
Month planted: March		-9.1768	-9.1768
Cutblock size: 8 acres	8	-0.5367	-4.2936
Intercept		38.7272	38.7272
Predicted percent stocked			33.2338
Actual percent stocked (from survey)			32.40

[1] Data from cutblock 3. Predictions are valid only for the two Ranger Districts from which data for the regression model were obtained.

DISCUSSION

Many of the findings of this study conform to expectations, and can be accounted for by well-established biological relationships. Other findings seem to contradict these known patterns of relationships. Some possible explanations for the regeneration patterns encountered are presented here.

Influence of Ranger District and Site

The average stocking by Ranger District showed a definite pattern of decline from the most northerly to the most southerly of these three Districts. This is not surprising since sites become hotter and drier—and consequently less favorable for Douglas-fir—as one moves southward within the Six Rivers National Forest. Vegetation patterns are a clue—oak types increasingly intermingle with grassy glades as one reaches the Mad River (most southerly) Ranger District. Forest personnel recognize these adverse conditions and are currently doing less clearcutting and more shelterwood cutting on the Mad River District.

The importance of site quality in influencing regeneration success was noted earlier. This is not to say that the best sites are necessarily the easiest to regenerate. The very conditions (good soil depth, texture, moisture, and nutrient status) which favor conifer seedling establishment also favor the establishment and growth of competing vegetation. Also, animal damage is sometimes more severe on good sites than on poor ones. Nevertheless, if there is thorough site preparation followed by prompt planting and timely release, the best stocking can logically be expected to be associated with the best sites.

Age

The pattern of increased stocking with increased age of plantation is most likely due to the establishment of natural seedlings among the planted trees. In our survey we made no attempt to distinguish between planted and natural seedlings, and, indeed, such a distinction would not always be easy to make in the older plantations. That naturals do "seed in" among planted trees is, however, a well-established fact, as evidenced by numerous plantations where ponderosa pine was the only species planted, but where a prominent Douglas-fir component later appeared. We noticed this mixture on 7 of the 10 cutblocks in our survey which had been planted initially with pine.

Although mortality obviously does occur in plantations, and sometimes even results in a regeneration failure, there nevertheless appears to be a definite countertrend with age in many plantations. Early mortality is frequently offset by the subsequent establishment of new trees through natural seeding.

The possibility was also examined that the pattern of better stocking in the older plantations might be partly due to greater precipitation in the growing season (April through September) during the year of establishment. Although this possibility cannot be ruled out entirely, the pattern of wet and dry years is quite erratic. There is no definite trend to suggest that the older plantations were favored with greater growing-season precipitation than were the more recent ones. For example, the growing season of 1964 (the earliest year included in our study) was the fourth driest, 1965 was the third wettest, and 1966 was the second driest of the 12 years in the study.

Cutblock Size and Logging Method

The finding that stocking tends to decrease as cutblock size increases is a pattern which others also have noted (Worthington, 1953; Roy, 1960). Proximity to a seed source is certainly one explanation for this. Large portions of the larger cutblocks are beyond the range of normal seed dispersal from the surrounding forest. Also, especially on south and west aspects, the microclimate following clearcutting on large cutblocks is sometimes harsh and unfavorable for the survival of young conifers, either planted or natural. If thorough site preparation precedes careful planting with good stock, however, and competing vegetation is kept under control, good survival of planted Douglas-fir is possible on harsh sites (Strothmann, 1972, 1976).

Logging method apparently affected regeneration success for several reasons. Tractor logging and the associated piling and burning of slash normally exposes more mineral soil than does cable logging and broadcast burning. Therefore, tractor logging provides a greater proportion of favorable seedbed on which natural regeneration can become established. Also, tractor-logged areas may be somewhat easier to plant because they have fewer obstructions for the planting crew and are on gentler slopes than cable-logged areas. And, because of the gentler slopes, the soils may sometimes be deeper.

Elevation and Planting Time

It is not clear why stocking was better on cutblocks below an elevation of 3000 feet (914 m) than on cutblocks at higher elevations. Perhaps the most likely explanation is that the timing of planting is often more critical at higher elevations. There is a relatively short period when planting conditions are favorable, and consequently when reasonable success can be expected.

On the one hand, planting may have been done too early on some of the higher elevation cutblocks. Even though the ground may not have been frozen, soil temperatures may have been too low for prompt seedling root growth. Under such circumstances, the seedlings are vulnerable to desiccation by sun and wind because their root systems are still relatively inactive and thus unable to replace seedling moisture losses adequately.

On the other hand, planting may sometimes have been done too late, as when a cutblock is free of snow and otherwise in good planting condition, but portions of the access road are still snow-blocked. When the road finally becomes driveable, the soil at the planting site may already be too dry for optimum planting success.

Another reason for the poorer average stocking on the higher elevation cutblocks could be gopher activity, which is generally more common at higher elevations.

The variable "month of planting" showed an expected relationship to stocking in some instances, but an unexpected relationship in others. The negative regression coefficient for November, and the positive coefficients for December and January *(table 1)* conform to normal experience. November is often regarded as too early to plant, but December and January are generally considered to be good planting months. February is also generally thought to be a good month to plant, but in this survey it was characterized by a large negative regression coefficient, as was March. May had a very high positive coefficient, suggesting it is an excellent month to plant.

Possible explanations for these seemingly anomalous patterns include sample size, soil moisture and temperature, and the physiological condition of the planting stock. Sample size was obviously smaller than desirable for some elements of this variable, and any untypical cutblocks which may have been included within the small sample for a particular month could have distorted the normal pattern.

Deficiencies in soil moisture and soil temperature could also influence the month-of-planting responses which we encountered. We had no information on the status of these at the time of planting, but both can have an important effect on regeneration success.

Perhaps of even greater importance is the physiological condition of the planting stock, particularly its root growth capacity. Even though soil moisture and temperature may be favorable for seedling growth, a plantation may fail if the seedlings are not in the proper physiological condition when they are planted. This is largely determined by their physiological condition at the time of lifting (Stone and others 1962), and by temperatures maintained during storage.

Administrative studies currently underway at the Forest Service's Humboldt Nursery at McKinleyville, California, show that there is considerable variation in root growth capacity and field survival of Douglas-fir, depending upon seed source and lifting date (Jenkinson and Nelson 1978). Some sources can be lifted and stored anytime during the 4 months between early November and early March and outplanted with first-year survival potentials ranging from 88 to 98 percent. Other sources have a much narrower "lifting window," in some cases covering only about a 6-week period centered around early February as the optimum lifting time.

Some unexplained failures in earlier regeneration efforts were undoubtedly due to lack of awareness of the importance of lifting and storage date as influenced by seed source. As previously mentioned, seed source information in this study was too limited to be of value, and hence was not used in the analysis.

In addition to not having information on soil moisture, soil temperature, and seedling physiological condition at time of planting, we also lacked information on weather conditions during planting, on how carefully the stock was handled, and on the overall quality of the planting job itself. The unknown impacts of these and other factors in our study are doubtless responsible for some of the apparent anomalies.

Choice of Dependent Variable

Some inconsistencies might be resolved if a "cleaner" dependent variable were used—that is, percent survival of the number of trees actually planted, rather than percent stocking of an assumed standard. If, for example, 270 uniformly spaced trees per acre were found at the time of the survey, this would represent 54 percent stocking, using the 500-tree-per-acre standard; the cutblock might be considered somewhat understocked. However, if only 300 trees per acre had been originally planted on this cutblock, the presence of 270 per acre (assuming none were "naturals") would represent a 90 percent survival rate. Viewed from this standpoint, the regeneration effort would be considered quite successful.

Obviously, the number of trees per acre which were originally planted is a valuable item of information for interpreting regeneration success. Unfortunately, this information was available for fewer than half of the cutblocks; hence, the cruder yardstick for evaluating regeneration success was used.

Relation of Quadrat Size to Stocking Standards

Because experience with 2-milacre quadrats is limited, no general guidelines exist as to what percentage of them might constitute satisfactory stocking. Stein (1978) states that there is also no current consensus on the percent of stocked 1- or 4-milacre plots required to constitute satisfactory stocking, although in the past, 65 to 70 percent stocking of 4-milacre plots, or 30 to 40 percent of 1-milacre plots was considered satisfactory.

My choice of a 2-milacre quadrat implies a stocking standard of 500 well-spaced trees per acre (1235/ha), but this does not mean that 500 trees per acre are desired at rotation age. As Stein (1978) points out, full stocking need not be tied to yield table data, nor to number of trees at rotation age. It can as readily be based on the maximum number of trees desired before the first commercial thinning, or it could simply be the number of well-distributed trees required per acre at the end of the reforestation period.

In this study I considered 500 well-spaced trees per acre to be a stocking goal which might be desirable about 3 to 5 years after planting. This would assure relatively early control of the site by the desired tree species, thereby reducing the chances of a take-over by brush, grass, or other types of vegetation.

How do the cutblocks examined in this study measure up when compared with several prescribed stocking standards for northern California? Personnel of the Six Rivers National Forest indicate that they would like to have at least 300 well-established trees per acre (741/ha) on their cutblocks, but they will accept fewer. The Forest Service Manual[2] states that "Minimum satisfactory stocking of a planted area is 100 thrifty well-scattered trees per acre (247/ha) that are free to grow and have completed one growing season. These can be natural seedlings of acceptable species for the site. Acceptable trees do not need to fit the original spacing pattern."

The California Forest Practices Act, although not applicable to federally-owned lands, is nevertheless of interest here. It defines minimum acceptable stocking as 300 trees per acre within 5 years after completion of harvesting operations. The 300-tree standard can be met by various combinations of tree sizes. If all trees on the area are less than 4 inches in diameter, the full count of 300 is required; this number is reduced if larger trees are present.

If we use the 100-trees-per-acre Forest Service guide as the minimum acceptable stocking, only two cutblocks in our survey failed to meet this standard. However, some of the other cutblocks would fall short of the specification that the trees be well scattered.

If we use 300 trees-per-acre as the minimum acceptable stocking, only 54 percent of the surveyed cutblocks were adequately stocked *(fig. 1B)*. An additional 23 percent, however, had at least 200 trees per acre (494/ha), and might be considered as having marginally adequate stocking if subsequent mortality is low.

Although this study has identified numerous variables as having favorable or unfavorable influences on stocking, not all can be altered by the regeneration specialist. He cannot, for example, change the aspect of a cutblock from south to north, or change its elevation, or appreciably change its site quality. However, if he knows which of these variables tend to be associated with poor stocking, he can compensate for this by planting more trees per acre.

Other variables, such as logging method and cutblock size, are under the forest manager's control, although also influenced by topographic, economic, and environmental constraints. Within these constraints, the forest manager can improve his chances for regeneration success by keeping the size of clearcut blocks as small as feasible, and by doing a good job of site preparation.

[2]Forest Service, U.S. Department of Agriculture. 1965. Forest Service Manual 2472.b (Seeding and Planting). R-5 Supp. 57.

LITERATURE CITED

Cochran, W.G.
1963. **Sampling techniques.** 2nd ed., 413 p. Wiley, New York.

Draper, N.R., and H. Smith
1966. **Applied regression analysis.** 407 p. Wiley, New York.

Jenkinson, James L., and James A. Nelson
1978. **Seed source lifting windows for Douglas-fir in the Humboldt Nursery.** *In* Proc. Western Forest Nursery Conf. [Eureka, Calif. Aug. 7-9, 1978], p. B-77 to B-95.

McArdle, Richard E., Walter H. Meyer, and Donald Bruce
1961. **The yield of Douglas-fir in the Pacific Northwest.** U.S. Dep. Agric. Tech. Bull. 201, 74 p.

Roy, Douglass F.
1960. **Douglas-fir seed dispersal in northwestern California.** U.S. Forest Serv. Pacific Southwest Forest and Range Exp. Stn. Tech. Paper 49, 22 p. Berkeley, Calif.

Society of American Foresters
1975. **Forest cover types of North America (exclusive of Mexico),** 67 p. Soc. Amer. For., Bethesda, Md.

Stage, A.R.
1976. **An expression for the effect of aspect, slope, and habitat type on tree growth.** Forest Sci. 22:457-460.

Stein, William I.
1978. **Reforestation evaluation.** *In* Regenerating Oregon's forests, Brian D. Cleary, Robert D. Greaves, and Richard K. Hermann, eds. 287 p. Oreg. State Univ. Ext. Serv., Corvallis.

Stone, Edward C., James L. Jenkinson, and Stanley L. Krugman
1962. **Root-regenerating potential of Douglas-fir seedlings lifted at different times of the year.** Forest Sci. 8:288-297.

Strothmann, R.O.
1976. **Douglas-fir seedlings planted by four methods ... results after 10 years.** USDA Forest Serv. Res. Note PSW-310, 4 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Strothmann, Rudolph O.
1972. **Douglas-fir in northern California: effects of shade on germination, survival, and growth.** USDA Forest Serv. Res. Paper PSW-84, 10 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Worthington, Norman P.
1953. **Reproduction following small group cuttings in virgin Douglas-fir.** U.S. Forest Serv. Pacific Northwest Forest and Range Exp. Stn. Res. Note 84, 5 p. Portland, Oregon.

Zinke, Paul J., and W.L. Colwell, Jr.
1965. **Some general relationships among California forest soils.** *In* Forest-soil relationships in North America, proceedings, 2d North American Forest Soils Conf. [Corvallis, Oreg. 1963], p. 353-365.

The Forest Service of the U.S. Department of Agriculture

... Conducts forest and range research at more than 75 locations from Puerto Rico to Alaska and Hawaii.

... Participates with all State forestry agencies in cooperative programs to protect and improve the Nation's 395 million acres of State, local, and private forest lands.

... Manages and protects the 187-million-acre National Forest System for sustained yield of its many products and services.

The Pacific Southwest Forest and Range Experiment Station

represents the research branch of the Forest Service in California and Hawaii.

Strothmann, R.O.
1979. **Regeneration of Douglas-fir cutblocks on the Six Rivers National Forest in northwestern California.** Res. Paper PSW-142, 9 p. illus. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

A survey of 61 cutblocks planted since 1964 evaluated stocking of conifers (trees 1 foot tall or taller) on 2-milacre quadrats. Overall stocking percentage averaged 42.2 and ranged from 15 to 81. Overall number of trees per acre averaged 396. In the regression model, based on 36 cutblocks, better stocking was associated with high site class, northerly aspect, elevation below 3000 feet, and tractor (rather than cable) logging. Stocking tended to increase with increasing age of plantation, but decreased with increasing size of cutblocks.

Retrieval Terms: artificial regeneration; planting; plantations; stocking; Six Rivers National Forest; California; Douglas-fir; *Pseudotsuga menziesii*.

Strothmann, R.O.
1979. **Regeneration of Douglas-fir cutblocks on the Six Rivers National Forest in northwestern California.** Res. Paper PSW-142, 9 p. illus. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

A survey of 61 cutblocks planted since 1964 evaluated stocking of conifers (trees 1 foot tall or taller) on 2-milacre quadrats. Overall stocking percentage averaged 42.2 and ranged from 15 to 81. Overall number of trees per acre averaged 396. In the regression model, based on 36 cutblocks, better stocking was associated with high site class, northerly aspect, elevation below 3000 feet, and tractor (rather than cable) logging. Stocking tended to increase with increasing age of plantation, but decreased with increasing size of cutblocks.

Retrieval Terms: artificial regeneration; planting; plantations; stocking; Six Rivers National Forest; California; Douglas-fir; *Pseudotsuga menziesii*.

Strothmann, R.O.
1979. **Regeneration of Douglas-fir cutblocks on the Six Rivers National Forest in northwestern California.** Res. Paper PSW-142, 9 p. illus. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

A survey of 61 cutblocks planted since 1964 evaluated stocking of conifers (trees 1 foot tall or taller) on 2-milacre quadrats. Overall stocking percentage averaged 42.2 and ranged from 15 to 81. Overall number of trees per acre averaged 396. In the regression model, based on 36 cutblocks, better stocking was associated with high site class, northerly aspect, elevation below 3000 feet, and tractor (rather than cable) logging. Stocking tended to increase with increasing age of plantation, but decreased with increasing size of cutblocks.

Retrieval Terms: artificial regeneration; planting; plantations; stocking; Six Rivers National Forest; California; Douglas-fir; *Pseudotsuga menziesii*.

Strothmann, R.O.
1979. **Regeneration of Douglas-fir cutblocks on the Six Rivers National Forest in northwestern California.** Res. Paper PSW-142, 9 p. illus. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

A survey of 61 cutblocks planted since 1964 evaluated stocking of conifers (trees 1 foot tall or taller) on 2-milacre quadrats. Overall stocking percentage averaged 42.2 and ranged from 15 to 81. Overall number of trees per acre averaged 396. In the regression model, based on 36 cutblocks, better stocking was associated with high site class, northerly aspect, elevation below 3000 feet, and tractor (rather than cable) logging. Stocking tended to increase with increasing age of plantation, but decreased with increasing size of cutblocks.

Retrieval Terms: artificial regeneration; planting; plantations; stocking; Six Rivers National Forest; California; Douglas-fir; *Pseudotsuga menziesii*.