PACIFIC SOUTHWEST Forest and Range Experiment Station

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DOUGLAS-FIR IN NORTHERN CALIFORNIA: effects of shade on germination, survival, and growth

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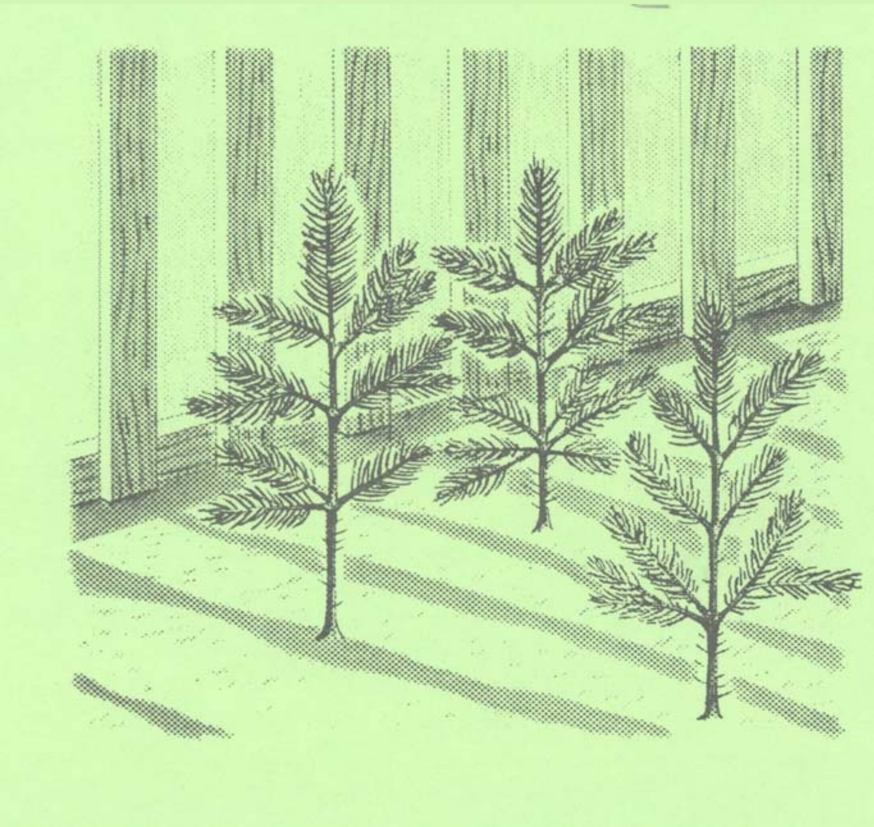

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Effects of four light intensities on germination, survival, and early growth of Douglas-fir *(Pseudotsuga menziesii)* were studied on south-facing cutblocks in northwestern California. Tested were four shade intensities: 0, 25, 50, and 75 percent. On seeded spots, 50 percent shade resulted in greatest germination and survival, being significantly better than either no shade or 25 percent shade, but not better than 75 percent-shade. Shade did not significantly improve the survival of planted trees (either 1-0 or 2-0 age class), but growth was generally best on plots with least shade. Good survival on all treatments was probably due to careful planting, excellent stock, periodic weeding, and deep loam soil. An implication of these findings is that for direct-seeding, early shading is desirable, though difficult to achieve. A possible solution is to use a nurse crop converted to dead shade the spring after seeding.

Oxford: 174.7 *Pseudotsuga menziesii:* 232.324: 236.3: 232.33.
Retrieval Terms: Pseudotsuga menziesii: California (northwestern); artificial regeneration; light relations; protective shading; germination; survival; early growth; height increment.

CONTENTS

The Author

RUDOLPH O. STROTHMANN is doing research on the silviculture of redwood forests, with headquarters in Arcata, Calif. 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

I thank the personnel of the Hoopa Indian Reservation for their help in preparing the site, and in constructing and erecting the shading frames.

Getting satisfactory regeneration of Douglas-fir *(Pseudotsuga menziesii* [Mirb.] Franco var. *menziesii)* on south-facing cutblocks in northwestern California is often a challenge to foresters. The hot, dry summers put a severe stress on the seedlings and many fail to survive the first growing season.

One technique for modifying the harsh environment is to provide shade for the seedlings. Effects of shade on Douglas-fir have been explored in several areas. In southwestern Oregon, Minore (1971) studied the survival and growth of Douglas-fir seedlings–60 growing under existing brush (live shade), 60 in the open, but shaded artificially with rocks, logs, or bark (dead shade), and 60 in the open without any shade. After two growing seasons, only 10 percent of the unshaded seedlings were still alive compared to 47 percent of those under the brush and 60 percent of those in dead shade. Shading did not significantly affect growth.

In California, the response of planted Douglas-fir to artificial shading was studied at three sites by the California Division of Forestry (Adams, Ritchey, and Todd 1966). Shade was provided by shingles from 5 to 7 inches wide, inserted in the ground on the south-southwest side of each seedling. At one site, differences in survival between shaded and unshaded trees were not significant except for spring-planted 1-1 stock. At the other two sites, the shaded seedlings had significantly better survival than did the unshaded ones.

In the Oregon Cascades, Franklin (1963) found, in studying Douglas-fir cut blocks of various shapes and orientations, that there was a definite relationship between the number of hours of shade from the adjacent stand and the number of seedlings which became established.

Effects of specific light intensities were investigated by Brix (1970) and Isaac (1943). In a British Columbia study Brix sought to determine what degree of shade would be most beneficial for the survival and growth of Douglas-fir seedlings. Six light intensities were tested, ranging from 10 to 100 percent of full natural light. Results indicated that full light should not be given new seedlings until 5 weeks after germination, or after mid-July. Best first-season growth occurred at 50 to 70 percent of full light.

At the Wind River Experimental Forest in Washington, Isaac grew seedlings under ventilated shade frames that admitted three different intensities of light. Expressed as percentages of full light, the midday averages were about 2 percent, 8 percent, and 15 percent (with respective maximums of 3, 10, and 20 percent). Also, seedlings were grown under full sunlight, and under three natural forest canopies where midday light values averaged about 1, 2, and 3 percent of full light.

In the controlled-shade portion of his study, Isaac found that the planted 2-0 trees survived best inside the frame which admitted the most light (i.e., an average of 15 percent midday light); best height growth also occurred under this treatment but the seedlings were etiolated. Next best survival and height growth occurred in full light, and this treatment also produced the healthiest and most vigorous seedlings. Under the heavier shade conditions, survival became progressively poorer and height growth also declined. Isaac concluded that Douglas-fir reproduction has little or no chance of successful establishment in anything less than 20 percent of full overhead light, even when there is no root competition, and that roughly 50 percent of full light is probably necessary for reasonable growth.

These studies of Brix and Isaac provided valuable information applicable to British Columbia and Washington. Whether these guides could be followed in California was not known. This paper reports a study to provide some answers about the influence of shade on Douglas-fir seedling growth and seed germination in northern California.

STUDY SITE AND METHODS

The study aim was to determine which of four shade levels would promote the best survival and early growth of seeded and planted Douglas-fir on hot, dry, southerly aspects. On the Hoopa Indian Reservation (lat. 41°05′N, long. 123°37′W) in spring 1966, plots were laid out on a 50-percent, south-facing slope at about 3,000 feet elevation. The area had been logged in spring 1965 and the slash disposed of that fall. Douglas-fir was the main species present at the time of logging, but some tanoak *(Lithocarpus densiflorus* [Hook. & Arn.] Rehd.*)* and madrone *(Arbutus menziesii* Pursh*)* were present also.

The soil on the study site is 3 to 4 feet deep, with good internal drainage. It belongs to the Masterson series, derived from schistose sedimentary rock. The surface soil is a brown, moderately acid loam; the subsoil is a yellowish-brown, strongly acid gravelly loam.

Four levels of shade were tested: 0 (control), and 25, 50, and 75 percent. Shade for the study plots was provided by nailing redwood lath, at appropriate spacing, to a supporting framework *(fig. 1).* These lath strips were run north and south so that the sun's rays would not remain long on any given spot. No lath was used on the control plots, but they were enclosed around the sides with poultry netting to prevent deer and rabbits from damaging the seedlings. These plots were open on top, so that unobstructed sunlight would reach the seedlings except when the sun was low in the sky in the early morning or late afternoon.

Before planting and seeding, all plots were cleared of vegetation by hand scalping. They were subsequently kept weedfree by periodic removal of competing vegetation as it reappeared. This was done to prevent development of variable shading effects, which might be dense on one plot, and light or absent on another.

The four shading treatments were replicated three times, using a randomized block design. On each plot

Figure 1.—General view of the study site. Lath frames, left to right in foreground, provide 75, 50, and 25 percent shade.

Figure 2—Interior view of 25-percent shade frame just after planting. Each plot contained 2-0 seedlings, **right,** 1-0 seedlings, **center**, and screened seed spots, **left.**

10 1-0 and 10 2-0 Douglas-fir seedlings were planted with a planting hoe. Spacing was 2 feet between rows and 20 inches within rows.

In addition, 100 seeds were surface-sown on each plot in 10 groups of 10 seeds each. Each group was then covered with a dome-shaped hardware-cloth screen to protect the seeds from birds and rodents *(fig. 2).* These screens were left in place until late summer of the first year, when germination was essentially completed and the screens were removed.

Before the end of the first growing season it became apparent that one of the 12 plots was being adversely affected by a large tanoak growing nearby. Although this tree did not shade the plot, the considerable extent of its root system had not been fully appreciated at the time of study installation. When it was later discovered how completely the soil on this plot was permeated by the far-reaching lateral roots of this tanoak, the reason for the unusually poor survival and growth of the Douglas-fir seedlings became evident. The data for this plot were therefore discarded and the missing data technique described by Snedecor and Cochran (1967) was used in the subsequent statistical analysis.

RESULTS

Germination and Survival on Seeded Spots

It was not feasible to follow germination and mortality on a daily or even weekly basis; thus, precise figures for total germination are not available. The June 9, 1967 seedling count, however, is probably a reasonable approximation, since most germination had taken place by then and mortality was not yet high. Using the seedling counts of June 9 as a base, the subsequent survival under the four shade levels was calculated *(table 1).*

Germination was best on the plots with 50 percent shade, followed in order by the plots with 75 percent shade, 25 percent shade, and 0 shade. It should be recognized that protective hardware-cloth screens increased the shade actually received on the seed spots by an estimated 15 to 20 percent, but for

Table 1–*Average height growth and stein diameter of Douglas-fir seedlings of three age classes grown under four shade treatments, Hoopa Indian Reservation, California*

Percent shade	Height growth		Stem diameter
	First year	Second year	Second year
	Feet	*Feet*	*Inches*
Seeded spots:			
0	–	–	–
25	0.26	0.47	0.17
50	.19	.30	.10
75	.24	.35	.09
1-0 planted stock			
0	.43	.80	.53
25	.41	.75	.45
50	.25	.59	.34
75	.29	.59	.27
2-0 planted stock			
0	.48	.93	.67
25	.32	.69	.53
50	.32	.71	.45
75	.26	.54	.36

convenience and simplicity the plot-treatment percentages will be used in discussion. In these terms, germination on the various shade treatments was as follows: 50 percent shade, 15 percent germination; 75 percent shade, 11 percent germination; 25 percent shade, 5 percent germination; and 0 shade, 2 percent germination.

Subsequent survival was also best on the plots which had received 50 percent shade. At the end of two growing seasons under this treatment, 80 percent of the seedlings which had been present in June of the previous year were still alive and healthy. Next best survival was on the plots with 25 percent shade, where survival was 56.2 percent. Third best was on the plots with 75 percent shade (36.4 percent survival). On the unshaded plots no seedlings survived to the end of the second growing season.

For each 100 seeds sown, the numbers of live seedlings present after two growing seasons were: 0 percent shade, 0 seedlings; 25 percent shade, three seedlings; 50 percent shade, 12 seedlings; and 75 percent shade, four seedlings. Analysis of variance revealed that the effect of treatment on seedling numbers was statistically significant (5 percent level), primarily because of the superior germination and survival on the plots with 50 percent shade. This shading level produced significantly more seedlings than did either 0 shade or 25 percent shade, though not more than 75 percent shade. No other treatment differences were statistically significant.

Survival of Planted Trees

Survival figures were computed for only the first 2 years because some seedlings were excavated from each plot at the end of the second and third years to examine root development and determine dry-weight.

Survival percent after 2 years ranged from 83 to 100 for the seedlings planted as 1-0 stock, and from 93 to 100 for those planted as 2-0 stock. For both age classes, 100 percent survival occurred only on the plots receiving 50 percent shade. Analysis of variance revealed, however, that the differences attributable to shade treatment were not statistically significant. Even the poorest survival was good when compared to that attained on operational planting jobs in northern California. Possible reasons for this are suggested in the Discussion section.

Growth Responses

Height

Height growth rather than total height was used as a basis of comparison because small treatment effects could be obscured by differences in initial heights of seedlings *(table 1).*

In general, height growth appeared to be inversely proportional to the amount of shade received, with some exceptions. For both age classes of planted trees, best growth occurred on the unshaded plots. On the seeded spots, trees without shade did not survive beyond the first year. Best height growth for this age class occurred on the plots with 25 percent shade.

Analysis of variance revealed, however, that the differences in average height growth were not statistically significant. This may have been due to the considerable within-plot variation. Only treatment differences within each age class were tested, since the study was not designed to test differences between age classes.

Stem Diameter

Like height growth, the growth of stem diameter was inversely proportional to the amount of shade received *(table 1).*

Differences in average diameter under the various shade treatments were sizable, but analysis of variance revealed that they were statistically significant only for the 1-0 age class. The large within-plot variation on most plots precluded a sensitive test of stem-diameter response to different shade treatments.

For the 1-0 seedlings, there was no significant difference in average stem diameter between the 0 shade and 25 percent shade treatments, nor between the 50 percent and 75 percent shade treatments. There were significant differences, however, between either of the two lighter shade treatments and either of the two heavier ones.

Root Length

At the end of both the second and third growing seasons, we carefully excavated a few seedlings of each age class from each plot *(fig. 3)* to examine root development and obtain oven-dry weight. The distance from the root collar to the tip of the longest root was measured, with gentle tension applied to straighten out major crooks.

For all age classes, average root length decreased as the amount of shade increased *(table 2)*. Only the third-year measurements of the 2-0 stock showed an interruption of the trend, the sample trees in the 25 percent shade treatment having a shorter maximum root length than those growing under the two heavier shade levels. This could easily have been due to sample variations, since different trees were used for each year's root measurements.

Analysis of variance revealed that differences in root length attributable to shade treatment were statistically significant (5 percent level) for both age classes of planted stock at the end of the second year but not the third. Root length differences among seedlings on the seeded spots were not statistically significant.

Within the 1-0 age group, there were no significant differences in average maximum root length among any of the three heavier shade levels (25, 50, or 75

Table 2—*Average length of the longest root for seedlings of three age classes grown under four shade levels*[1], *Hoopa Indian Reservation, California*

Percent shade	Second year	Third year[2]
	Feet	
Seeded spots:		
0	—	—
25	1.23	—
50	.96	—
75	.64	—
1-0 planting stock:		
0	3.14	4.32
25	2.56	3.39
50	2.32	3.08
75	1.84	2.13
2-0 planting stock:		
0	3.26	4.38
25	2.63	2.74
50	2.52	3.07
75	1.99	2.83

[1]Based on 12 trees per treatment the second year, and 6 per treatment the third year.

[2]Seeded spots were observed for only 2 years.

Figure 3—Seedlings were excavated at the end of the third growing season to allow measurement of root length and plant weight. Part of the lath framework has been dismantled to make the excavation work easier.

percent shade). Only the unshaded seedlings had significantly longer roots than the others, and this only in comparison with trees receiving either 50 or 75 percent shade.

For the 2-0 age group, both the unshaded and the 25-percent-shaded seedlings had roots significantly longer than those grown under 75 percent shade. In addition, the roots of the unshaded seedlings were significantly longer than those of seedlings grown under 50 percent shade. Thus, for this age class, any two treatments which differed by at least 50 percent in shade level showed a significant difference in the average length of the longest root.

Oven-Dry Weight

Dry weights of the tops and roots of excavated seedlings (12 per treatment for each age class the second year, and six per treatment for each age class the third year) were obtained by oven-drying the plant material to constant weight at 70°C. *(table 3).*

A clear pattern of decreasing dry-matter production with increasing shade is evident for all age classes of seedlings. On the seeded spots the dry-weight accumulation was more than five times as great for seedlings receiving 25 percent shade as for those receiving 75 percent shade. For the planted stock of both age classes the contrasts were somewhat smaller because these trees had grown under full light in the nursery for either 1 or 2 years before being outplanted under the various shade levels. Even so, at the end of 2 years in the field, the unshaded 1-0 seedlings averaged three times the dry weight of those which had received 75 percent shade. The unshaded 2-0 seedlings averaged more than three and one-half times the weight of those which had received 75 percent shade.

Although treatment means differed widely, variances within treatments were also large. Thus, analyses of variance showed that only for the 1-0 planting stock at the end of the second growing season were oven-dry weight differences among treatment means statistically significant (5 percent level). These differences were significant for all dry-weight variables (i.e., weight of top, weight of roots, and total weight).

For all three variables for this age group (1-0) after two growing seasons, the unshaded treatment produced significantly more dry matter than any other treatment. Also, the seedlings receiving 25 percent shade produced significantly more dry matter than those receiving 75 percent shade, except for dry weight of tops. Other differences among treatment means were not significant.

Environmental Measurements

Light

Since the lath strips in the shading frames were about one-quarter-inch thick, the bands of sunlight reaching the seedlings were full-width for only a short period each day, when the sun was most nearly overhead. At times other than midday the bands of sunlight were slightly narrower than the standard in proportion to the bands of shade. Thus, in the course of a day, the area inside the shading frames received somewhat more shade than the 25, 50, and 75 percent specified. Also, slight variations in plot orientation, as well as irregularities in the dimensions of the lath and a certain amount of warping, could be expected to cause minor variations in the amount of shade actually provided by the lath framework.

To find out how much light was actually reaching the seedlings within the shading frames, measurements of light intensity were made during a 6-hour period on a clear day in mid-July of 1967. Measurements were made simultaneously on all plots, using Ozalid paper light meters similar to the type described by Friend (1961). The penetration of light through a packet of this paper closely follows Lambert's law of absorption, and consequently the number of sheets bleached is proportional to the logarithm of the light energy received.

These measurements revealed that the actual amount of shade provided by the shading frames was 3 to 5 percent more than was intended. The nominal 25 percent treatment actually received about 30 percent shade; the 50 percent treatment received about 55 percent shade; and the 75 percent treatment received about 78 percent shade.

Also, during the first growing season, additional shade had been provided on the seeded spots on all plots by the hardware-cloth screens used to prevent seed losses to rodents and birds. No measurements of light intensity were made under these screens, since they had already been removed by the time measurements were taken. As noted earlier, however, these screens probably provided an extra 15-20 percent shade.

Temperature

Maximum soil surface temperatures were measured by using heat-sensitive tablets with melting points of

Table 3–*Average oven-dry weight of seedlings of three age classes grown under four shade treatments,*[1] *Hoopa Indian Reservation, California*

Percent shade	Second year			Third year[2]		
	Top	Roots	Total	Top	Roots	Total
	Grams			*Grams*		
Seeded spots:						
0	–	–	–	–	–	–
25	3.4	1.7	5.1	–	–	–
50	1.0	.7	1.7	–	–	–
75	.6	.3	.9	–	–	–
1-0 planted stock:						
0	37.5	31.8	69.3	170.4	111.5	281.9
25	25.2	21.0	46.2	100.0	56.1	156.1
50	18.0	16.2	34.2	69.0	45.7	114.7
75	13.3	9.5	22.8	33.0	14.4	47.4
2-0 planted stock:						
0	62.7	41.3	104.0	428.7	240.9	669.6
25	42.8	28.2	71.0	171.2	94.6	265.8
50	42.6	27.8	70.4	94.7	49.4	144.1
75	17.0	11.5	28.5	70.2	35.8	106.0

[1]Based on 12 trees per treatment the second year, and 6 per treatment the third year.
[2]Seeded spots were observed or only 2 years.

113°, 125°, 138°, and 150°F. As before, no measurements were made under the hardware-cloth Screens.

Weekly examinations of the tablets showed that the soil surface temperature during the first growing season exceeded 125° (but not 138°) on the plots with 75 percent shade and those with 50 percent shade; it exceeded 138° (but not 150°) on the plots with 25 percent shade and those with zero shade. During the second growing season the soil surface temperature exceeded 125° (but not 138°) on the plots with 75 percent shade; it exceeded 138° (but not 150°) on the plots with 50 percent shade; and it exceeded 150° on both the unshaded and the 25 percent shaded plots.

Midsummer air temperatures at one foot above the surface were also measured. Three recording hygrothermographs were installed on replication 3 for this purpose. Each instrument was placed on a level wooden platform to which was attached a sheet of heavy-gauge aluminum foil formed into an inverted U-shape to shield the instrument from rain, dust, dew, and the direct rays of the sun. The open ends allowed free circulation of air around the temperature-sensing element.

One instrument was kept on the unshaded plot, a second on the plot receiving 75 percent shade, and a third was alternated on a weekly basis between the plot receiving 25 percent shade and the one receiving 50 percent shade.

There was virtually no difference in the minimum temperature (either weekly lowest or mean minimum) between the unshaded and the 75-percent-shaded plots *(table 4).* The highest temperature attained each week, however,averaged 7° F. higher on the unshaded plots than on the heavily shaded plots (104° vs. 97°), and the mean maximum temperatures for each week averaged 6° higher (99° vs. 93°). The weekly mean temperature (based on chart readings at 4-hour intervals) averaged 4° higher (72° vs. 68°) on

Table 4–*Air temperature means and extremes (at one foot above the ground) on the unshaded and the heavily shaded plots during summer 1967,*[1] *Hoopa Indian Reservation, California*

Shade treatment and temperature characteristic	For 7-day period starting on–							Average
	July 10	July 17	July 24	July 31	Aug. 7	Aug. 14	Aug. 21	
	Degrees F.							
0 percent shade:								
Highest	101	94	102	103	108	110	107	104
Mean max.	99	89	96	96	102	107	103	99
Mean	73	65	69	711	76	78	76	72
Mean min.	53	46	50	51	55	57	57	53
Lowest	48	41	46	46	52	52	54	48
75 percent shade:								
Highest	95	88	96	97	101	104	100	97
Mean max.	92	84	90	89	96	100	97	93
Mean	68	61	65	65	70	74	*72*	68
Mean min.	52	46	49	49	53	56	57	52
Lowest	48	41	44	44	51	51	54	48

[1]Based on data from recording hygrothermographs.

the unshaded than on the heavily shaded plot. The highest air temperature recorded on the unshaded plot was 110°F. and was reached several times during the week of August 14, 1967.

Soil Moisture

During the first two growing seasons, soil moisture was determined gravimetrically for two different depths on each plot—6 to 8 inches and 16 to 18 inches. Samples were taken in May and again in August *(table 5).*

Since analysis of variance revealed that shading treatment did not significantly influence soil moisture percent, no additional soil moisture parameters (such as percent moisture at wilting point or at field capacity) were ascertained.

For the most part, differences in average soil moisture at the two depths sampled on any given date were small. During the first growing season the samples came from soil essentially free of live roots, since the plots had been completely cleared of all vegetation prior to planting, and the roots of the planted seedlings had only begun their lateral extension. By August of the second year however, Root extension had increased considerably, and this probably contributed to the decreased soil moisture at both sampling depths by the end of the second summer. The precipitation pattern undoubtedly also contributed to this reduced second-year soil moisture by late summer, since no measurable amounts of rain fell in either July or August of that year, whereas about one-third of an inch had fallen in each of these months during the previous year.

Table 5–*Average[1] soil moisture under Jour shade treatments at two sampling depths[2] during the first two growing seasons, Hoopa Indian Reservation, California*

Percent shade	May 1966		August 1966		May 1967		August 1967	
	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep
	Percent (by weight)							
0	21.7	22.2	17.5	18.6	24.0	23.7	13.3	14.6
25	19.9	21.8	16.0	17.3	25.1	23.2	11.0	13.5
50	20.9	19.6	19.0	16.7	25.3	22.5	16.1	15.7
75	21.8	20.2	17.6	17.5	24.6	22.8	15.0	15.9
Average	21.1	21.0	17.5	17.5	24.8	23.1	13.9	14.9

[1]Average of six samples for each entry.

[2]Shallow sample depth, 6 to 8 inches; deep sample depth, 16 to 18 inches.

DISCUSSION AND CONCLUSIONS

The large within-plot variability ill this study made the test of shade level less sensitive than I had hoped for. This variability was probably due mainly to genetic differences. Both seed and seedlings were from regular nursery seed lots, which normally consist of seeds from many trees in a given locality. Seed from a single tree would have been more desirable.

A larger sample size would also have improved the sensitivity of the test. This would have required the construction of larger shading frames, and thus increased installation costs, hut, in retrospect, the added cost appears worthwhile.

The study nevertheless clearly demonstrated the value of shade for increasing the number of seedlings that will develop from seed and survive beyond the first growing season. Although the causes of mortality were not specifically identified in this study, heat or drought or both are probably the main causes for poor seedling establishment on the unshaded plots. Isaac (1938) found that a soil surface temperature of 123°F. is sufficient to injure Douglas-fir seedlings only a le W days old. In laboratory studies, Silen[1] found that seedlings died at a temperature as low as 122°F. after 4 hours exposure in a water-bath apparatus. In the field he noted that the 138°F. temperature pellet appeared to be a reliable indicator of probable heat mortality on cicarcut areas. In my study this temperature was exceeded on both the unshaded and the 25-percent-shaded plots.

The good survival of the planted trees of both age classes, regardless of shade level, was somewhat surprising since survival of unshaded Douglas-fir on south aspects has frequently been poor in operational plantings in northern California. Also, some of the research trials cited earlier had indicated that shading significantly improves the survival of planted Douglas-fir. The explanation for the good survival in the present study, regardless of shading treatment, probably lies in a combination of factors, including excellent planting stock, careful planting, removal of vegetative competition, and a deep, loamy soil.

[1]Silen, Roy Ragner. *Lethal surface temperatures and their interpretation for Douglas-fir.* 1960. (Unpublished Ph.D. thesis cm file Ore. State Univ., Corvallis, Ore.)

Precipitation was considerably below normal for the 5-month period from May through September during both the first and second growing seasons. Thus, the good survival cannot be attributed to an unusually favorable precipitation pattern.

The main findings of the study were as follows:

- In direct seeding of Douglas-fir on a south aspect and a loamy soil in northwestern California, with competing vegetation periodically eliminated, the greatest number of seedlings became established with a shade level of about 50 percent (plus the shade provided by the protective hardware-cloth screens).

- Shade did not significantly improve the survival of good quality, carefully planted Douglas-fir seedlings (either 1-0 or 2-0 age class).

- Subsequent growth of the surviving seedlings averaged considerably better with 0 or 25 percent shade than under deeper shade. This pattern was readily apparent in terms of seedling dry weight, stem diameter, root length, and to a lesser degree, height growth. Although differences among treatment means were not statistically significant for every variable in every age class, the consistent over-all pattern of increased growth associated with the higher light intensities suggests that full sun to 25 percent shade is the most favorable environment for growth of Douglas-fir seedlings more than a few months old, where competing vegetation is periodically eliminated.

The implications of the first finding are that, for direct seeding of Douglas-fir, "clean" site preparation may not give the best results in terms of getting the greatest initial catch of seedlings per pound of seed sown. The problem is how to get a mineral soil seedbed (generally regarded as the most favorable) without eliminating the beneficial early shading effect which might be derived by leaving a light scattering of slash or other material on the cutover areas. One solution might be to sow a nurse crop, such as brown mustard *(Brassica juncea* [L.] Cosson.*)*, after slash disposal–a technique which proved successful on south slopes in Oregon (Chilcote 1957). The mustard plants must, however, be sprayed with herbicide the following spring to convert them to dead shade so they do not compete with the young conifer seedlings for moisture after the rainy season ends.

In evaluating the findings of this study, it must be remembered that the seeding and planting were done in a single year and on only one site. Additional testing on other sites and under other weather patterns is needed before we will know how widely these findings may be applied. Furthermore, tests in which the competing vegetation is not periodically removed would be worthwhile to observe seedling response to shade level under more typical field conditions.

SUMMARY

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Retrieval Terms: Pseudotsuga menziesii: California (northwestern); artificial regeneration; light relations; protective shading; germination; survival; early growth; height increment.

Satisfactory regeneration of Douglas-fir *(Pseudotsuga menziesii)* on south-facing cutblocks in northwestern California is often difficult to achieve because hot, dry summers put severe stress on seedlings. Several studies of shade effects on Douglas-fir seedlings indicate that survival of unshaded seedlings is significantly lower than that of shaded ones.

This study was designed to determine which of four shade levels would promote best survival and early growth of seeded and planted Douglas-fir on hot, dry, southerly aspects in northwestern California. On the Hoopa Indian Reservation, in spring 1966, plots were laid out on a 50 percent south-facing slope at about 3,000 feet elevation, where

Douglas-fir had been logged the previous spring. Soil was moderately acid loam, 3 to 4 feet deep.

Four levels of shade were tested: 0 (control), and 25, 50, and 75 percent. Shade was provided by redwood lath nailed to a framework and appropriately spaced. Control plots were open on top but enclosed around the sides with poultry netting to protect seedlings from animal damage. Before planting and seeding, all plots were cleared of vegetation by hand scalping, and vegetation that appeared afterward was periodically removed to prevent variable shading effects.

In each of 12 plots (three replications of the four treatments) 10 1-0 and 10 2-0 Douglas-fir seedlings were planted. In addition, 100 seeds were surface sown on each plot, in groups of 10, and each group was covered with a hardware-cloth dome.

Seedling counts on June 9, 1967, showed that germination was best on plots with 50 percent shade, followed in order by the plots with 75 percent shade, 25 percent shade, and 0 shade. Subsequent survival at the end of two growing seasons was also best on plots with 50 percent shade, followed by 25 percent and 75 percent. On the unshaded plots, no seedlings survived to the end of the second season. Effect of treatment was statistically significant (5 percent level).

For planted trees, effect of treatment on survival after 2 years was not significant, as survival was good on all plots.

Growth responses measured included height, stem diameter, root length, and oven-dry weight. Best height growth for both age classes of planted trees occurred on the unshaded plots. Plants grown from seed did not survive beyond the first year on unshaded plots, and made best growth with 25 percent shade. Differences in height growth were not significant by treatment, however, possibly owing to within-plot variation.

Increases in stern diameter, root length, and dry weight were generally in inverse proportion to the amount of shade received, although differences between treatment means were not statistically signifycant for all age classes of seedlings, nor in all years.

The main findings of the study are that the greatest number of seedlings were established at the 50 percent shade level; shade did not significantly improve survival of planted stock; and subsequent growth averaged considerably better with 0 or 25 percent shade than under deeper shade. A consistent, though not always statistically significant, pattern of increased growth was associated with the higher light intensities.

An implication of the first finding is that for regeneration by direct-seeding, early shading is desirable, though difficult to achieve. A possible solution might be use of a nurse crop, such as brown mustard, converted to dead shade by herbicides the spring after seeding.

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Effects of four light intensities on germination, survival, and early growth of Douglas-fir *(Pseudotsuga menziesii)* were studied on south-facing cutblocks in northwestern California. Tested were four shade intensities: 0, 25, 50, and 75 percent. On seeded spots, 50 percent shade resulted in greatest germination and survival, being significantly better than either no shade or 25 percent shade, but not better than 75 percent-shade. Shade did not significantly improve the survival of planted trees (either 1-0 or 2-0 age class), but growth was generally best on plots with least shade. Good survival on all treatments was probably due to careful planting, excellent stock, periodic weeding, and deep loam soil. An implication of these findings is that for direct-seeding, early shading is desirable, though difficult to achieve. A possible solution is to use a nurse crop converted to dead shade the spring after seeding.

Oxford: 174.7 *Pseudotsuga menziesii:* 232.324: 236.3: 232.33.

Retrieval Terms: Pseudotsuga menziesii: California (northwestern); artificial regeneration; light relations; protective shading; germination; survival; early growth; height increment.

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