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Title REGENERATION PATTERNS ON SOME MODIFIED STAGGERED-SETTING CLEARCUTS ON THE H. J. ANDREWS EXPERIMENTAL FOREST

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(Major professor)

A survey of natural regeneration of Douglas-fir and associated species was made on 15 staggered-setting cuttings four and five years after logging. These areas were on the H. J. Andrews Experimental Forest which is located in the McKenzie River area of western Oregon. Five types of cuttings were represented: (1) four north-south orientated strip clearcuts varying from 50 to 350 feet in width; (2) three east-west orientated strip clearcuts varying from 100 to 300 feet in width; (3) six patch or group clearcuts varying from one-fourth to four acres in size; (4) a shade-seed-tree cutting on which residual trees were left to provide shade and seed; and (5) a typical staggered-setting clearcut. The modified cuttings were designed to utilize shade from the residual stand to favor regeneration by reducing high surface soil temperatures, a major deterrent to the establishment of tree seedlings in this area.

Results of the survey showed that all of the modified cutting units were better stocked than the typical staggered-setting clearcut and with two exceptions had at least 500 well-spaced trees per acre. The east-west orientated strips regenerated best with 69 to 89 percent of milacre plots stocked. The small group clearcuts also regenerated well; stocking varied from 58 to 72 percent of milacre plots stocked. The north-south orientated strips were the most poorly stocked group of small cuttings with from 35 to 61 percent of milacre plots stocked. The shade-seed-tree cutting had 61 percent of plots stocked and the staggered-setting clearcut 28 percent of plots stocked.

The statistical analysis indicated that the parameter of shade hours per plot was consistently related to regeneration of all species together and of Douglas-fir alone. The degree of this relationship varied considerably between types of units and to a lesser extent among units of a particular type. In addition there was some evidence that intermittent shading was more effective in favoring regeneration than a similar amount of shade received in a single period of time. Distance from seed source was not found to be related to stocking on the small cutting units studied.

The author concludes that consideration should be given to the use of special cutting methods such as east-west orientated strip clearcuts, small patch clearcuts, and shade-seed-tree cuttings, to aid in natural regeneration of Douglas-fir, especially on severe sites. These cuttings should be laid out primarily to provide shade rather than from the standpoint of seed dispersal.

REGENERATION PATTERNS ON SOME MODIFIED STAGGERED-SETTING CLEARCUTS ON THE H. J. ANDREWS EXPERIMENTAL FOREST

by

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INTRODUCTION

Foresters in the Douglas-fir region have continually striven to obtain natural regeneration of Douglas-fir on cutover forest lands. Many studies have been conducted toward this end and many harvesting techniques have been tried. Continuous clearcutting was eliminated as a possible system when Isaac established that Douglas-fir seed was not stored naturally in the duff. Selection systems were not applicable because of the intolerant nature of the species. The seed-tree system was generally discarded after it was found a majority of the seed trees died on cutover areas before regeneration could become established. After World War II a modified form of clearcutting in staggered-settings was developed which involved a system of patch cuttings, usually 40 to 80 acres in extent, interspersed with uncut forest stands. This system seemed to provide for adequate natural regeneration--full sunlight on the cutover areas and an adequate seed source within the known limits of Douglas-fir seed dissemination.

In 1948 the H. J. Andrews Experimental Forest was set aside for research in the management of old-growth Douglas-fir. A major portion of the initial program was a "pilot plant" test of the staggered-setting system. It was found that the clearcuts did not always develop the prompt and adequate regeneration of Douglas-fir expected, and heat appeared to be one of the major deterrents to the establishment of seedlings. Consequently a series of experimental cuttings was made during

1954 and 1955 to determine whether some modification of standard cutting procedures would be more favorable for regeneration. Included were group or patch clearcuts ranging in size from 1/4 to 4 acres, strip clearcuts of various widths and orientations, and a shade-seed-tree clearcut. All cuttings were designed to utilize shade from the residual stand to favor regeneration by reducing surface soil temperatures. Examination of these units in 1959, four or five years after cutting and burning, indicates that utilization of stand shade does produce favorable results. This thesis is a report of that examination and an analysis of the resulting data.

REVIEW OF LITERATURE

Considerable literature is available on the regeneration of Douglas-fir, but very little deals specifically with its regeneration on strip or small patch cuttings, or under a seed-tree system. Only the most relevant portions of the general studies are considered in this literature review.

Leo Isaac, in his monograph on the reproductive habits of Douglas-fir, reports several pertinent studies. In one experiment on the dissemination of Douglas-fir seed (12, p. 19-22), he found that approximately 39 percent of the seed fell 100 feet from the timber edge, 44 percent fell between 200 and 500 feet from the timber edge, and 17 percent beyond 500 feet. In an investigation of natural regeneration at Wind River, Washington (12, p. 78-80), a gentle, northeast-exposed slope was well-stocked (70 to 100 percent of 13.2-foot square sample plots) up to ten chains from the timber edge within five years. A southwest exposed slope was adequately stocked only one chain from the timber edge after five years. Medium stocking (40 to 69 percent of 13.2-foot square sample plots) occurred to 20 chains and eight chains on the respective slopes.

Isaac (11, p. 11-12) also studied in detail the mortality of Douglas-fir seed trees on eight cutover areas in Oregon and Washington which were 11 to 15 years old. Slash was burned on six of the areas and left unburned on the other two. Average survival on the unburned area was 65 percent and on the burned area nine percent. Twenty percent of the trees (approximately one-fourth of the mortality) died as a result of logging and slash burning. Windfall destroyed an additional 30 percent of the trees. Greater seed production was noted on the surviving single seed trees than on similar specimens in adjacent timber stands. Isaac thought that better seed-tree survival might be realized by using more care in selecting trees, locating trees in more windfirm locations, and leaving them where they might be more free of logging and slash-fire damage.

Garman (6, p. 28-33) studied Douglas-fir regeneration extensively in coastal British Columbia forests. He found that shade promoted germination and improved seedling survival. An analysis was made of the shade factor on an experimental area where regeneration from scattered seed-trees had been studied and the shade from mature trees had appeared to be definitely related to survival. The shadow patterns of the trees on May 21st were carefully determined and reproduction plots rated as either shaded or unshaded. The results indicated that shade of seed trees was beneficial. A full-crowned mature tree was found to give temporary protection to an area of one-third acre during critical times. In an earlier study (5, p. 30-31) he also found seed trees to be heavier cone producers and more efficient distributors of seed than marginal or border trees. Garman concluded (6, p. 36-41) that the practice of leaving seed trees was a very useful silvicultural tool, particularly on south slopes, and felt that "Douglas-fir should be cut by a method that leaves the shade of scattered seed-trees." He thought that cutting of Douglas-fir would eventually evolve to harvesting 300-foot-wide clearcut strips on good sites and a shelterwood system utilizing two to eight leave trees per acre on the most severe slopes.

Krauch (13, p. 17-18), after many years of research in Arizona and New Mexico, concluded that shade was essential for reproduction of Douglas-fir in that region. He thought its most beneficial effect was in regulating transpiration and as a result preventing wilting of seedlings.

Clark (4) studied regeneration of strip clearcuts in a subalpine spruce-alpine fir-Douglas-fir stand in interior British Columbia. Strips two chains wide with four-chain reserve strips were cut in north-south and east-west directions. Reproduction was surveyed with plots located at 1 1/4-chain intervals in a zig-zag pattern across the strips. The eight north-south strips averaged 34.7 percent milacre stocking while the three east-west strips averaged 32.1 percent milacre stocking. Division of the logged area on the basis of direction of strips did not show any significant difference in percent stocking or species preference between north-south and east-west strips, however. Mineral-soil seedbeds with partial or no shade and little or no competition had more seedlings than other condition-combinations.

Worthington (21) studied regeneration on six small clearcuttings in Douglas-fir stands on the Olympic National Forest (Washington) which ranged in size from 1.2 to 4.0 acres and on an adjacent clearcut area of 130 acres. The survey, utilizing reproduction counts on milacre quadrants, was made five years after burning on the large clearcut. Stocking of Douglas-fir was 40 and 26 percent respectively.

Seedlings on the small group clearcuts were noted as being more vigorous and of better form. Distance from uncut timber edge clearly affected stocking beyond 500 feet. Within 500 feet distance from seed source, stocking was 85 percent for the small group cuttings and 83 percent for the large clearcut. Stocking on the large clearcut was 48 percent between 500 and 1000 feet distance from the stand edge and 45 percent beyond 1000 feet distance. None of the group clearcuttings had any points beyond 500 feet from the stand edge. Windthrow was negligible around the group cuttings but excessive along the boundaries of the large clearcut. Worthington indicated that the small cuttings not only improved total stocking but favored Douglas-fir over hemlock as well because of its heavier, less-mobile seed. He concluded that all the group clearcuttings were qualified as adequately stocked except on compacted skid trails; on portions of the large clearcut beyond 500 feet from the stand edge adequacy of stocking was questionable.

A study by Bever (2, p. 18-33) of factors affecting natural regeneration in central western Oregon resulted in some interesting comparisons of seed-source values. In this investigation various study areas were divided into forty-acre sub-tracts and seed-source values assigned to each sub-tract. Two seed trees per acre, a two-acre seed block, 1320 feet of uncut timber within one-fourth mile of sub-tract center, or 3960 feet between one-half and one-fourth mile from subtract center were considered equivalent to a seed-source value of 100. Inspection of the data tabulated on this basis led the author to believe that the values were incorrectly assigned to the various seed sources. The seed-source value of seed trees appeared to be much higher than the others. Seed trees accounted for 23.65 percent of the total seed source value of all the sub-tracts; but 51 percent of the total stocking of all the sub-tracts was associated with these seed trees. Ratios of total seed source value on all sub-tracts to total stocking associated with the source gave ratios of 2.16 for seed trees, 0.33 for seed blocks, 0.43 for uncut timber edge within one-fourth mile of sub-tract center, and 0.84 for uncut timber edge between one-half and one-fourth mile of sub-tract center. From these figures, corrected, more comparable seed-source values were computed which indicated one seed tree per acre, six acres of seed block, 3300 feet of uncut timber edge within one-fourth mile, and 4620 feet of uncut timber edge within one-half to one-fourth mile were equivalent. By using these corrected seed source values, amount of seed source was found to be significantly related to stocking on burned sub-tracts. The pertinent point is the relative value of the various types of seed source. Unfortunately there were no observations on the possible effect seed trees might have had by shading. Bever concludes that the operator who leaves seed trees can expect considerably better stocking results than the operator who leaves seed blocks.

A similar study was made of regeneration on staggered settings in western Oregon (14). In this study it was found that "There was no correlation between setting size and distance from seed source; there was little correlation between distance from seed source and occurrence of coniferous reproduction; therefore, no correlation exists between the size of a staggered setting and speed of restocking" (p. 26).

Silen (18, p. 26-36) reported the results of a regeneration survey made of five clearcuts on the H. J. Andrews Experimental Forest. Percentage of seedlings on the south edge of the clearcuts was unusually high. All milacre plots on two of the clearcuts in this location were stocked. He found between 75 and 90 percent of the surviving seedlings had stem shade the entire day. Forty-six to 82 percent of the "Tempil" stations (p. 43-46) established on south-slope clearcuts indicated soil-surface temperatures exceeding 138°F., a temperature which was closely related to seedling mortality. Temperatures decreased in years following logging.

In detailed laboratory studies of the effect of heat on seedlings Silen (18, p. 67-98) established a strong relationship between the length of time of exposure to a particular surface soil temperature and mortality of seedlings. This relation varied with the seedbed used. This fact led him to suggest (p. 147) that heat injury be minimized using seed-tree shade to break up the seedling's day into short periods of exposure.

One regeneration study conducted at the Fremont Experiment Station in the Rocky Mountains (17) compared Douglas-fir regeneration under the selection, shelterwood, and clearcutting systems with a control area. The species involved were Douglas-fir, ponderosa and limber pines, and Engelmann spruce. There were 83 and 271 Douglas-fir trees left on the 200- by 200-foot shelterwood and selectively-cut plots, respectively.

Established seedlings (at least three years old) ten years after cutting were 1005, 6891, 4638, and 1237 on the clearcut, shelterwood, selectively-cut, and control plots of which 62, 80, 85, and 57 percent were Douglas-fir. Growth of the seedlings, especially Douglas-fir, was best with shelterwood cutting. The author concluded, on the basis of quality and quantity of reproduction, that the shelterwood method was the most desirable for Douglas-fir.

Hawley and Smith (9, p. 71-76), in their discussion of clearcutting in patches or strips, indicated the chief advantage of these modifications is in providing an effective seed source for natural restocking, although they do mention: "This kind of modification (strips or patches) may also be employed . . . to create an environmental condition intermediate between the protection of a shelterwood and the drastic exposure of a large clearcut area." Shade from the stand edge is not mentioned. Likewise, in their discussion of advantages of the seed-tree method (p. 100-101), no mention is made of any modifying influences (such as shading) which seed trees might exert. This system is also thought of primarily in terms of supplying seed rather than aiding in seedling establishment.

Troup (20) discusses both the "group system" (p. 64-72) and "strip systems" (p. 79-104). The protection afforded regeneration by adjacent timber on group cuttings is emphasized ". . . so long as the gap is small . . . to secure protection against frost, cold winds, and the desicating action of the sun . . ." It was noted, however, that ". . . as the gaps are enlarged the sun beats down on its northerly edges. . . this may cause heavy mortality amongst young seedlings. . ." A system known as "Wagner's Blendersaumschlag" is discussed in detail under strip systems. Cuttings are narrow strips extending in an east-west direction and advancing from north to south with the particular objective of protecting from the sun seedlings on the strip being regenerated. This system is based on the favorable influence that side or lateral protection, particularly when on the south and east, have on establishment of reproduction; this protection was considered to be accomplished mainly by conservation of soil moisture. Most of the clear-strip systems described are kept to widths of from half the height to the full height of the adjacent forest in order to secure side protection from the sun for either natural or artificial regeneration.

Clear cutting in alternate strips and small groups and single-tree selection cutting have been compared in a long-term study of harvesting techniques in the subalpine fir-Engelmann spruce type of the Rocky Mountains (16, p. 19-21). Advance reproduction, dominated by subalpine fir, was abundant on the study areas before logging. Horse-logging reduced milacre stocking by 29, 36, and 38 percent on the group clearcuts, selection cuttings, and strip clearcuts, respectively. Fifteen years after logging total stocking and stocking of spruce alone differed little between plots. "Stocking was good (89 to 92 percent of milacres) regardless of cutting method. From 61 to 69 percent of all milacres were stocked with spruce."

Clearcutting in strips has also been tried in the western white pine type (8, p. 81-83). Results were generally good although some strip cuttings failed to regenerate satisfactorily because of "adversity of site." Strip cuttings in this type were wide (350 to 400 feet) and located advantageously for seed dissemination rather than for protection of the harvested areas for regeneration purposes.

Lexen (15, p. 4-7) proposed alternate clear-strip cutting for certain situations in the lodgepole pine forests found in the Rocky Mountains. It was considered a useful system for: protecting young growth left following cutting from wind-throw; reducing fire hazard by avoiding large, contiguous bodies of slash following logging; retarding the development of the alpine fir-Engelmann spruce climax; and protecting a residual stand after heavy thinning. Alternate clear-strip cuttings were also considered to aid in regenerating poor sites but only as a reserve supply of seed and not as an aid in seedling establishment.

The initial harvesting technique to be tested in old-growth red fir stands is clear cutting in strips about 300 feet wide (3, p. 10-11). The system was evidently selected primarily to protect the windward edge of uncut timber from blowdown and help scatter seed into the clearing.

Clear-cut strips and patches were included in a test of cutting systems in the swamp black spruce type (Picea mariana (Mill.) B.S.P.) of Minnesota (10, p. 2-3). The strips were about one chain wide, six to ten chains long, and orientated north and south; the patches were one-half to one-quarter acre in size. In appraising the overall effectiveness of the systems it was found (p. 16-18) that only the clear-cut patches met the objective of 60 percent milacres stocked four to six years after logging. The failure of the strips to meet this goal was attributed to the pattern of slash concentrations, plus possible site and seedbed differences. It was thought that clear-cut strips with slash disposal would be equally effective in obtaining regeneration. Clear-cut strips 150 to 200 feet wide, of both north-south and east-west orientation and with burning of windrowed slash, were just then being tested. Both of the clear-cut systems were noted for providing "an open area in which regeneration can develop free of overstory competition, yet within seed dispersal range of uncut stands."

Tomanek (19) studied the microclimate during the early summer on some: (1) 20-meter diameter group clearcuts; (2) 40-meter diameter group clearcuts; (3) 20- by 60-meter north-south orientated strip clearcuts; and (4) 20- by 60-meter east-west orientated strip clearcuts. He noted little variation in the minimum temperatures under the different cutting methods, but maximum temperatures were least on the east-west strips and small groups and highest on the north-south strips and larger groups. Variation in evaporation rates were small during the night but considerable during the day. They were highest on the strip cuttings (the maximum on the north-south strips) and least on the group clearcuts. Regeneration of pine, oak, and fir was best on the east-west orientated strip clearcuts.

Geiger (7, p. 350) discussed the microclimate of small cuttings in forest stands. He generalized that the ". . . moderate temperature range, the high atmospheric humidity and the calm air of the surrounding trunk space, characterize the habitat climate of the hole cutting." His main interest was in the extreme ground temperature and great frost danger that such cuttings apparently entail as they are enlarged. He felt there was a critical size of opening at which the climate was most severe. Below this size the climate is milder due to less radiation while above this size it is milder because more wind can reach into it. He does not discuss regenerative aspects of such cuttings or the effects of shade.

Most of the references cited, particularly concerning studies conducted on small strip and group clearcuts elsewhere in the United States, concentrated on the seed supply aspects of such cuttings. The results of the study to be reported emphasize their protection function in the establishment of reproduction.

STUDY AREA

The H. J. Andrews Experimental Forest occupies the drainage of Lookout Creek, a tributary of the McKenzie River, in the western Oregon Cascades (see Figure 1). An approximately 400-year-old virgin timber stand, typical of old-growth stands found in the western Oregon and Washington Cascades, covers most of the drainage. Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) predominates although considerable western hemlock (Tsuga heterophylla (Raf.) Sarg.) and western redcedar (Thuja plicata Donn) and some grand fir (Abies grandis (Dougl.) Lindl.), sugar pine (Pinus lambertiana Dougl.), and incense cedar (Libocedrus decurrens Torr.) are also present. At higher elevations--over 3000 feet--noble fir (Abies procera Rehd.), western white pine (Pinus monticola Dougl.), Pacific silver fir (Abies amabilis (Dougl.) Forbes), and mountain hemlock (Tsuga mertensiana (Bong.) Carr.) are common constituents. Precipitation on the forest is heavy, varying from 89 to as much as 140 inches per year on the ridge tops. Mean temperatures are from 35°F. in January to 65°F. in the summer months and extremes are uncommon (1, p. 2).

Five general types of cuttings were represented in this study: (1) north-south orientated strip clearcuts; (2) east-west orientated strip clearcuts; (3) small patch or group clearcuts; (4) a shade-seed-tree clearcut (residual trees were left to provide shade and seed); and (5) a typical staggered-setting clearcut. Physical and historical data for the units are given in Table 1 and their relative locations and configurations on the experimental forest in Figures

Figure 1. Location of the H. J. Andrews Experimental Forest (1, p. 1).

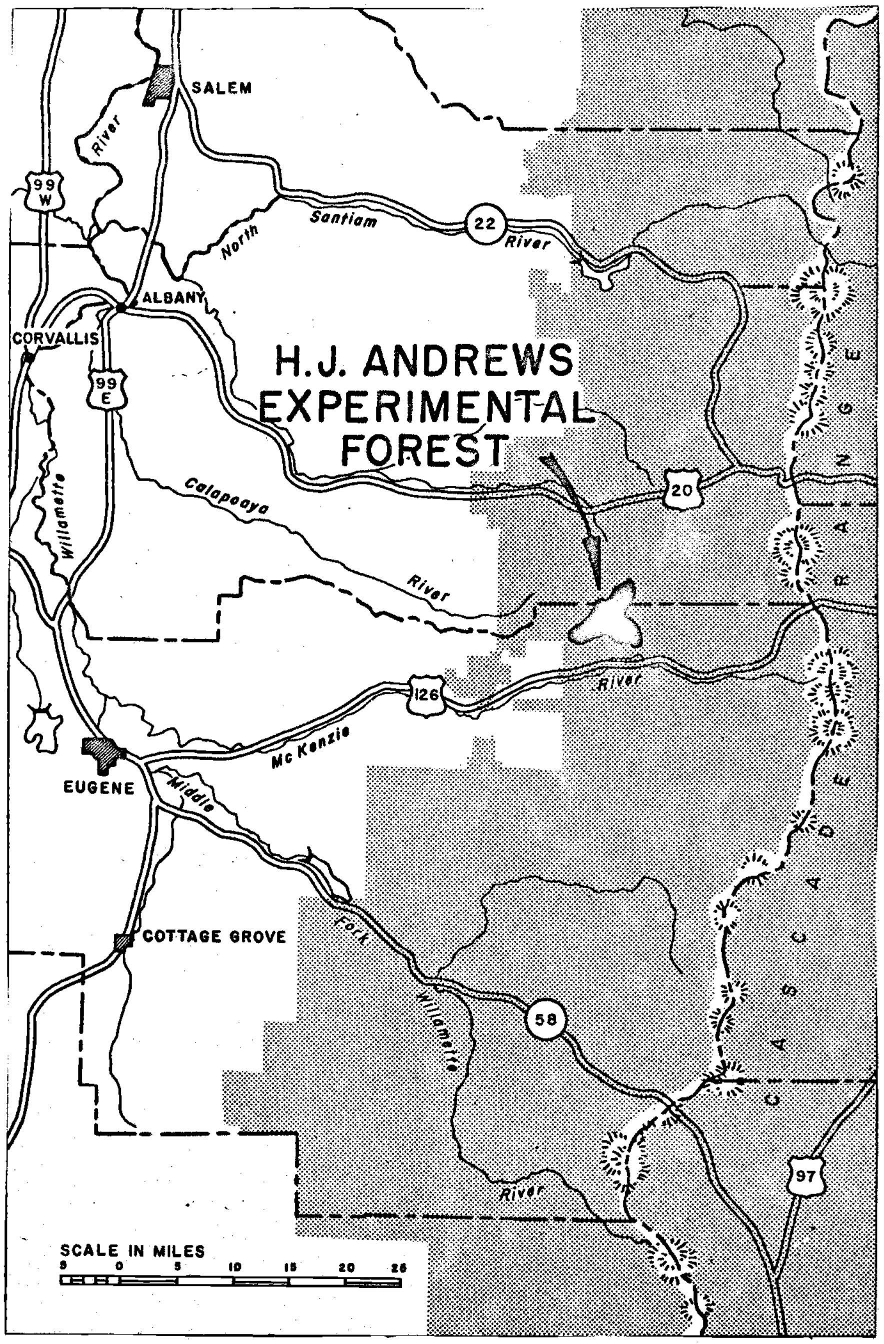


Table 1. Physical and historical data on the cutting units examined.

Unit	Shape	Size	Dimensions		Avg. Slope	Avg. Elev.	Historical Data		
			Width	Length			Logged	Burned	Volume Removed
		Acres	Feet		Percent	Feet			M.B.F./Acre
S1	North-South	0.7	50	600	60	2025	1954	1954	51.7
S2	Orientated	1.2	100	550	60	2100	1954	1954	47.2
S3	Strip	3.6	200	800	50	2125	1954	1955	54.1
S4	Clearcuts	8.4	350	1050	40	2175	1954	1955	68.8
S5	East-West	2.3	100	1000	10	2550	1954	1954	79.1
S6	Orientated	3.1	200	650	10	2600	1954	1954	102.7
S7	Strip Clearcuts	4.0	300	575	20	2650	1954	1955	100.7
G1	Rectangular	4.0	435	400	20	3100	1955	1955	78.3
G2	Group	2.0	250	350	10	3125	1955	1955	83.2
G3	Clearcuts	1.0	200	220	0	3075	1955	1955	70.3
G4	Circular	0.75	102 radius		0	3025	1955	1955	78.7
G5	Group	0.50	83 radius		10	3025	1955	1955	137.4
G6	Clearcuts	0.25	59 radius		20	3050	1955	1955	50.0
5B	Typical Staggered-Setting Clearcut	48.4			20	3200	1955	1955	56.4
5C	Shade-Seed-Tree Cutting	20.4			10	3300	1955	1955	49.1

2, 3A and 3B. All but the north-south strip clearcuts occupy comparable sites: gentle, south-exposed slopes with deep, clay-loam soils at elevations of 2550 to 3500 feet. The north-south orientated strips occupy a steep, south-exposed slope with a shallow, clay-loam soil at elevations of 1850 to 2375 feet.

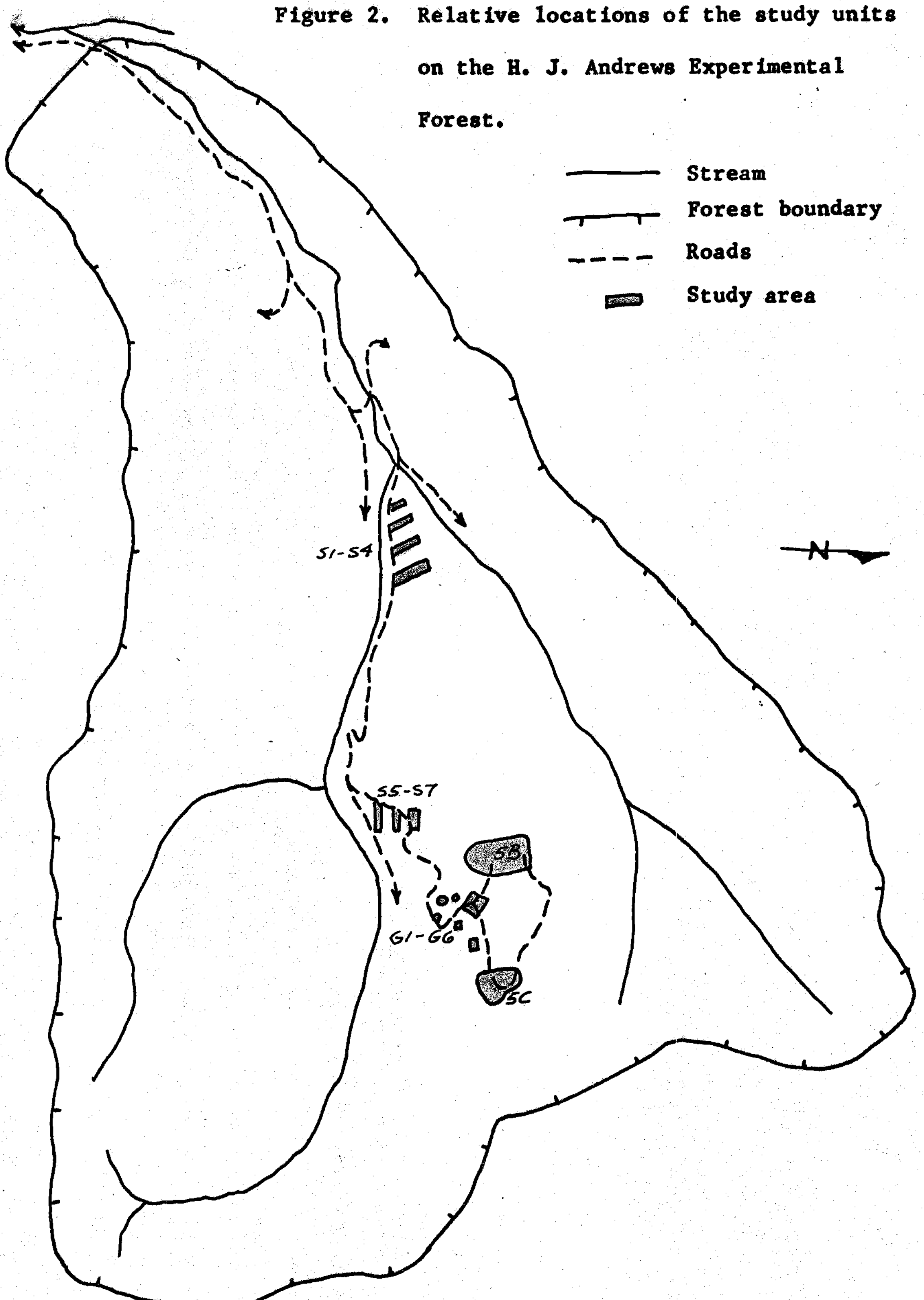
Ground cover was relatively uniform on all areas with no outstanding differences between units. Plants which were prominent on the cut-over areas were trailing blackberry (*Rubus ursinus* var. *vitifolius*), modest whipplea (*Whipplea modesta*), vine maple (*Acer circinatum*), snowbrush ceanothus (*Ceanothus velutinus*), common beargrass (*Xerophyllum tenax*), and fireweed (*Epilobium angustifolium*).

Continuous records have been kept of Douglas-fir and western hemlock cone crops in the vicinity. Cone crops of these species since 1954 were rated as follows:[1/]

Years	Douglas-fir	Western Hemlock
1954	Medium	Abundant
1955	Light	Light
1956	Abundant	Medium
1957	Failure	Medium
1958	Failure	Light

1/ These data are based on averages of general observations of number of cones on Douglas-fir and hemlock at seven locales throughout the experimental forest. They provide a relative measure of cone crops only. Data are on file in the Pacific Northwest Forest and Range Experiment Station, U. S. Forest Service, Portland, Oregon.

Figure 2. Relative locations of the study units on the H. J. Andrews Experimental Forest.



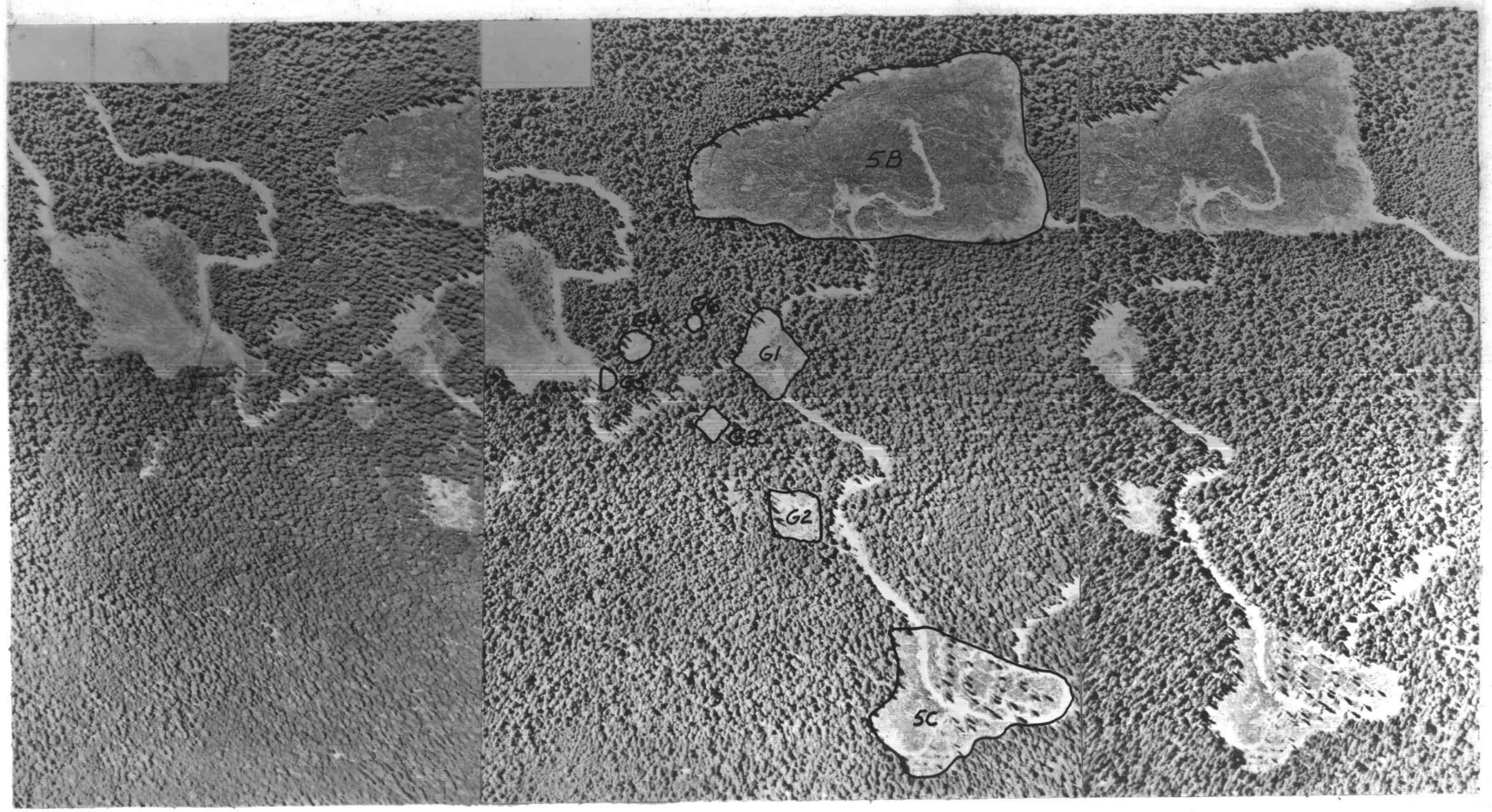
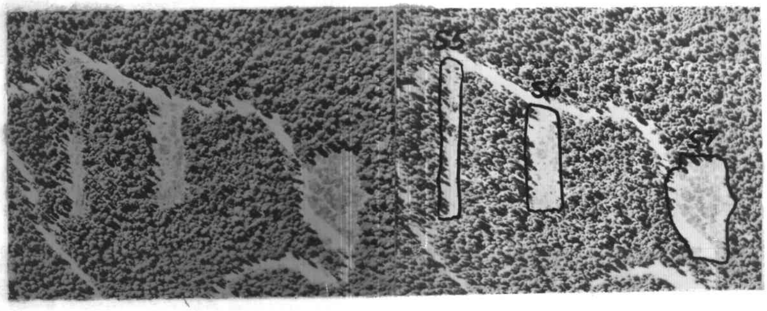


Figure 3A. Stereogram showing aerial views of the group clearcuts, shade-seed-tree cutting, and standard clearcut.



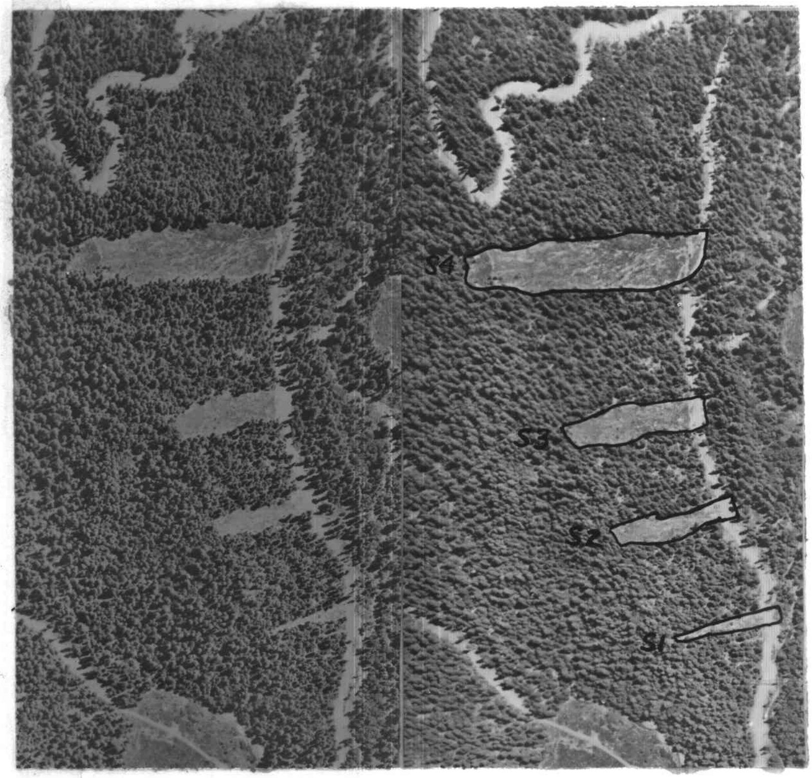


Figure 3B. Stereogram showing aerial views of the east-west orientated strip clearcuts (top) and north-south orientated strip clearcuts (bottom).

EXPERIMENTAL TECHNIQUE

The purpose of this study was to evaluate the various cutting methods using resulting regeneration as the criterion for comparison. It was decided that a regeneration survey using a systematic sampling procedure was best suited to this objective. Because of differences in size and shape of the units no single system was possible. A summary of the sampling procedures used is given in Table 2. The smaller units have a minimum of 90 plots while the larger have a lower sampling intensity; sample size was not proportional to the size of the unit. Circular milacre plots were used in order to have a larger number and better distribution of plots than would have been possible with four-milacre plots. Examinations were made during the late summer and fall of 1959.

The regeneration surveys were conducted using a staff compass and tape. As a plot was located, a small stake was placed in the center and the area of the plot carefully examined. All of the Douglas-fir seedlings on the plots were counted. Established Douglas-fir seedlings were considered to be trees in their second growing season or older; two seedlings in their first growing season were also considered equivalent to an established seedling. Up to twenty western hemlock and western redcedar seedlings were counted on a plot but when there were more than that number the fact was recorded but total seedlings were not counted. Hemlock and cedar seedlings were considered to be established if in their third season. Three one-year-old seedlings were considered equivalent to an established seedling.

Table 2. Details of sampling procedures used.

Area	Number of Lines	Direction of Lines	Spacing of Plots on Line (feet)	Number of Plots Per Line	Actual Number of Plots (expected)	Remarks
S1	10	East-west	10	8	102	First plot on each line starts 10' from the west edge of the timber
S2	10	East-west	10	9	118	
S3	10	East-west	20	9	96	
S4	10	East-west	20	19	141	
S5	10	North-south	10	9	90	First plot on each line starts 10' from the south edge of the timber
S6	10	North-south	20	9	99	
S7	10	North-south	20	14	174	
G1	10	North-south	20	21	204	
G2	10	North-south	20	10	116	Same as S5-S7
G3	10	North-south	20	9	102	
G4					114	Area divided into approximately 100 squares and plots taken in middle of squares
G5					107	
G6					130	
5B	10	East-west	50		225	First plot on each line starts 25' from the west edge of the timber
5C	10	East-west	50		125	

The hours during which the center of the plots were receiving shade from adjacent timber between 6 a.m. and 6 p.m. were recorded for the strip and group clearcutting areas. The technique was described and used by Silen (18, p. 31-32). It involves the use of a protractor placed with its index mark at the center of the plot and orientated with its 90° mark toward the south. The protractor is tilted at a 45° angle toward the north to align its surface with the celestial equator. The path of the sun for the six spring and summer months lies somewhere in a band 23° wide north of the celestial equator marked by the protractor edge. The stand edge producing shade on the plot must lie within the skyward projection of the imaginary band. Since the sun moves along the band at 15° per hour (the earth's rotation in degrees per hour) the hours of shade on each plot can be estimated with the protractor in terms of degrees and converted to hours.

RESULTS AND ANALYSIS

The overall results of the regeneration survey are tabulated in Table 3. The statistical analyses are confined to the smaller strip and group clearcuts; units 5B and 5C were included in the study mainly for comparative purposes. In all of these analyses stocking was measured in three ways: (1) percentage of plots stocked with any species; (2) percentage of plots stocked with Douglas-fir; and (3) number of Douglas-fir seedlings per plot. Two general lines of approach were used. Initially an attempt was made to relate stocking to a characteristic of the 13 small units (strip and group clearcuts): (1) size of the units; (2) average hours of shade on the units; and (3) width of the unit in the north-south dimension. In these regression analyses each unit provided a single observation.

After this approach failed to provide any aids in interpreting the data, a second was tried involving tests of the relations between stocking and (1) shade hours on the plot, and (2) distance of plot from seed source. These relations were tested first for the plots on each of the strip and group clearcuts, a total of 78 individual regression analyses (6 for each unit). Then the plot data for each of the major types of cuttings--east-west strip clearcuts, north-south strip clearcuts, and group clearcuts--were pooled and the same relations tested for the three groups of pooled data. A covariance analysis between three regression lines developed in the analyses of the pooled data completed the statistical portion of the study.

Table 3. Results of regeneration survey

Unit	Description	Total Plots	Plots Stocked (any spp.) Percent	Plots Stocked (fir) Percent	Number of Established Douglas-fir/acre
S1	50' north-south strip	102	61	57	1466
S2	100' north-south strip	118	35	31	597
S3	200' north-south strip	96	40	34	573
S4	350' north-south strip	141	60	45	908
S5	100' east-west strip	90	81	68	1733
S6	200' east-west strip	99	89	81	4561
S7	300' east-west strip	174	69	60	1899
G1	4-acre group	204	58	42	824
G2	2-acre group	116	60	29	474
G3	1-acre group	102	81	45	814
G4	3/4-acre group	114	75	58	1658
G5	1/2-acre group	107	72	64	2276
G6	1/4-acre group	130	72	44	888
5B	Staggered-setting clearcut	225	28	21	407
5C	Shade-seed-tree cutting	125	61	50	1448

Relations between stocking and characteristics of the strip and group clearcuttings

The results of attempts to relate stocking to characteristics of the clearcut units are presented in Table 4.[2] Only one of the linear relationships tested proved significant, that between the width of the clearcut units in the north-south dimension and percent of plots stocked with established seedlings of any species. This relation is illustrated in Figure 4.

Inspection of the plotted data from each of the analyses where significance could not be shown, revealed that no different results were to be expected by dropping units S1 through S4 from the analysis, which might be justified on the basis of site differences. Indeed, the reverse appeared true. Therefore a similar analysis using the more homogeneous group of units (S5-S7, G1-G6) was not attempted. A preliminary analysis of the relationships between the narrowest dimension of the clearcut units and stocking and between the average distance of plots on the clearcut units from the stand edge and stocking were undertaken. The plotted data looked very unpromising, however, and no further analyses were made.

2/ An example of the method used in making these analyses is given in the appendix.

Table 4. Results of regression analyses of the relationships between regeneration and characteristics of the group and strip clearcuts.

Width of clearcut in north-south dimension (independent variable)		
Percent of plots stocked with any species	1 & 11 d.f.	F = 10.756 **
Percent of plots stocked with Douglas-fir	1 & 11	2.295
Number of established Douglas-fir seedlings per acre	1 & 11	1.150
Size of clearcut in acres		
Percent of plots stocked with any species	1 & 11	0.335
Percent of plots stocked with Douglas-fir	1 & 11	0.052
Number of established Douglas-fir seedlings per acre	1 & 11	0.009
Average hours of shade on clearcut		
Percent of plots stocked with any species	1 & 11	1.660
Percent of plots stocked with Douglas-fir	1 & 11	0.004
Number of established Douglas-fir seedlings per acre	1 & 11	0.156

** Significant at the one percent level.

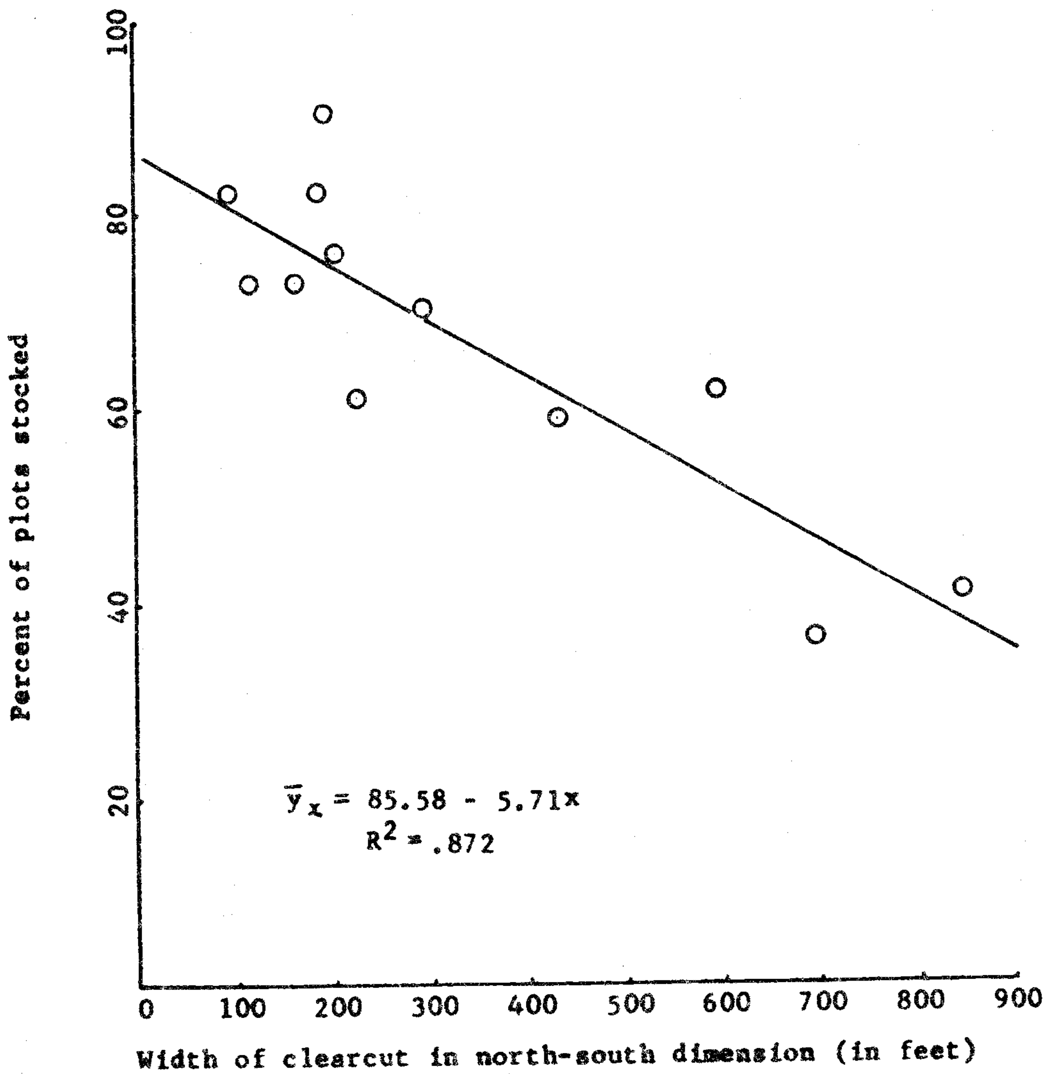


Figure 4. Regression line showing the relation between stocking of any species and width of clearcut in north-south dimension.

Relations between shade and distance from seed source and stocking

The major portion of this analysis procedure was regression analyses of stocking on shade hours and on distance from seed source for each of the 13 small units. The results of these analyses, showing the F-values from the test of the hypothesis that $B = 0$, are given in Table 5.[3/]

Results of similar analyses of three groups of polled data are given in Table 6. These pooled data were obtained by grouping the plots from the north-south strips, east-west strips, and four of the group clearcuts, respectively. These groupings were quite homogeneous with respect to site, type of cutting, and quantity of reproduction.

A covariance analysis was conducted between the regression lines from the three groups of pooled data for the relation between shade hours on a plot and the number of Douglas-fir seedlings per plot stocked with Douglas-fir. This was the only relationship which was significant for all three groups of pooled data. The results of the covariance analysis indicated that the three regression coefficients were significantly different ($F = 54.31$ with two and 688 degrees of freedom). The regression coefficients for the north-south strip clearcuts and group clearcuts were not significantly different ($F = 0.82$ with one and 144 degrees of freedom), but the adjusted treatment means were not the same for both sets of data.

3/ An example of one of these analyses is given in the appendix.

Table 5. Results of regression analyses (F-ratios) of stocking on shade hours and on distance from seed source (individual units).

Unit	Percent Plots Stocked (any species)		Percent Plots Stocked (Douglas-fir)		Number of Douglas-fir Seedlings per Plot Stocked with Douglas-fir	
	vs. shade hours	vs. distance from stand	vs. shade hours	vs. distance from stand	vs. shade hours	vs. distance from stand
G1	12.54 **	6.12 *	9.07 **	1.55	9.96 **	0.89
G2	1.87	0.02	0.13	1.63	0.57	0.76
G3	7.51 **	1.66	19.05 **	0.58	4.65 *	0.78
G4	18.40 **	0.94	14.10 **	0.62	9.75 **	0.57
G5	1.04	3.00	0.01	1.85	0.07	5.08 *
G6	8.44 **	0.81	10.75 **	4.00 *	21.59 **	7.24 **
S1	0.80	0.38	0.15	0.25	3.34	3.04
S2	3.13	0.18	4.15 *	0.43	2.42	3.06
S3	7.38 **	6.78 *	3.59	2.73	6.00 *	5.12 *
S4	0.04	0.11	0.43	2.18	5.71 *	4.27 *
S5	4.80 *	0.20	0.99	0.60	2.41	0.30
S6	2.29	0.21	1.55	0.07	39.20 **	17.71 **
S7	6.79 **	2.18	4.50 *	5.00 *	9.21 **	4.05 *

** Indicates significance at the 1 percent level.
 * Indicates significance at the 5 percent level.

Table 6. Results of regression analyses (F-ratios) of stocking on shade hours and on distance from seed source (pooled data).

Units	Percent Plots Stocked (any species)		Percent Plots Stocked (Douglas-fir)		Number of Douglas-fir Seedlings per Plot Stocked with Douglas-fir	
	vs. shade hours	vs. distance from stand	vs. shade hours	vs. distance from stand	vs. shade hours	vs. distance from stand
S1-S4	0.11	0.00	0.10	0.03	15.37 **	14.42 **
S5-S7	13.41 **	3.29	6.82 **	5.14 *	34.28 **	28.52 **
G1, G3, G4, G6	64.11 **	6.16 *	45.71 **	2.40	28.98 **	2.14

** Indicates significance at the 1 percent level.
* Indicates significance at the 5 percent level.

A single regression line could not, therefore, be used to describe the relation for the three sets of pooled data or even for two sets. Although all three groups showed a significant relation between the number of Douglas-fir seedlings per plot stocked with Douglas-fir, the slope and/or position of the line is different in each case. The regression lines for these three groups of pooled data are illustrated in Figure 5.

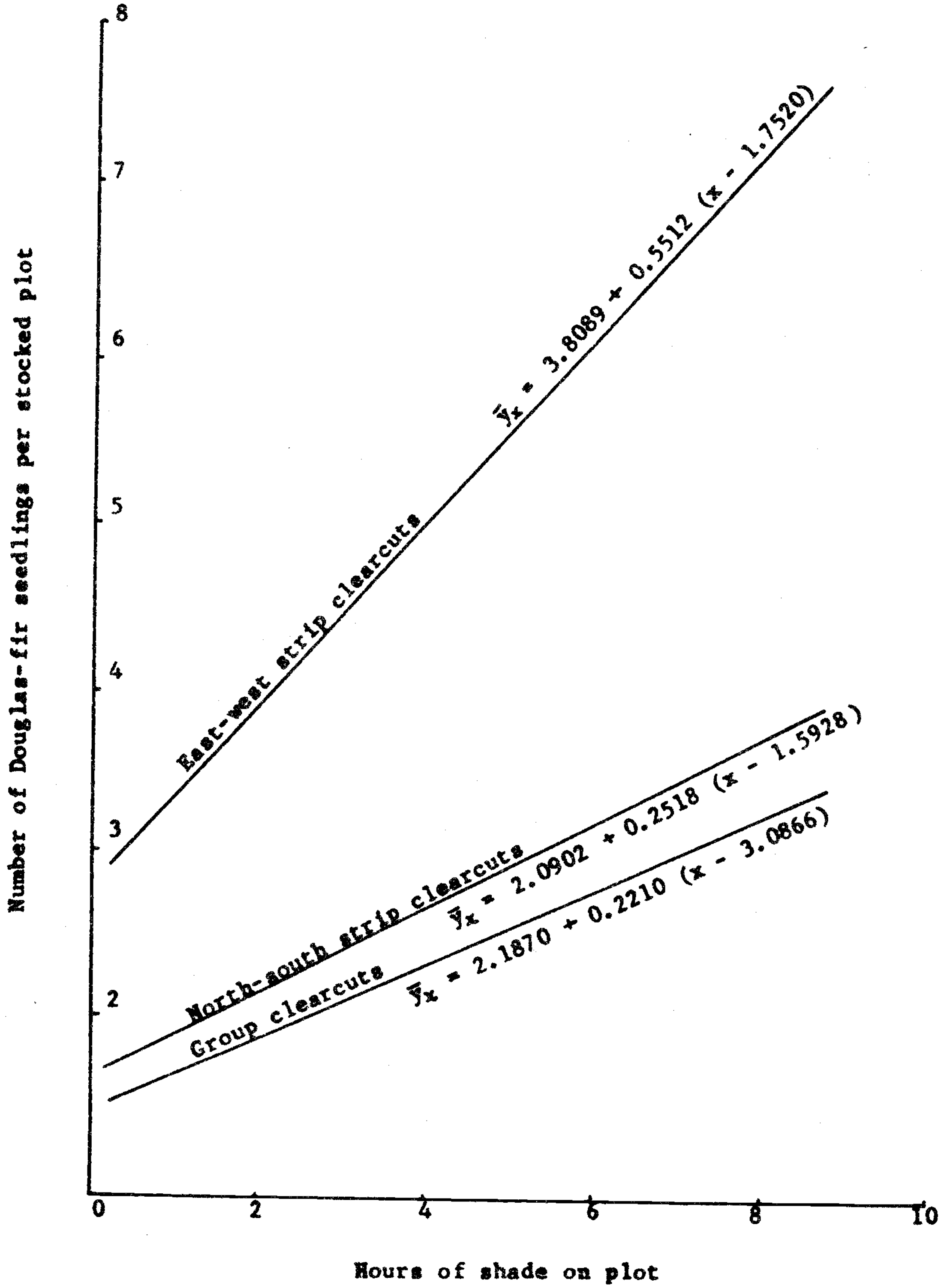


Figure 5. Regression lines from the three groups of pooled data showing the relation of stocking and shade hours.

DISCUSSION

All of the modified clearcuts were better stocked than the typical staggered-setting clearcut (Table 3) and with two exceptions they had at least 500 well-spaced trees per acre. Even these two exceptions (Units S2 and S3) should have this stocking within two or three years. The large clearcut, on the other hand, had only 28 percent of 225 milacre plots stocked with established seedlings of any species. This is not atypical of standard staggered settings in this area. Silen (18, p. 24-30) found, for example, that five north slope clearcuts on the H. J. Andrews Experimental Forest had an average of only 313 (range 165-538) seedlings per acre two to three years after logging, although direct comparisons are impossible because of differences in seed crops, slope, etc. Of the modified clearcuts, the north-south orientated strips had the poorest stocking. East-west orientated strip clearcuts had the best stocking and the group clearcuts and shade-seed-tree cutting were intermediate.

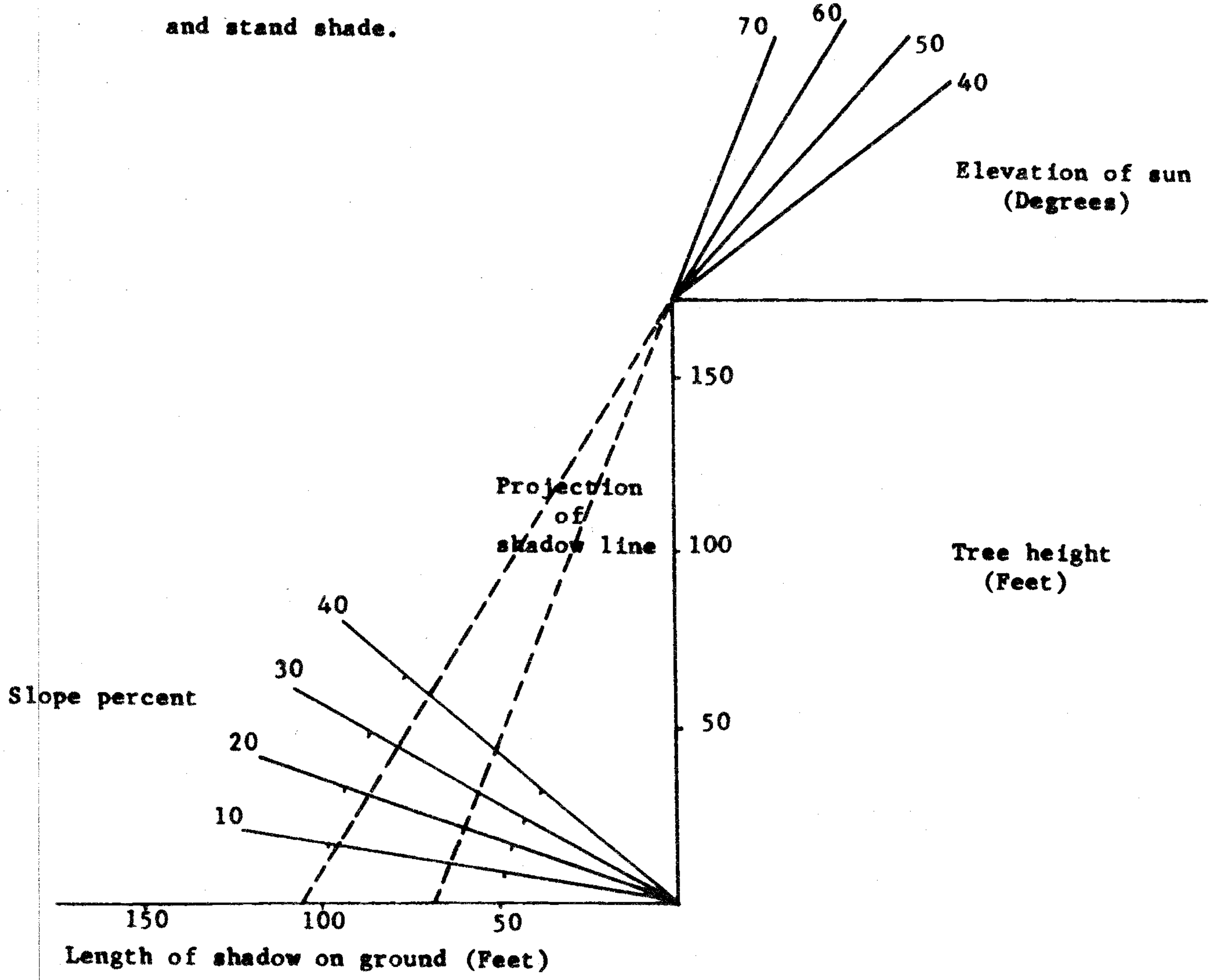
Effect of stand shade on regeneration

The results of the statistical analyses indicate the very favorable influence of stand shade on natural regeneration. Eleven of the 13 units analyzed in detail and all three groups of pooled data showed significant relations between stand shade and number of Douglas-fir seedlings per plot stocked with Douglas-fir. Significant relations were also generally established between shade hours and stocking of any coniferous species and of Douglas-fir.

Stand-shade hours and stocking are not always closely related, however, and the degree of the relationship, as indicated by the regression coefficients, varies considerably from unit to unit. This is particularly noticeable on the north-south orientated strip clear-cuts. One reasonable explanation for this is the time-temperature relationship established by Silen (18, p. 67-98) in his studies of heat damage to Douglas-fir seedlings. In effect this relationship would indicate that intermittent shade, the sort that would break up the seedling's day, is much more effective than an identical duration of stand shade which is received in a single, continuous period. On those units which receive the latter type of shading, i. e. the north-south strips, the relationship between shading and stocking would be minimized. Other factors such as ground shade, variations in micro-exposure, seedbed, etc., would exert a dominant influence.

How much shade can be expected from a particular stand edge? The theoretical relationship of tree height, slope, and stand shade is indicated in Figure 6. In practice this is modified by the nature

Figure 6. Theoretical relationship between tree height, elevation of the sun, and slope percent and stand shade.



of the residual stand edge--continuity, crown conditions, etc. The plotted results (Figure 7) from two units indicate that the effects of the stand are less than those indicated by the diagram. The difference between the obviously shade-influenced areas of these two units reflects differences in the timber stand which is doing the shading. The low value for the ten-foot plots on Unit S5 probably is due to a lack of disturbed seedbed in this zone. Disturbance was more uniform on the other unit.[3/]

Effects of distance from seed source

Results of the study indicate stocking was generally unrelated to distance from seed source. Considering the seedfall study cited earlier (12, p. 19-22) these results are reasonable. No portion of the group or strip clearcuts was over 200 feet from a timber edge and therefore seed dissemination would not be expected to have any major influence on the distribution of regeneration. The results also concur with those of Worthington (21) discussed in the literature review. On the large clearcut used as a check there was some relation:

Distance from stand edge	Total plots	Plots stocked	Percent stocked
10 to 160 feet	106	52	49
Over 160 feet	119	10	8

3/ The two units shown in the figure were chosen because the relationships between stand edge and stocking were least influenced by extraneous factors such as roads, irregularities in boundaries, etc.

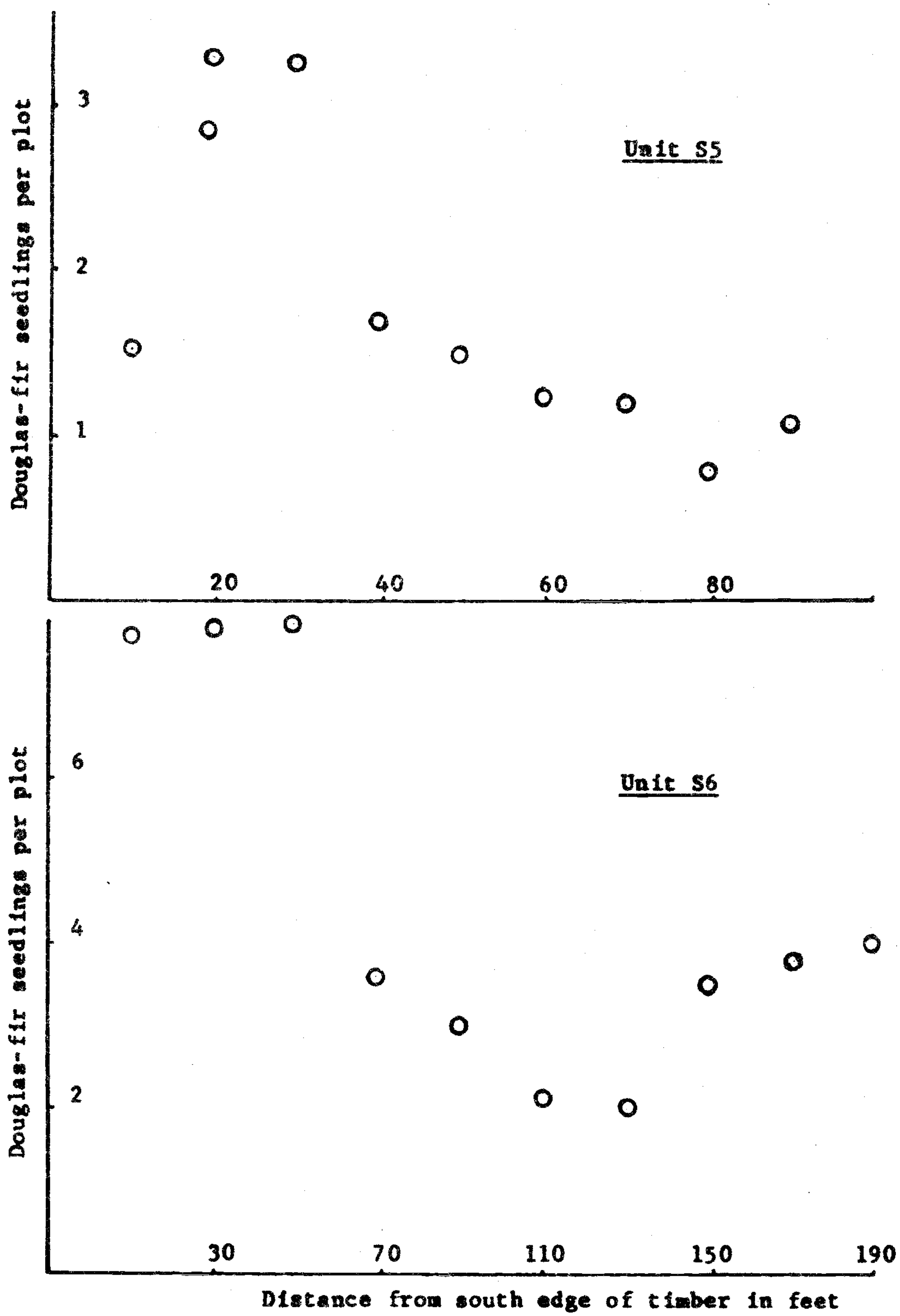


Figure 7. Relation between stocking and distance from south edge of timber on two east-west orientated strip clearcuts.

In the analyses of the individual units some significant relationships between stocking and distance from seed source were obtained. In all likelihood this is not due to any real differences in the amount of seed received on various portions of the area, but rather the result of the partial relationship between shade and distance from seed source. In other words, distance from seed source was only significant where the shade-hours-stocking relationship was highly significant.

North-south orientated strip clearcuts

These units were, as previously mentioned, the most poorly stocked group of small cutting units examined due to the steep, hot, south-exposed slope which they occupy. Considering this severe environment they are suprisingly well stocked, however, and when compared with standard staggered-setting clearcuts on similar sites elsewhere on the H. J. Andrews Experimental Forest they are well stocked.

The analysis of the individual units revealed some interesting facts. Generally, there appeared to be no relation or a poor relation between either shade hours or distance from seed source and any of the three measures of stocking used (Table 5). Since shade hours showed a close relation to regeneration on other units and in other studies (18), this requires some explanation. Practically all of the shade cast by the surrounding timber edge on the plots taken in these units, whether it was one hour or five hours in duration, was cast in a single shading period. For example, a plot near the east side of the strip might have five hours of shade during the day, but this would be received during the morning and there would be none for the remainder of the day. The shading received on these units is illustrated in Figure 8. On the other units shading tended to be more intermittent in character, plots with much shading getting this scattered throughout the day. In terms of alleviation of insolation losses of seedlings, plots on the north-south strips were receiving the most ineffective shade. Other factors affecting regeneration were more important and obscured any shade-stocking relationships. There was some relation, however, as illustrated by the significant relation indicated between shade and number of Douglas-fir seedlings at the five percent level in Units S3 and S4 and the one percent level for the pooled data.

Among these units there does not appear to be any particular relation between size and stocking, etc. The largest unit, which might reasonably be expected to have the poorest stocking, is better stocked than the 100 and 200 foot wide strips. This is probably because the unit is somewhat broken-up topographically by a small stream on its east edge, and does not present an unbroken south-exposure as do the others.

<u>East-west orientated strip clearcuts</u>

The long timber edge available to shade the regeneration on the east-west orientated strip clearcuts is probably responsible for the superior stocking on these units. Surprisingly, the individual analyses did not indicate a highly consistent relationship between

Figure 8. Pattern of shading on the north-south orientated strip clearcuts. Top, in the morning; middle, at midday; bottom, in the afternoon.

stocking and shade (Table 5). This relationship was most pronounced on the 300 foot strip and much less pronounced on the 100 and 200 foot wide strips. One explanation which can be offered for this is that stocking was so high on these two units--81 and 89 percent respectively --that it wasn't possible to obtain a significant relationship on the individual units. Another explanation is that a number of plots on Units S5 and S6 which had seven to nine hours of shading had not been disturbed by logging. Therefore they presented a less favorable seedbed than most other plots on these units.

The analyses of the pooled data from the east-west strips (Table 6) indicate a strong relationship between shade hours and stocking of any species and of Douglas-fir and the number of Douglas-fir seedlings per plot stocked with Douglas-fir.

Group Clearcuts

There is little concerning the group clearcuts that requires special comment. As a group they showed a consistent relationship between shade and stocking and stocking was generally intermediate between the east-west and north-south orientated strip clearcuts. The two exceptions were Units G2 and G5 (Table 5).

The factors resulting in the apparently inconsistent behavior of Unit G5 are readily apparent. The unit was located on the north edge of a road (Figure 2). As a result the conditions present on the unit were not representative of those one would expect to find on a one-half-acre clearcut. In addition, a new unit was logged directly across the road in the spring of 1958 and it was therefore impossible to obtain an accurate estimate of shading when G5 was surveyed later in the summer.

Unit G2 is the most inconsistent unit of the group clearcuttings. Although only two acres in extent and on gentle topography it had the poorest Douglas-fir stocking of any unit with the single exception of the large clearcut. Analysis of the data from this unit indicated stocking was not related to any of the factors measured. The only explanation which can be offered is as follows: Part of the unit is low and swampy with dense herbaceous growth and most was lightly disturbed during logging. It offered a minimum of mineral seedbed. In addition, the timber stand along the south and west edges is a very decadent stand of western redcedar and western hemlock which offered little in the way of Douglas-fir seed source and about as little shade as an old-growth timber stand does in the Douglas-fir region.

The pooled data, with Units G2 and G5 eliminated, reflects the strong shade-stocking relationships of the individual units.

Shade-seed-tree unit

The shade-seed-tree cutting was one of the most interesting examined in the study. It was a small unit of 20 acres in which approximately three dozen old-growth Douglas-fir trees were selected and left at the time of logging to supply seed and--more important--shade (see Figure 9). The average residual stand of only 1.8 trees per acre is somewhat misleading as they were located within two-thirds of the

Figure 9. General view of the shade-seed-tree cutting.

area of the unit. The trees were selected for vigor and location (in rows with an approximate spacing of 120 feet square). Slash was pulled away from these trees at the time of logging to prevent damage from slash burning.

The regeneration survey revealed this unit was well-stocked--61 percent of the milacres examined and 1448 Douglas-fir seedlings per acre--within four years after logging. The excellent stocking is undoubtedly the result of several factors. An important one is the shade cast by the seed trees. This was of an intermittent type over most of the affected area. The disturbed, mineral seedbed resulting from the yarding and slash-disposal work is another. Finally, there was additional seed from the seed trees.

Poorest stocking on the unit was on the portion without seed trees. A statistical comparison of the areas with and without seed trees was not possible, however, because of complicating factors such as difference in slope and the effects of timber edges.

It is noteworthy that none of the Douglas-fir trees left in 1955 have blown down or died from any cause. Most are full-crowned and have been producing seed. Studies of seed-tree mortality in the past have not been encouraging; wind, logging, and slash burning have destroyed most of the trees. Perhaps the results on this unit are more indicative of what can be accomplished by careful selection of sound, vigorous seed-trees in windfirm locations and by taking care to avoid damage to them in logging and slash burning.

Relations between units

The negative results from this portion of the statistical analysis require little discussion. The one significant relation--between width of the clearcut in a north-south direction and percentage of plots stocked with any species--is undoubtedly the result of the close relationship between effective shade and this parameter of the units. The lack of a clearcut size-stocking relationship is reasonable in view of the earlier discussion about the effects of distance from stand edge on stocking; the units involved were simply too small to show such a relation, if one exists (Lavender et. al., 14, felt that it did not). The failure to establish a relation between average hours of shade on the clearcuts and stocking was a little surprising. Evidently, this resulted from the great variation in the level of stocking associated with a particular level of shading on the different groups of units (note Figure 4). A large amount of variation with the small number of degrees of freedom would effectively mask any relation.

SUMMARY AND CONCLUSIONS

The results of this study indicate that the modified staggered-setting clearcuts did improve the promptness and adequacy of natural regeneration of Douglas-fir. This improvement is definitely related to shade cast by the residual stand. Initially, the author intended to try to relate regeneration to some average characteristic of the cutting areas such as size, but this approach did not prove valid, at least on the areas examined. Even clearcutting small units did not, in itself, insure prompt natural restocking.

The fact that natural restocking was not generally related to distance from seed source indicates seed was probably not a limiting factor on the areas studied. This suggests that the chief value of modified clearcutting systems in the Douglas-fir region, as compared with staggered-setting clearcuts, may be as an aid in seedling establishment rather than by supplying additional seed, although they undoubtedly do result in increased seed supply.

There is some indication that intermittent shade may be more effective than a similar amount of shade received in a single period, although this was not demonstrated conclusively in this study.

In conclusion, consideration should be given to the use of special cutting methods such as east-west orientated strip clearcuts, small group or patch clearcuts, and shade-seed-tree cuttings, to aid in natural restocking of Douglas-fir. These cuttings should be laid out primarily to provide shade rather than from the standpoint of seed dispersal.

BIBLIOGRAPHY

1. Berntsen, Carl M. and Jack Rothacher. A guide to the H. J. Andrews Experimental Forest. Portland, Ore., U. S. Dept. of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, 21 p.

2. Bever, Dale N. Evaluation of factors affecting natural reproduction of forest trees in central western Oregon. Salem, 1954. 15 p. (Oregon. State Board of Forestry. Research Bulletin no. 3)

3. California Forest and Range Experimen Station, U. S. Dept. of Agriculture, Forest Service. Annual report-1956 forest research in California. Berkeley, 1957. 66 p.

4. Clark, M. B. Regeneration following strip clear cutting in a subalpine spruce-alpine fir-Douglas fir type. British Columbia Forest Service Forest Research Review for year ended March, 1959: 7-9. 1959.

5. Garman, E. H. Seed production by conifers in the coastal region of British Columbia related to dissemination and regeneration. Victoria, B. C., 1951. 47 p. (British Columbia. Forest Service. Dept. of Lands and Forests. Technical Publication T 35)

6. ____________. Regeneration problems and their silvicultural significance in the coastal forests of British Columbia. Victoria, B. C., 1955. 67 p. (British Columbia. Forest Service. Dept. of Lands and Forests. Technical Publication T 41)

7. Geiger, Rudolph. The climate near the ground. 2d ed. rev. Boston, Harvard University Press, 1957. 494 p.

8. Haig, Irvine T., Kenneth P. David, and Robert H. Weidman. Natural regeneration in the western white pine type. Washington, 1941. 99 p. (U. S. Dept. of Agriculture. Technical Bulletin no. 767)

9. Hawley, Ralph C. and David M. Smith. The practice of silviculture. 6th ed. New York, John Wiley and Sons, 1954. 525 p.

10. Heinselman, M. L. Natural regeneration of swamp black spruce in Minnesota under various cutting systems. Washington, 1959. 22 p. (U. S. Dept. of Agriculture. Forest Service. Production Research Report no. 32)

11. Isaac, Leo A. Mortality of Douglas fir seed trees on cutover lands. Portland, 1940. 2 p. (U. S. Dept. of Agriculture. Forest Service. Pacific Northwest Forest and Range Experiment Station. Research Note no. 31)

12. ____________. Reproductive habits of Douglas-fir. Washington, Charles Lathrop Pack Forestry Foundation, 1943. 107 p.

13. Krauch, Hermann. Management of Douglas-fir timberland in the southwest. Fort Collins, 1956. 59 p. (U. S. Dept. of Agriculture. Forest Service. Rocky Mountain Forest and Range Experiment Station. Station Paper no. 21)

14. Lavender, Denis P., Morris H. Bergman, and Lyle D. Calvin. Natural regeneration on staggered settings. Salem, 1956. 36 p. (Oregon State Board of Forestry, Research Bulletin no. 10)

15. Lexen, Bert. Alternate clear-strip cutting in the lodgepole pine type. Fort Collins, 1949. 20 p. (U. S. Dept. of Agriculture. Forest Service. Rocky Mountain Forest and Range Experiment Station. Station Paper no. 1)

16. Rocky Mountain Forest and Range Experiment Station, U. S. Dept. of Agriculture, Forest Service. Annual report 1960. Fort Collins, 1956. 59 p.

17. Roeser, Jacob, Jr. A study of Douglas-fir reproduction under various cutting methods. Journal of Agricultural Research 28: 1233-1242. 1924.

18. Silen, Roy Ragnar. Lethal surface temperatures and their interpretation for Douglas-fir. Ph. D. thesis. Corvallis, Oregon State College, 1960. 170 numb. leaves.

19. Tomanek, J. Badania nad przebiegiem temperatury parowania i opadu rebri gniazdowej. Sylwan 102:13-31. 1958. (Abstracted in Forestry Abstracts 20: no. 1355. 1959)

20. Troup, R. S. Silvicultural systems. 2d ed. London, Oxford University Press, 1952. 216 p.

21. Worthington, Norman P. Reproduction following small group cuttings in virgin Douglas-fir. Portland, 1953. 5 p. (U. S. Dept. of Agriculture. Forest Service. Pacific Northwest Forest and Range Experiment Station. Research Note no. 84)

APPENDIX

EXAMPLE OF REGRESSION ANALYSES CONDUCTED ON THE RELATIONS BETWEEN CHARACTERISTICS OF THE CLEARCUT UNITS AND STOCKING

DATA:

Unit	Avg. Shade Hours Per Plot	% Plots Stocked
S1	2.518	.61
S2	1.822	.35
S3	1.198	.40
S4	0.922	.60
S5	1.800	.81
S6	1.566	.89
S7	1.422	.69
G1	0.912	.58
G2	2.422	.60
G3	3.355	.81
G4	3.491	.75
G5	1.673	.72
G6	3.085	.72

n	13				
Σx	26.186			Σy	8.53
$\bar{x}$	2.01430769			$\bar{y}$	.65615385
$(\Sigma x)^2$	685.706596	$(\Sigma x)(\Sigma y)$	223.36658	$(\Sigma y)^2$	72.7609
$(\Sigma x)^2/n$	52.74666123	$(\Sigma x)(\Sigma y)/n$	17.182045	$(\Sigma y)^2/n$	5.59699231
Σx^2	62.116824	Σxy	17.78272	Σy^2	5.8907
SS_x	9.370163	SP	0.60068	SSy	0.2937

$b = SP/SS_x = 0.0641$

$\text{Reg. SS} = (SP)^2/SS_x = 0.038507$

$\text{Res. SS} = SS_x - \text{Reg. SS} = 0.255193$

$s^2 = \text{Res. SS}/n - 2 = 0.023199$

$F = \text{Reg. SS}/s^2 = 1.6598$ with 1 & 11 d.f. (non-significant)

Therefore we accept the hypothesis that $B = 0$.

EXAMPLE OF REGRESSION ANALYSES CONDUCTED ON RELATIONS BETWEEN HOURS OF SHADING AND DISTANCE FROM SEED SOURCE AND STOCKING ON THE INDIVIDUAL CUTTING UNITS AND POOLED DATA

Analysis of relation between hours of shade on plot and number of Douglas-fir seedlings on plot

No. of seedlings	Hours of shade 0	1	2	3	4	5
½	1					
1	7	4		4	5	3
1½				1		
2	3		2	2	3	1
2½						1
3	1		1	1	1	1
3½				1		
4	2		1	2	2	
4½				1		
5					1	
5½				2		
6			1		1	1
7½						1
8				1		

ANALYSIS:

n	58				
Σx	151			Σy	150
$\bar{x}$	2.603448			$\bar{y}$	2.586207
$(\Sigma x)^2/n$	407.160714	$(\Sigma x)(\Sigma y)/n$	390.517241	$(\Sigma y)^2/n$	387.931034
Σx^2	567	Σxy	432.5	Σy^2	579
SS_x	159.839286	SP	41.482759	SSy	191.068966

Reg. SS = 10.76593456
Res. SS = 180.3030314
s^2 = 3.21969698
F = 3.3437 with 1 & 56 d.f. (non-significant)

Therefore we accept the hypothesis that B = 0.