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Title: THE EFFECT OF THINNING INTENSITY UPON UNDERSTORY GROWTH AND SPECIES COMPOSITION IN AN OREGON COAST RANGE PSEUDOTSUGA MENZIESII STAND

Abstract approved: Signature redacted for privacy.
Alan B. Berg

Cover, frequency, and biomass of understory vegetation were estimated on 14 study plots in a central Oregon Coast Range *Pseudotsuga menziesii* stand. The treatments included a control and three different thinning intensities. Basal area of active growing stock, defined as young-growth *P. menziesii* with diameter at breast height of 7.6 inches (19.3 cm) or greater, determines thinning intensity. Heavily thinned stands are maintained between 100 and 130 square feet per acre (23-30 m^2/ha) of active growing stock, moderate thinnings between 130 and 160 square feet per acre (30-37 m^2/ha), and light thinnings between 160 and 190 square feet per acre (37-44 m^2/ha). The amount of canopy opening and of light reaching the understory were found to be negatively correlated with the log of active growing stock basal area.

Despite much plot-to-plot variation in cover, several trends corresponding with thinning treatment were detected. Berberis nervosa and Eurhynchium oreganum are the dominant species on unthinned plots, whereas Pteridium aquilinum and E. oreganum predominate on all thinning treatments.

Herbaceous species are most responsive to thinning, with highest cover in the moderate and heavy thinnings. Herbs showing the greatest increases with thinning are Pteridium aquilinum, Campanula scouleri, Collomia heterophylla, Festuca occidentalis, Hieracium albiflorum, and Trientalis latifolia. Further, a few species are confined to either thinned or to unthinned plots, but of these species, only Lotus crassifolius and Lupinus latifolius, both on thinned plots, occur with relatively high frequencies. No species that attains high cover or frequency on any treatment significantly decreases with thinning intensity. Trends in understory biomass are similar to those for cover and frequency, though sampling error was larger for the biomass estimates.

In general, cover and frequency data on woody plants show no clear response to thinning. Biomass estimates, especially for the large shrubs, show a trend towards increased woody vegetation with thinning intensity. Data on stem density, however, best indicate that some large woody plants are responding to thinning. Large woody stems are scattered widely throughout the plots, but where the shrubs

Acer circinatum, Corylus cornuta, and Holodiscus discolor, in particular, occur on thinned plots, they often are growing in clumps of many young, erect stems. Such clumps do not occur on unthinned plots. These findings suggest the hypothesis that the occurrence of these woody plants in the original forest was infrequent and that the clumps result vegetatively from the original stems or root systems in response to thinning.

Understory competition does not prevent initial establishment of Pseudotsuga menziesii seedlings on the thinned plots. Although stocking levels for P. menziesii seedlings on the thinned plots are high, growth is slow, and few seedlings survive past the fifth year. Few tree seedlings are found on the unthinned plots.

The Effect of Thinning Intensity upon Understory Growth and Species Composition in an Oregon Coast Range *Pseudotsuga menziesii* Stand

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INTRODUCTION

Most studies on the effects of partial cuttings describe only the growth response of the trees. Relatively few have looked at the understory vegetation. Yet the understory response may affect growth of advanced regeneration as well as growth of the overstory trees. The changes in cover and species composition will affect nutrient cycling and water usage by the forest. The changes will also determine the amount of food available for wildlife and livestock. In addition, understory species can serve as indicators of site growing potential.

Studies in Western Oregon

The only study in western Oregon specifically designed to measure understory growth response to thinning was published by Krueger in 1960. He looked at the understory in two 108-year-old *Pseudotsuga menziesii* stands. The two stands differed in topography, soils, and initial understory cover and composition, so results were reported separately for each. In one, nine percent of the stand volume was removed. Cover dropped immediately after logging due to mechanical destruction. Six years later, cover and species composition had not changed from what they were immediately after logging. In the second stand, 27 percent of the stand volume was removed. Again cover dropped immediately after logging, but after six years, it had increased slightly. *Pteridium aquilinum,* which had been a minor component of the original vegetation, doubled in extent. Krueger, however, recognized some weaknesses in his study. Cover was estimated ocularly on three-milacre plots, too large for precise estimates, and successive estimates were taken at different times in the summer. Further, trends on adjacent, uncut areas were not followed, though this vegetation did not appear to change during the study period.

Logan (1974) examined some of the factors affecting *Pseudotsuga menziesii* seedling establishment, including competition from understory vegetation, on a south-slope shelterwood cut in the Willamette Valley. One year after cutting, average moisture stress on planted *P. menziesii* seedlings was less in the shelterwood cut than in an uncut stand due to decreased water use by the recently thinned overstory and the disturbed understory. Logan found no clear trend in survival at various levels of understory cover. He did not record the understory composition, which is also important due to differences in competitive ability.

Studies on natural stand openings may provide clues to understory response in partially cut stands, though other factors besides canopy opening, such as logging disturbance, operate in thinned stands. Sabhasri and Ferrell (1960) described brush invasion into small, natural openings in south-slope Willamette Valley Pseudotsuga menziesii stands. Symphoricarpos albus, Acer macrophyllum, and Corylus cornuta cover in stand openings was greater than under the forest canopy. Rosa sp. showed no difference, whereas Rhus diversiloba had less cover in stand openings. Shrub cover in stand openings and under the forest canopy also varied according to soil type.

Bailey's (1966) study in the southern Oregon Coast Range demonstrates that understory response to stand opening depends on the original plant communities. Bailey identified five plant associations in a 190-year-old Pseudotsuga menziesii stand and described the differences in understory vegetation in lightspots and under the canopy in each association. In four of the associations, herbaceous and woody vegetation coverage was greater in the lightspots than in the dense forest. In many cases, the lightspot vegetation, some of which was rarely found in the dense stand, was more useful in differentiating between the plant associations than was the vegetation under the canopy. The lightspot trend from mesic to xeric associations was an increase in large, deeply-rooted shrubs and a decrease in small shrubs and herbs. In Bailey's fifth association, however, the vegetation did not show this lightspot response, though tree regeneration was better in the lightspots. This association, the <u>Pseudotsuga</u>/<u>Holodiscus</u>/<u>Gaultheria</u> association, is the most xeric. Its ridgetop position and sparsely foliated, short trees apparently permit enough light to reach the ground that understory growth is not limited by light.

Two other studies conducted in the Pacific Northwest, though not specifically dealing with understory response to canopy opening, may bear upon the results of any understory investigation. Both Becking (1954) and Spilsbury and Smith (1947) found understory composition in natural stands to be correlated with quality of growing site for <u>Pseudotsuga</u> <u>menziesii</u>. Not all understory species respond to the same site factors as the overstory trees, and some may respond mainly to the presence of the overstory itself, yet many species or species groups are associated with particular growing sites. The response of some species or species groups to thinning, then, may roughly indicate what the response of the overstory trees will be.

<u>Studies in Other Areas</u>

Most studies on understory response to thinning have shown that as crown cover or basal area decreases, the amount of understory vegetation increases. Agee and Biswell (1970), for example, found that 12 years after thinning, herbaceous vegetation under a <u>Pinus</u> <u>ponderosa</u> stand in the north Coast Range of California had increased in cover and dry weight with thinning intensity. McConnell and Smith (1970) demonstrated a significant negative linear relationship between total understory dry-weight yield and canopy coverage eight years after thinning in eastern Washington P. ponderosa stands. Grass and shrub yields were related to tree spacing, whereas forb yields were not. Below 45 percent canopy coverage, grasses were the superior producers. When tree canopy coverage exceeded 45 percent, forbs produced more than grasses. Many individual plant species changed in coverage relative to one another at different thinning intensities. Hetherington (1969), working in thinned Picea sitchensis stands in Great Britain, found that the understory responds to thinning intensity, but that the response also depends on the level of vegetation development at the time of thinning and on the frequency of thinning.

Midstory trees and shrubs can exert considerable influence on the understory. Schuster and Halls (1962) followed understory response in Texas Pinus echinata-Pinus taeda-hardwood stands that were cut by the shelterwood and selection methods. Eleven years after cutting, the plots were alike in timber volume and basal area, but midstory hardwoods, defined as trees with crowns above five feet (1.5 m) and below the upper canopy, covered 37 percent of the selectively cut plots and 57 percent of the shelterwood plots. Deer forage was lower on the shelterwood plots. Forage yield was further reduced when a midstory tree was overtopped by a dominant or codominant tree. However, crown cover of overstory trees was not correlated with forage yield due to the overriding influence of the midstory. Blair (1967) obtained similar results for a young Pinus taeda plantation in central Louisiana. After two thinnings, deer browse yields were positively correlated with the amount of P. taeda removed. After a third thinning, browse yields were inversely proportional to thinning intensity, due to the formation in heavily thinned stands of a multi-layered cover of midstory hardwoods and shrubs that had grown beyond the reach of deer and inhibited plant growth beneath.

Under certain conditions, understory response to thinning is linked to overstory response. Barrett (1970), in central Oregon Pinus ponderosa sapling stands, found that the dense understory resulting from heavy thinnings reduced diameter, height, and thus cubic volume growth on the remaining trees. When the understory was removed, overstory growth increased. The greatest growth increases with vegetation removal occurred on the most heavily thinned plots, which had the greatest amount of understory vegetation, and corresponded with decreased moisture losses from evapotranspiration.

Conversely, Dahms (1971), working in young Pinus contorta stands just ten miles from Barrett's study area, found no change in the understory due to thinning up to 11 years after cutting. Annual soil moisture withdrawal was at first greatest at the high density levels, due to the failure of the understory to develop on heavily thinned plots. However, after a few years, expansion of crowns and roots negated any differences in moisture withdrawal between thinning levels. Dahms attributed the seemingly contradictory findings to several factors. First, Barrett's sapling stand had been growing under an old-growth stand that was removed just before the thinning treatments. Therefore, a large amount of new growing space that the newly thinned, suppressed stand could not use immediately became available to the understory vegetation. Dahms' stand was growing vigorously before thinning, so the remaining trees were better able to compete with the understory. Also, the original plant communities differed between the two study areas. This difference might imply other environmental differences as well as differences in understory competitiveness.

Understory vegetation may actually enhance overstory response to thinning. Mead _et al._ (1968) attributed a substantial part of the increased growth rate of _Pinus radiata_ stands in New Zealand after thinning to _Lupinus arboreus_, a nitrogen-fixing legume strongly stimulated by thinning. Experimental exclusion of _L. arboreus_ resulted in a lower growth rate of _P. radiata_ after thinning, presumably due to lower potential nitrogen availability in the soil. Similarly, McQueen (1973) speculated that increases in nitrogen-fixing species after thinning of young _P. radiata_ in New Zealand stimulate growth of other understory species.

The work of Clary and Ffolliott (1966) in Arizona *Pinus ponderosa* stands points out a potential problem in using relationships from natural stands to predict response to thinning. These workers found that for any given timber basal area of less than 70 square feet per acre (16 m^2/ha), herbage production is significantly greater under thinned stands than under unthinned stands. Herbage composition in thinned and unthinned areas was similar.

Extrapolation of results from natural to thinned stands, therefore, requires caution, but studies on natural stand openings may suggest changes to be anticipated from thinning. In a study on natural openings in a northern Arizona *Pinus ponderosa* stand, Cooper (1960) obtained a negative linear relationship between grass dry weight and percent tree crown coverage. Halls and Schuster (1965) obtained a curvilinear relationship between herbage yield and tree basal area or crown coverage in Texas *Pinus echinata*-*Pinus taeda*-hardwood stands. Good deer browse species predominated under the dense canopy, whereas cattle forage predominated where trees were sparse. Pase and Hurd (1958), looking at understory response in immature *P. ponderosa* stands in the Black Hills of South Dakota and Wyoming, demonstrated a curvilinear relationship between herbage yield and crown cover, basal area, or litter production. Grasses and forbs increased relative to browse herbage as the levels of these three factors decreased.

Gaines et al. (1954), studying Pinus palustris stands in southern Alabama, also found that herbage production increases as basal area and litter weight decrease. Older stands with high basal area but fewer trees than young stands with the same basal area supported greater herbage production, possibly due to the presence of more side light than in comparable young stands. Basal area thus accounted for only 14 percent of the variation in herbage production. Litter weight accounted for 21 percent of the variation, perhaps because the heavy litter crushes the herbs and forbs. Litter and soil type together accounted for 31 percent.

Anderson et al. (1969) conducted one of the few studies concerning the environmental factors that control understory growth response to canopy opening. Working in northern Wisconsin Pinus resinosa and P. strobus stands, they found that the understory response to canopy opening correlated better with throughfall and random drip precipitation than with light intensity in the understory. They reasoned that the droughty subsoil and high tree basal area in their study plots make moisture availability critical and that the moisture content of the lower litter layer and upper soil layer, where most northern understory herbs are rooted, is strongly influenced by variations in throughfall and random drip as determined by canopy opening. The amount of light coming through the canopy is less critical, because it is generally above threshold level for the shade-adapted species studied.

In contrast, Emmingham (1972) found that the occurrence of many of the understory species under mixed-conifer stands in the Siskiyou Mountains of southwestern Oregon largely depends on the level of light in the understory. Moisture is marginal on most sites in the Siskiyous, so light, which varies over a wide range, becomes the controlling factor in species distribution. Robinson (1967) found that in central Oregon _Pinus ponderosa_ stands, herbs generally growing in relatively mesic areas show an affinity for deep shade, whereas those growing in relatively xeric areas show an affinity for high insolation.

The understory apparently responds to many factors. Thinning intensity and frequency, logging disturbance, original understory composition, growing condition of the overstory, stand age, midstory development, soil type, litter production, and light and moisture relationships have been discussed, and many others may be involved. Further, these factors certainly interact with one another. In order to study understory response, one must recognize these complexities and experimentally control them when possible.

METHODS

Description and History of the Study Area

All study plots lie within the Black Rock Unit of the George T. Gerlinger State Experimental Forest. The forest is located on the east side of the Coast Range, about three miles west of Falls City, Oregon and 40 miles northwest of Corvallis. Research is conducted at Black Rock by the Oregon State University Forest Research Laboratory in cooperation with the Oregon State Forestry Department.

The climate is wet but mild, with an average annual precipitation of about 200 centimeters, falling mostly as rain in the winter, and a frost-free growing season of more than 200 days. The soils have developed in residuum and colluvium from Eocene sandstones, shales, and siltstones and from Miocene coarse-grained gabbro and diorite, both basic igneous intrusive rocks (Youngberg, 1964). A large portion of the sedimentary formation, where the study plots are located, occurs as a large, south-facing, gentle, uneven slope. The soils have strong granular structure in the surface and moderate subangular blocky structure in the subsoil. They are moderately acid in the surface and become strongly acid in the subsoil.

According to United States Soil Conservation Service maps, three soil series are found in the study area. The Klikitat series ranges from a well-drained gravelly to very gravelly clay loam. Formed in moderately fine and medium textured colluvium, the series belongs to the loamy-skeletal, mixed, mesic family of Typic Haplumbrepts. Roots are generally restricted to 100 to 125 centimeters. The Honeygrove and Peavine series both belong to the clayey, mixed, mesic family of Typic Haplohumults. The Honeygrove consists of deep, well-drained, silty clay loam over clay soils formed in deep colluvial and residual material. Effective rooting depth ranges from 100 to over 150 centimeters. The Peavine series consists of well-drained, silty clay loam over silty clay soils formed in weathered siltstone and shale. Effective rooting depth ranges from 50 to 100 centimeters.

The Black Rock area presently supports a naturally regenerated young-growth Pseudotsuga menziesii stand. Some Tsuga heterophylla, Abies grandis, and Thuja plicata are scattered throughout the forest. Growing site classes range from II to IV, with most of the areas in Site Class III. Dominant and codominant trees are about 40 meters tall. The most common hardwoods are Acer macrophyllum, Cornus nuttallii, and Alnus rubra. Most of the original old-growth forest was logged between 1909 and 1913. Slash was probably burned after the original logging. Accidental surface fires periodically have fingered through part of the area up until the 1930's, but fire has been excluded since then.

Since the stand is young, the understory at Black Rock has not yet fully developed. Therefore, the community type or types to which the vegetation on the study plots belongs can be identified only tentatively. The species composition on undisturbed areas is similar to that of Becking's lowland salal-Douglas-fir type (Becking, 1954). It is also similar to the ocean spray-salal and the vine maple-salal communities described by Corliss and Dyrness (1961, 1965) and to the Acer circinatum/Gaultheria shallon community, Corylus californica-Holodiscus discolor subtype, and the Holodiscus discolor/Gaultheria shallon community described by Anderson (1967). All of these communities are generally characterized by a greater coverage of Gaultheria shallon than is found on the study plots. This small shrub is easily damaged by fire and requires moderately high light intensities, so that the fire history and dense canopy of the young stand at Black Rock may account for its relative scarcity.

The basic experimental study unit at Black Rock is a one-quarter acre (0.10 ha) plot on which basal area or number of trees is controlled according to the particular experimental design. Usually, four of these units are combined to form a one acre (0.40 ha) experimental plot. A buffer area treated similarly to the experimental plot surrounds each group of units to minimize edge effects.

The plots selected for this study are thinned according to three regimes. Thinned plots are maintained between 100 and 130 square feet per acre (23-30 m^2/ha), 130 and 160 square feet per acre (30-37 m^2/ha), and 160 and 190 square feet per acre (37-44 m^2/ha). These basal area figures include only young-growth *Pseudotsuga menziesii* with a diameter at breast height of 7.6 inches (19.3 cm) or over, these trees being considered the active growing stock. Any old-growth *P. menziesii*, *P. menziesii* less than 7.6 inches in diameter, or other conifers or hardwoods that do not interfere with spacing of the active trees or are not merchantable may be left on the plots. All yarding on these plots is done by horse in order to minimize logging damage. Unthinned control plots are maintained for growth comparisons.

Basic data on the selected study plots are listed in Table 1. The three thinning treatments plus control plots have been replicated four times at Black Rock. However, only 14 plots, all on the same south slope, were used in this study in order to obtain more uniformity between plots and thus facilitate comparisons. The aspects range from S45°W to S45°E. Slope percent is also similar on the plots. Elevation of plot centers ranges from 332 meters to 579 meters. The average age of the active growing stock drops slightly with elevation. Each replication has been thinned from two to five times. In some cases, the original stand was cut in two stages to get it down to the desired basal area. For ease of reference, the Black Rock experimental plot numbers are suffixed with the letters "U,"

Table 1. Study Plot Physical and Historical Data.

	Elevation of Plot Center (meters)	Aspect	Slope (percent)	Average Stand Age (years)	Thinning Years
			Replication 1		
Plot 27U[1]	332	SW	15-25	64	1960, 1965, 1972
Plot 30H	335	SSE	10-20	64	
			Replication 2		
Plot 21U	354	SW	20-45	66	1959, 1960, 1965, & 1971
Plot 25L	357	S	5-15	66	
Plot 24M	329	S	15-25	66	
Plot 22H	360	SSW	15-20	66	
			Replication 3		
Plot 37U	494	SE	20-30	62	1964, 1966
Plot 34L	463	SE	25-30	61	
Plot 35M	476	S	20-35	61	
Plot 36H	503	S	15-25	62	
			Replication 4		
Plot 46U	552	SE	25-40	55	1957, 1960, 1962, 1966, 1969
Plot 40L	549	S	20-35	57	
Plot 38M	497	SSE	15-25	57	
Plot 36H	579	S	30-35	56	

[1] U = Unthinned control plot
L = light thinning treatment (37-44 m^2/ha)
M = moderate thinning treatment (30-37 m^2/ha)
H = heavy thinning treatment (23-30 m^2/ha)

"L," "M," and "H" to designate unthinned control, light thinning, moderate thinning, and heavy thinning, respectively.

Estimation of Understory Cover and Frequency

A 15 by 25 meter (0.038 ha) sampling macroplot was established in the center of each group of quarter-acre (0.10 ha) units. The long side of the plot was oriented perpendicular to the slope direction. If the group of units did not form a square, the sampling macroplot was placed between the two units that faced most nearly south. The sampling macroplot was then divided into three 5 by 25 meter sections. Coverage was estimated ocularly within the macroplots with 20 by 50 centimeter (0.1 m^2) sampling microplots (Daubenmire, 1959). These small plots reduce observer error compared to larger plots. Estimates can be made quickly, so that many readings can be taken and a good representation of the vegetation obtained. For each species up to six meters in height within a sampling microplot, the midpoint of one of seven coverage classes was recorded:

Coverage Class	Midpoint
0+ to 5%	2.5%
5+ to 20%	12.5%
20+ to 40%	30.0%
40+ to 60%	50.0%
60+ to 80%	70.0%
80+ to 95%	87.5%
95+ to 100%	97.5%

Cover was defined as the vertical projection of the plant onto the ground. Due to overlapping of the various species, total vegetation coverage for any one microplot could be greater than 100 percent. The large estimation classes can give reasonably precise averages when applied to many small plots (Daubenmire, 1959).

One unthinned and one heavily thinned plot were sampled first in order to determine the optimal number of sampling microplots. One sample was taken every one meter along three of the 25 meter plot lines, for a total of 75 microplots (Figure 1). If a plot fell on a log or stem, it was not counted. If a plot fell on a skid trail, the vegetation coverage was recorded, but tallied separately. Woody plants taller than one meter were recorded separately from smaller woody plants. All species falling within a sampling macroplot, but not within a microplot, also were recorded.

Figure 2 shows the species-area curves for the two plots, 27U and 30H. Cain (1938) suggested that the optimal number of sample plots has been taken when the number of species sampled rises a predetermined percentage, such as five or ten percent, for a ten percent rise in the number of sample plots. For plot 27U, the ten percent point is only eight sample plots. For plot 30H, the ten percent point is 25 sample plots.

The data were analyzed in other ways. For example, on plot 27U, only one new species that was first recorded after 50 microplots

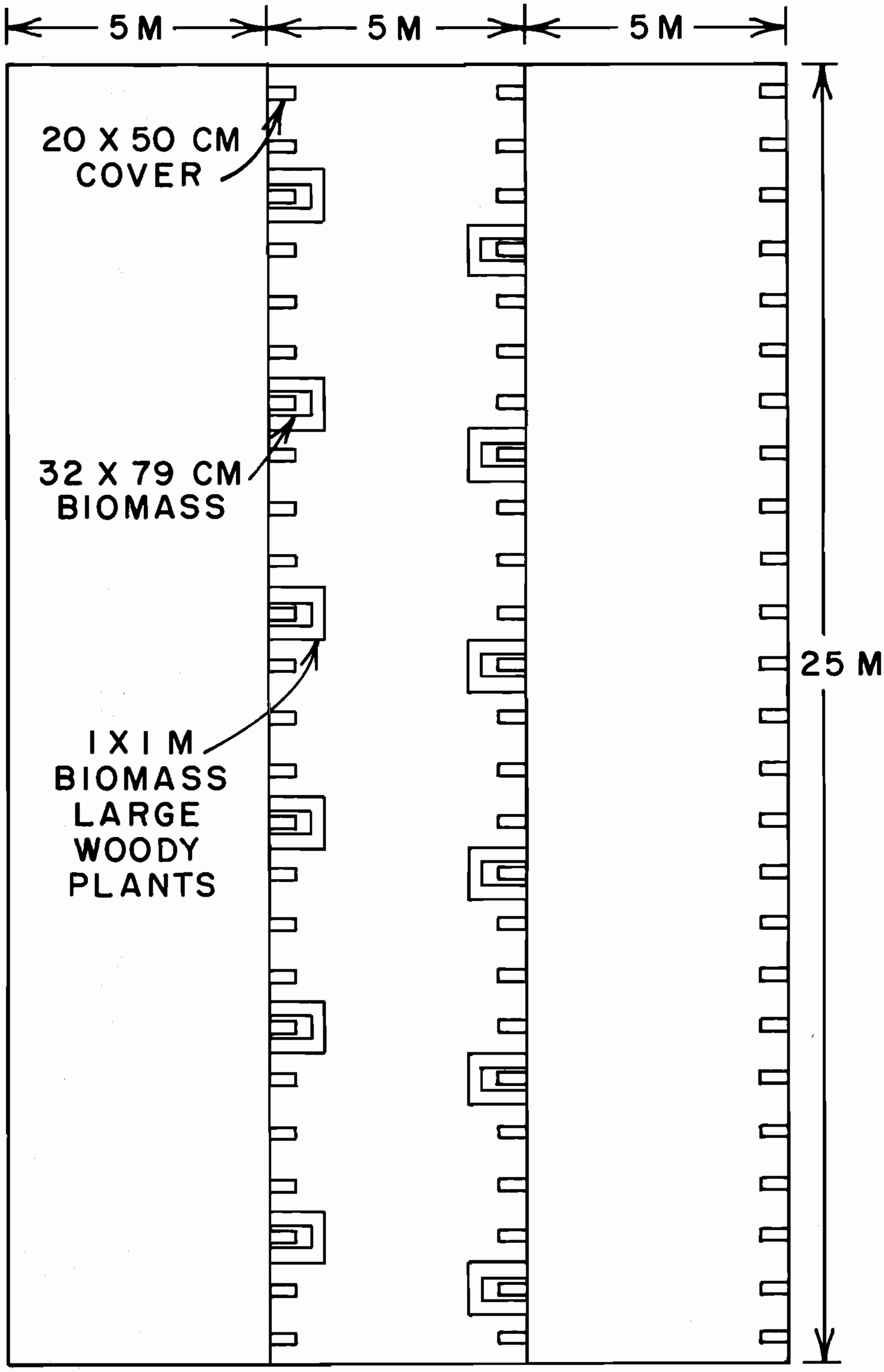

Figure 1. Sampling macroplot. The row of microplots on the right was used only for cover sampling on plots 27U and 30H.

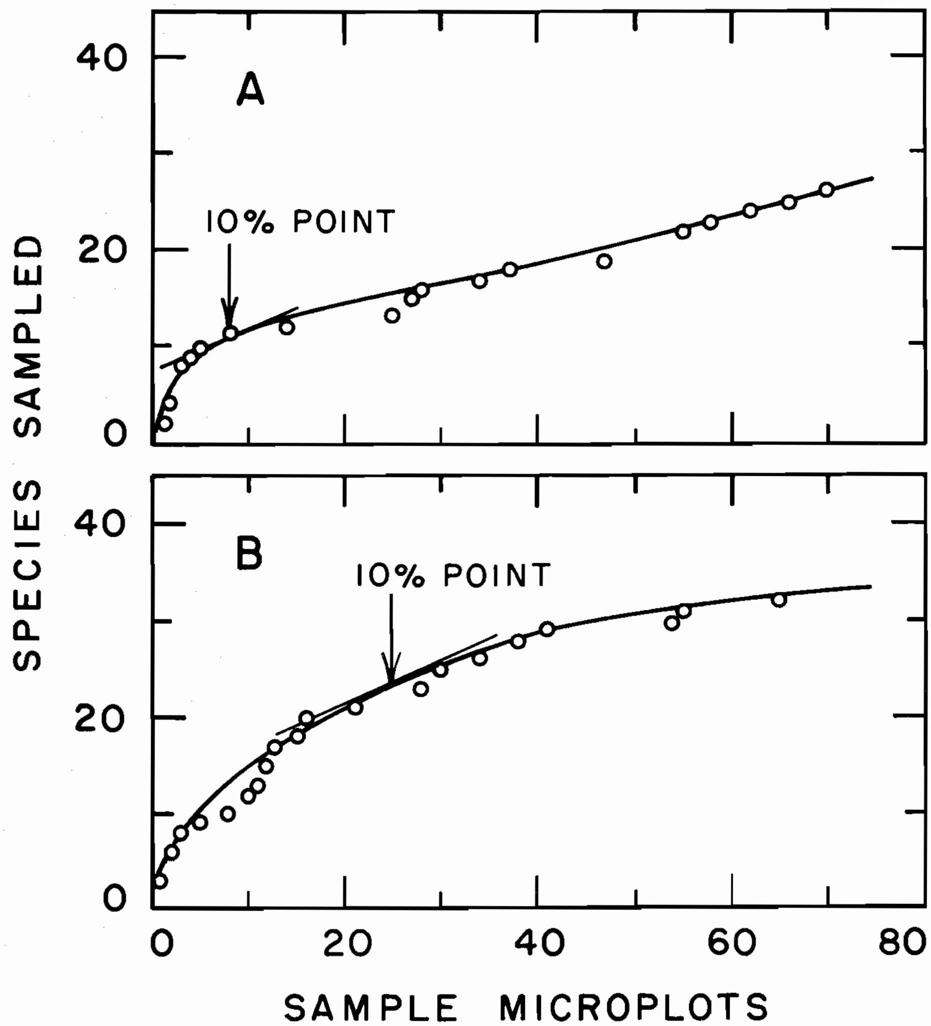

Figure 2. Species-area curves: (A) Plot 27U, (B) Plot 30H. The 10 percent points are those points where the cumulative number of species sampled rises 10 percent for each 10 percent rise in the number of sample microplots.

had been sampled reached one percent cover. Only two new species first recorded after 40 plots reached one percent cover by 75 plots. On plot 30H, only one new species first recorded after 40 microplots had been sampled reached one percent cover by the time all 75 microplots had been sampled. No species first recorded after 50 plots reached one percent.

Tables 2 and 3 show the change in cover and frequency with number of sample plots for the major species on plots 27U and 30H. Frequency was defined as the percentage of sampling microplots in which a given species occurred. The 95 percent confidence intervals for mean cover and frequency of each species are also given. In most cases, the mean and confidence interval change little with increasing number of sample microplots from 40 to 75. The relatively large change for the moss Eurhynchium oreganum on plot 30H reflects the heterogeneous distribution of this species. The change in cover for this moss with sample size accounts for most of the change in total vegetation cover on plot 30H.

The above considerations suggest that 40 sampling microplots would adequately represent the vegetation on each study plot. However, 50 microplots were used because this number permits one sample every one meter along two transects through the macroplot. Therefore, for the remaining 12 study plots, samples were taken at one meter intervals on the side towards plot center along the two inner

Table 2. Change in Cover and Frequency with Number of Sample Microplots for the Important Species on Plot 27U.

	Number of Microplots			
	40	50	60	75
Berberis nervosa				
Mean cover (%)	23	23	20	25
95% Confidence interval for the mean	13-33	14-32	12-28	17-33
Frequency (%)	45	42	38	45
95% Confidence interval for the mean	29-62	28-57	26-52	33-58
Symphoricarpos mollis				
Mean cover (%)	4	5	5	5
95% Confidence interval for the mean	1-6	2-8	2-8	2-7
Frequency (%)	29	31	34	32
95% Confidence interval for the mean	16-46	18-46	22-47	22-45
Eurhynchium oreganum				
Mean cover (%)	79	73	73	72
95% Confidence interval for the mean	72-85	67-80	67-79	66-77
Frequency (%)	100	100	100	100
95% Confidence interval for the mean	91-100	93-100	94-100	95-100
Total vegetation				
Mean cover (%)	112	107	108	114
95% Confidence interval for the mean	103-121	98-117	99-117	104-123
Frequency (%)	100	100	100	100
95% Confidence interval for the mean	91-100	93-100	94-100	95-100

Table 3. Change in Cover and Frequency with Number of Sample Microplots for the Important Species on Plot 30H.

	Number of Microplots			
	40	50	60	75
Corylus cornuta				
Mean cover (%)	6	5	5	4
95% Confidence interval for the mean	0-12	0-10	0-10	0-8
Frequency (%)	11	9	11	9
95% Confidence interval for the mean	3-25	2-20	4-22	3-18
Holodiscus discolor				
Mean cover (%)	9	7	6	6
95% Confidence interval for the mean	2-16	1-13	1-11	1-11
Frequency (%)	30	24	20	19
95% Confidence interval for the mean	17-47	13-38	11-33	11-30
Symphoricarpos mollis				
Mean cover (%)	9	9	9	11
95% Confidence interval for the mean	5-14	5-13	6-13	7-15
Frequency (%)	60	59	65	69
95% Confidence interval for the mean	43-75	44-72	52-77	57-79
Lupinus latifolius				
Mean cover (%)	7	7	6	6
95% Confidence interval for the mean	0-14	1-13	1-11	1-11
Frequency (%)	19	24	20	22
95% Confidence interval for the mean	8-34	13-38	11-33	12-33

(Continued on next page)

Table 3. (Continued)

	Number of Microplots			
	40	50	60	75
Pteridium aquilinum				
Mean cover (%)	11	13	13	13
95% Confidence interval for the mean	3-19	6-20	7-20	7-18
Frequency (%)	27	30	35	34
95% Confidence interval for the mean	14-43	18-44	23-48	23-47
Trientalis latifolia				
Mean cover (%)	6	7	7	6
95% Confidence interval for the mean	3-8	4-10	4-9	4-8
Frequency (%)	51	61	63	60
95% Confidence interval for the mean	34-68	46-74	49-75	47-72
Eurhynchium oreganum				
Mean cover (%)	69	64	57	52
95% Confidence interval for the mean	58-80	54-75	47-67	43-61
Frequency (%)	100	100	100	100
95% Confidence interval for the mean	91-100	93-100	94-100	95-100
Total vegetation				
Mean cover (%)	141	136	128	120
95% Confidence interval for the mean	124-158	121-152	114-142	107-134
Frequency (%)	100	100	100	100
95% Confidence interval for the mean	91-100	93-100	94-100	95-100

division lines of the sampling macroplot (Figure 1). Data were taken in mid-June, 1974.

Understory Biomass Estimation

The sampling microplots for biomass estimation were 32 by 79 centimeters (0.25 m^2) for all herbs and all woody plants with stems less than one meter in length. For larger woody plants, the microplots were one meter by one meter (1.0 m^2). The smaller plot was nested within the larger. All above-ground vegetation up to six meters tall was removed at every fourth meter along the same transects used for coverage estimates (Figure 1). Plots falling on stems, logs, or skid trails were skipped, so that between 10 and 12 microplots were sampled per macroplot. The number and size of microplots were limited mainly because the collection process was time-consuming as well as destructive. The larger sampling microplot size for the larger woody plants reflects the fact that these plants are widely scattered on the study plots and thus biomass estimates were subject to high sampling error.

For each woody plant, wood and leaves were separated. Woody plants taller than one meter were separated from smaller plants. The herbaceous species found to be most important in the coverage sampling were collected separately. All grasses and rushes were combined into a single category, as were the minor herbs and the mosses.

All samples were oven-dried at 70°C to a constant weight and weighed to at least the nearest gram for wood and the nearest 0.1 gram for non-woody material. Samples were collected from mid-July through mid-August, 1974.

Estimating biomass of all vegetation at one time when it is near its peak does not necessarily give the maximum production potential for the plant community, because different species will reach their maximum biomass at different times during the growing season (Malone, 1968). However, at Black Rock the major producers appear to reach their peaks at about the same time, so that the maximum standing biomass in mid-summer is close to the maximum production potential.

Root biomass, an important component of understory production, was not sampled in this study due to lack of time. This limitation on interpretation of the results of this study must be acknowledged.

Additional Data on Understory Woody Plants

Stem diameter and growth form were recorded for each woody plant falling within a sampling macroplot with a stem at least one meter in length and up to six meters in vertical height. Stem diameter was measured with a diameter tape at the base of the stem or just above the base when the base was noticeably swollen. Form was recorded according to the classifications devised by Anderson (1967, 1969):

> Erect--stem within 20° of vertical.
>
> Leaning--stem reasonably straight, but leaning more than 20° from vertical.
>
> Convex--stem arched; end of branches may be touching the ground, but no roots have anchored at the branch end.
>
> Convex and Layering--stem arched; branch ends have rooted in the ground.
>
> Decumbent--stem prostrate on the ground for one-half to three-quarters of its length; end of stem is turned upwards.

A sixth category was added for this study:

> Decumbent and Layering--same as decumbent, but branch ends have rooted in the ground.

The age of all shrub stems removed for biomass estimation was determined by counting growth rings at the base of the stem. The height and age of all *Pseudotsuga menziesii* seedlings removed for biomass estimation were also recorded. Seedling age was determined by a count of growth nodes and confirmed, when possible, by a growth ring count.

Overstory Cover and Basal Area

Overstory cover on the sampling macroplots was determined with a cover sight similar to that used by Buell and Cantlon (1950) and modified by Robinson (1967). The device contains a mirror at a 45° angle, so that one can look into the sight from the side and see the canopy above. Two sets of superimposed crosshairs and a levelling needle assure that the sight is held vertically. A pointed rod is attached to the sight to mark the canopy edge along the ground. The canopy was mapped on graph paper for each sampling macroplot with the aid of stem maps available for the Black Rock experimental plots. Percent crown cover was then estimated from the maps for all species greater than six meters tall. Due to overlap of different overstory species, total cover could exceed 100 percent. Diameter for all overstory species on the sampling macroplots was measured with a diameter tape at 4.5 feet (1.4 m), breast height, above the ground.

Light Intensity Reaching the Understory

The amount of light coming through the overstory canopy was estimated with ozalid light integrators by the method of Friend (1961). The light-sensitive paper was calibrated with a Kipp solarimeter on a clear day in mid-July, 1974. For the calibration, the paper was exposed in the open for 1, 2, 4, 8, 16, and 30 minutes and 1, 2, 4, 8, and 16 hours and all day, with the midpoint of each exposure period at 12:00 noon, Pacific Standard Time. This calibration procedure reflects the logarithmic response of the paper to light as well as the fact that a graph of light intensity versus time of day is nearly symmetrical around solar noon.

On another clear day soon after calibration, the ozalid integrators were placed on the study plots. Stakes with horizontal platforms were set at every fourth meter along the lines used for understory cover and biomass estimation (Figure 1). Thus each sampling macroplot contained 12 ozalid integrators. In order to insure that understory vegetation did not influence the light readings, some integrators were placed as high as 1.8 meters. In a few cases, the understory vegetation at the predetermined sample location was taller than 1.8 meters, so the stakes were offset slightly at these points. The ozalid paper was set out in the evening and collected the next evening in order to insure equal exposure time for all light integrators. The readings for each macroplot were averaged and expressed as percent of full sunlight in the open. Full sunlight for one day in the open was derived from the calibration.

Emmingham (1972) and Emmingham and Waring (1973) have discussed thoroughly the ozalid light integrator method for general ecological studies. Briefly, the main advantage to the method is that many measurements in different parts of a stand can be taken at the same time with simple and inexpensive equipment. The major potential drawback is that the paper is most sensitive to wavelengths in the 325 to 425 nanometer range, with a maximum sensitivity around

410 nanometers. Photosynthesis is most sensitive to the 400 to 700 nanometer range. However, if the relative amounts of light in each wave band do not change from the open when transmitted through the forest canopy, the method will give a good approximation of photosynthetic light. To some extent, this condition holds true for conifer stands. Atzet and Waring (1970) showed that, unless the forest canopy is very dense and few sunflecks come through, light in the 400 to 700 nanometer range is transmitted uniformly by a conifer canopy. Only the far red band, 700 to 750 nanometers, shows a significant change compared to unfiltered sunlight, but this band is important for such plant processes as the reversible reactions of the phytochrome system. Thus, while the limitations of the ozalid integrator method must be kept in mind when interpreting the results, the method should give acceptable approximations to the true values.

RESULTS

General Description of the Understory Vegetation

Table 4 shows the average cover and frequency by thinning treatments for each species found in the sampling macroplots. The significant differences at the five percent probability level are listed in Table 5. Appendix I gives the full scientific and common names for each species encountered in the study, and Appendix II lists the coverages and frequencies for each of the 14 plots.

Vegetation coverage varies considerably between plots, even between those subjected to the same treatment. However, overall species composition and relative coverage of the different species is similar for plots treated similarly. For example, plot 27U, an unthinned control, has a total vegetation coverage of 114 percent. The moss, *Eurhynchium oreganum*, covers 72 percent of the area and the low shrub, *Berberis nervosa*, covers 25 percent. In contrast, plot 37U, also unthinned, has a total coverage of only 12 percent. Yet *E. oreganum* and *B. nervosa* are still the most important species, comprising four and six percent of the cover, respectively. These two species, along with *Cornus nuttallii*, account for most of the cover on unthinned plots. Other shrubs and herbs are widely

Figure 3. Plot 27U. Berberis nervosa and Eurhynchium oreganum dominate the understory.

Figure 4. Plot 37U. A patch of Berberis nervosa is visible in the right-center portion of the photograph.

Figure 5. Plot 21U. Berberis nervosa and Polystichum munitum are visible in background.

Figure 6. Plot 25L. A skid trail runs up the center of the photograph.

Figure 7. Plot 34L. Pteridium aquilinum dominates. The support platforms for the ozalid light integrators are visible in the photograph.

Figure 8. Plot 35M. Pteridium aquilinum again is the most common understory species.

Figure 9. Plot 24M. Pteridium aquilinum and Berberis nervosa are visible in the foreground. The arching stems are Cornus nuttallii.

Figure 10. Plot 30H. Pteridium aquilinum, Berberis nervosa, and Lupinus latifolius are visible in the foreground.

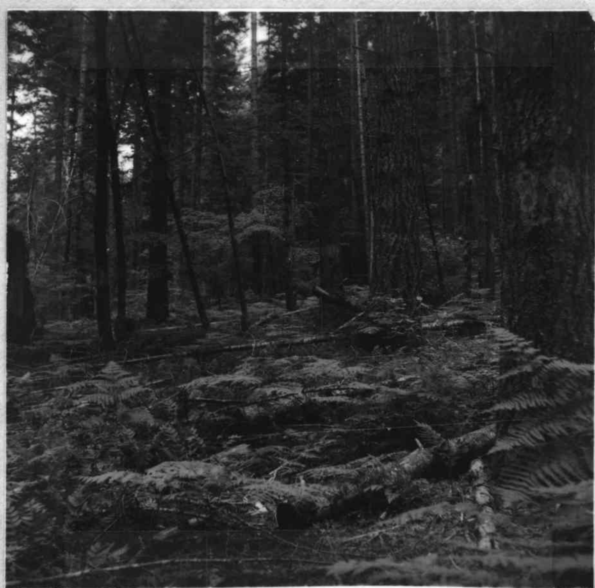

Figure 11. Plot 22H. Pteridium aquilinum and Berberis nervosa are visible in the foreground. The large stump in the left-center portion of the photograph remains from the original logging at Black Rock.

Table 4. Understory Cover and Frequency by Thinning Treatment. Data are presented as percent cover over percent frequency. the letter "p" indicates that the species was present in a sampling macroplot, but did not fall in a sampling microplot. the symbol "+" indicates that the species was sampled, but cover is less than 0.5 percent. The letter "a" denotes an annual herb, and the letter "b" denotes a biennial or short-lived perennial herb. All other herbs are perennials.

	Thinning Treatment			
	Heavy	Moderate	Light	Unthinned
Tall shrub layer (1-6 m)				
Tree species				
Abies grandis				p
Acer macrophyllum		p	p	1/2
Cornus nuttallii	6/7	6/8	p	4/4
Pseudotsuga menziesii	p			
Shrub species				
Acer circinatum	p	1/2	8/12	1/1
Amelanchier alnifolia	p			
Corylus cornuta	1/2	1/2	p	p
Holodiscus discolor	2/4	p		+/1
Rhamnus purshiana		p		
Rosa gymnocarpa	p	p		
Rubus leucodermis	p	1/1		
Vaccinium parvifolium		p	p	
Herb and small shrub layer (0-1 m)				
Tree species				
Acer macrophyllum	+/4	1/14	1/14	+/11
Arbutus menziesii			p	
Cornus nuttallii	3/8	2/7	+/1	+/4
Pseudotsuga menziesii	1/19	4/19	1/23	+/1
Taxus brevifolia	p	p		
Shrub species				
Acer circinatum	+/1	p	1/5	p
Amelanchier alnifolia	p			
Berberis nervosa	7/14	6/13	1/6	14/32
Ceanothus sanguineus	+/1	p	+/1	
Corylus cornuta	+/1	+/1	1/3	+/1

(Continued on next page)

Table 4. (Continued)

	Thinning Treatment			
	Heavy	Moderate	Light	Unthinned
Gaultheria shallon	1/4	2/9	+/1	1/1
Holodiscus discolor	1/1	p	p	p
Rhamnus purshiana		p	p	
Rhus diversiloba	+/1		p	p
Rosa gymnocarpa	1/5	+/1	1/3	+/2
Rubus leucodermis	1/2	+/1		
Rubus parviflorus	p	p		
Rubus ursinus	+/3	+/1	+/2	+/2
Symphoricarpos mollis	4/23	1/4	1/9	1/9
Vaccinium parvifolium	p	p	p	+/1
Unidentified seedling	p		p	p
Herbaceous species				
Achlys triphylla			+/2	+/1
Actaea rubra		p		
Adenocaulon bicolor	p	+/1	p	p
Adiantum pedatum				+/1
Anaphalis margaritacea	p	+/1	p	
Anemone deltoidea	+/1	+/2	1/10	p
Arenaria macrophylla	p	1/8	p	+/1
Asarum caudatum			p	
Bromus vulgaris	+/10	+/9	+/1	+/2
Calypso bulbosa			+/2	p
Campanula scouleri	11/52	7/36	2/12	p
Cardamine pulcherrima	+/2	+/2	+/1	
Chimaphila menziesii	p	+/1	+/1	+/6
Cirsium vulgare (b)	+/1	p		
Collomia heterophylla (a)	1/35	1/35	+/8	+/2
Eburophyton austinae				+/1
Epilobium angustifolium	+/1			
Erythronium grandiflorum	p			p
Festuca occidentalis	4/30	1/11	1/9	+/1
Festuca subulata	p	+/3	+/1	p
Fragaria vesca	+/2	+/1	+/1	+/1
Galium aparine (a)	p			
Galium triflorum	1/16	2/37	2/20	1/10
Goodyera oblongifolia		p	+/3	+/2
Hieracium albiflorum	2/11	+/7	+/4	+/1

(Continued on next page)

Table 4. (Continued)

	Thinning Treatment			
	Heavy	Moderate	Light	Unthinned
Holcus lanatus		p		
Hypochaeris radicata	+/1	+/1	p	
Iris tenax	1/6	1/6	+/3	+/1
Lathyrus polyphyllus	1/3	1/2	1/2	p
Lilium columbianum		p		+/1
Linnaea borealis	1/4		+/2	
Lotus crassifolius	2/10	+/1	3/13	
Lotus micranthus (a)	+/1	+/3		p
Lupinus latifolius	2/8	+/4	+/1	
Luzula campestris	1/12	1/16	+/4	p
Montia perfoliata (a)		+/1		
Montia sibirica	+/1			
Nemophila parviflora (a)	+/1	1/3	p	+/1
Osmorhiza chilensis	+/1	+/1	+/2	p
Polystichum munitum	1/2	3/4	+/1	4/9
Pteridium aquilinum	19/39	17/38	12/26	1/7
Pyrola picta	p		+/1	p
Rumex acetosella	+/1	+/1		
Senecio jacobaea (b)	+/1	1/2	+/1	
Smilacina stellata	p	p	+/2	p
Trientalis latifolia	5/50	5/38	5/40	1/12
Trillium ovatum	p	p	+/2	+/1
Trisetum canescens	+/2	p	p	p
Viola glabella				+/1
Viola sempervirens	+/1	2/12	+/4	+/1
Unidentified herb			p	
Mosses				
Atrichum selwynii	+/3			
Dicranum fuscescens		p		p
Eurhynchium oreganum	31/97	44/99	26/96	36/99
Rhizomnium glabrescens				+/1
Rhytidiadelphus loreus				+/1
Rhytidiadelphus triquetrus	1/5	+/2	+/2	+/1
Unidentified moss #1	p			
Unidentified moss #2		p		

(Continued on next page)

Table 4. (Continued)

	Thinning Treatment			
	Heavy	Moderate	Light	Unthinned
	Totals			
Tall shrub layer (1-6 m)				
Tree species	6/7	6/8	p	5/6
Shrub species	2/4	4/6	8/12	1/2
Herb and small shrub layer (0-1 m)				
Tree species	4/29	7/35	2/37	1/13
Shrub species	14/39	10/28	6/23	17/40
All herbaceous species	50/94	50/90	31/74	7/44
Grasses and rushes	4/38	2/33	1/16	+/3
Mosses	32/98	44/99	26/96	36/99
All vegetation	108/100	120/100	73/100	67/99

Table 5. Treatment Differences Significant at the Five Percent Probability Level for Understory Cover and Frequency.

		Comparisons	
		Thinning Treatment(s)	vs. Thinning Treatment(s)
Pseudotsuga menziesii	frequency	Mean (H + M + L)[1]	U
		H	U
		L	U
Campanula scouleri	cover	Mean (H + M)	Mean (L + U)
		H	L
		H	U
	frequency	Mean (H + M)[2]	Mean (L + U)
		H[2]	L
		H[2]	U
		M	L
		M[2]	U
Collomia heterophylla	frequency	Mean (H + M)[2]	Mean (L + U)
		H[2]	L
		H[2]	U
		M[2]	L
		M[2]	U
Festuca occidentalis	frequency	H	Mean (M + L + U)
		H	L
		H	U
Hieracium albiflorum	frequency	H	Mean (M + L + U)
		H	U

(Continued on next page)

Table 5. (Continued)

		Comparisons	
		Thinning Treatment(s)	vs. Thinning Treatment(s)
Pteridium aquilinum	cover	Mean (H + M + L)	U
		H	U
	frequency	Mean (H + M + L)	U
		H	U
Trientalis latifolia	cover	Mean (H + M + L)	U
		M	U
	frequency	Mean (H + M + L)	U
		H	U
		M	U
		L	U
Grasses and rushes	frequency	Mean (H + M)[2]	Mean (L + U)
		H	L
		H[2]	U
		M[2]	U
Herbaceous species	cover	Mean (H + M)[2]	Mean (L + U)
		H[2]	U
		M[2]	U
	frequency	Mean (H + M + L)[2]	U
		H[2]	U
		M[2]	U
		L	U

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Table 5. (Continued)

		Comparisons		
		Thinning Treatment(s)	vs.	Thinning Treatment(s)
All vegetation	cover	Mean (H + M)[2]		Mean (L + U)
		H		U
		M[2]		L
		M[2]		U

[1]The means of several treatment combinations were significantly different for many of the species or species groups. Only the difference significant at the highest probability level is given for the means of treatment combinations. All significant differences between the means of single treatments are given.

[2]These differences are also significant at the one percent probability level.

scattered. Figures 3, 4, and 5 show the understories on plots 27U and 37U, as well as on plot 21U.

Overall species composition for all thinning treatments is similar. The most important species are *Eurhynchium oreganum* and *Pteridium aquilinum*. These species also vary considerably within treatments. For example, *E. oreganum* ranges from 16 percent to 52 percent coverage and *P. aquilinum* from 5 percent to 39 percent coverage on heavily thinned plots. Other herbs are also important on the thinned plots, especially those heavily and moderately thinned. Most of these herbs are perennials. *Campanula scouleri*, *Festuca occidentalis*, *Galium triflorum*, *Trientalis latifolia*, and the annual, *Collomia heterophylla*, are the most common. Occasionally, woody plants, such as *Acer circinatum*, *Berberis nervosa*, *Corylus cornuta*, *Holodiscus discolor*, and *Cornus nuttallii*, are important. *Pseudotsuga menziesii* seedlings occur with high frequency. Figures 6 through 11 show several of the thinned plots.

Understory Cover and Frequency and Thinning Treatment

Despite the large within-treatment variations, several trends in cover and frequency related to thinning intensity were noted. Total cover is highest on heavily and moderately thinned plots. The most marked change is the increase in herbaceous cover with thinning intensity. The heavy and moderate thinnings each average about 50 percent cover, whereas light thinnings and unthinned plots average 31 percent and 7 percent, respectively. Many important herbaceous species follow this trend. For example, Pteridium aquilinum, Campanula scouleri, Collomia heterophylla, and Hieracium albiflorum increase with thinning intensity. The grasses also increase, Festuca occidentalis being the most important. Trientalis latifolia increases markedly with thinning, but remains at about the same level regardless of intensity. Galium triflorum, another important herb, increases little with thinning.

A few herbaceous species are confined to thinned plots. These species include Anaphalis margaritacea, Cardamine pulcherrima, Cirsium vulgare, Hypochaeris radicata, Lotus crassifolius, Lupinus latifolius, Rumex acetosella, and Senecio jacobaea, but only L. crassifolius and L. latifolius occur with relatively high frequencies. Lathyrus polyphyllus, Lotus micranthus, and Luzula campestris are found only in small amounts on unthinned plots. Adiantum pedatum, Eburophyton austinae, Viola glabella, Rhizomnium glabrescens, and Rhytidiadelphus loreus grow in small amounts only on unthinned plots. However, no important species significantly decrease with thinning. The total number of herbaceous species and of all species, as well as the average number of species per sampling macroplot, drops slightly from heavily thinned to unthinned plots (Table 6).

Table 6. Number of Species by Thinning Treatment. The first figure given is the total number of species in each category found on all sampling macroplots for each treatment. The figure in parentheses is the average number of species per macroplot for each treatment.

	Thinning Treatment				
	Heavy	Moderate	Light	Unthinned	All Treatments Combined
Tree species	4 (3)	4 (3)	4 (3)	4 (3)	6 (3)
Shrub species	15 (8)	13 (7)	13 (8)	11 (7)	16 (8)
Herbaceous species	39 (24)	38 (27)	36 (23)	35 (20)	51 (23)
Moss species	4 (2)	4 (2)	2 (1)	5 (2)	8 (2)
All species	62 (36)	59 (40)	55 (36)	55 (33)	81 (36)

In general, the cover and frequency of woody species, whether greater or less than one meter in height, show no consistent relationship with thinning. Some, such as Ceanothus sanguineus, Rubus leucodermis, and R. parviflorus, are found only on thinned plots, but in small amounts. Tall shrubs occur at relatively low frequencies on all treatments. Pseudotsuga menziesii seedling frequency, however, increases significantly with thinning to about the same average level for all treatments.

Moss cover shows no consistent relationship to thinning, though it does show a statistically significant relationship at the five percent probability level with the basal area of active growing stock before the first thinning on each replication (Figure 12). The regression explains 31 percent of the variation in moss cover. No other understory species now has a similar relationship with original stand basal area. Further, the data were examined carefully to detect any differences between or within treatments due to differences in frequency of thinning, stand age, year of thinning, or elevation, but no consistent differences were found.

Overall species composition for the thinning treatments, weighted by the cover or frequency of each species, was examined graphically by a similarity ordination (SIMORD) technique (Dick-Peddie and Moir, 1970). A similarity index was computed for each possible combination of plots according to the following formula:

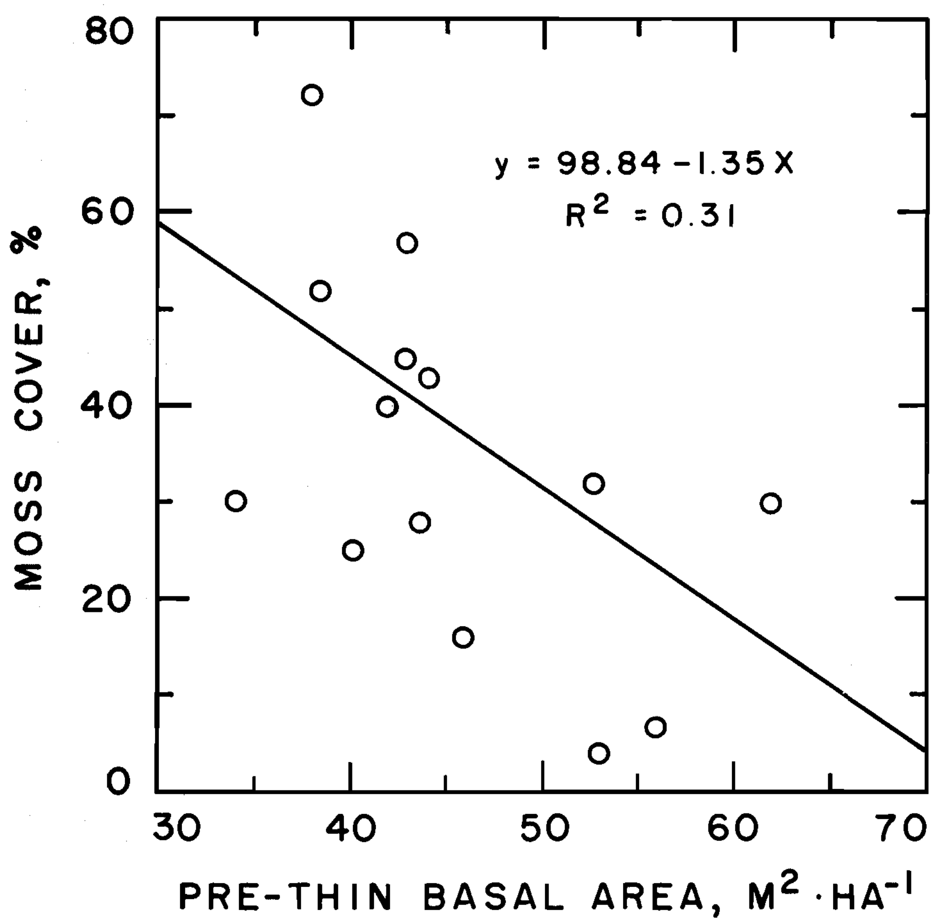

Figure 12. The relationship between moss coverage and basal area of active growing stock immediately before the first thinning on each replication. The regression is significant at the five percent probability level.

$$SIM(I, J) = (2/n) \left[\sum_{k=1}^{n} \text{Minimum } (a_{ik}, a_{jk})/(a_{ik} + a_{jk}) \right] ,$$

where SIM(I, J) is the similarity index between plots I and J, "n" is the total number of species in the two plots, and a_{ik} and a_{jk} are cover or frequency values for the k^{th} species in plots I and J, respectively. For this analysis, species with less than one percent cover were assigned a cover of one percent. Species present on a macroplot but not falling in a sampling macroplot were assigned one percent cover and frequency. After all possible indices were computed, the 14 plots were ordinated along two axes. The left plot on the x-axis was chosen to be that least similar to all other plots, as determined by the sums of the 13 similarity indices for each plot. The right end plot is least similar to the left end plot. The lower plot of the y-axis is that plot in the central cluster of plots, within 12 units of the center of ordination, that is least similar to the end plots of the x-axis, as determined by the average similarity to the x-axis end plots. The upper plot on the y-axis is that plot in the central cluster with the least similarity to the lower plot. The scale of the x-axis is the same as that of the y-axis, both being based on the degree of similarity between the various plots.

Figure 13 gives the results of the ordination for cover and for frequency. The unthinned plots appear distinctly different from the thinned plots, whereas the thinning treatments show considerable overlap with each other.

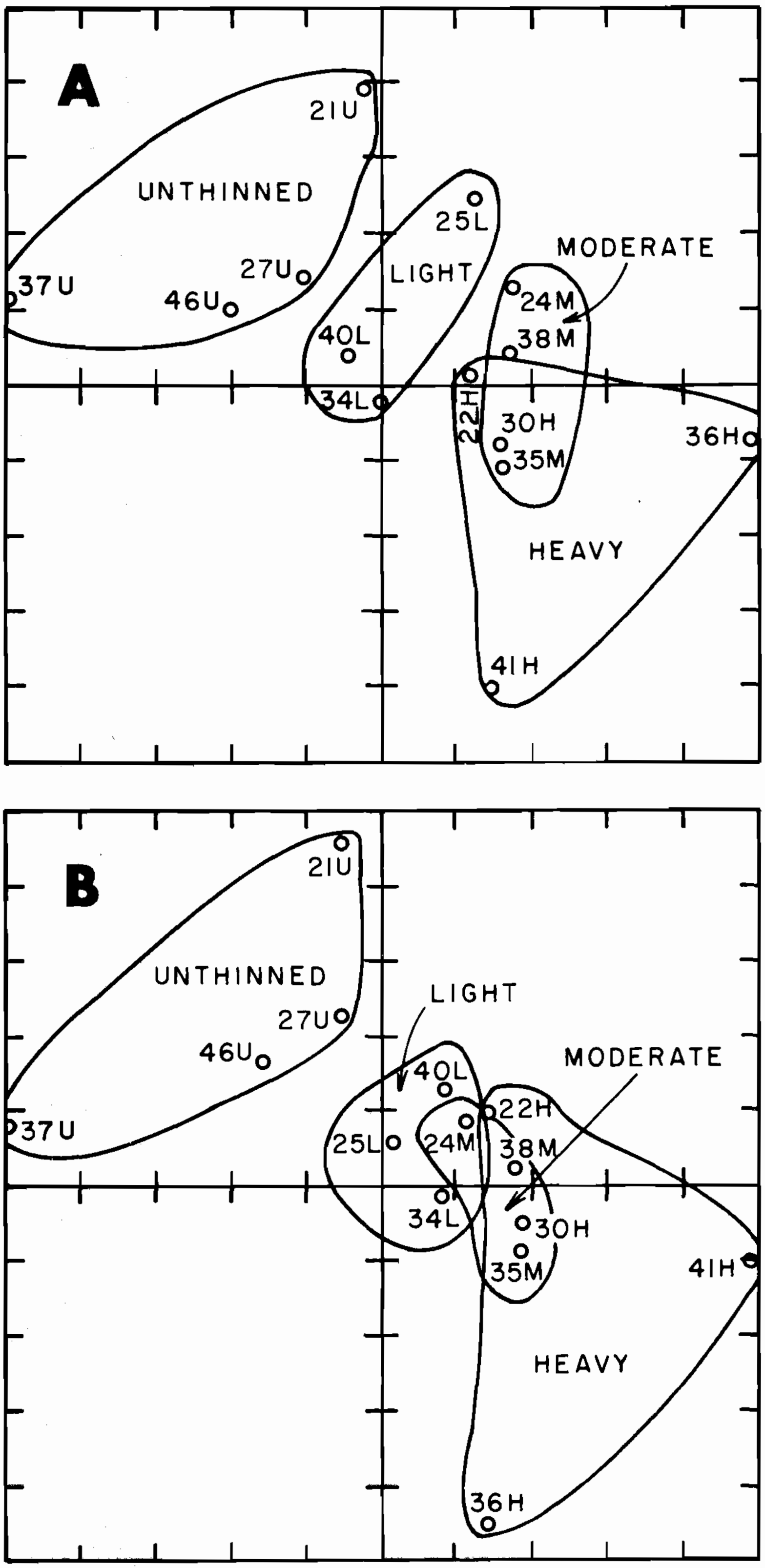

Figure 13. Similarity ordinations for understory (A) cover and (B) frequency.

Understory Biomass and Thinning Treatment

The results for understory biomass are given in Table 7 by thinning treatment. Differences significant at the five percent probability level are shown in Table 8. Data for each plot are given in Appendix III.

The findings for biomass roughly parallel those for cover. Biomass for all non-woody material is highest for heavy and moderate thinnings, as is herbaceous biomass. Pteridium aquilinum is the most important herb. Due to the greater variability in the biomass samples, fewer differences between treatments are statistically significant than for the cover and frequency samples. This fact is particularly evident in the figures for total vegetation biomass. Average biomass ranges from 7488.2 kg/ha for heavily thinned plots to 960.6 kg/ha for unthinned, yet this difference is not significant at the five percent probability level due to the high variation in woody biomass from plot to plot.

Other Data for Woody Species and Thinning Treatment

Large woody species, those with stems longer than one meter, occur sporadically in all treatments. For example, the macroplot on experimental plot 30H contained 26 such stems of Holodiscus

Table 7. Understory Biomass by Thinning Treatment. All data are given in kilograms per hectare. The symbol "+" indicates an average biomass of less than 0.05 kg/ha.

		Thinning Treatment			
		Heavy	Moderate	Light	Unthinned
		Tall shrub layer (1-6 m)			
Tree species					
Acer macrophyllum	leaves			4.2	3.1
	wood			2.1	7.8
Cornus nuttallii	leaves	86.4	43.1		10.6
	wood	4816.7	546.9		235.5
Shrub species					
Acer circinatum	leaves		21.5	40.1	1.4
	wood		142.7	681.8	70.0
Corylus cornuta	leaves	0.2	9.6		0.1
	wood	+	28.1		
Holodiscus discolor	leaves	38.2			
	wood	1694.7			
		Herb and small shrub layer (0-1 m)			
Tree species					
Acer macrophyllum	leaves	1.7	0.9	2.2	0.2
	wood	3.4	0.7	2.5	0.2
Cornus nuttallii	leaves	7.3	2.8		
	wood	6.0	111.0		
Pseudotsuga menziesii	leaves	10.9	8.8	3.9	
	wood	9.2	6.4	1.8	
Shrub species					
Acer circinatum	leaves	0.4		2.4	
	wood	0.8		27.1	
Berberis nervosa	leaves	179.4	192.7	36.2	292.0
	wood	66.7	85.1	7.4	56.0
Ceanothus sanguineus	leaves			0.7	
	wood			1.2	
Corylus cornuta	leaves	0.8		4.1	
	wood	0.3		5.5	
Gaultheria shallon	leaves	4.4	31.7	10.4	
	wood	0.6	10.8	3.7	
Holodiscus discolor	leaves	2.0	+		
	wood	3.6			
Rhus diversiloba	leaves				0.3
	wood				1.0

(Continued on next page)

Table 7. (Continued)

		Thinning Treatment			
		Heavy	Moderate	Light	Unthinned
Rosa gymnocarpa	leaves	0.3	0.1	1.9	+
	wood	0.4		2.5	
Rubus leucodermis	leaves	4.6	0.6		
	wood	5.2	0.4		
Rubus ursinus	leaves	0.2		1.4	0.2
	wood	0.1		0.6	+
Symphoricarpos	leaves	9.6	1.3	3.0	1.5
mollis	wood	16.1	4.2	7.7	3.0
Vaccinium	leaves				0.9
parvifolium	wood				1.9
Herbaceous species					
Campanula scouleri		19.0	19.2	3.4	
Galium triflorum		1.9	2.6	3.5	1.8
Hieracium albiflorum		6.1	0.2	0.2	
Lathyrus polyphyllus		6.9	4.8		
Lotus crassifolius		16.5	0.5	8.2	
Lupinus latifolius		57.9			
Polystichum munitum			55.1		64.4
Pteridium aquilinum		159.6	136.9	48.6	1.7
Trientalis latifolia		14.3	13.3	9.6	0.1
Grasses and rushes		6.9	4.0	3.2	0.3
Other herbs		11.5	11.2	3.4	1.5
Mosses		217.6	208.4	164.2	204.7
		Totals			
Tall shrub layer (1-6 m)					
Tree species	leaves	86.4	43.1	4.2	13.8
	wood	4816.7	546.9	2.1	243.3
Shrub species	leaves	38.4	31.1	40.1	1.4
	wood	1694.7	170.9	681.8	70.0
Herb and small shrub layer (0-1 m)					
Tree species	leaves	19.8	12.5	6.1	0.3
	wood	18.6	118.1	4.3	0.2
Shrub species	leaves	201.8	226.3	60.0	295.0
	wood	93.7	100.6	55.8	62.0
Herbaceous species		300.6	248.0	80.3	69.8

(Continued on next page)

Table 7. (Continued)

	Thinning Treatment			
	Heavy	Moderate	Light	Unthinned
All vegetation				
Non-woody parts	864.6	769.4	355.0	585.0
Wood	6623.7	936.5	744.0	375.5
Total	7488.2	1705.9	1099.0	960.6

Table 8. Treatment Differences Significant at the Five Percent Probability Level for Understory Biomass.

	Comparisons		
	Thinning Treatment(s)	vs.	Thinning Treatment(s)
Campanula scouleri	Mean (H + M)[1]		Mean (L + U)
Hieracium albiflorum	H[2]		Mean (M + L + U)
	H[2]		M
	H[2]		L
	H[2]		U
Grasses and rushes	Mean (H + M + L)		U
	H		U
Herbaceous species	Mean (H + M)[2]		Mean (L + U)
	H		L
	H		U
	M		U
All non-woody parts	Mean (H + M)		Mean (L + U)
	H		L
	M		L

[1] In some cases the means of several treatment combinations are significantly different. Only the difference significant at the highest probability level is given for the means of treatment combinations. All significant differences between the means of single treatments are given.

[2] These differences are also significant at the one percent probability level.

discolor, whereas no other heavily thinned plot contained even one. The sampling macroplot on plot 40L contained 49 large Acer circinatum stems, whereas the macroplot on experimental plot 34L contained none. Nevertheless, when only those plots containing large woody species were compared, some differences between thinned and unthinned plots were noted.

Table 9 compares the growth forms and diameter classes for large Acer circinatum stems on all sampling macroplots that contained such stems. Thinned plots have several clumps of young, small diameter stems that are either erect or leaning. Unthinned plots do not have any such clumps. The thinned plots also contain stems in larger diameter classes than the unthinned plots. The large stems in all treatments tend to be convex. Tables 10 and 11 show similar comparisons for Holodiscus discolor and Corylus cornuta, respectively.

Cornus nuttallii grows on the study plots in both tree and shrub form and as a seedling. Unlike the other large understory woody plants, C. nuttallii is found on most of the study plots. Table 12 shows the growth form and size classes for all sampling macroplots with large C. nuttallii stems. The trend towards many small, erect or leaning stems on thinned plots is not as marked for C. nuttallii as it is for the other large woody plants. Also, the larger diameter classes are often small trees. Nevertheless, the thinned plots do tend to contain larger diameter classes than the unthinned plots.

Table 9. Growth Form[1] by Diameter Class for Large _Acer circinatum_ Stems.

Diameter Class (cm)	Experimental Plot					
	22H	38M	25L	40L	21U	46U
0+ to 1		E-1	E-8 L-2	E-7 L-9		
1+ to 2	E-1	E-4 L-6	E-5 L-3 C-1 D-1 CL-1 DL-2	E-17 L-5		
2+ to 3			L-1 D-1 CL-1 DL-1	D-1 DL-1	C-2	C-2
3+ to 4				L-2 C-1 CL-1 DL-1		
4+ to 5			CL-3 DL-1	D-1 DL-2		
5+ to 6				DL-1		

[1] E = erect
L = leaning
C = convex
D = decumbent
CL = convex and layering
DL = decumbent and layering

Number of stems follows the growth form symbols.

Table 10. Growth Form[1] by Diameter Class for Large *Holodiscus discolor* Stems.

Diameter Class (cm)	Experimental Plot			
	30H	35M	40L	27U
0+ to 1	E-3 L-2	E-1		E-2
1+ to 2	E-7 L-3 C-1		E-1 L-1	E-1 C-1
2+ to 3	E-3 C-3			
3+ to 4	L-1 C-1			E-2
4+ to 5	E-1 C-1			

[1]E = erect
L = leaning
C = convex

Number of stems follows the growth form symbols.

Table 11. Growth Form[1] by Diameter Class for Large Corylus cornuta Stems.

Diameter Class (cm)	Experimental Plot				
	30H	41H	38M	25L	27U
0+ to 1	E-3	E-2 L-1	E-2	E-2	
1+ to 2	E-3 L-6 C-1	E-2 L-2	L-2		L-1
2+ to 3	E-2 C-2 CL-1	D-1 CL-1	C-1		C-1
3+ to 4	E-1		L-1		
4+ to 5		C-1			

[1] E = erect
L = leaning
C = convex
D = decumbent
CL = convex and layering

Number of stems follows the growth form symbols.

Table 12. Growth Form[1] by Diameter Class for Large Cornus nuttallii Stems.

Diameter Class (cm)	Experimental Plot									
	30H	22H	36H	24M	38M	40L	27U	21U	37U	46U
0+ to 1		E-2								
1+ to 2		E-2 L-2								
2+ to 3					L-1 C-1 D-1					
3+ to 4										E-2[2] L-1
4+ to 5	C-1	C-1			E-1 C-1 D-1	L-1				E-1 C-1
5+ to 6					L-1 C-2		L-1			E-1[3] C-4
6+ to 7		C-3 D-1		C-1	L-1 C-3 D-2			C-1		E-1[3] L-1
7+ to 8		L-1 C-2	C-1 D-1		C-1		C-1	E-2[3]		

(Continued on next page)

Table 12. (Continued)

Diameter Class (cm)	Experimental Plot									
	30H	22H	36H	24M	38M	40L	27U	21U	37U	46U
8+ to 9		E-1[3] C-1 D-1	L-1[3]	C-1	E-1[3]				E-1[3]	
9+ to 10	C-1	C-1		C-1			C-1			
10+ to 11	E-1[3]		C-1			L-1				
11+ to 17	C-1		E-1[3]							

[1]E = erect
L = leaning
C = convex
D = decumbent

Number of stems follows the growth form symbols.

[2]One of these two stems is a small tree (greater than six meters in vertical height).

[3]These stems are small trees (greater than six meters in vertical height).

Acer macrophyllum generally occurs either as a seedling or as an overstory tree. Very few stems are found in intermediate stages.

The number of stems for which age was determined is small, so no conclusions about the relationship between size and age can be drawn. The sample shows, however, that many of the stems on the thinned plots originated after the initial thinnings.

Pseudotsuga menziesii is the other important woody species found on the study plots. Like *Acer macrophyllum*, it occurs only as an overstory tree or a seedling. The tallest seedling found on any sampling macroplot was 1.2 meters, and no others were over one meter in height. The stocking level is high, since average frequency for the three thinning treatments ranges from 19 to 23 percent (Table 4), based on the 0.1 m^2 cover sampling microplots. Table 13 gives the average height at a given age for seedlings found in the biomass sampling microplots. Since average height does not differ significantly between thinning treatments, data for the treatments are combined. No seedlings fell within the sampling microplots in unthinned stands. Few one-year-old seedlings were found on any of the study plots, and none fell within a sampling microplot. Despite the high seedling frequency in thinned stands, height growth is slow. Further, few seedlings appear to survive longer than five years in the understory.

Table 13. Age and Height of *Pseudotsuga menziesii* Seedlings on Thinned Plots.

Age	Average Height (cm)	Height Range (cm)	Sample Size
1	-	-	0
2	6	3-10	24
3	10	6-22	23
4	16	7-50	21
5	21	13-30	12
6	21	15-30	4
7	26	-	1
10	70	-	1

Table 14. Percentage of Microplots Skipped in Cover Sampling by Thinning Treatment.

	Thinning Treatment			
	Heavy	Moderate	Light	Unthinned
Skid trails	2	5	2	-
Old-growth logs	1	3	3	1
Second-growth logs[1]	2	2	1	2
Tree stems, stumps, or snags	3	2	4	3
Totals	8	12	10	6

[1]These figures include cut logs as well as those that fell naturally.

Evidence of Logging Disturbance

The degree of damage to the understory from frequent logging is difficult to assess, especially since the most recent logging took place in 1972. Damage does not seem to be very extensive. Except for the skid trails, very little mineral soil is exposed. Litter covers most of the area that is not covered by understory plants. Table 14 shows the percentage of microplots skipped during cover sampling for each treatment due to skid trails, downed logs, stems, or stumps. Thinned and unthinned plots do not differ significantly from each other in the amount of material on the ground.

Only 16 sampling microplots fell on skid trails. These samples generally contained little vegetation, coverage averaging only 38 percent. Twenty-eight percent of the cover is herbaceous. *Campanula scouleri* and *Trientalis latifolia* contribute most to this figure. The moss *Eurhynchium oreganum* covers eight percent of the skid trail area. The skid trails range from a high percentage of exposed mineral soil to almost complete litter cover (Figure 6).

Woody plants arched or broken under the weight of downed tree stems provide further evidence of logging damage. The growth habit of many of the convex or decumbent stems can be attributed to fallen stems. Such deformation and breakage appear more frequently on thinned than on unthinned plots.

The Relationship of Tree Basal Area to Canopy Opening and the Level of Light Reaching the Understory

Tables 15, 16, and 17 give the tree basal areas, crown coverages, and percentages of full sunlight reaching the understory for the thinning treatments. The trees on the sampling macroplots appear to be representative of the experimental plots as a whole, because the average basal areas of the active growing stock fall within the ranges allowed in the three thinning regimes.

The amounts of canopy opening and of light reaching the understory also vary with thinning treatment. The amounts of canopy opening differ significantly between all treatments. Except for the light and moderate thinnings, understory light levels differ significantly between treatments. Comparison of the coefficients of variation indicates that the light environment in the unthinned stands is more uniform than that in the thinned stands. Pseudotsuga menziesii crown cover also differs significantly with treatment. However, due to the relatively large amounts of Acer macrophyllum in the moderate thinnings, total crown coverages for moderate and light thinnings are nearly equal.

Figures 14 and 15 show the relationships between basal area of active growing stock and canopy opening and between basal area and light reaching the understory. Both relationships are statistically

Table 15. Basal Area Averages by Thinning Treatment. All figures are given in square meters per hectare.

	Thinning Treatment			
	Heavy	Moderate	Light	Unthinned
Second-growth *Pseudotsuga menziesii* (19.3+ cm DBH)[1]	23 A	36 A	44 B	59 C
Other *Pseudotsuga menziesii*	7	2	< 1	3
Acer macrophyllum	0	2	1	1
Cornus nuttallii	< 1	< 1	0	< 1
Totals[2]	30 A	40 A	45 A	63 B

[1]The differences between the means of the following treatments are significant at the one percent probability level: heavy vs. unthinned, heavy vs. light, moderate vs. unthinned, light vs. unthinned. The differences between the means of the following treatments are significant at the five percent level: heavy vs. moderate, moderate vs. light.

[2]The differences between the means of the following treatments are significant at the one percent probability level: heavy vs. unthinned, moderate vs. unthinned, light vs. unthinned. The difference between the means of the heavy and light thinnings is significant at the five percent level.

Table 16. Crown Cover Averages by Thinning Treatment.

	Thinning Treatment			
	Heavy	Moderate	Light	Unthinned
Pseudotsuga menziesii cover (%)[1]	64	75	86	97
Acer macrophyllum cover (%)	1	17	8	8
Cornus nuttallii cover (%)	3	1	<1	3
Total cover (%)[2]	68	93	94	108
Open canopy (%)[1]	34	18	11	2

[1] The differences between the means of the following treatments are significant at the one percent probability level: heavy vs. unthinned, moderate vs. unthinned, heavy vs. light. The differences between the means of the following treatments are significant at the five percent level: heavy vs. moderate, moderate vs. light, light vs. unthinned.

[2] The difference between the means of the heavy thinnings and the unthinned plots is significant at the one percent probability level. The differences between the means of the heavy and moderate thinnings and between the means of the heavy and light thinnings are significant at the five percent level.

Table 17. Light Intensity in the Understory by Thinning Treatment.

	Thinning Treatment			
	Heavy	Moderate	Light	Unthinned
Average percent of full sunlight[1]	16	8	6	2
Range	2-31	2-13	2-13	1-4
Coefficient of variation (%)	37	41	46	19

[1]The differences between the means of the following treatments are significant at the one percent probability level: heavy vs. unthinned, heavy vs. light, heavy vs. moderate, moderate vs. unthinned. The difference between the means of the light thinnings and unthinned plots is significant at the five percent level.

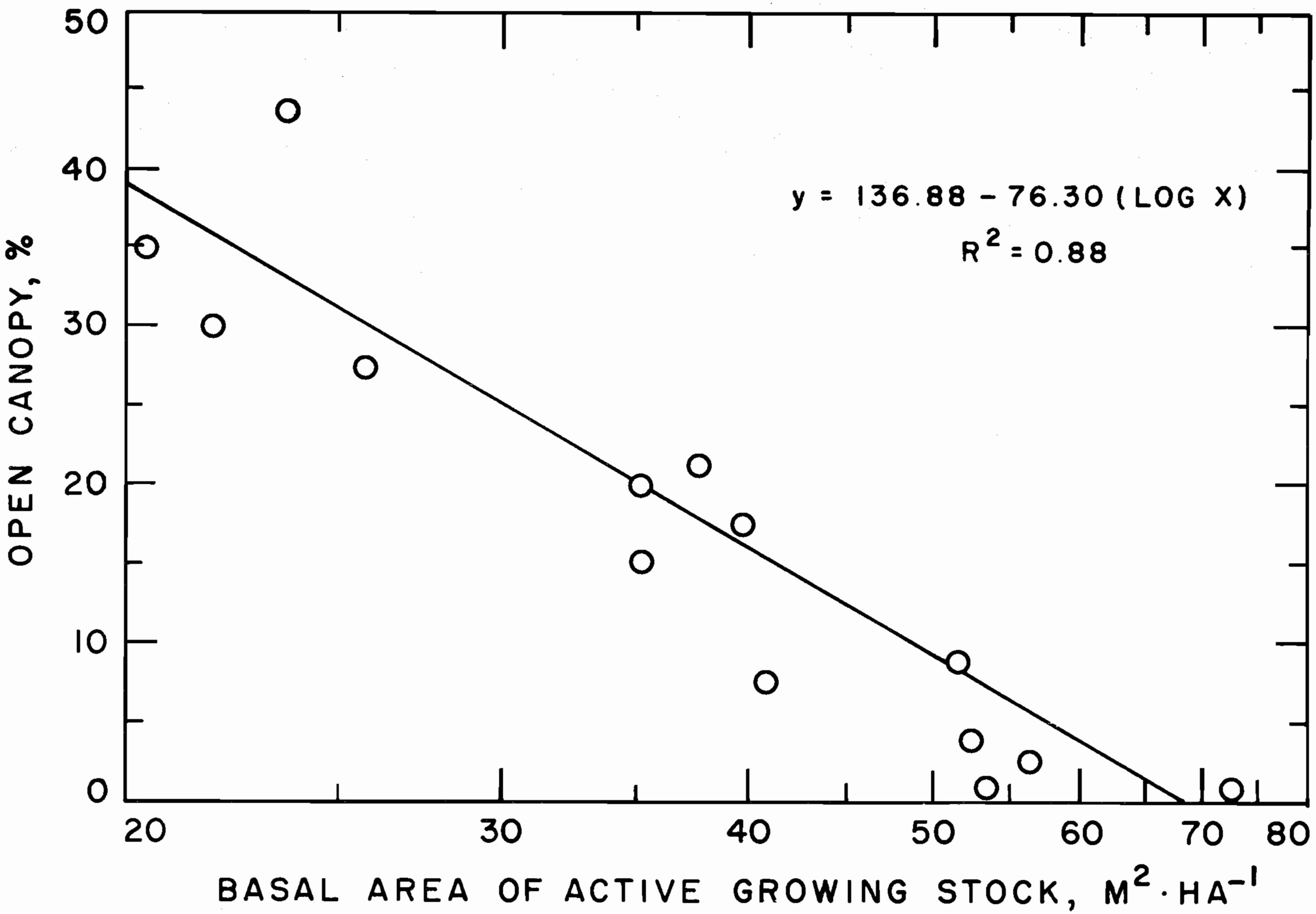

Figure 14. The relationship between the percentage of open canopy and basal area of active growing stock. The regression is significant at the one percent probability level.

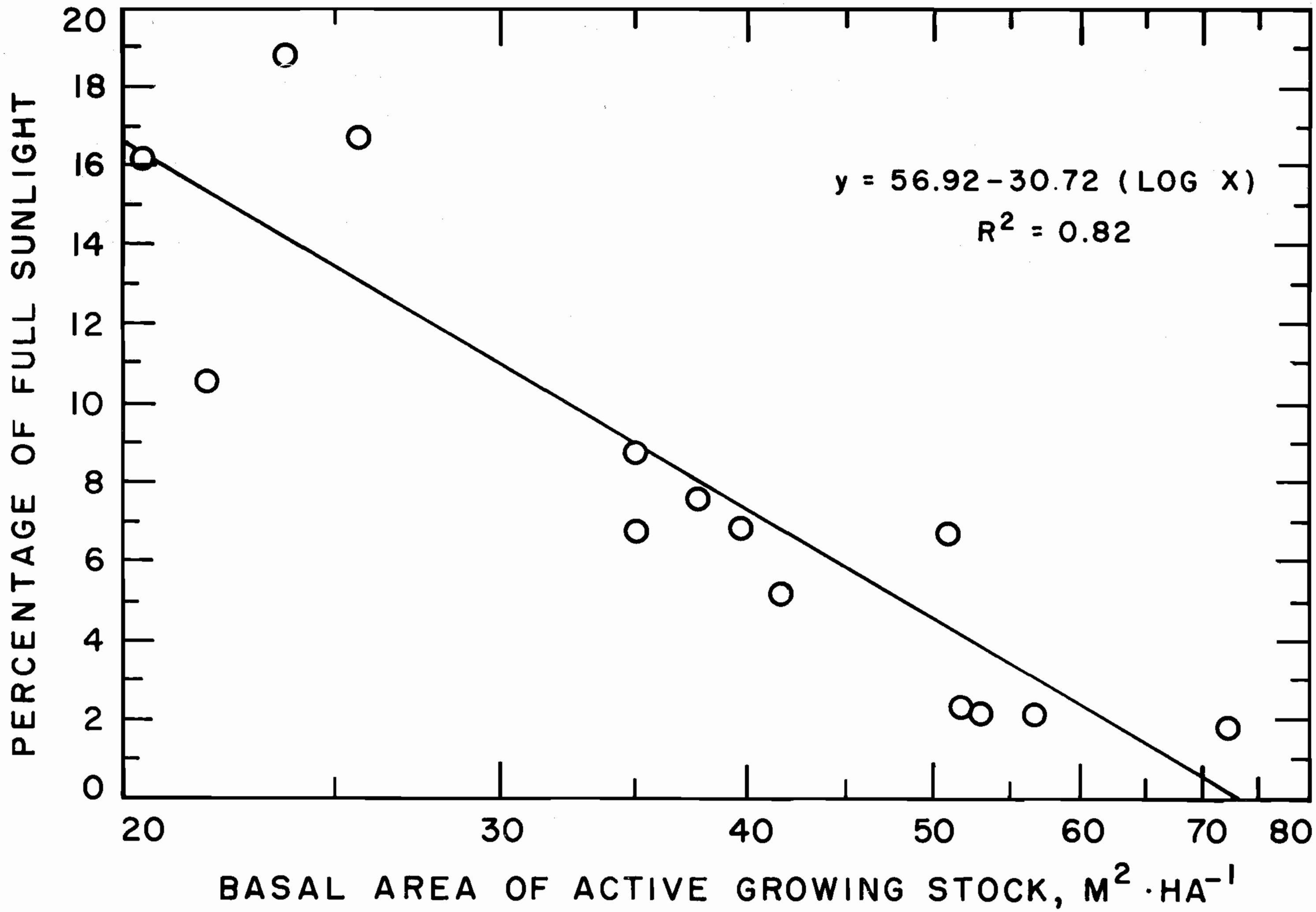

Figure 15. The relationship between the average percentage of full sunlight reaching the understory and basal area of active growing stock. The regression is significant at the one percent probability level.

significant at the one percent probability level. Graphs using total tree basal area or total Pseudotsuga menziesii basal area are similar, but the coefficients of determination are slightly less.

DISCUSSION

The finding that herbaceous cover increases and species composition changes agree with results discussed earlier from thinning studies in other areas (Agee and Biswell, 1970; Barrett, 1970; McConnell and Smith, 1970). The increase in Pteridium aquilinum with thinning that Krueger (1960) noted in the western Cascades occurs at Black Rock, though to a greater degree. Also, as in Krueger's study, the coverages of many of the understory species, especially the woody plants, have not changed with thinning.

Some of the changes in herbaceous cover described in this study can also be compared with studies on western Oregon clearcuts. For example, Dyrness (1973) found that species growing most often on disturbed, unburned areas after clearcutting in the western Cascades include Campanula scouleri, Festuca occidentalis, and Trientalis latifolia, all important species in the thinned stands at Black Rock. Other species Dyrness noted that either invade clearcuts or increase from the original stand include Anaphalis margaritacea, Galium triflorum, and Hieracium albiflorum. However, these species often are characteristic of burned areas. All three show an affinity for thinned stands at Black Rock. Isaac (1943) recorded increases in A. margaritacea, H. albiflorum, Lathyrus spp., P. aquilinum, and some grasses after clearcutting in several areas of western Oregon and

Washington. Chilcote (1971) found that the coverages of such species as *Lotus crassifolius*, *Senecio jacobaea*, *Cirsium vulgare*, *Hypochaeris radicata*, *Luzula campestris*, *Iris tenax*, *Trientalis latifolia*, and *Pteridium aquilinum* all peak within a few years after clearcutting and burning in the central Oregon Coast Range. All of these species attain their maximum coverages on thinned plots at Black Rock. The above similarities indicate that the environment on thinned stands has been changed in such a way that many species that do well on clearcuts can do well in the thinned stands. However, many differences in response to clearcutting and to thinning also exist.

The response of woody species to thinning is less clear than that of herbaceous species. Cover data show no consistent relationship with thinning for woody species. The biomass estimates indicate a trend towards increased woody biomass with thinning intensity, though the heterogeneity in woody plant distribution limits the conclusions one can draw from these data. However, the tendency towards increased biomass with thinning intensity is supported by the data on number of stems per plot (stem density), size, and growth form (Tables 9 through 12). Apparently, shrubs such as *Acer circinatum*, *Corylus cornuta*, and *Holodiscus discolor* are responding to thinning by producing many new stems from the original stems or root systems present before thinning. The erect form of these young stems may be a response to direct overhead light. Since these species spread mainly by vegetative means, the occurrence of a clump on a thinned plot is largely a function of the occurrence of the species in the original stand before thinning. Probably few shrubs grew under the dense canopy of the young stand. Therefore, these clumps are widely scattered.

Similar responses to canopy opening have been found in other studies. For example, Acer circinatum and Corylus cornuta increase in natural stand openings (Bailey, 1966; Sabhasri and Ferrell, 1960) and on clearcuts (Dyrness, 1973; Isaac, 1943). However, Bailey did not find a lightspot response for Holodiscus discolor in his study area in southwestern Oregon, but this shrub was growing in relatively sparse forest stands in which much light generally reaches the understory.

In unthinned stands, overhead light intensity is lower, so stems lean or curve. On thinned plots, older stems that were present before thinning might also lean or curve. These plants, under the lower light intensities of unthinned stands, are unable to support a large woody biomass. Thus few new stems sprout. Also, plants on unthinned plots are unable to support as large a stem as plants on thinned plots, as the data suggest (Tables 9 through 12). Russel (1974) used a similar explanation for the different behaviors of Acer circinatum clumps on clearcuts and in old-growth stands.

If the shrubs at Black Rock do, in fact, respond to thinning by producing new stems, continued thinning could eventually lead to a shrub-dominated understory and thus result in a higher biomass for thinned stands compared with unthinned. Such a tall shrub layer would then strongly influence small understory plants, and some of the effects of a well-developed midstory described earlier could occur (Blair, 1967; Schuster and Halls, 1962). On the other hand, the unthinned canopies will open as the stand matures, and shrub biomass will also increase on these plots.

At present, the biomass on all plots is relatively low compared to mature stands in western Oregon. The heavy thinnings average only about 7500 kg/ha (Table 7). Tarnócai (1968) found that old-growth Coast Range stands from the vine maple-salal and ocean spray-salal communities of Corliss and Dyrness (1961, 1965), whose species composition is similar to that of the study plots, average 21,000 and 22,000 kg/ha, respectively. Given time, the understory biomass at Black Rock may approach these figures. The high variation in biomass samples might decrease as the shrub layer becomes more uniform. The high biomass sampling errors compared to errors for cover sampling might be attributed also to the smaller number of biomass samples and to the fact that for a given amount of vegetative cover on a sample plot, biomass can vary widely.

Data on the tree species in the sampling macroplots suggest the possible future roles of these species at Black Rock under continued thinning. Cornus nuttallii is found as a seedling, large shrub, and a small tree in both thinned and unthinned stands. Apparently, it will continue to reproduce and remain an important stand component. Acer macrophyllum, however, is found mainly as a seedling and as an overstory tree on both thinned and unthinned plots. Its failure to reproduce successfully in the understory indicates that it may become less important in the overstory unless the amount of canopy opening is significantly increased. Sabhasri and Ferrell (1960) found that Acer macrophyllum does respond to canopy openings, but, for the most part, they were dealing with larger openings than in this study.

Pseudotsuga menziesii seedlings, though able to temporarily establish themselves, do not grow well or survive more than a few years under thinned stands (Table 13). Isaac (1943) found that P. menziesii seedlings under a shade frame have little chance of survival in less than 20 percent of full overhead sunlight at midday. This figure is greater than the average light intensity reaching the forest floor in any of the thinning treatments. However, Logan (1974) noted good growth and survival of planted seedlings in the Willamette Valley under lower light intensities, with a maximum survival rate at 18 percent of full sunlight. Atzet and Waring (1970) found that P. menziesii seedlings in the eastern Siskiyou Mountains could survive at lower light intensities than are available under the thinned stands at Black Rock. The reasons for these discrepancies are not clear, though competition from the overstory and from understory plants, soil moisture relationships, nutrient availability, and many other factors are certainly involved.

The environmental factors responsible for the understory response at Black Rock may be the increased levels of light, moisture, or nutrients available to the understory after thinning. Because tree basal area, canopy opening, and light reaching the understory are constantly changing with time, although within limits, the level of any environmental factor at any one time is not necessarily the level to which the present vegetation has responded. The relationship between moss coverage and pre-thinning basal area (Figure 12) points up the difficulty in determining why the vegetation is in its present state. The moss may respond to canopy opening, but response lags behind the changes in the canopy.

Light reaching the understory certainly has increased with thinning (Table 17). Since light level is related to thinning treatment and thinning treatment is related to understory response, light may be an important determinant of understory response. Emmingham (1972) found that the distribution of many of the plants in the Siskiyou Mountains is related to light levels, because in the Siskiyous, moisture is generally limiting, and light becomes the major controlling environmental factor. The species growing in relatively high light included Campanula scouleri, Galium triflorum, Hieracium albiflorum, Lathyrus polyphyllus, and Pteridium aquilinum, all important species in the thinned stands at Black Rock. As mentioned earlier, the response of many of the woody plants to thinning might also be attributed to increased light levels. The wide range of light intensities reaching the understory of thinned stands at Black Rock (Table 17) and shading from tall shrubs can explain why few plants, including those generally considered shade tolerant, are confined to unthinned stands.

Although the rainfall at Black Rock is high, moisture may limit understory growth, at least during the later part of the growing season. Moisture available to the understory may be greater in thinned stands than unthinned because thinned stands intercept less rainfall and often lose less moisture through evapotranspiration than unthinned stands. On the other hand, the root systems of the remaining trees may expand to occupy the same growing space as the original stand and thus use as much moisture. At Black Rock the active growing stock has responded well to thinning. Similarly, some understory species may limit the amount of moisture available to other species. For example, Drew (1968) found that Acer circinatum and Lotus crassifolius growing on clearcuts in the Oregon Coast Range are deeply rooted and rapidly deplete the soil moisture down to at least

0.6 meters during the growing season. Both of these plants have increased with thinning at Black Rock.

Moisture and light may interact to alter response to canopy opening, as Robinson (1967) demonstrated in central Oregon *Pinus ponderosa* stands. The lightspot trend of increasing large shrubs and decreasing small shrubs and herbs from mesic to xeric sites that Bailey (1966) noted in southern Oregon also demonstrates such an interaction.

Whether more nutrients are available to the understory again depends somewhat upon the degree of overstory response to thinning. In addition, some understory species will make more nutrients available to others as well as to the overstory trees. For example, the increases in legumes such as *Lotus crassifolius*, *Lathyrus polyphyllus*, and *Lupinus latifolius* could significantly improve the nitrogen status in thinned stands. The increase in plants such as *Cornus nuttallii* will probably increase calcium cycling.

The understory could also be responding to disturbed soil conditions, altered soil surface temperatures, the special micro-environments created by other understory species, or many other interacting factors. For example, the light, wind-disseminated seeds of such species as *Anaphalis margaritacea*, *Cirsium vulgare*, *Hieracium albiflorum*, and *Senecio jacobaea* will germinate more readily on bare mineral soil and under high light intensities, conditions more prevalent in thinned than in unthinned stands. Pseudotsuga menziesii seeds also will germinate best under these conditions. The seeds of legumes, which generally are large and have hard seed coats, may be present in small amounts in the unthinned stands or may be carried to the area by animals, but few germinate. The combination of greater throughfall precipitation, higher light intensities, and the possibly higher soil surface temperatures in thinned stands may break the dormancy of such seeds.

The relative importance of the various factors affecting understory response to thinning must be determined by further study. Whatever the important factors are, though, they result in about the same understory coverage for moderately and heavily thinned stands (Table 4). At least one environmental factor, the amount of light reaching the forest floor, differs significantly for these two treatments (Table 17). The additional light available in the heavy thinnings apparently is not used by most understory species.

CONCLUSIONS

The results of this study have some implications for forest management. For example, stocking of Pseudotsuga menziesii seedlings is high at all three thinning intensities, indicating that the maximum level of understory competition does not prevent initial seedling establishment. However, competition from established vegetation apparently slows the growth of these seedlings and prevents them from becoming part of the overstory. Therefore, if one plans to regenerate P. menziesii by the shelterwood method in a similar stand, the thinnings must be even heavier. Since vegetative competition appears not to increase from moderate to heavy thinnings, it may not significantly increase at even heavier thinnings. Another possibility is careful removal of the entire overstory to release the advanced regeneration now present. In this case, the level of understory coverage before overstory removal will be related to the level, and thus to the ability to compete for light, moisture, and nutrients, of the vegetation after clearcutting. One must determine whether the growth of brush will be accelerated more than the growth of P. menziesii seedlings.

The results also have consequences for wildlife management. Many black-tailed deer (Odocoileus hemionus columbianus) have been observed at Black Rock. Acer circinatum and Cornus nuttallii, for example, are among their preferred summer foods, and grasses are often utilized in the fall. These foods appear to be increasing due to thinning. Black-tailed deer will also clip Pseudotsuga menziesii seedlings, but no such damage is evident at Black Rock.

Other aspects of the forest ecosystem are affected by the response of the understory vegetation to thinning. Nutrient cycling processes depend on the kind and amounts of understory vegetation. The value of the legumes in adding nitrogen to the system and of Cornus nuttallii in rapidly cycling calcium has been mentioned. Understory responses will also affect water use by the system and thus the value of the area as a watershed. The soil moisture depletion trends that Drew (1968) measured under Acer circinatum and Lotus crassifolius in western Oregon clearcuts may occur in thinned stands as well. The roles of these and other understory species require further study.

In the strictest sense, the data from this study apply only to similar stands with respect to history, age, original understory vegetation, topography, soils, thinning regime, and degree of logging disturbance. Though the general finding of increasing vegetation and changes in relative species abundance applies to other forest types, the need for specific research in other areas is apparent. No consistent differences associated with variation in thinning frequency, stand age, original basal areas before thinning (except for the mosses), or elevation were detected in this study. Nevertheless, such differences, as well as any correlations between overstory and understory response, could show up in data based on many more stands. Long-term studies on permanent plots could improve the sensitivity of similar work by reducing sampling error. In addition, permanent plots would provide a record of successional trends after thinning.

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APPENDICES

APPENDIX I

SPECIES LIST

Scientific names for woody and herbaceous species follow Hitchcock and Cronquist (1973). Scientific names for the mosses follow Lawton (1971). Common names are derived from a variety of sources.

Tree species

Abies grandis (Dougl.) Forbes	grand fir
Acer macrophyllum Pursh	big-leaf maple
Arbutus menziesii Pursh	Pacific madrone
Cornus nuttallii Aud.	Pacific dogwood
Pseudotsuga menziesii (Mirb.) Franco	Douglas-fir
Taxus brevifolia Nutt.	Pacific yew

Shrub species

Acer circinatum Pursh	vine maple
Amelanchier alnifolia Nutt.	western serviceberry
Berberis nervosa Pursh	long-leaved Oregongrape
Corylus cornuta Marsh var. californica (DC.) Sharp	western hazel
Ceanothus sanguineus Pursh	buckbrush
Gaultheria shallon Pursh	salal
Holodiscus discolor (Pursh) Maxim.	ocean-spray
Rhamnus purshiana DC.	cascara
Rhus diversiloba T. & G.	poison-oak
Rosa gymnocarpa Nutt.	baldhip rose
Rubus leucodermis Dougl.	blackcap
Rubus parviflorus Nutt.	thimbleberry
Rubus ursinus Cham. & Schlecht. var. macropetalus (Dougl.) Brown	wild blackberry
Symphoricarpos mollis Nutt.	creeping snowberry
Vaccinium parvifolium Smith	red huckleberry

(Continued on next page)

Herbaceous species

Achlys triphylla (Smith) DC.	vanillaleaf
Actaea rubra (Ait.) Willd.	western red baneberry
Adenocaulon bicolor Hook.	pathfinder
Adiantum pedatum L.	northern maidenhair fern
Anaphalis margaritacea (L.) B. & H.	pearly-everlasting
Anemone deltoidea Hook.	Columbia windflower
Arenaria macrophylla Hook.	bigleaf sandwort
Asarum caudatum Lindl.	wild ginger
Bromus vulgaris (Hook.) Shear	brome-grass
Calypso bulbosa (L.) Oakes	angel-slipper
Campanula scouleri Hook.	pale blue-bell
Cardamine pulcherrima Greene	slender toothwort
Chimaphila menziesii (R. Br.) Spreng.	little prince's-pine
Cirsium vulgare (Savi) Tenore	bull thistle
Collomia heterophylla Hook.	varied-leaf collomia
Eburophyton austinae (Gray) Heller	phantom-orchid
Epilobium angustifolium L.	fireweed
Erythronium grandiflorum Pursh	yellow fawn-lily
Festuca occidentalis Hook.	western fescue
Festuca subulata Trin.	nodding fescue
Fragaria vesca L.	strawberry
Galium aparine L.	bedstraw
Galium triflorum Michx.	fragrant bedstraw
Goodyera oblongifolia Raf.	western rattlesnake-plantain
Hieracium albiflorum Hook.	white hawkweed
Holcus lanatus L.	common velvet-grass
Hypochaeris radicata L.	false dandelion
Iris tenax Dougl.	purple iris
Lathyrus polyphyllus Nutt.	leafy peavine
Lilium columbianum Hanson	tiger lily
Linnaea borealis L.	western twinflower
Lotus crassifolius (Benth.) Greene	big deervetch
Lotus micranthus Benth.	small-flowered deervetch
Lupinus latifolius Agardh	broadleaf lupine
Luzula campestris (L.) DC.	field woodrush

(Continued on next page)

Montia perfoliata (Donn) Howell	miner's lettuce
Montia sibirica (L.) Howell	candyflower
Nemophila parviflora Dougl.	wood nemophila
Osmorhiza chilensis H. & A.	mountain sweet-cicely
Polystichum munitum (Kaulf.) Presl	sword-fern
Pteridium aquilinum (L.) Kuhn. var. pubescens Underw.	western bracken
Pyrola picta Smith	white-veined shin-leaf
Rumex acetosella L.	sour dock
Senecio jacobaea L.	tansy ragwort
Smilacina stellata (L.) Desf.	small false Solomon's seal
Trientalis latifolia Hook.	western starflower
Trillium ovatum Pursh	wood lily
Trisetum canescens Buckl.	tall trisetum
Viola glabella Nutt.	wood violet
Viola sempervirens Greene	evergreen violet

Moss species

Atrichum selwynii Aust.
Dicranum fuscescens Turn.
Eurhynchium oreganum (Sull.) J. & S.
Rhizomnium glabrescens (Kindb.) Koponen
Rhytidiadelphus loreus (Hedw.) Warnst.
Rhytidiadelphus triquetrus (Hedw.) Warnst.

APPENDIX II

UNDERSTORY COVER AND FREQUENCY BY EXPERIMENTAL PLOT

Data are presented as percent cover over percent frequency. The letter "p" indicates that the species was present in a sampling macroplot, but did not fall in a sampling microplot. The symbol "+" indicates that the species was sampled, but cover is less than 0.5 percent. The letter "a" denotes an annual herb, and the letter "b" denotes a biennial or short-lived perennial herb. All other herbs are perennials.

	Experimental Plot													
	30H	22H	36H	41H	24M	35M	38M	25L	34L	40L	27U	21U	37U	46U
							Tall shrub layer (1-6 m)							
Tree species														
Abies grandis											P			
Acer macrophyllum					P	P		P			+/2			2/4
Cornus nuttallii	+/2	6/7	16/20		5/10		12/15			P	1/2	P		15/16
Pseudotsuga menziesii				P										
Shrub species														
Acer circinatum		P					4/7	20/27		5/9		2/4		P
Amelanchier alnifolia	P													
Corylus cornuta	3/7			P			4/7	P			P			
Holodiscus discolor	6/16					P					1/3			
Rhamnus purshiana						P								
Rosa gymnocarpa				P	1/2									
Rubus leucodermis			P			2/2								
Vaccinium parvifolium					P			P						
							Herb and small shrub layer (0-1 m)							
Tree species														
Acer macrophyllum	+/4	+/2	1/8		1/24	2/18	+/2	1/29	1/15	P	+/16	1/21	+/4	+/2
Arbutus menziesii									P					
Cornus nuttallii	2/9	9/22	+/2		P	+/2	5/20	+/2		P	+/2	P	+/4	1/8
Pseudotsuga menziesii	1/16	+/7	2/28	1/24	+/5	12/45	+/7	+/5	1/34	1/30	P	+/2		P
Taxus brevifolia			P		P									
Shrub species														
Acer circinatum		+/4					P	1/7		2/7		P		P
Amelanchier alnifolia	P													
Berberis nervosa	1/6	26/52		P	18/40		P	2/2	2/15		25/45	19/44	6/20	8/18
Ceanothus sanguineus			+/2			P		1/2	P					
Corylus cornuta	1/2	P		P	+/2		+/2	P	P	3/9	P	+/2		P
Gaultheria shallon	+/2	2/13			+/5		6/22	P		1/2	+/2	P		2/2
Holodiscus discolor	+/3			2/2		P	P			P	P			
Rhamnus purshiana						P		P						
Rhus diversiloba		+/2	P					P				P	P	P
Rosa gymnocarpa	2/13	+/4	P	+/4	1/2		P	P	1/2	2/7	1/4	+/2		

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Appendix II. (Continued)

	Experimental Plot													
	30H	22H	36H	41H	24M	35M	38M	25L	34L	40L	27U	21U	37U	46U
Rubus leucodermis			2/8			+/2								
Rubus parviflorus	P	P			P	P								
Rubus ursinus	+/2	1/7		+/2		1/4	P	1/5		P	+/3	1/4		+/2
Symphoricarpos mollis	11/69	3/17	+/2	2/4	+/2	P	2/11	P	1/6	3/22	5/32		P	+/4
Vaccinium parvifolium	P				P			P		P	+/3	P		
Unidentified seedling			P					P				P		
Herbaceous species														
Achlys triphylla								1/5				+/2		P
Actaea rubra					P									
Adenocaulon bicolor		P				P	1/2			P		P	P	P
Adiantum pedatum											P			+/4
Anaphalis margaritacea	P			P	P	+/2				P				
Anemone deltoidea		+/2			+/5		+/2	4/29				P		
Arenaria macrophylla				P	P	3/23			P		+/3	+/2		P
Asarum caudatum								P						
Bromus vulgaris	1/27	+/9	+/2	P	1/26	P	+/2	+/2	+/2	P	+/2	+/4		P
Calypso bulbosa								+/5				P		
Campanula scouleri	2/31	6/43	14/59	22/73	4/31	13/50	5/26	1/12	1/6	4/20	P	P	P	P
Cardamine pulcherrima	P	+/4	+/2		+/5		+/2	+/2						
Chimaphila menziesii				P			+/2		+/2	P			+/9	+/16
Cirsium vulgare (b)	+/2		P		P	P								
Collomia heterophylla (a)	1/43	+/20	1/45	1/33	2/33	1/54	1/17	+/2	1/19	+/4	P	+/6		
Eburophyton austinae													+/2	
Epilobium angustifolium			+/2											
Erythronium grandiflorum	P											P		
Festuca occidentalis	1/24	+/2	5/41	5/51	+/5	+/9	2/20	+/5	+/4	2/17	+/3	+/2		
Festuca subulata		P		P	+/10	P	P	+/2				P		
Fragaria vesca	1/9	P		P		+/2			+/2		+/2			
Galium aparine (a)				P										
Galium triflorum	1/22	1/9	2/24	1/9	3/57	2/32	2/22	5/56	+/2	P	1/11	1/23	+/4	P
Goodyera oblongifolia					P			+/10	P		+/7	+/2	P	P
Hieracium albiflorum	1/9	2/7	1/14	3/13	+/2	1/16	+/2	+/5	P	+/9	P	+/2	P	P
Holcus lanatus						P								
Hypochaeris radicata	P	+/2	P	+/2		+/4			P					
Iris tenax	+/4	1/7	1/10	+/2	+/2	2/7	1/9	P	+/2	1/7	P	+/2		+/2
Lathyrus polyphyllus			3/12		4/7	P	P	4/7		P		P		
Lilium columbianum					P							+/2		
Linnaea borealis	2/16										1/6			
Lotus crassifolius	1/15	1/4	8/20	P	P		+/2		9/38	P				
Lotus micranthus (a)		P	+/2	+/2		+/9	P							P
Lupinus latifolius	6/22	1/2		1/7	1/5	+/9				1/2				

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Appendix II. (Continued)

	Experimental Plot													
	30H	22H	36H	41H	24M	35M	38M	25L	34L	40L	27U	21U	37U	46U
Luzula campestris	+/9		1/12	1/29	+/2	2/36	+/9	+/7	+/4	+/3		P		
Montia perfoliata (a)						+/4								
Montia sibirica			+/4											
Nemophila parviflora (a)			+/6			P	3/9	P	P	P	+/3		P	P
Osmorhiza chilensis	+/2	P			+/2			1/5		P	P	P	P	
Polystichum munitum	1/2	2/4		P	5/7	P	4/7	P	1/2	P	1/6	12/25	P	1/4
Pteridium aquilinum	13/34	18/39	5/16	39/67	13/31	24/45	15/37	6/17	21/47	9/15	1/2	2/17	1/7	+/2
Pyrola picta				P					P	+/2	P		P	P
Rumex acetosella			P	+/4		1/4								
Senecio jacobaea (b)	+/3	+/2	P	P	P	3/7	P	+/2						
Smilacina stellata		P			P	P	P	1/7		P	P	P	P	P
Trientalis latifolia	6/60	4/57	9/69	1/13	10/62	2/27	3/26	9/68	1/26	4/24	2/25	2/17	P	+/4
Trillium ovatum		P					P	+/7		P	+/2	P		P
Trisetum canescens	+/4			+/2	P	P	P			P		P		
Viola glabella												+/2		
Viola sempervirens	+/2	+/2		P	7/36			1/7	+/6		+/2			+/2
Unidentified herb										+/2				
Mosses														
Atrichum selwynii				+/11										
Dicranum fuscescens						P								P
Eurhynchium oreganum	52/100	25/100	32/100	16/87	57/100	30/95	45/100	28/100	7/87	43/100	72/100	40/100	4/96	30/100
Rhizomnium glabrescens											+/2			P
Rhytidiadelphus loreus											+/2			
Rhytidiadelphus triquetrus	2/13	+/7			+/2		+/4	1/7			+/3	1/2		
Unidentified moss #1				+/4										
Unidentified moss #2						+/2								
							Totals							
Tall shrub layer (1-6 m)														
Tree species	+/2	6/7	16/20	P	5/10	P	12/15	P		P	2/3	P		17/20
Shrub species	10/18	P	P	P	1/2	2/2	9/13	20/27		5/9	1/3	2/4		P
Herb and small shrub layer (0-1 m)														
Tree species	2/30	9/26	3/35	1/24	1/26	14/55	5/24	2/34	2/47	1/30	+/16	1/21	+/4	1/10
Shrub species	18/73	31/61	3/12	4/11	19/45	1/7	9/33	4/17	4/17	10/35	32/68	20/48	6/20	10/23
All herbaceous species	36/96	39/87	51/94	74/98	50/90	62/100	38/80	35/90	35/87	22/46	6/49	17/77	1/20	3/31
Grasses and rushes	2/45	+/11	7/45	6/51	1/29	2/41	3/28	1/17	+/9	2/22	+/4	1/7		P
Mosses	54/100	26/100	32/100	16/91	57/100	30/98	46/100	29/100	7/87	43/100	72/100	40/100	4/96	30/100
All vegetation	120/100	111/100	104/100	95/100	134/100	109/100	118/100	90/100	48/100	81/100	114/100	80/100	12/98	61/100

APPENDIX III

UNDERSTORY BIOMASS BY EXPERIMENTAL PLOT

All data are given in kilograms per hectare. The symbol "+" indicates an average biomass of less than 0.05 kg/ha.

	Experimental plot													
	30H	22H	36H	41H	24M	35M	38M	25L	34L	40L	27U	21U	37U	46U
Tall shrub layer (1-6 m)														
Tree species														
Acer macrophyllum - leaves								12.7						12.5
wood								6.3						31.2
Cornus nuttallii - leaves		77.3	268.2		81.1		48.1							42.5
wood		2156.8	17110.0		943.9		696.8							942.0
Shrub species														
Acer circinatum - leaves							64.5	117.9		2.5		5.7		
wood							428.2	2014.0		31.4		280.1		
Corylus cornuta - leaves	0.9						28.8				+			
wood	0.1						84.4							
Holodiscus discolor - leaves	152.8													
wood	6778.8													
Herb and small shrub layer (0-1 m)														
Tree species														
Acer macrophyllum - leaves	0.2	5.0	1.4		2.5	0.1		2.1	4.5		0.3	0.6		
wood	0.3	13.1	0.1		2.1			1.6	6.0		0.4	0.6		
Cornus nuttallii - leaves	8.9	20.0	0.3				8.6				0.1	0.2		0.1
wood	12.1	12.0					333.0							
Pseudotsuga menziesii - leaves	2.3	0.4	21.9	18.9	2.4	23.9			7.7	4.1				
wood	1.1	0.7	20.4	14.4	2.6	16.7			1.5	3.9				
Shrub species														
Acer circinatum - leaves		1.6						6.6		0.5				
wood		3.0						75.6		5.7				
Berberis nervosa - leaves	5.0	712.8			578.0			16.7	92.0		593.3	233.6	57.5	283.6
wood		266.8			255.3			1.8	20.5		120.6	34.4	8.4	60.8
Ceanothus sanguineus - leaves								2.0						
wood								3.8						
Corylus cornuta - leaves	3.0									12.4				
wood	1.3									16.4				
Gaultheria shallon - leaves		17.8			8.0		87.0			31.1				
wood		2.3			5.0		27.5			11.2				
Holodiscus discolor - leaves				8.0			0.1							
wood				14.4										
Rhus diversiloba - leaves											+			1.2
wood											+			4.2

(Continued on next page)

Appendix III. (Continued)

	Experimental plot													
	30H	22H	36H	41H	24M	35M	38M	25L	34L	40L	27U	21U	37U	46U
<u>Rosa gymnocarpa</u> - leaves				1.2			0.2			5.8	0.1			
wood				1.4						7.6				
<u>Rubus leucodermis</u> - leaves			18.6			1.7								
wood			20.9			1.3								
<u>Rubus ursinus</u> - leaves		0.7						4.1				0.6		0.1
wood		0.3						1.7				0.1		
<u>Symphoricarpos mollis</u> -														
leaves	33.2	3.8		1.5	0.1	+	3.9		4.3	4.6	6.1			
wood	45.8	9.2		9.5	0.1	+	12.6		9.8	13.3	11.9			
<u>Vaccinium parvifolium</u> -														
leaves											3.7			
wood											7.5			
<u>Herbaceous species</u>														
<u>Campanula scouleri</u>	3.5	13.1	27.7	31.9	9.6	43.0	5.2	0.2	0.7	9.2				
<u>Galium triflorum</u>	1.8	1.6	0.8	3.3	5.8	1.7	0.4	10.5			2.5	4.7		
<u>Hieracium albiflorum</u>	6.5	5.5	9.6	2.7		0.6	0.1			0.6				
<u>Lathyrus polyphyllus</u>			27.6		14.2		0.4							
<u>Lotus crassifolius</u>	12.4		53.6				1.5		24.6					
<u>Lupinus latifolius</u>	229.8		1.8											
<u>Polystichum munitum</u>					165.2						74.7	132.2		50.8
<u>Pteridium aquilinum</u>	100.2	146.0	35.5	356.7	45.8	276.1	88.8	50.1	65.5	30.4	2.1	4.1	0.6	
<u>Trientalis latifolia</u>	22.0	8.5	24.5	2.3	32.7	4.1	3.1	15.9	1.5	11.4	0.2			
Grasses and rushes	10.1	1.1	7.8	8.6	0.6	5.3	6.0	5.5	+	4.2		1.2		
Other herbs	33.7	1.9	9.6	0.7	5.3	18.1	10.3	8.0	+	2.4	0.2	0.1	2.9	2.9
<u>Mosses</u>	456.0	115.8	215.3	83.2	279.9	218.1	127.2	188.4	51.9	252.3	377.7	232.2	22.0	186.9
							<u>Totals</u>							
<u>Tall shrub layer</u> (1-6 m)														
Tree species - leaves		77.3	268.2		81.1		48.1	12.7						55.0
wood		2156.8	17110.0		943.9		696.8	6.3						973.2
Shrub species - leaves	153.7						93.3	117.9		2.5	+	5.7		
wood	6778.9						512.6	2014.0		31.4		280.1		
<u>Herb and small shrub layer</u> (0-1 m)														
Tree species - leaves	11.4	25.4	23.6	18.9	4.9	24.0	8.6	2.1	12.2	4.1	0.4	0.8		0.1
wood	13.5	25.8	20.5	14.4	4.7	16.7	333.0	1.6	7.5	3.9	0.4	0.6		
Shrub species - leaves	41.2	736.7	18.6	10.7	586.1	1.7	91.2	29.4	96.3	54.4	603.2	234.2	57.5	284.9
wood	47.1	281.6	20.9	25.3	260.4	1.3	40.1	82.9	30.3	54.2	140.0	34.5	8.4	65.0
Herbaceous species	420.0	177.7	198.5	406.2	279.2	348.9	115.8	90.2	92.4	58.2	79.7	142.3	3.5	53.7
<u>All vegetation</u>														
Non-woody parts	1082.3	1132.9	724.2	519.0	1231.2	592.7	484.2	440.7	252.8	371.5	1061.4	615.2	83.0	580.6
Wood	6839.5	2464.2	17151.4	39.7	1209.0	18.0	1582.5	2104.8	37.8	89.5	140.4	315.2	8.4	1038.2
Total	7921.8	3597.1	17875.6	558.7	2440.2	610.7	2066.7	2545.5	290.6	461.0	1201.8	930.4	91.4	1618.8