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Environment, Vegetation, and Regeneration After Timber Harvest in the Hungry-Pickett Area of Southwest Oregon

Joseph N. Graham, Edward W. Murray, and Don Minore

Abstract

Environmental factors were related to forest regeneration on clearcut and partially cut areas managed by the Bureau of Land Management in the Hungry-Pickett area northwest of Grants Pass, Oregon. The multiple regression equations developed for this study can be used to compare the relative difficulty of regenerating forested sites within the study area. The equations show that difficulty of regenerating clearcuttings increases with increasing solar radiation, temperature, rock cover, and depth of the soil A horizon. Difficulty of regenerating partial cuts increases with surface gravel cover and is related to slope, aspect, and vegetation.

Keywords: Regeneration (natural), logging (-regeneration, environmental effects, southwest Oregon.

Introduction

Forest management problems probably are more intricate and varied in southwest Oregon than in any other part of the Pacific Northwest (Hayes 1959). Climate ranges from cool and moist near the coast to hot and dry in the interior valleys, where unshaded soil temperatures may reach 175° (79°C) on west aspects (Hallin 1968). Much of the area (the Klamath Mountain complex) is "a genuine geologic nightmare" (McKee 1972); and this confusing geology is associated with extremely varied soils.

Vegetation in southwest Oregon has elements of the California, north coast, and eastern Oregon floras; but many species are indigenous (Franklin and Dyrness 1973). Brush competition is often severe where adequate moisture is available. Grasses rapidly exhaust soil mositure on many south-facing slopes (Preest 1975).

The environments of southwest Oregon are not all severe, but they are diverse and difficult to identify. Selecting a successful regeneration regime is also difficult, and the selection often must be based on subjective observations. Unfortunately, those observations may not be effective in predicting the relative difficulty of obtaining adequate post-harvest regeneration on a given site. More objective methods are needed to help identify sites that require extra effort or specialized regeneration techniques.

JOSEPH N. GRAHAM and EDWARD W. MURRAY were research foresters and DON MINORE is plant ecologist at the Pacific Northwest Forest and Range Experiment Station, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, Oregon 97331.

The moisture and temperature characteristics of sites in southwest Oregon have been identified and correlated with vegetation in several previous studies (Waring 1969, Minore 1972, Minore et al. 1982). Environmental factors have also been correlated with forest regeneration (Carkin and Minore 1974; Minore et al. 1977, 1982; Minore and Carkin 1978) . All of these studies involve relatively small portions of southwest Oregon, however; and none are applicable outside the areas in which they were developed. This is proper, for a large and diverse region like southwest Oregon is best studied by stratifying it into smaller, more homogenous units. This study of the Hungry-Pickett area constitutes one more piece of information about the complex southwest Oregon mosaic.

The Hungry-Pickett area is northwest of Grants Pass in the mixed-conifer and mixed-evergreen forest types described by Franklin and Dyrness (1973). Within the 120-square-mile study area elevations range from 1,000 to 4,000 ft (300 to 1 200 m). Steep slopes are common. Soils vary from shallow, stoney profiles to deep and well developed silty clay loams. Annual precipitation tends to increase from east to west, ranging from about 30 to 80 in (75 to 200 cm). Air temperatures monitored at 25 locations in 1979 ranged from a low of 12°F (-11°C) in January to a high of 121°F (49°C) in July.

We studied the Hungry-Pickett area to derive relationships between environmental factors and post-harvest forest regeneration in clearcut and partial cut areas. These relationships were developed on Bureau of Land Management land, but they should be useful throughout the study area. Our objective was to compare forested sites in terms of relative difficulty of regeneration.

Methods

Clearcuts

From about 70 potential sample areas, 50 were selected to include as many different combinations of aspect and elevation as possible and provide a good geographic distribution (fig. 1). All were 3 to 20 years old and had a nearby, uncut stand of similar slope, aspect, soils, and elevation to represent pre-harvest vegetation and environment.[1] We established a grid of 30 subplots spaced 33 ft (10 m) apart on a relatively uniform area[2] in each sample unit. Each grid was located away from road fills and adjacent stands of timber. The subplots were systematically located and equally spaced. Each consisted of two concentric circles with areas of 1/250 and 1/60 acre (0.0016 and 0.0067 ha).

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[1] An uncut or lightly partial cut stand with differences no greater than 30 percent slope, 35° azimuth, and 200-foot elevation from the clearcut unit.

[2] Uniform slope and aspect for this study were defined as being within a range of 30 percent slope and 35° azimuth.

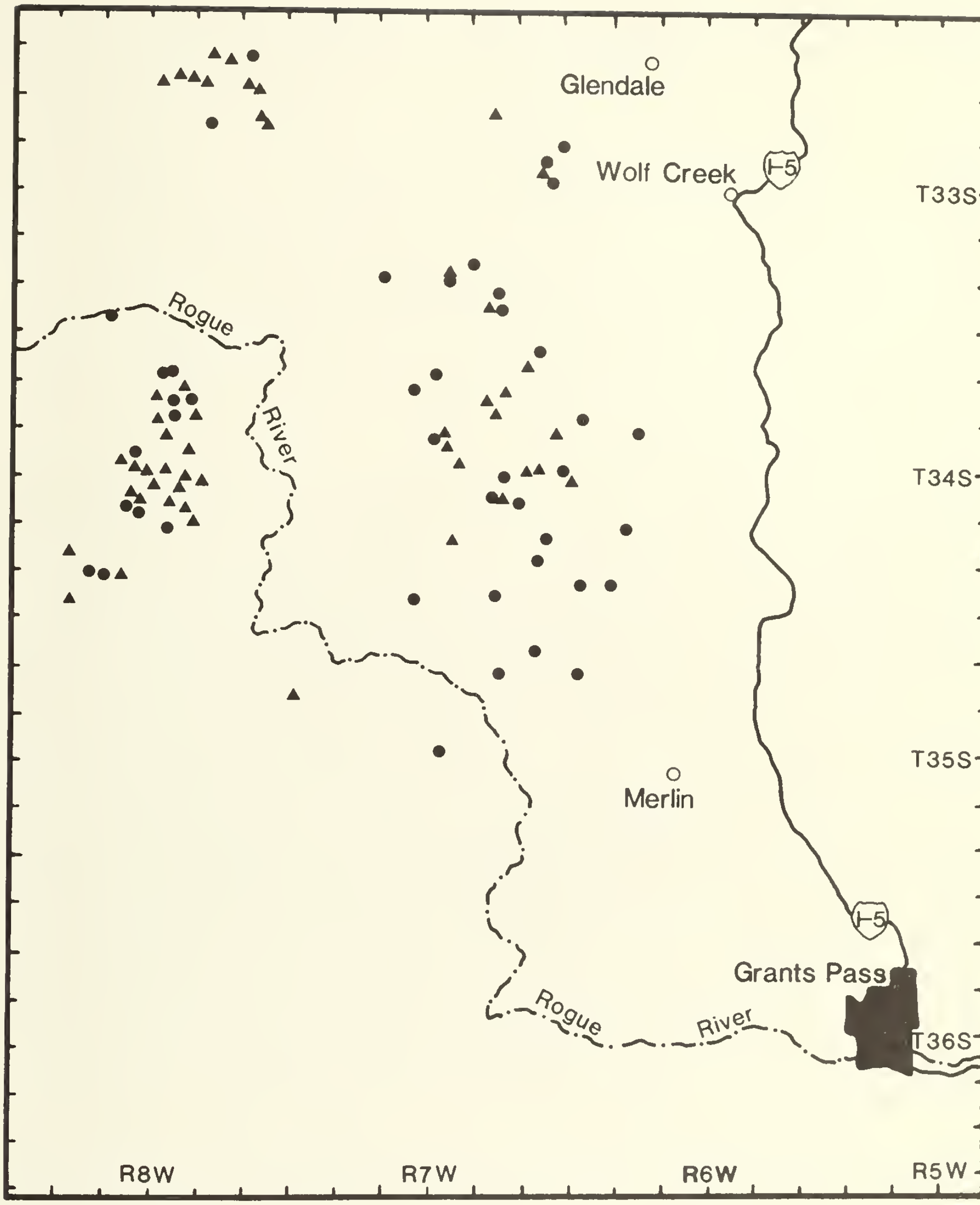

Figure 1. — Sample plot locations in the Hungry-Pickett study area. Clearcuts are indicated by triangles; partial cuts by circles.

On the 1/250-acre (0.016-ha) subplots, conifer seedlings were counted and recorded as established post-harvest,[3] unestablished, or pre-harvest. Established post-harvest seedlings were tallied by species. Cover estimates of grass, forbs, slash, exposed rocks, and surface gravel were recorded; and the dominant grass and forb species were also identified and tallied on the 1/250-acre subplots. Depth of duff was measured to the nearest 0.2 in (0.5 cm). Percent shrub and tree cover and the dominant species of each were estimated on the larger 1/60-acre (0.0067-ha) subplots.

[3] *Pseudotsuga* and *Abies* seedlings were considered established if they had branched before 1979. Establishment of other conifers was determined by their size and vigor.

Information on slope and aspect was also collected at each subplot. Average plot-grid elevation was determined with an altimeter calibrated daily against known bench marks.

We dug a 20-in (50-cm) soil pit at four well-distributed points in each grid, measured the depth of the A horizon, and estimated percent of coarse fragment content of both the A horizon and the entire 20-in (50-cm) profile. Total soil depth was determined by extending one of the subplot soil pits or by digging in an adjacent road cut down to the C horizon or to 50 in (127 cm). We collected a soil sample at 10 in (25 cm) in each pit, then combined equal volumes of the four samples to obtain a composite sample for the grid. These composite samples were air-dried indoors, then tested by a modified hydrometer technique to estimate silt + clay content. Each composite soil sample was also analyzed for cation exchange capacity, pH, Ca, K, P, No_3, NH_4, Mg, and Fe.

The subplot data for each sample grid were averaged to obtain plot parameters. We used the tables of Frank and Lee (1966) to generate a radiation index for each plot (table 1). The optimum aspect for regeneration was computed by using a procedure similar to that described by Stage (1976). We used the optimum aspect in conjunction with an aspect transformation equation published by Beers et al. (1966) to obtain an aspect code for each plot. The aspect code was used as an independent variable in multiple regression analyses.

Plants found in the uncut stands were identified. Regeneration indicator species were selected and weighted as described by Minore and Carkin (1978), and a clearcut stocking index (CCSI) was calculated for each plot (table 2). Similarly, temperature and moisture indices were also determined for each sample plot. Although vegetative indices do not give precise estimates of environmental variables on a particular site, they do provide a means of gauging the relative differences between sites. Multiple regression was used to correlate these indices and the quantitative environmental variables to stocking percent and number of seedlings per acre.

Table 1 — Radiation indices for 42° N. latitude (from Frank and Lee 1966)

Slope percent	N	S	NNE NNW	SSE SSW	NE NW	SE SW	ENE WNW	ESE WSW	E W
0	.4704	.4704	.4704	.4704	.4704	.4704	.4704	.4704	.4704
10	.4329	.5039	.4359	.5014	.4442	.4942	.4562	.4833	.4700
20	.3930	.5323	.3994	.5278	.4168	.5148	.4416	.4944	.4689
30	.3524	.5553	.3625	.5492	.3898	.5314	.4271	.5032	.4670
40	.3133	.5728	.3270	.5656	.3640	.5441	.4133	.5096	.4644
50	.2786	.5854	.2943	.5773	.3403	.5531	.4005	.5136	.4611
60	.2496	.5935	.2662	.5849	.3191	.5588	.3887	.5156	.4573
70	.2246	.5981	.2424	.5891	.3006	.5617	.3781	.5158	.4530
80	.2030	.5998	.2219	.5906	.2847	.5624	.3685	.5146	.4484
90	.1839	.5993	.2042	.5901	.2710	.5615	.3599	.5124	.4436
100	.1677	.5972	.1887	.5880	.2593	.5593	.3520	.5094	.4388

Table 2 — Indicator species and values to be used in estimating relative regeneration difficulty after clearcutting. A clear-cut stocking index (CCSI) may be obtained by averaging the values of all species present in a given stand. High index values indicate better regeneration (less regeneration difficulty) than low values.

Species	Indicator value
Achlys triphylla	14
Trientalis latifolia	14
Vancouveria hexandra	14
Berberis nervosa	13
Vaccinium ovatum	11
Galium aparine	11
Polystichum munitum	11
Viola sempervirens	11
Libocedrus decurrens	3
Sanicula graveolens	3
Pinus ponderosa	2
Nemophila parviflora	1

Partial Cuts

We sampled 42 partial cut stands (fig. 1) by using the same selection criteria and subplot design used with the clearcuts. All partial cuts which were at least 3 years old were sampled. Similar measurements were also made of environmental factors and regeneration. The only major deviation from our clearcut data collection procedure was the identification of vegetation within the cutting unit instead of in an adjacent uncut stand. For each 1/250-acre (0.0016-ha) subplot, we recorded the cover of herbaceous plants by species and estimated total grass and forb cover percentages. Shrub and tree cover were recorded on a larger 1/60-acre (0.0067-ha) concentric subplot.

At each subplot, we measured residual overstory basal area with a 20-factor prism and estimated stump basal area. Two methods were employed to measure overstory canopy density: we averaged four spherical densiometer readings (one taken in each cardinal direction) and estimated the percent of canopy cover directly above the center of the subplot by sighting through a tube formed by a 10¾ oz. soup can.

At each subplot we also recorded the species, diameter, age, and condition of the nearest live conifer at least 4.5 ft (1.37 m) tall. Breast height age of these trees was estimated by using an increment borer or by counting the branch whorls on saplings. Growth rings were examined to determine the effect of release on individual trees.

We assumed that most plant species in partially cut stands were the same as those present before logging. Using these species, we applied the same methods used with the clearcuts to derive a partial cut stocking index (PCSI, table 3), a moisture index, and a temprature index for each sample stand. These indices and the other quantitative variables were analysed by stepwise multiple regression to obtain an equation for natural regeneration in the sampled partial cuts.

Table 3 — Indicator species and values to be used in estimating relative regeneration difficulty after partial cutting. A partial cut stocking index (PCSI) may be obtained by averaging the values of all species present in a given stand. High index values indicate better regeneration (less regeneration difficulty) than low values.

Species	Indicator value
Xerophyllum tenax	13
Arctostaphylos viscida	12
Lathyrus nevadensis	12
Phlox spp.	12
Pyrola dentata	12
Sanicula graveolens	12
Pinus ponderosa	11
Arctostaphylos patula	11
Melica harfordii	11
Chimaphila menziesii	11
Pyrola picta	11
Rubus leucodermis	3
Rubus parviflorus	3
Deschampsia elongata	3
Hypericum perforatum	3
Quercus kelloggii	2
Aster radulinus	2
Polystichum munitum	2
Symphoricarpos albus	1

Temperature

We established 25 temperature stations (10 recording thermographs and 15 maximum/minimum thermometers) in undisturbed stands throughout the study area. These stands were chosen to sample the range of aspect and elevation present in the Hungry-Pickett area and to obtain an equitable geographic distribution. Only areas with relatively uniform slope and aspect were used. Ridgetops, road cuts, and drainages were avoided.

Air temperature was measured under a shelter at 8 inches (20 cm) above the soil surface at each temperature station. The stations were monitored and calibrated monthly from November 1978 to September 1979 except when prohibited by winter snow accumulations.

A 1/5-acre (0.08-ha) vegetation plot was established at each temperature station in the spring of 1979. All plant species that appeared between April and August were identified and recorded by abundance. Applying a modified version of the procedure described by Warner and Harper (1972), we used maximum temperatures recorded during the growing season and vegetation data to derive indicator species (table 4) and develop temperature indices for our clearcut and partial cut sample areas.

Table 4 — Indicator species and values to be used in estimating relative temperature conditions in undisturbed stands. A temperature index may be obtained by averaging the values of all species present in a given stand. High values indicate warm temperatures. Low values indicate cool temperatures.

Species	Indicator value
Quercus kelloggii	13
Rhus diversiloba	12
Elymus glaucus	12
Arbutus menziesii	11
Ceanothus integerrimus	11
Apocynum androsaemifolium	11
Asarum hartwegii	11
Habenaria spp.	11
Carex spp.	10
Cynoglossum grande	10
Epilobium minutum	10
Madia spp.	10
Achlys triphylla	2
Disporum hookeri	2
Polystichum munitum	2
Chimaphila umbellata	1

Moisture

We established 57 moisture stress plots in undisturbed stands throughout the range of slopes, aspects, and elevations occuring within the study area. Sites that might exhibit unusual soil moisture conditions (e.g., areas near road cuts or fills, draws, creek bottoms, and ridge tops) were avoided. Plant species were identified, and a vegetation list was compiled for each of these plots.

Waring and Cleary's (1967) technique was used to measure nocturnal plant moisture stress with a pressure bomb. On each plot, at least two Douglas-fir saplings between 5 and 10 ft (1.5 and 3 m) tall were sampled during the third week of August 1979. We derived a set of moisture indicator species from these moisture and species data. Here again, a modified version of the procedure described by Warner and Harper (1972) was utilized.

Results

Clearcuts

The clearcut samples ranged in elevation from 1,200 to 3,950 ft (366 to 1 204 m). All aspects were represented, and slopes ranged from 22 to 77 percent. Post-harvest regeneration ranged from 3- to 100-percent stocking. Less than half of the plots were 60 percent stocked, however; and many of the clearcut environments were dominated by seral vegetation.

Several types of seral vegetation occupied the clearcuts in 1979. Tanoak (*Lithocarpus densiflorus*) and whipple-vine (*Whipplea modesta*) appeared as dominant or codominant species on 72 and 76 percent of the sample plots, respectively. Where whipple-vine was absent, beargrass (*Xerophyllum tenax*) and bracken fern (*Pteridium aquilinum*) usually were dominant. Madrone (*Arbutus menziesii*) was prominent on only 12 percent of the sample units, and it was never dominant at elevations above 3,000 ft (914 m). Instead, salal (*Gaultheria shallon*) and varnish-leaf ceanothus (*Ceanothus velutinus*) tended to be dominant above 2,300 ft (701 m).

Variation in dominant seral vegetation was not associated with variation in regeneration on the clearcuts, with two exceptions. Clearcut areas dominated by poison oak (*Rhus diversiloba*) or manzanita (*Arctostaphylos* ssp.) tended to be poorly stocked.

The moisture index, considered separately, was not significantly correlated with post-harvest regeneration or with aspect. Dry and moist sites were found on all aspects. All of the moist sites were at elevations above 2,500 ft (762 m), however; and all of the dry sites were below 3,100 ft (955 m).

Several field observations were confirmed by simple correlations. For example, content of surface gravel and coarse soil fragments tended to increase with increasing slope, and temperature indices decreased with elevation.

Vegetation, slope, and aspect were well correlated with regeneration stocking. Considered separately, the clearcut stocking indices (CCSI's) derived from indicator plants listed in table 2 accounted for 34 percent of the variation in relative clearcut stocking.

Slope and aspect, expressed as radiation indices (table 1), provided a significant indication of regeneration difficulty on the clearcut areas. When regeneration, slope, and aspect are combined in a mathematical model similar to the one described by Stage (1976), the trends can be expressed as a series of curves (fig. 2). These curves indicate that steep slopes on south-southwest aspects tended to have the poorest clearcut regeneration.

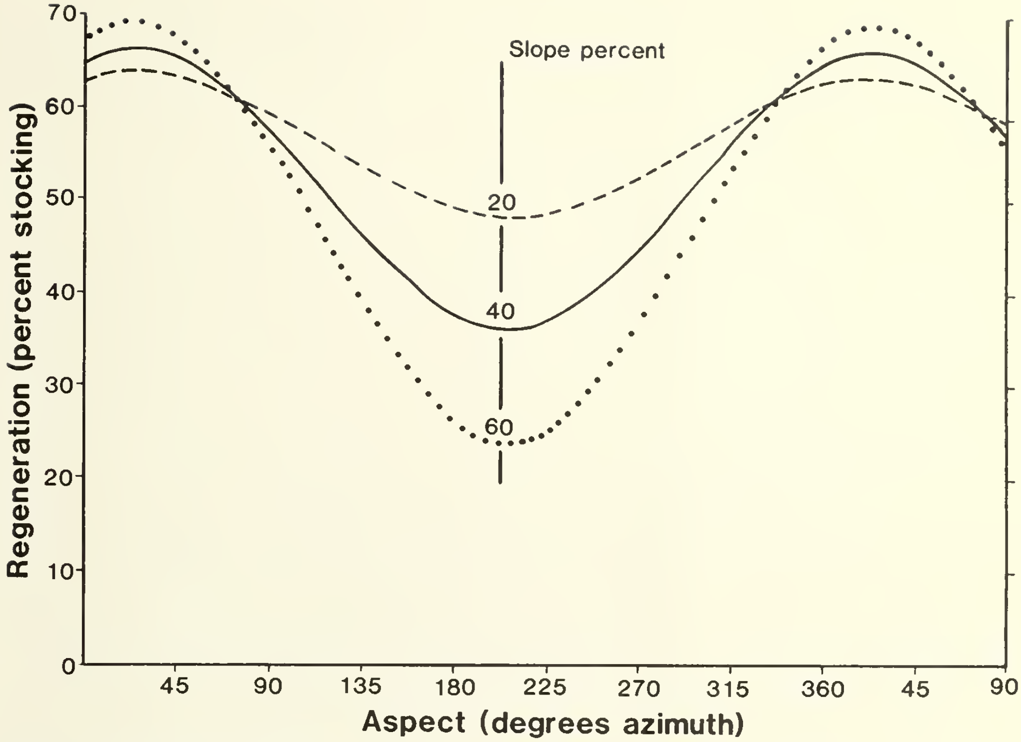

Figure 2. — Post-harvest regeneration trends of clearcuts with different slopes and aspects. Percent stocking = 60.7102 + 0.3412 (slope)(cos. aspect) + 0.1622 (slope) (sin. aspect) - 0.2433 (slope). r^2 = 27.

We used stepwise multiple regression analyses to derive mathematical models for estimating relative regeneration difficulty in terms of past regeneration success. The best multiple regression equation in which all coefficients were significant accounted for 57 percent of the total variation:

Relative clearcut stocking percent = 69.633572 - 103.54307 (radiation index)
- 1.879096 (temperature index)
- 0.706681 (depth A horizon in cm)
- 1.147246 (percent rock cover)
+ 5.173157 (clearcut stocking index)

$R^2 = .575$

$S_{y \cdot x} = 18.67$

$n = 49.$

This equation is not suitable for the precise prediction of absolute stocking levels, but it should be useful in comparing the relative regeneration difficuity of sites to be clearcut. The user should calculate relative clearcut stocking percents for the areas to be compared, then use those percents to assess relative regeneration difficulty.

Partial Cuts

We used only post-harvest natural regeneration in our partial cut analyses. The partially cut stands ranged in elevation from 1,100 to 3,800 ft (335 to 1 158 m). Aspects on 17 ranged from 90° to 180°, and 13 had aspects between 270° and 360°. The remaining 12 sample stands were on aspects of 0° to 90° (7 stands) and 180° to 270° (5 stands). Stocking ranged from 0 to 90 percent.

Age structure of the residual overstory varied with the stand sampled; but more than half of the partial cuts (24 of the 42 stands sampled) had two or three distinct age classes. These age classes were about 10 to 20, 140, 230 to 250, or 340 years old. Ten of the sample stands were even aged, with 50 to 100 years being the most common age class. Well balanced uneven aged overstories corresponding to the classic "inverted J" distribution were present in seven sample stands, and one was all aged with conifers ranging from seedlings to 700-year-old trees.

Most of the partial cutting probably was not designed for release purposes, but more than half (59 percent) of the residual trees responded with accelerated radial growth. The percentage of sample trees released varied erratically among sample stands, however, ranging from 8 to 100 percent. Radial growth increased up to more than a millimeter per year in some trees. It was not well correlated with stand age, diameter, or environment but tended to be greatest soon after partial cutting and then tapered off a few years later. This post-harvest increase in radial growth appeared to be sustained longer in grand fir than in Douglas-fir.

A mathematical model described by Stage (1976) relating slope and aspect to natural regeneration (fig. 3) accounted for 24 percent of the variation in stocking. It showed that partial cuts with the best natural regeneration tended to occur on gentle slopes with south-southeast or northwest aspects. When we used this technique to examine the relationship of residual stand basal area and aspect to stocking (fig. 4), the best natural regeneration occurred on south-southeast aspects under residual stands with high basal areas.

Several other partial cut environmental variables showed significant simple correlations ($p < .01$) with regeneration. Both slope/aspect index (table 5) and sugar pine basal area increased with increases in natural regeneration stocking percent. Moisture, depth of the A horizon, and percent of coarse fragment increased with elevation. Temperature indices decreased with decreasing elevation and with increasing pre-harvest basal area.

When dominant species were used as classification criteria for plant communities in the partial cuts, natural regeneration tended to be worst in the *Pseudotsuga/ Ceanothus cuneatus* and *Pseudotsuga/Corylus-Holodiscus* communities. It was best where *Pseudotsuga/Lithocarpus/Whipplea* occurred.

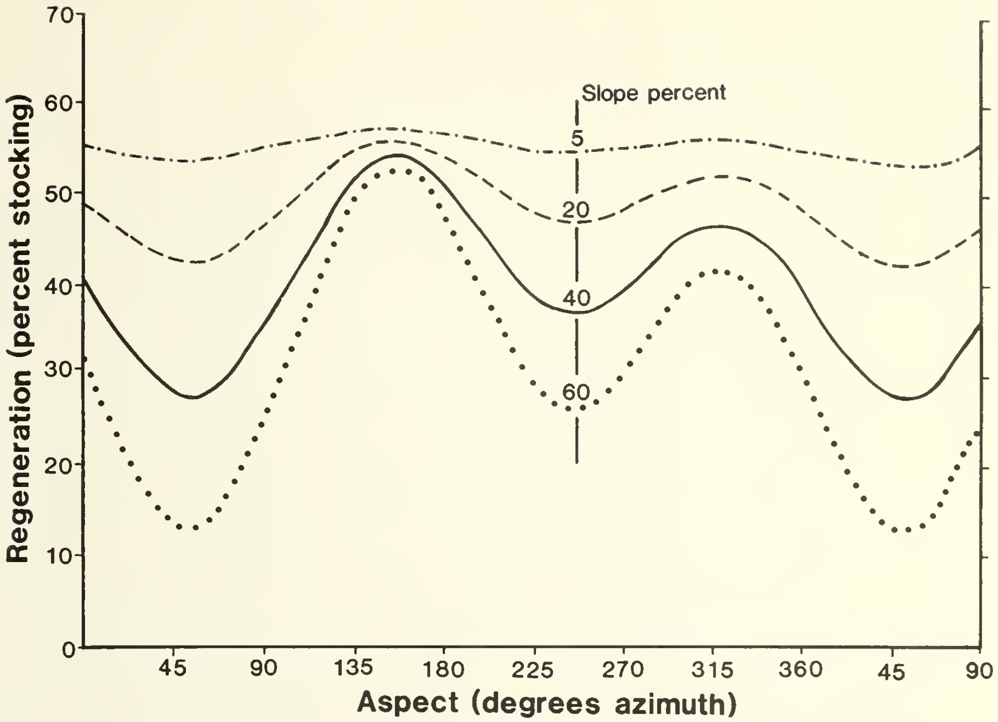

Figure 3. — Post-harvest regeneration trends of partial cuts with different slopes and aspects. Percent stocking = 57.5185 - 0.1374 (slope)(cos. aspect) - 0.0515 (slope)(sin. aspect) + 0.0963 (slope)(cos. [2·aspect]) - 0.1991 (slope)(sin. [2·aspect]) - 0.4025 (slope). r^2 = .24.

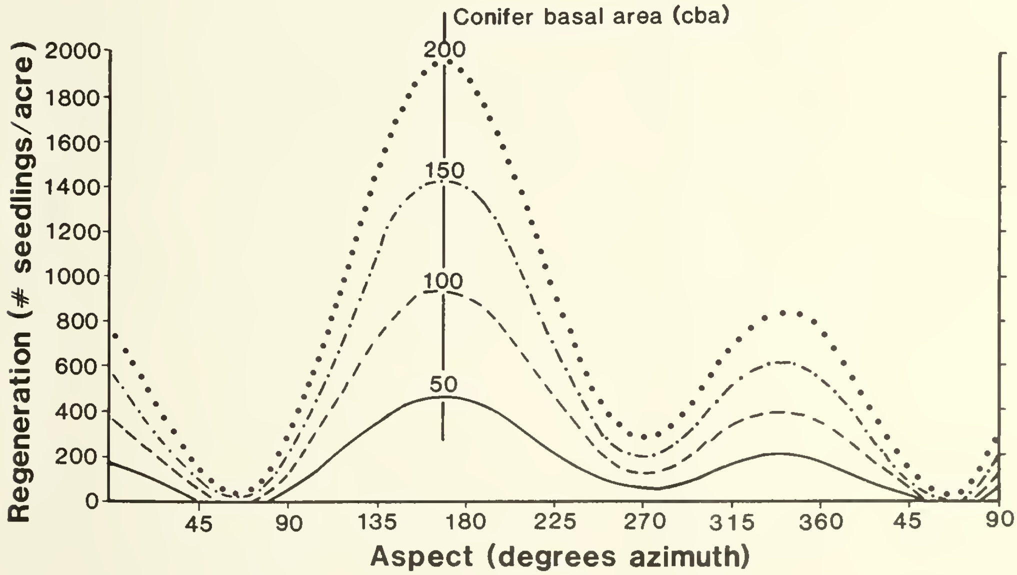

Figure 4. — Post-harvest regeneration trends of partial cuts with different aspects and conifer basal areas. Number of seedlings per acre = -2.1754 - 0.3444 (cba)(cos. aspect) + 0.3140 (cba)(cos. [2·aspect]) - 0.1721 (cba)(sin.[2·aspect]) + 0.4944 (cba). r^2 = .504.

Table 5 — Indices used in relating partial cut regeneration to slope and aspect [1]

Aspect azimuth (degrees)	Slope percent									
	0	10	20	30	40	50	60	70	80	90
0	58	53	49	44	40	36	31	27	23	18
10	58	52	47	42	37	32	27	21	16	11
20	58	52	46	40	34	28	22	16	10	4
30	58	50	44	38	31	24	18	11	4	0
40	58	50	43	36	29	22	14	7	0	0
50	58	50	43	35	28	20	13	5	0	0
60	58	50	43	35	28	21	13	6	0	0
70	58	50	43	36	29	22	15	8	1	0
80	58	51	45	38	32	25	19	13	6	0
90	58	52	46	41	35	30	24	19	13	8
100	58	53	48	44	39	35	30	26	21	17
110	58	54	51	47	43	40	36	33	29	26
120	58	55	52	50	47	45	42	40	37	35
130	58	56	54	52	51	49	47	46	44	42
140	58	56	55	54	53	52	51	50	50	48
150	58	57	56	55	54	54	53	52	51	51
160	58	57	56	55	54	54	53	52	51	51
170	58	56	55	54	53	52	51	50	49	48
180	58	56	54	53	51	50	48	47	45	44
190	58	55	53	51	49	46	44	42	40	37
200	58	55	52	49	46	43	40	37	34	31
210	58	54	50	46	43	39	35	31	28	24
220	58	53	49	44	40	36	31	27	22	18
230	58	53	48	43	38	33	28	23	19	14
240	58	52	47	42	37	32	27	22	17	11
250	58	52	47	42	37	32	27	22	16	11
260	58	53	48	43	38	33	28	23	18	13
270	58	53	48	44	39	35	30	26	21	17
280	58	53	49	45	41	37	33	29	25	21
290	58	54	50	47	43	40	36	33	29	26
300	58	54	51	48	45	42	39	36	33	30
310	58	55	52	49	47	44	41	38	36	33
320	58	55	52	50	47	45	42	39	37	34
330	58	55	52	49	47	44	41	39	36	33
340	58	54	51	48	45	42	39	36	33	30
350	58	54	50	47	43	39	36	32	29	25

[1]These slope/aspect indices were calculated by using the procedure described by Stage (1976).

When considered alone, partial cut stocking indices (PCSI's) derived from the indicator species listed in table 3 accounted for 46 percent of the variation in stocking. This PCSI can be used individually to estimate the relative difficulty of obtaining natural regeneration in Hungry-Pickett partial cuts. Using the partial cut stocking index in conjunction with additional variables, however, provides a more accurate estimate of relative regeneration difficulty. The best multiple regression equation in which all coefficients were significant accounted for 53 percent of the variation in stocking:

$$\text{Relative partial cut stocking percent} = -8.414803 + 6.118036\,(\text{partial cut stocking index}) + 0.369486\,(\text{slope/aspect index}) - 0.204111\,(\text{percent of surface gravel cover})$$

$$R^2 = 0.524$$
$$S_{y \cdot x} = 15.52$$
$$n = 42.$$

Like the equation previously given for clearcuts, this multiple regression equation should be used to assess relative regeneration difficulty, not absolute stocking levels.

Discussion

Adequate regeneration is not easily attained in the Hungry-Pickett area. Only 38 percent of the clearcut sample plots and 21 percent of the partial cut sample plots had stocking of 60 percent or greater (using 1/250-acre (0.0016-ha) subplots and post-harvest seedlings as the stocking criteria). Since these data are based on stands cut before 1976, they do not reflect current silvicultural procedures. They do, however, emphasize the relative regeneration difficulties encountered.

Clearcut harvesting resulted in the best regeneration on north, northeast, northwest, and east aspects with slopes greater than 20 percent. Post-harvest natural regeneration was best after partial cutting on south, southeast, and southwest aspects. Aspect was not critical where slopes were less than 20 percent.

Preharvest regeneration was ignored in our analysis, but it constitutes an additional source of regeneration that should be evaluated on each site. Regeneration damage caused by overstory removal should also be evaluated. We were unable to do so in this study.

Regression data are not suitable for determining cause and effect, and we cannot use our equations to explain the low level of regeneration observed. The study was not designed to determine which environmental factors are most responsible; subjective field observations, however, indicate that vegetative competition was one of the most important problems in the Hungry-Pickett area.

This study included many environmental variables that influence post-harvest regeneration, but several important silvicultural variables could not be measured or evaluated. Site preparation, planting techniques, and condition of the planting stock were all important factors influencing clearcut regeneration. Consequently these variables constitute unmeasured sources of error in our correlations of regeneration and the environment. The partial cut correlations were less affected by these unmeasured variables than clearcut correlations; unlike the clearcuts, the partial cuts were not planted.

We assumed that the effects of environmental factors were not masked by past site preparation or planting treatments, and that regeneration differences related to environmental factors, though somewhat attenuated, were still evident among the plots sampled. When the harsh environment in the Hungry-Pickett area and the poor regeneration frequently recorded in the study plots are considered, this seems to be a valid assumption.

Our results reflect practices in effect 3 to 20 years before the beginning of this study. Increased efforts to improve planting stock or regeneration techniques may result in stocking levels higher than those resulting from our mathematical models, but the relative differences in regeneration difficulty among areas sampled should not change with improvements in reforestation technology. Sites with low relative predicted stocking should be more difficult to regenerate than those with high relative predicted stocking. The mathematical models presented here are not intended to serve as precise, absolute predictors of future stocking levels. Their purpose is to indicate where special techniques and additional effort will be required to obtain adequate regeneration.

The quality of planting stock has improved and more intensive regeneration methods are available; but money, workforce, or management limitations may negate many of these technological gains. Such limitations may enhance the value of this study. By using the equations to predict the relative difficulty of regeneration, reforestation efforts could be given priority.

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Appendix I
List of Pertinent Clearcut Data, by Location

Location (T.R.S.)	Stocking	Elevation	Aspect azimuth	Slope	Clearcut stocking index	Temperature index	Radiation index	Rock	Depth A	Estimated[1] relative stocking
	Percent	Feet	Degrees	Percent				Percent	Centimeters	Percent
35-7-7	63	1400	8	79	10.8	8.5	.2118	1	14	76
34-7-23	27	2600	111	76	5.6	7.9	.5097	2	17	17
33-7-13	20	2400	253	63	8.0	7.9	.4741	19	5	22
34-6-19	77	2100	30	71	11.3	7.4	.2605	2	16	74
34-7-27	47	2550	82	52	12.8	7.6	.4390	1	18	62
33-8-12	47	3750	112	51	13.5	4.7	.5110	20	5	51
34-7-11	63	1300	51	60	12.8	7.1	.3389	1	14	76
34-8-33	27	2400	74	77	10.1	6.8	.3936	22	14	33
34-8-23	50	3000	61	43	13.2	3.6	.3940	2	22	72
34-8-15	47	2550	133	57	11.2	5.8	.5510	4	28	35
34-8-15	73	3100	55	53	13.0	4.8	.3633	1	16	78
34-8-15	73	3050	154	74	11.0	5.0	.5834	3	2	52
34-8-21	47	3950	119	45	13.2	1.8	.5219	8	16	60
34-8-21	57	3800	266	39	8.7	6.0	.4733	5	11	41
34-8-16	30	3700	265	28	8.0	1.0	.4589	1	8	55
33-7-11	80	1850	173	31	12.6	7.3	.5530	3	4	58
33-7-35	7	1700	192	22	5.0	9.4	.5330	0	12	14
34-8-22	97	2850	51	59	10.3	6.5	.3388	2	18	61
34-8-22	3	3050	172	35	8.5	6.8	.5611	2	8	35
34-8-22	37	2550	155	61	11.5	5.8	.5804	2	12	47
34-7-11	13	2450	307	56	9.6	5.8	.3523	5	34	42
34-7-11	53	2050	34	76	12.5	6.5	.2661	4	22	74
33-8-12	53	3500	21	59	13.5	6.3	.2712	15	7	77
33-8-1	50	3800	321	54	12.6	4.3	.3198	37	27	32
34-8-22	87	3500	326	47	12.6	3.6	.3293	11	30	60
34-8-22	27	3150	146	68	9.3	6.5	.5731	2	18	31
34-8-15	37	3450	197	43	12.7	4.0	.5679	1	4	65
34-8-10	17	2800	220	45	9.7	6.8	.5510	0	28	30
34-8-10	40	2700	212	32	7.5	6.5	.5430	0	17	28
33-8-1	47	3100	332	68	11.5	7.0	.2639	25	13	51
33-8-2	77	2700	37	38	11.9	8.4	.3592	1	10	70
34-7-1	50	1200	256	29	7.5	11.3	.4896	1	12	27
33-8-2	47	2600	277	63	12.7	9.3	.4336	1	12	63
34-8-32	47	2150	346	70	11.0	7.0	.2389	5	17	71
34-8-29	23	2950	163	57	2.6	--	.5838	34	13	--
34-7-15	83	2600	19	73	11.1	7.6	.2370	5	22	67
34-7-15	20	2750	43	67	9.6	7.1	.3031	19	22	37
34-7-13	47	2700	24	66	12.8	6.5	.2602	19	19	61
33-8-3	97	3300	73	60	11.4	4.0	.4076	4	18	62
33-8-3	43	3300	288	65	10.1	7.4	.3974	11	11	46
33-7-27	100	1350	7	65	13.2	7.4	.2445	1	14	88
34-7-13	90	2000	353	67	12.6	7.6	.2419	0	21	81
34-7-13	13	2400	268	70	7.0	7.0	.4581	13	33	7
33-8-2	97	2700	344	74	12.6	1.8	.2296	13	18	80
33-8-2	93	2650	23	67	13.0	4.0	.2553	4	26	80
34-7-15	60	2300	78	69	9.9	6.0	.4137	8	23	41
34-8-11	10	2850	165	67	11.0	5.0	.5883	1	20	41
34-8-10	70	2050	75	45	11.4	1.8	.4247	1	7	75
34-8-16	33	3000	305	62	10.4	5.6	.3486	24	23	33
34-8-15	83	3000	312	51	11.4	4.0	.3484	3	11	74
34-8-16	30	3700	265	28	8.0	1.0	.4589	1	8	55

[1]Calculated from: Relative stocking percent = 69.633572 - 103.54307 (radiation index) - 1.879096 (temperature index) - 0.706681 (depth A horizon) - 1.147246 (percent rock cover) + 5.173157 (clearcut stocking index).

Appendix II
List of Pertinent Partial Cut Data, by Location

Location (T.R.S.)	Stocking	Elevation	Aspect azimuth	Slope	Partial cut stocking index	Slope aspect index	Surface gravel cover	Estimated[1] relative stocking
	Percent	Feet	Degrees	Percent			Percent	Percent
37-7-11	67	1100	130	27	7.2	52.96	11	57
35-7-15	53	2450	107	10	11.5	53.74	13	84
34-8-27	90	3400	134	17	11.8	54.65	11	86
34-8-10	27	2900	268	24	5.8	46.51	14	47
35-6-7	30	1450	348	24	3.4	49.03	17	34
35-7-1	53	1600	320	73	6.1	38.48	25	48
34-6-31	60	1600	174	46	8.2	51.70	20	65
34-6-31	40	1750	152	47	5.6	53.85	10	48
34-8-10	83	3100	252	30	9.6	42.29	36	77
34-8-10	50	2900	271	28	9.6	45.05	37	74
34-7-13	70	2800	167	58	7.3	51.88	40	64
34-6-7	23	1900	104	40	4.7	41.16	36	43
34-6-29	27	1700	60	48	5.9	22.17	20	40
34-6-17	13	1900	69	35	5.0	32.85	15	37
34-7-25	30	1500	37	54	3.5	19.36	18	24
34-7-23	20	2400	214	65	5.2	31.26	44	44
34-7-23	37	2600	230	61	7.2	27.87	34	53
34-7-33	70	2100	305	47	6.8	44.10	36	57
34-7-25	37	2100	288	66	6.6	33.82	76	60
33-7-29	20	2000	64	46	3.7	24.15	21	27
34-7-23	30	2900	320	59	5.5	42.13	53	52
33-7-35	30	2000	7	40	5.9	37.66	22	46
33-7-35	23	1950	118	36	4.9	47.85	41	48
33-7-27	27	1900	135	37	5.9	52.47	26	52
34-7-15	63	2450	294	65	5.6	36.10	18	43
34-7-1	17	1200	341	49	3.5	42.13	50	39
34-7-3	40	1400	50	21	5.0	41.93	14	40
34-7-9	7	1800	230	66	3.7	25.44	72	38
34-8-33	23	3600	91	44	6.7	33.74	39	53
34-8-32	0	3500	290	56	6.9	37.98	42	56
34-8-3	40	2600	241	37	8.2	38.61	13	59
34-8-3	43	2550	114	43	9.0	44.32	22	68
34-7-35	47	2000	91	55	5.9	27.79	40	46
34-8-21	67	2800	138	36	8.8	53.20	49	75
34-8-21	90	3800	123	37	9.1	49.25	20	70
34-8-16	40	3600	285	33	6.9	45.16	52	61
33-8-11	47	2600	119	52	8.8	44.04	30	68
33-7-13	53	2100	171	60	7.7	50.76	33	64
33-7-13	20	2200	38	65	5.5	11.31	46	39
33-7-13	43	3000	352	58	6.9	35.46	54	58
33-8-1	30	2150	293	61	8.5	37.13	72	72
33-7-27	20	1400	139	44	5.2	52.45	33	50

[1]Calculated from: Relative stocking percent = -8.414803 + 6.118036 (partial cut stocking index) + 0.369486 (slope/aspect index) - 0.204111 (percent surface gravel cover).

Pacific Northwest Forest and Range
Experiment Station
809 NE Sixth Avenue
Portland, Oregon 97232

GPO 996-112

United States
Department of
Agriculture

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Forest and Range
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Predicting Wildfire Behavior in Black Spruce Forests in Alaska

Rodney A. Norum

Abstract

The current fire behavior system, when properly adjusted, accurately predicts forward rate of spread and flame length of wildfires in black spruce (*Picea mariana* (Mill.) B.S.P.) forests in Alaska. After fire behavior was observed and quantified, adjustment factors were calculated and assigned to the selected fuel models to correct the outputs to more nearly coincide with observed values. Spotting distance models predict maximum spotting distances if some corrections and assumptions are made. Field-tested procedures are described.

Keywords: Fire behavior (forest), Alaska, black spruce, *Picea mariana*.

Dependable predictions of fire behavior are essential for making tactical plans for suppressing wildfire. Fires in Alaska's black spruce (*Picea mariana* (Mill.) B.S.P.) forests pose some unique problems in prediction.

In recent years, the current fire behavior system—Rothermel (1972) fire spread model—has gained acceptance as an accurate means of predicting fire behavior. Although the field-usable (Albini 1976) version of the model, in the form of nomographs, provides flexibility, some situations are not adequately described by the 13 stylized fuel models. In such cases, adjustment and adaptation of the model are necessary before fire behavior can be accurately forecast. The typical black spruce/feathermoss (*Picea mariana/Hylocomium splendens-Pleurozium schreberi*) forests of Alaska present such a problem.

The first documented attempt to use the Albini nomographs to predict wildfire behavior was made in 1977, when I was fire behavior officer for a fire in an area of black spruce near the village of Hughes in interior Alaska. The fire burned for several days, traversing slopes that ranged in steepness from flat to 32 percent under a variety of weather conditions. The fire burned as a surface fire, presenting an ideal opportunity for measuring rates of spread and flame lengths under varied conditions of slope and fuel moisture content. In addition, the availability of an accurate experimental prototype model of a microwave fuel moisture meter (McLeod 1976) made it possible to measure the moisture content of fuels collected near the fire. Temperature, relative humidity, and the velocity and direction of the wind were measured hourly and when fuel samples were collected. Everything necessary to document fuel conditions and fire behavior was available for comparison with values calculated by the Albini nomographs.

RODNEY A. NORUM is a research forester, Pacific Northwest Forest and Range Experiment Station, Institute of Northern Forestry, 308 Tanana Drive, Fairbanks, Alaska 99701.

The comparison procedure used is conceptually simple but is difficult to perform under field conditions. The first step was to use weather variables to calculate the moisture content of 1-hour timelag fuels (less than ¼-inch diameter). At the same time, fuel samples were gathered and their moisture content was measured with the microwave fuel moisture meter for comparison with calculated values. This step was necessary because a large percentage of the fine fuels in this fuel type is live material that behaves more like finely divided dead fuel, and the procedures for calculating fuel moisture apply to dead fuels only. The often deep, spongy layer of feathermosses and lichens has an enormous surface-to-volume ratio (estimated at 4,300:1 square foot per cubic foot).[1] Because the feathermosses have tiny, long, filamentous rhizoids that transport soil water remarkably long vertical distances to green surface tissues, mosses (and lichens) respond to atmospheric moisture and temperature as if they were dead fuels. Of perhaps even greater importance is the rapid rate of response of these fuels, which is caused by the high surface-to-volume ratio. These fuels take only minutes to reach equilibrium moisture content when the relative humidity changes (Mutch and Gastineau 1970). This is important when fire behavior is predicted, because changes in relative humidity have an almost immediate effect on fire behavior. In this test, the calculations of fine fuel moisture content agreed closely with the measured values.

The next step was to record the rate of forward spread and flame length, along with slope steepness, wind velocity and direction, temperature, and relative humidity. None of the many methods that have been used to measure rate of spread is entirely satisfactory. In this case, the fire could be observed from either flank, and the simple method of timing its progress between points was used. Distances between timing points were measured after the fire passed and the area cooled down. Thirty-one such measurements were made over 5 days. Fortunately, a wide range of weather conditions allowed a reasonably reliable test of the fire spread model.

The question was, would any of the 13 available fire behavior fuel models predict what was being observed? The stylized fuel model 6 suggested by Albini (1976) was the first one I tried. Measured input variables from the fire site, and the nomograph for fuel model 6 (dormant brush model) were used to calculate rate of spread and probable flame length. Model 6 considerably overpredicted both rate of spread and flame length. At that point the best approach appeared to be to try the other 12 fuel models to determine if one of them would predict the fire behavior observed. The result of this trial-and-error process was the discovery that fuel model 9 (hardwood litter model) gave values consistently close to the observed rate of spread. Plotting observed versus measured values produced the nearly linear relationship shown in figure 1. Calculation of simple linear regression led to the tentative conclusion that the rate of spread predicted by fuel model 9, if multiplied by the constant 1.2, would yield values very close to the rate of spread observed in black spruce/feathermoss forests, provided fire continued to spread as a surface fire and did not exhibit erratic behavior, such as spotting ahead or moving as a running crown fire.

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[1] James K. Brown, Northern Forest Fire Laboratory, Missoula, Montana, personal correspondence, 1977.

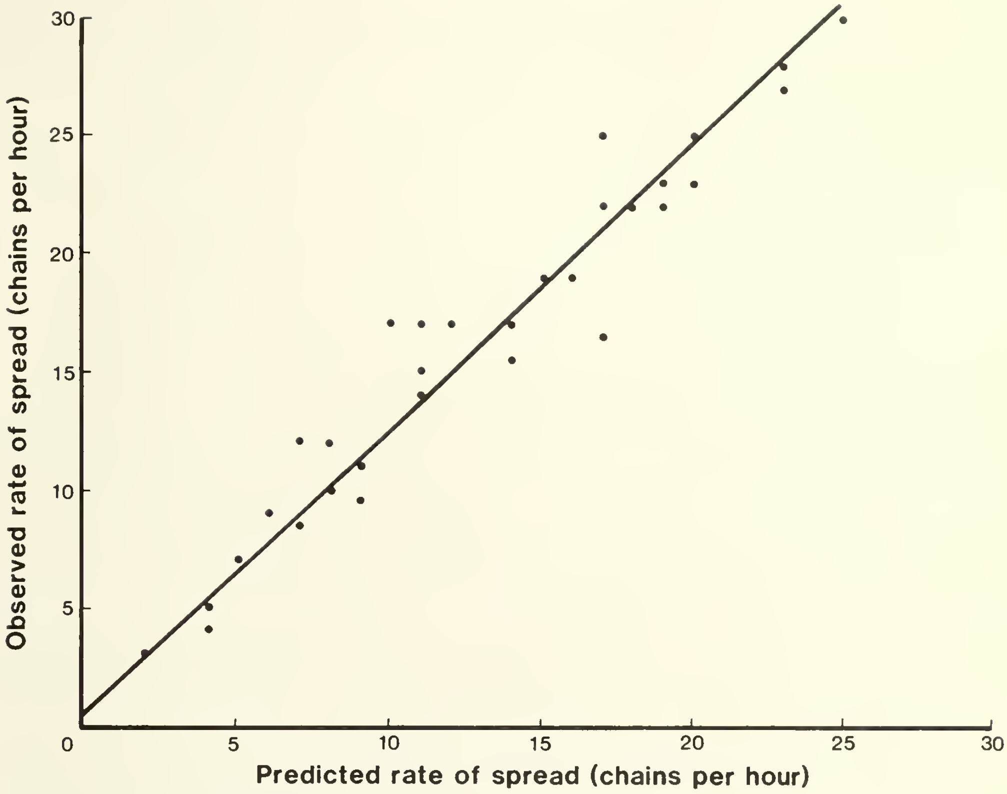

Figure 1.—National Forest Fire Laboratory (NFFL) fuel model 9 predicts rates of spread that are linearly related to observed values.

The actual regression equation is:

$$Y = 1.2 + 1.18X;$$

where:

Y = observed rate of spread (chains per hour),
X = calculated rate of spread (chains per hour) using model 9, and
$r^2 = 0.94$.

The standard error is:

$$S_{y \cdot x} = 1.88.$$

The slope factor is significant at the 99-percent level. Because the Y intercept (when X=0) is small and a zero intercept is well within the 95-percent confidence limits, and because the purpose of this effort was to yield a practical procedure usable in the field, the simplification to Y=1.2X is justified and was subsequently used. This procedure, which was complemented by good spot weather forecasts, accurately predicted the rate of progress of the fire for several more days until it was controlled. Since that time, the procedure has been used many times to accurately predict behavior of fires in Alaska.

One other important characteristic of fire behavior remained to be described: flame length, which is directly related to fireline intensity. For tactical decisions about fire suppression, fireline intensity is as important as rate of spread.

Fireline intensity (often called Byram's intensity) is the rate at which heat is released per foot of fireline at the head of a fire (British thermal units (Btu) per second per foot). It is internationally recognized as a way to estimate the limits of control, as described by Hodgson (1968).

Estimates of flame length were noted, along with observations of rate of spread, for the fire near Hughes. Although flame length is more difficult to measure than rate of spread, visual estimates were made for 5-minute intervals and recorded, along with observed rates of spread. Using the same process with the nomographs, I found that fuel model 5 (short brush model) gave acceptably close estimates for flame length. All calculated and observed values are listed in table 1. The procedure for estimating flame length was not precise enough to justify a numerical analysis, but a simple correlation coefficient between calculated flame length and the average of observed values gave a correlation of 0.96. It should be noted, however, that the range of values for flame length (0 to 6 feet) is not large.

At the time the work was done, there were two fairly easy methods for estimating Byram's fireline intensity under field conditions. One is the procedure described by Albini (1976, p. 60) where rates of spread and the reaction intensity (Btu per minute per square foot) are combined. The second method, which works well if rates of spread are low (less than 10 chains per hour for fuel model 5), is to use the 13 stylized fuel model nomographs (Albini 1976) in a slightly modified way. The procedure is described in the appendix.

To estimate flame length, if you know the rate of spread, enter one of Albini's (1976) nomographs in the upper right-hand quadrant (such as the one shown in fig. 2) on the "dead fuel moisture" axis. Intersect the proper turning line and draw the first vertical line running down through the "fire intensity" axis (reaction intensity). Then construct a horizontal line, starting on the "rate of spread" axis, using a known rate of spread, and extend it to the right. The intersection of the two lines marks the value of flame length. Figure 2 converts flame length to Byram's fireline intensity. A combination of these two procedures gives a reaction intensity that, when combined with known rates of spread, accurately predicts flame length. After considerable trial and error, fuel model 5 proved best. A value of 100 percent was used for the live fuel moisture content, and this value seems to hold true for black spruce stands during most of the fire season in Alaska.

The Albini (1976) nomographs use a 20-foot windspeed and a built-in wind adjustment factor of 0.5. Later nomographs and the recently developed TI-59 calculator procedures using a custom, read-only memory (Burgan 1979) require a windspeed that is adjusted to midflame height.

During the remainder of the 1977 fire season and for the next 3 years, I applied these findings to make several hundred estimates on roughly a million acres of wildfire in Alaska, with good results. When I used the procedures described, fuel model 9 gave consistently good estimates for rate of spread (when multiplied by 1.2), and fuel model 5 predicted flame length acceptably well.

Table 1—Observed and calculated variables of fire behavior in a wildfire in black spruce in Alaska

Rate of spread: Observed	Rate of spread: Calculated	1-hour fuel moisture content	Mid-flame wind-speed	Slope	Temperature	Relative humidity	Observed flame length	Reaction intensity	Calculated flame length
- *Chains per hour* -		*Percent*	*Miles per hour*	*Percent*	*°F*	*Percent*	*Feet*	*Btu per minute per square foot*	*Feet*
2	3	13	2	15	50	65	0 -1	929	1.0
4	4	10	3	20	68	35	1 -2	990	1.5
5	4	11	3	25	65	44	1 -2	978	1.5
7	5	7	3	25	76	25	2	2,296	2.5
8.5	7	10	5	12	68	35	2	990	2.2
9	6	14	5	10	50	65	2	883	1.9
9.5	9	6	5	15	71	38	2.5-3.5	2,652	3.6
10	8	7	5	15	71	38	2 -3	2,296	3.3
11	9	10	6	0	62	66	2 -3	990	2.4
12	7	6	4	15	70	37	2 -3	2,652	3.2
12	8	8	5	10	62	55	3	1,702	2.8
17	10	8	6	10	62	55	3	1,702	3.2
14	11	7	6	0	73	43	3 -4	2,296	3.8
17	11	7	6	0	73	43	3 -4	2,296	3.8
15	11	7	6	0	73	43	3 -4	2,296	3.8
17	12	9	7	10	65	57	1.5-2.5	1,001	2.7
15.5	14	8	7	25	64	52	3 -4	1,702	3.8
17	14	8	7	25	64	52	3 -4	1,702	3.8
25	17	7	8	10	68	41	4 -4.5	2,296	4.6
19	15	6	7	10	67	32	4 -4.5	2,652	4.6
19	16	6	7	25	67	32	4 -5	2,652	4.8
25	17	7	8	10	71	46	4 -5	2,296	4.6
22	17	7	8	10	71	46	4 -5	2,296	4.6
22	18	7	8	25	71	46	4 -5	2,296	4.8
22	19	4	7	20	76	24	4 -5	3,067	5.6
23	19	4	7	20	76	24	4 -5	3,067	5.6
23	20	8	9	5	73	50	4 -5	1,702	4.3
25	20	8	9	5	73	50	4 -5	1,702	4.3
27	23	9	10	20	70	56	3.5-4	1,001	3.7
28	23	9	10	20	70	56	3.5-4	1,001	3.7
30	25	5	9	10	71	28	5 -6	2,887	6.5

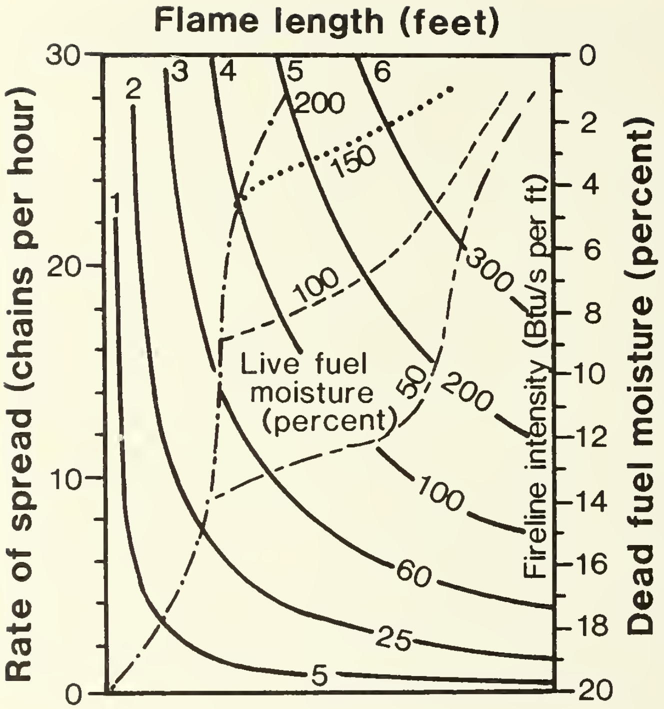

Figure 2.—NFFL fuel model 5 can be used with a predetermined rate of spread to estimate flame lengths (see fig. 4 in appendix) in fires in black spruce forests in Alaska (from Albini 1976).

Although fires in Alaska black spruce most often burn in tree crowns, running crown fires are rare. The fire is carried by surface fuels, with a crown fire often following closely behind the fire front, giving the impression of a full-blown running crown fire. As a consequence, the limitation placed on the use of the fire spread model (Albini 1976) that the fire must be a surface fire is usually met in black spruce fires in Alaska when the fire is not spotting ahead. The fire spread model has predicted fire behavior accurately up to a windspeed of 22 miles per hour (20 ft) at a relative humidity of 25 percent. One fire became a running crown fire at that point. It was in a black spruce forest where the trees were about 10 feet apart, 20 feet tall, and the crown closure was roughly 60 percent. It was the only case of a true running crown fire I have observed in Alaska and illustrates one example of threshold conditions necessary to create such a fire.

No summary of fire behavior forecasting in Alaska black spruce fuels would be complete without mentioning spot fires and spotting distances. Because fires in Alaska black spruce most often burn in the crowns, ignition ahead of the fire front by airborne firebrands is common. Although substantiating data are scanty and will likely remain so, I have successfully predicted spot fire distances by using Albini's (1979) procedure. Some experimentation was necessary because the procedure requires an estimate of the number of trees burning simultaneously. In a typical fire in Alaska black spruce, thousands of trees are burning simultaneously. These form a wall of fire many miles long.

I have monitored weather conditions and observed spot fire distances on many occasions during 1977 and the years since. A suitable value for the number of trees burning simultaneously was found by using observed and measured conditions and by entering various values into Albini's procedure for determining maximum spot fire distances. In the absence of curves for black spruce, those for Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) serve well. If the fire consists of a long line of burning black spruce trees and you use six as the number of trees burning simultaneously, good estimates of spot fire distances are possible using the procedure described by Albini (1979).

Although fires in Alaska are sometimes much larger than those in the rest of the United States, the job of forecasting fire behavior is simpler in many ways. The fuels are often homogeneous and continuous for many miles. For most of the fire season, the long daylight hours prevent large diurnal changes in ambient temperature and relative humidity and lead to long periods of nearly constant burning conditions. The major carrier fuels (the moss-lichen layer) respond rapidly and predictably to relative humidity. The fire spread model and the procedures for estimating spot fire distances work well for estimating fire behavior. Consequently, fire behavior can be estimated many hours ahead. I commonly forecast fire behavior for the ensuing 7 or 8 hours under such circumstances, and in one emergency, successfully predicted the fire perimeter location 10 hours in advance, simply because conditions and fuels remained constant.

Summary

Fire behavior fuel model 9 (Albini 1976) should be used to predict rate of spread of fire in Alaska black spruce forests, with the result multiplied by 1.2. Fuel model 5 should be used to determine reaction intensity. Fireline intensity can then be determined by combining rate of spread and reaction intensity by the procedure described by Albini (1976, p. 60). Figure 3 can be used to convert fireline intensity to flame length if needed. For the newer nomographs (using midflame wind) or the TI-59, the fireline intensity and the flame length are read directly, using the rate of spread calculated from fuel model 9. Use of these procedures, coupled with good weather forecasts, yields remarkably accurate predictions of fire behavior in black spruce fires in Alaska.

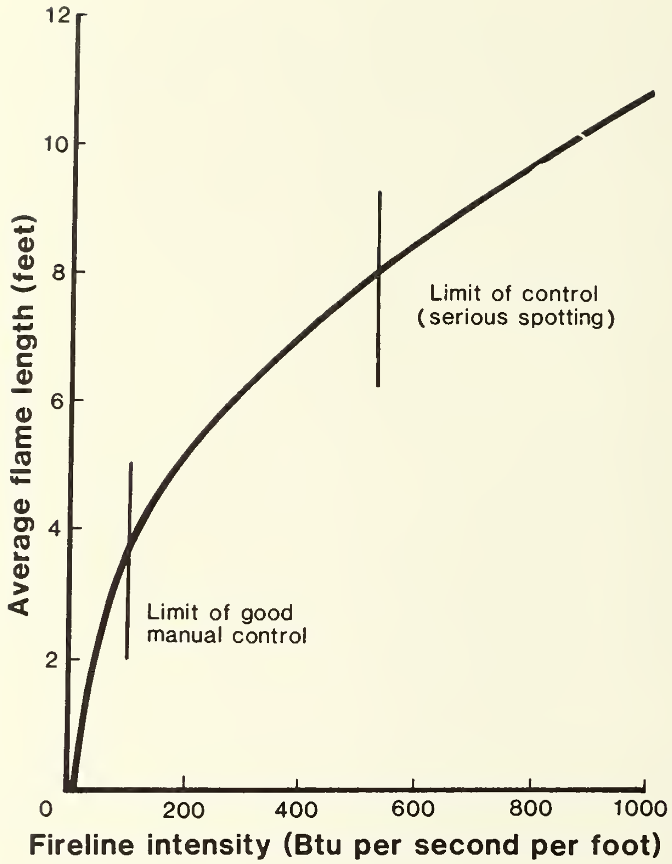

Figure 3.—Flame length versus Byram's intensity. The limits of control are from Hodgson (1968).

Metric Units

1 square foot per cubic foot = 0.033 square centimeter per cubic centimeter
1 Btu per second per foot = 0.820 kilogram calory per second per centimeter
1 Btu per minute per square foot = 161.46 kilogram calories per second per square meter
1 chain = 20.1 meters
1 mile = 1.609 kilometers

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Appendix

Sample solution for estimating the behavior of fire in black spruce forests in Alaska:

Suppose conditions on a given day cause the moisture content of 1-hour timelag dead fuels to be 7 percent, the 20-foot standard wind velocity is 8 miles per hour, and the slope is 10 percent. To get the rate of spread, use the nomograph for fuel model 9 (Albini 1976) and follow the standard procedure to get rate of spread. If you are using the TI-59 or the 1979 nomographs, adjust the windspeed to midflame height. In this case, rate of spread is 6 chains per hour. Multiply this by 1.2 to get a predicted rate of spread of approximately 7 chains per hour. At this point, use the nomograph for fuel model 5 and work only in the upper right-hand quadrant (shown in fig. 2). Enter the nomograph as shown on the right-hand axis at 7-percent moisture content. Draw a horizontal line to the left until the line intersects the 100-percent live fuel moisture curve. Draw a line (A) at that intersection, extending vertically through the quadrant. Then take the rate of spread value calculated earlier (7 chains per hour) and enter it on the axis labeled "Rate of spread, chains per hour" at the value of 7. Draw a line extending to the right as shown in figure 4 until the line intersects the previously drawn line at a flame length value of just over 3 feet. If desired, Byram's fireline intensity can be determined from figure 3 at about 60 Btu per second per foot.

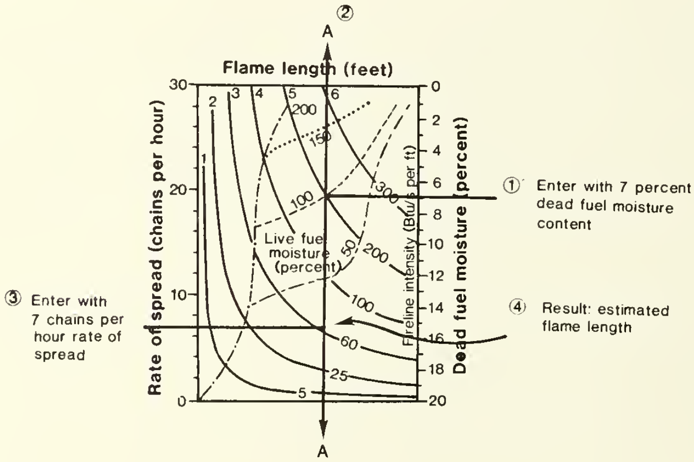

Figure 4.—Use of NFFL fuel model 5 (see fig. 2) to estimate flame lengths in fires in black spruce forests.

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Pacific Northwest Forest and Range
Experiment Station
809 NE Sixth Avenue
Portland, Oregon 97232

GPO 996-110

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Pacific Northwest Forest and Range Experiment Station

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Invertebrates of the H.J. Andrews Experimental Forest, Western Cascades, Oregon II. An Annotated Checklist of Caddisflies (Trichoptera)

N.H. Anderson, G.M. Cooper, and D.G. Denning

Abstract

At least 99 species, representing 14 families of Trichoptera, are recorded from the H.J. Andrews Experimental Forest, near Blue River, Oregon. The collecting sites include a wide diversity of environmental conditions in a 6 000-hectare watershed of the western Cascade Range (from 400 to 1 630 meters in altitude and from 1st- to 7th-order streams).

Keywords: Checklists (invertebrata), invertebrata, caddisflies, Trichoptera, Oregon (H.J. Andrews Exp. For.).

Introduction

The Trichoptera is one of the largest orders of aquatic insects with about 10,000 known species (Wiggins 1977). In Oregon there are more than 280 species representing 80 genera in 16 families (Anderson 1976). Larval caddisflies are an important component of the biota in both standing and running waters. As the aquatic habitats in the H.J. Andrews Experimental Forest are primarily streams, the lentic species are poorly represented in the area.

The purpose of this note is to bring together the published and unpublished records of caddisflies as a contribution to an inventory of the invertebrates of the study area. Though stream biologists are primarily interested in the immature stages because they occur in the water, identification of species in most genera is possible only for adults. A local checklist will help to associate the larvae with the adults. Adult records are important for documenting occurrence and flight periods but, because of the ability of adults to disperse, microhabitat requirements of the larvae cannot be inferred from such records.

N.H. ANDERSON and G.M. COOPER are at the Department of Entomology, Oregon State University, Corvallis, Oregon.

D.G. DENNING, 2016 Donald Drive, Moraga, California, is retired.

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Compilation of records was started from material collected by Oregon State University stream biologists in the International Biological Program (IBP) stream project in the early 1970's. C.D. Kerst made a preliminary survey of stream insects in 1970 and established collecting sites on Mack Creek and Lookout Creek. E. Grafius conducted an emergence trap program from 1971 to 1973 on Mack Creek, Lookout Creek, and watersheds 2 and 10 which provided a substantial number of the records.

Material was also obtained from the River Continuum project which focused on streams in the H.J. Andrews Experimental Forest but also included a site on the McKenzie River at Rainbow (Naiman and Sedell 1979). Thus, some records from outside the H.J. Andrews boundary are given to include the large river fauna.

A systematic collecting program with the specific purpose of obtaining an inventory of the insect fauna was supervised by J.D. Lattin, Entomology Department, Oregon State University, shortly after the site was designated an Experimental Ecological Reserve (see Lauff and Reichle 1979). Trichoptera adults were collected weekly from late May to mid-September 1978, by B.B. Frost at 9 sites using a beating sheet to collect from streamside vegetation. The collecting was continued at 3-week intervals from October 1978 through May 1979 by G.M. Cooper. His collecting was by both beating and sweeping the streamside vegetation.

Records listed as "canopy collections" are from the IBP project of G. Carroll and collaborators, Biology Department, University of Oregon, who studied the community in the overstory Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) canopy. As part of this project, D. Voegtlin trapped insects in the canopy using a black light shielded from below. Therefore, these records indicate the species were flying at this level rather than being attracted up to the light.

Extensive black-light collecting for Trichoptera has not been done in the H.J. Andrews Forest. This approach is needed to provide a more complete list of the fauna. Microcaddisflies (Hydroptilidae) and species from temporary ponds and Lookout Reservoir are currently underrepresented.

The arrangement of families, genera, and species in the list of collection records for Trichoptera of the H.J. Andrews Experimental Forest (p. 6) is that used by Anderson (1976), except that the Goeridae is given family rank following Schmid (1980). Unless otherwise indicated, determinations are based on adults identified by D.G. Denning. Immature stages are abbreviated as la. (larva), pp. (prepupae), p. (pupa), and ad. (adult); most of these were identified by G.B. Wiggins, Royal Ontario Museum, Toronto (indicated by det. ROM).

Collection Sites

The H.J. Andrews Experimental Forest occupies the 6 000-hectare drainage of Lookout Creek, a stream that flows into Blue River Reservoir which drains into the McKenzie River about 64 kilometers east of Eugene. Most of the watershed is in Lane County, but the northern portion (sites 4, 6, and 7) is in Linn County (fig. 1).

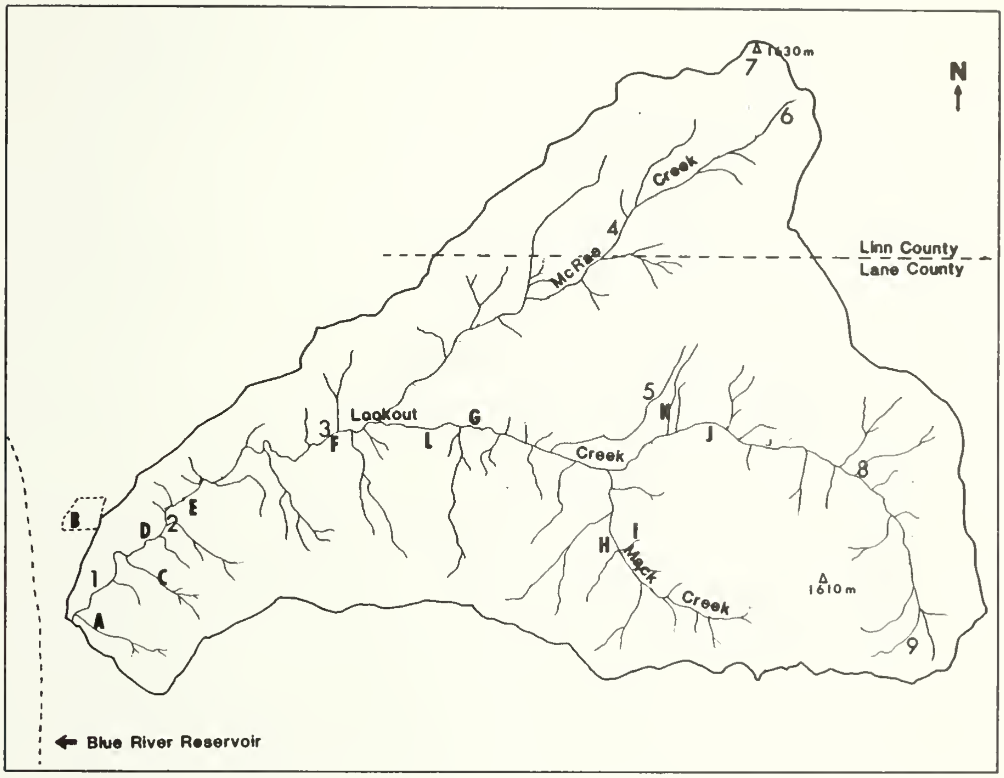

Figure 1. — Map of the Lookout Creek drainage indicating collection sites for Trichoptera. Numbers 1 to 9 are terrestrial inventory sites for adult aquatic insects. Letters A to K are named sites where aquatic studies were undertaken. Canopy collections were made at site L.

The elevation extends from 400 meters at the reservoir to 1 630 meters at Carpenter Mountain. According to Franklin and Dyrness (1971), this area has climate, soils, topography, and bedrock geology typical of the western Cascades, which are the older Oligocene-Miocene segment of the Oregon Cascade Range. All rock formations are volcanic in origin with tuffs, breccias, and basalts common at lower elevations and andesite on the ridges. The stream drainages are well defined with sharp ridges and steep slopes, except at higher elevations where there are some areas of gentle, undulating topography. The climate is maritime with a dry summer; 90 percent of the precipitation occurs from October to April. Annual precipitation ranges from 2 300 millimeters at lower elevations to 2 800 millimeters or more on the ridges. Winter snowpacks accumulate to 1 meter or more above 900 meters. Air temperatures are moderate; the mean July maximum is about 29°C and the January minimum about -3°C (at the weather station at 450 m).

The site designations in the list denote material obtained from three types of collecting programs. Numbered sites (1 to 9) are collections of adult caddisflies from riparian areas where the objective was to inventory all aquatic insects. The purpose of the "canopy collections" was to study the fauna in the overstory old-growth Douglas-fir; caddisflies are a very minor component of this fauna. Sites listed by names (Mack Cr., Old Growth; Ws10; McKenzie Riv., etc.) are locations where ecological studies of the stream fauna were conducted. Records are based mainly on emergence trap collections or larval or pupal rearing, but some adults were collected on the wing adjacent to the water. Thus, most records from the named sites provide a finer level of resolution for habitat requirements of the aquatic stages than do the riparian or canopy collections.

No site designation (---) indicates that specimens were pooled for one date, so the collection site could not be determined.

Site locations (except McKenzie River and watershed 9) are shown on figure 1 and described below. The arrangement generally goes upstream from the McKenzie River to the highest collection points, site 7 at 1 460 meters and site 9 at 1 220 meters.

McKenzie River at Rainbow covered bridge: Elevation, 410 meters; 7th-order stream, 30 to 40 meters wide, mostly riffle-runs over a substrate of cemented cobble and boulders; zone of fontinalis moss along both banks; water temperature range, 3°-12°C (further description in Naiman and Sedell 1979).

Watershed 9: Elevation, 500 meters; a 1st-order stream in a 8.5-hectare watershed draining into Blue River Reservoir from the east; shaded by old-growth Douglas-fir (uncut control for watershed 10); steep gradient. Collections are from emergence traps in 1978, set over moss on bedrock or over a small pool.

Watershed 1: (Fig. 1, A) elevation, 460 meters; a 2d-order stream draining into Lookout Creek near the entrance to the H.J. Andrews Forest; the watershed was burned after it was cleared in 1966 (Rothacher et al. 1967); riparian regrowth is primarily alder (*Alnus* Mill.). Collections were made in 1978 from emergence traps in shaded area with substrate of gravel and small cobble upstream of the settling basin.

Site 1: Elevation, 425 meters, along Lookout Creek, 5th-order stream at gaging station; 6 to 8 meters wide with a pool 9 to 12 meters wide; east side is shaded by old-growth Douglas-fir and understory trees and shrubs; west side has young stand of Douglas-fir; substrate is cobble and boulder.

Watershed 10: (Fig. 1, B) elevation, 430 meters; a 1st-order stream in a 10-hectare watershed draining into Blue River; densely shaded by old-growth Douglas-fir until clearcut in June-July 1975 (Grier and Logan 1977); steep gradient, with stairstep channel formed by wood debris and rubble.

Watershed 2: (Fig. 1, C) elevation, 500 meters; a 2d-order stream draining into Lookout Creek near site 1; watershed is an uncut control for two adjacent experimental watersheds (Rothacher et al. 1967). Most aquatic collections were made from the settling basin, but some were from emergence traps set over rubble and bedrock substrate. Canopy collections, listed as Ws. 2, were taken downstream of this site by D. Voegtlin with black light or sticky traps at 42 meters above ground in old-growth Douglas-fir.

Show & Tell: (Fig. 1, D) elevation, 425 meters; Lookout Creek, 5th-order stream; shallow riffle and small pools; water temperature ranges from 1° to 18°C; gradient, 3 percent; open canopy; substrate of large cobble and bedrock. Site is described and illustrated by Naiman and Sedell (1979).

Site 2: Elevation, 455 meters; watershed 3 (Rothacher et al. 1967); 2d-order feeder stream to Lookout Creek; 1 to 2 meters wide, with settling basin about 2 meters deep and 4 meters wide at collecting site; steep-sided banks; stream slightly shaded with young Douglas-fir and shrubs; substrate is cobble to boulder.

Swimming Hole: (Fig. 1, E) elevation, 500 meters; Lookout Creek, 5th-order stream; canopy open; a shallow riffle on bedrock and cobble, dropping over bedrock ledge into plunge pool.

Site 3: Elevation, 535 meters; Lookout Creek, 5th-order stream; 10 to 20 meters wide; canopy open; two channels around gravel bar with stand of young alder and willows (*Salix* L.); substrate is cobble to boulder.

Lookout Cr., Concrete Bridge: Same as site 3, except collections were from emergence traps or rock-surface collections (Grafius 1974). Emergence traps were set over rubble in midstream and slower cobble riffles near the shore.

Site 4: Elevation, 840 meters; McRae Creek, 2d-order stream, 2 to 3 meters wide; shaded on north side of road by old-growth Douglas-fir on steep banks; gradual slope on south side of road with cover of willow and alder; cobble to boulder substrate.

Quarry: (Fig. 1, G) elevation, 610 meters; Lookout Creek, 4th-order stream; open canopy; substrate is bedrock, gravel, cobble, boulders and wood in a debris jam.

Canopy Collection: (Fig. 1, L) elevation, 625 meters; collections by D. Voegtlin with black light in old-growth Douglas-fir at 42 meters in the tree, or at ground level with black light. Records of specimens collected at ground level are indicated as "grd. level."

Mack Creek: (Fig. 1, H) elevation, about 800 meters; 3d-order stream, 5 to 10 meters wide; gradient, 13 percent. Old-growth area above road has slightly open canopy; substrate ranges from fine organic debris in pools formed by log jams, to rubble and boulders, but mostly loose cobble; water temperature ranges from 1° to 17°C; site is illustrated and described by Naiman and Sedell (1979). Emergence traps were set in a pool over organic debris and on cobble riffle. Clearcut area, logged in 1965, is downstream from old growth; substrates are generally unshaded but with steep side slopes; substrate is eroded to bedrock and boulders with less cobble and organic debris than in old growth. Emergence traps are set over cobble riffle and in slack water behind boulders.

Devilsclub Creek: (Fig. 1, I) elevation, 810 meters; 1st-order tributary to Mack Creek; heavily shaded and choked with large and small organic debris (also see Naiman and Sedell 1979).

Lookout Creek, Upper Site: (Fig. 1, J) elevation, 760 meters; 3d-order stream; collections from area with relatively low gradient and both old-growth and clearcut sections, with stairsteps of riffles and pools; substrate is gravel, cobble, and wood debris.

Shorter Creek: (Fig. 1, K) elevation, 760 meters; 2d-order tributary to Lookout Creek; heavily shaded and choked with logs and debris. Collections limited to larvae on wood substrates taken during a debris removal experiment.

Site 5: Elevation, 825 meters; along 2d-order tributary to Lookout Creek, 1 meter wide; heavily shaded with alder, willow, and young Douglas-fir; cobble to boulder substrate.

Site 6: Elevation, 1 220 meters; headwaters of McRae Creek; 1 to 2 meters wide; open site with regrowth of conifers, large Sitka alder (*Alnus sinuata* (Regel.) Rydb.), and willow mostly 1 to 2 meters tall; low gradient; gravel to cobble substrate.

Site 7: Elevation, 1 460 meters; intermittent stream on Carpenter Mountain; 1 meter wide; shaded with small Sitka alder and vine maple (*Acer circinatum* Pursh); low gradient; gravel to rubble substrate.

Site 8: Elevation, 990 meters; feeder stream to Lookout Creek; 1 to 2 meters wide; heavily shaded; gravel and cobble substrate.

Site 9: Elevation, 1 220 meters; feeder stream to Lookout Creek; 1 to 2 meters wide; stream shaded; substrate is bedrock and moss-covered boulders.

Collection Records for Trichoptera[1]

FAMILY RHYACOPHILIDAE

Himalopsyche phryganea (Ross)	Mack Cr.	21-Aug-75 (det. ROM); 15-Nov-74 (la., det. Anderson)
	Canopy coll. (grd. level)	16-July-77
Rhyacophila		
Oreta group:		
R. oreta Ross	Site 8	10-Aug-73
	Ws. 9	5-Oct-78 (det. Harper)
Alberta group:		
R. tucula Ross	Site 9	17-Aug-78
Hyalinata group:		
R. vocala Milne	Mack Cr., Clearcut	10-June-78
	Site 2	3-June-73
	Site 6	3-June-78
	Site 8	13-July-78

[1] la. = larva; pp. = prepupae; p. = pupa; ad. = adult.

Coloradensis group:		
R. jenniferae Peck & Smith	Site 2	10-Aug-78
Angelita group:		
R. angelita Banks	Lookout Cr., Concrete Br.	11-July-72
	Site 3	2,10-Aug-78
	Site 3 (blk. light)	26-June-80
R. vuzana Milne	Mack Cr., Clearcut	2-Sept-72
Sibirica group:		
R. blarina Ross	Devilsclub Cr.	9-June-76 (p. det. ROM)
	Site 7	3-June-78
R. narvae Navás	Mack Cr., Clearcut	15,22-June-78 (det. Harper)
	Mack Cr., Old Growth	27-June-72; 28-June-78 (det. Harper)
	Site 3	3-June-78
	Site 8	27-July-78
	---	6,13-19-July-78
R. pellisa Ross	Site 3	13-July-78
R. valuma Milne	Lookout Cr., Swimming Hole	23-June-77 (det. ROM)
Vofixa group:		
R. iranda Ross	Site 8	6-July-78
	Site 9	13,19-July-78
R. vobara Milne	---	13-July-78
Betteni group:		
R. fenderi Ross	Site 2	19-July-78
	Site 5	27-July-78
	Site 6	29-Aug-78
	Site 9	27-July-78
	---	10-Aug-78
R. perda Ross	Mack Cr., Clearcut	18-25-Aug-72
	Mack Cr., Old Growth	18-Aug-72
	Site 6	6-July-78
R. vaccua Milne	Mack Cr., Clearcut	18,25-Aug-72, 11-Sept-72
	Mack Cr., Old Growth	11-Sept-72
	Site 2	17-Aug-78
	Site 3	30-Oct-79
	Site 4	29-Aug-78
R. vedra Milne	Lookout Cr., Concrete Br.	13-Aug-71, 28-Aug-72
	Site 3	9,16,30-Oct-79
	---	11,27,29-Aug-78
R. willametta Ross	Ws. 10	31-Aug-72
	---	19-July-78
	---	10-Aug-78

Verrula group:		
R. verrula Milne	Mack Cr., Clearcut	14-Sept-71 to 6-Oct-71
	Mack Cr., Old Growth	12-Sept-72, 13-Oct-71
	Site 6	13-July-78, 16-Oct-78
Ecosa group:		
R. ecosa Ross	Ws. 10	22-June-72
	Site 2	26-May-78
	Site 5	3,13-June-78
Acropedes group:		
R. acropedes Banks	McKenzie Riv., Rainbow	22-June-77 (det. ROM)
	Lookout Cr., Concrete Br.	28-June-76 (det. ROM); 10-July-76, 27-July-72
	Site 4	17-Aug-78
R. grandis Banks	Mack Cr., Old Growth	7-July-72
	Site 2	13-June-78
	Site 5	19-July-78
	Site 6	6-July-78
	Site 7	13-July-78
	Site 8	13,19-July-78
	Site 9	19-July-78
R. vao Milne	Site 2	2-Aug-78
	Site 4	2-Aug-78
	Site 8	27-July-78, 10,17-Aug-78
	Site 9	29-Aug-78
	---	26-May-78, 6,19-July-78, 2-Aug-78
Lieftincki group:		
R. arnaudi Denning	Site 3	27-May-78
Nevadensis group:		
R. jewetti Denning	Mack Cr., Old Growth	17-June-72, 25-Aug-71
	Mack Cr., Clearcut	18,25-Aug-72
	Site 8	19,27-July-78, 2-Aug-78
	---	10-Aug-78
R. vaefes Milne	Lookout Cr., Swimming Hole	23-June-78 (det. ROM)
	Mack Cr., Old Growth	5-July-78 (det. Harper)
	---	29-Aug-78

FAMILY GLOSSOSOMATIDAE

Agapetus occidentis Denning	Lookout Cr., Concrete Br.	Late July to mid-Sept 1972 & 73 (p. det. Anderson)
	Site 3	17-Aug-78
	Canopy coll.	15-Aug-77
	Canopy coll. (grd. level)	6-Sept-77

Anagapetus bernea Ross	Mack Cr., Clearcut	8,15,22,29-June-78 (det. Harper); 10,14,28-June-73; 5,12-July-78 (det. Harper)
	Mack Cr., Old Growth	3-Mar-72, 8,15,22,29-June & 18-July-78 (det. Harper); 22-June-77 (pp., p., ad. det. ROM); 3-July-72
	Devilsclub Cr.	9-June-76 (la., p. det. ROM)
	Lookout Cr., Upper site	23-June-77 (p. det. ROM)
	Site 4	13-July-78
	Site 5	2-Aug-78
	Site 6	3-June-78
	Site 8	19-July-78
Glossosoma califica Denning	McKenzie Riv., Rainbow	22-June-77 (la., p. det. ROM)
	Canopy coll.	15-Aug-77
G. oregonense Ling	Canopy coll. (grd. level)	1-Aug-77
G. penitum Banks	Lookout Cr., Site 1	22-June-77 (p. det. ROM)
	Lookout Cr., Show & Tell	22-June-77 (p. det. ROM)
	Lookout Cr., Swimming Hole	22-June-77 (p. det. ROM)
	Lookout Cr., Concrete Br.	22-June-72, 19-Sept-73
	Lookout Cr., Quarry	22-June-77 (p. det. ROM)
	Mack Cr., Old Growth	23-June-77 (p. det. ROM)
	Ws. 1	26-July-78 (det. Harper)
G. pyroxum Ross	Lookout Cr., Concrete Br.	4-Apr-72, 11-May-73, 27-June-73 (p.), 9-July-71, 13-Aug-73 (p.)
	Canopy coll.	29-July-76
	Lookout Cr., Quarry	23-June-77 (p. det. ROM)
G. velona Ross	Site 3	14-Mar-79

FAMILY HYDROPTILIDAE

Agraylea multipunctata Curtis	Site 3	29-Aug-78
	Site 4	13-July-78
	---	7-Aug-78
A. saltesea Ross	Site 3	No date
	Canopy coll.	11-Apr-77
Hydroptila sp.	Lookout Cr., Concrete Br.	14-Sept-71
	Canopy coll.	19-Aug-76
	Site 3	10-Aug-78
Ochrotrichia (subgenus *Ochrotrichia)*	Lookout Cr., Concrete Br.	24-July-72 (la., det. Flint)
Palaeagapetus sp.	Shorter Cr. (in moss on wood)	10-June-78 (la., det. ROM)

FAMILY PHILOPOTAMIDAE

Dolophilodes dorcus (Ross)	Lookout Cr., Show & Tell	23-June-77 (det. ROM)
	Lookout Cr., Concrete Br.	22-June to 9-July-71; 7-Aug-72
	Mack Cr., Clearcut	22,29-June-78 (det. Harper); 25-June-73, 12-July-78
	Mack Cr., Old Growth	15,22,29-June-78 (det. Harper); 30-June-72; 5,12, 18,27-July-78 (det. Harper); 17-July-72, 1-Aug-74
	Canopy coll.	No date
	Ws. 1	25-May-78, 15,22-June-78 (det. Harper)
	Site 2	26-May-78, 3-June-78, 19-July-78
	Site 3	4-June-80, 13-June-78, 19-July-78, 26-June-80, 9-July-80
	Site 3 (blk. light)	26-June-80
	Site 4	13-July-78, 2-Aug-78
D. novusamericanus (Ling)	Mack Cr., Old Growth	23-Feb-73, 4-Apr-72, 14-Sept-71
	Ws. 9	12-Oct-78 (det. Harper)
	Ws. 10	21-Apr-72, 3,17-July-72
	Canopy coll. (grd. level)	25-July-77, 3-Sept-77
	Site 3	5-June-79
	Site 5	10,17-Aug-79
	Site 7	27-July-78
	Site 9	6-July-78, 2-Aug-78
D. pallidipes (Banks)	Mack Cr., Clearcut	2-Sept-72, 14-Sept-71
	Mack Cr., Old Growth	5,19-Oct-78, 9-Nov-78 (det. Harper)
	Site 5	29-Aug-78
	Site 6	17,29-Aug-78
	Site 9	10-Aug-78
D. sisko (Ross)	Lookout Cr., Concrete Br.	7-Aug-72
	Ws. 1	22-June-78, 18-July-78 (det. Harper)
	Ws. 9	18-May-78 (det. Harper)
	Ws. 10	7-July-73, 17-July-72
	Site 2	19-July-78
	Site 7	19-July-78
Wormaldia anilla (Ross)	Ws. 1	22-June-78 (det. Harper)
	Ws. 9	12-July-78 (det. Harper)
	Ws. 10	7-July-72, 6-Oct-71
	Site 2	13-June-78, 2,17-Aug-78
	Site 7	6-July-78

W. gabriella (Banks)	Lookout Cr., Concrete Br.	18-28-Aug-72
	Site 1	29-Aug-78
	Site 2	17-Aug-78
	Site 3	17,29-Aug-78, 2-Sept-79

FAMILY PSYCHOMYIIDAE

Psychomyia lumina (Ross)	Lookout Cr., Show & Tell	22-June-77 (det. ROM)
Tinodes cascadia Denning	Ws. 9	12-July-78 (det. Harper)

FAMILY POLYCENTROPODIDAE

Polycentropus halidus Milne	Mack Cr., Clearcut	14-Aug-72
	Ws. 1	15-June-78 (det. Harper)
	Site 3 (blk. light)	26-June-80
	Canopy coll.	25-July-77
	Canopy coll. (grd. level)	15-Aug-77, 6-Sept-77

FAMILY HYDROPSYCHIDAE

Arctopsyche grandis (Banks)	McKenzie Riv., Rainbow	22-June-77 (det. ROM)
	Lookout Cr., Concrete Br.	21-Sept-73 (la.)
	Mack Cr., Clearcut	25-June-73
	Mack Cr., Old Growth	18-June-73
Parapsyche elsis Milne	Mack Cr., Clearcut	15-June-73 (p.), 25-June-73
Homoplectra luchia Denning	Site 4	13-June-78
Homoplectra sp.	Ws. 9	20-Apr-78, 25-May-78 (det. Harper)
Hydropsyche andersoni Denning	Canopy coll.	25-June-77, 25-July-77
H. oslari Banks	Canopy coll. (grd. level)	12-June-76, 12-Aug-76, 4-July to 3-Sept-77

FAMILY LIMNEPHILIDAE

Subfamily Dicosmoecinae

Dicosmoecus gilvipes (Hagen)	Canopy coll. (grd. level)	19-Sept-76, 4-Oct-77

Allocosmoecus partitus	Site 3	6-Nov-78
Banks	Mack Cr., Clearcut	11,14,20-Sept-72
	Mack Cr., Old Growth	11-Sept-72
	Canopy coll.	4-Oct-76
	Canopy coll. (grd. level)	19-Sept-76
Onocosmoecus unicolor	Canopy coll.	20-Sept-76
(Banks)	Canopy coll. (grd. level)	3,6-Sept-77
Cryptochia pilosa	---	3-June-78
(Banks)		
Cryptochia sp.	Mack Cr., Old Growth	11-May-77 (la. det. Anderson)
Pedomoecus sierra	McKenzie Riv., Rainbow	June-76 (la. det. Anderson)
Ross	Lookout Cr., Concrete Br.	Summer-76 (la. det. Hawkins)
	Canopy coll.	22-Aug-77
Ecclisocosmoecus scylla	Lookout Cr.,	13-June-72 (det. ROM)
(Milne)	Concrete Br.	
	Site 8	29-Aug-78
	Site 9	10,29-Aug-78
Ecclisomyia maculosa	Mack Cr., Old Growth	8-June-73
Banks	Site 4	13-June-78

Subfamily Apataniinae

Apatania sorex (Ross)	Lookout Cr., Concrete Br.	4-June-73
	Mack Cr., Clearcut	23-Feb-73, 12,26-June-73
	Mack Cr., Old Growth	19-June-73
	Canopy coll.	No date
	Site 3	29-Mar-80

Subfamily Neophylacinae

Neophylax occidentis	Mack Cr., Clearcut	6 to 28-June-73,
Banks		30-June-72
	Mack Cr., Old Growth	30-June-72
	Canopy coll.	No date
N. rickeri Milne	Mack Cr., Clearcut	13-Oct-71
	Mack Cr., Old Growth	2-Oct-71
	Canopy coll. (Ws. 2)	July-76 (det. ROM)
	Canopy coll.	4,18-Oct-76
	Canopy coll. (grd. level)	1-Nov-76
	Site 3	2-Oct-79
	Site 8	13-Nov-79
N. splendens Denning	Mack Cr., Clearcut	6-Oct-71, 20-Nov-72
Oligophlebodes minuta	Mack Cr., Clearcut	6 to 10-June-73
(Banks)		11-June-78 (p. det. ROM)

O. sierra Ross	Mack Cr., Clearcut	8,15-June-78 (det. Harper)
	Mack Cr., Old Growth	15-June-78 (det. Harper); 30-June-72
	Canopy coll.	19-June-77
	Canopy coll. (grd. level)	13,27-June-77
Neothremma didactyla Ross	Mack Cr., Clearcut	31-July-72
	Mack Cr., Old Growth	27-July-78 (det. Harper)
	Site 8	6-July-78
Neothremma sp.	Devilsclub Cr.	27-July-76 (la. det. ROM)

Subfamily Pseudostenophylacinae

Pseudostenophylax edwardsi (Banks)	Ws. 2	8-Nov-76 (la. det. Anderson)

Subfamily Limnephilinae

Limnephilus externus Hagen	Canopy coll. (grd. level)	19-Nov-76
L. nogus Ross	Mack Cr., Old Growth	31-July-72
	Canopy coll. (Ws. 2)	July-76 (det. ROM)
L. occidentalis Banks	Mack Cr., Clearcut	10-Aug-72
	Mack Cr., Old Growth	31-Aug-72
L. sitchensis (Kolenati)	Canopy coll. (grd. level)	19-Sept-76
Halesochila taylori (Banks)	Lookout Cr., Concrete Br.	2-Oct-71 (reared, det. ROM)
	Mack Cr.	8-Nov-76 (det. Anderson)
	Site 3	13-Nov-79
Lenarchus vastus (Hagen)	Mack Cr., Old Growth	14-Aug-72
	Canopy coll.	12-Aug-76, 3,20-Sept-76
Hydatophylax hesperus (Banks)	Canopy coll. (grd. level)	19-Aug-77
	Site 7	10-July-78
	---	29-Aug-78
Philocasca rivularis Wiggins	Canopy coll. (grd. level)	22-Aug-77, 19-Sept-76
	Site 5	17-Aug-78
Philocasca sp.	Shorter Cr.	19-June-78 (la., det. ROM)
Psychoglypha avigo (Ross)	Mack Cr. (seep above road)	26-Oct-76 (reared, det. ROM)
P. bella (Banks)	Lookout Cr., Concrete Br.	6-Oct-71 (reared, det. ROM)
P. browni Denning	Mack Cr.	Oct-71 (reared, det. ROM)
P. subborealis (Banks)	Canopy coll. (Ws. 2)	Dec-75 to Jan-76 (det. ROM)
	Canopy coll.	21-Feb-77

FAMILY GOERIDAE

Goeracea genota (Ross)	Shorter Cr. (on wood)	19-June-78 (la. det. Anderson)

FAMILY LEPIDOSTOMATIDAE

Lepidostoma cascadense (Milne)	Mack Cr., Clearcut	22-June-78, 5-July-78 (det. Harper)
	Mack Cr., Old Growth	20-June-73; 17-July to 6-Sept-74, and 24-June to 23-Aug-75 (Grafius 1977); 5-July-78 (det. Harper)
	Canopy coll. (grd. level)	10,16-July-77
	Lookout Cr., Show & Tell	23-June-77 (det. ROM)
L. hoodi Ross	Site 8	19-July-78
	---	10-Aug-78
L. mira Denning	Mack Cr., Clearcut	13-July-73
	Canopy coll.	8-Aug-77
L. podager (McLachlan)	Lookout Cr., Site 1	7-Nov-76 (reared, det. ROM)
L. recina Denning	Canopy coll.	12-Aug-76
L. roafi (Milne)	Lookout Cr., Concrete Br.	17-July-72
	Mack Cr., Clearcut	21-Aug-72
	Mack Cr., Old Growth	3-July-76, 19-Aug-76, 15-Sept-77 (det. ROM); 2-Sept-71
	Canopy coll.	22-Aug-77
	Canopy coll. (grd. level)	6-Sept-77
	Site 3	17-Aug-78
L. unicolor (Banks)	Mack Cr., Old Growth	17-July to 6-Sept-74, and 24-June to 23-Aug-75 (Grafius 1977)
L. veroda Ross	Mack Cr., Old Growth	27-July-78 (det. Harper)
	Ws. 9	15-June-78, 5-July-78 (det. Harper)

FAMILY BRACHYCENTRIDAE

Amiocentrus aspilus (Ross)	Canopy coll.	19-June-77
Brachycentrus americanus (Banks)	Canopy coll.	29-July-76, 6-Sept-77
	Canopy coll. (grd. level)	19,22-Aug-77, 6-Sept-77
Micrasema bactro Ross	Ws. 9	18-May-78, 29-June-78 (det. Harper)
M. onisca Ross	McKenzie Riv., Rainbow	22-June-77 (det. ROM)
	Ws. 1	22-June-78 (det. Harper)
M. oregona Denning	Canopy coll.	16-June-77

FAMILY ODONTOCERIDAE

Namamyia plutonis Banks	Ws. 10	24-Sept-72 (la. det. ROM)
Parthina linea Denning	Devilsclub Cr.	27-July-76 (la. det. ROM)

FAMILY CALAMOCERATIDAE

Heteroplectron californicum McLachlan	Mack Cr., Clearcut	6-July-73
	Mack Cr., Old Growth	(la., det. Anderson, many dates)
	Devilsclub Creek	27-July-76 (la., det. Anderson)
	Ws. 2, settling basin	(la., det. Anderson, many dates)

FAMILY LEPTOCERIDAE

Mystacides alafimbriata Hill-Griffin	Lookout Cr., nr. Reservoir	3-Oct-70 (la., det. ROM)
	Site 1	2-Aug-78
Oecetis inconspicua (Walker)	Canopy coll.	29-July-76
Triaenodes tarda Milne	Canopy coll.	12-Aug-76
Triaenodes sp.	Canopy coll. (Ws. 2)	July-76 (det. ROM)
	Canopy coll. (grd. level)	27-Aug-77

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Finally, we thank Susan McGregor who typed the manuscript and patiently made our many corrections.

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English Equivalents

1 millimeter	= 0.04	inch
1 meter	= 3.28	feet
1 kilometer	= 0.62	mile
1 hectare	= 2.47	acres

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Pacific Northwest Forest and Range
Experiment Station
809 NE Sixth Avenue
Portland, Oregon 97232

United States
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Research Note
PNW-403
February 1983

A Recirculating Stream Aquarium for Ecological Studies

Gordon H. Reeves, Fred H. Everest, and Carl E. McLemore

Abstract

Investigations of the ecological behavior of fishes often require studies in both natural and artificial stream environments. We describe a large, recirculating stream aquarium and its controls, constructed for ecological studies at the Forestry Sciences Laboratory in Corvallis.

Introduction

Environmental studies pose a host of problems for researchers. Natural ecosystems are complex, and investigators often have little control over environmental variables. It is difficult to determine the influence of an individual variable on other variables in a natural ecosystem because all variables operate concurrently. Also, the complexity of environmental research often causes logistical and budgetary problems.

As a result, many ecological studies are conducted in laboratories where researchers have control over environmental variables that influence the study. Under controlled conditions, an investigator can manipulate one variable or a combination of variables while other variables are held constant. Consequently, the effect of a variable is more easily isolated and identified under laboratory conditions.

Both natural and laboratory streams are necessary for studying the impact of human activities on streams. Warren and Davis (1971) present an excellent discussion of the use of laboratory streams for research and the applicability of such research to natural situations.

This paper describes a pair of circular laboratory stream channels constructed at the USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Forestry Sciences Laboratory in Corvallis, Oregon. The apparatus was designed to represent small stream habitats that are important spawning and rearing areas for anadromous fish.

GORDON REEVES is a graduate research assistant at Oregon State University, Corvallis, and a USDA Forest Service cooperator. FRED H. EVEREST is a research fisheries biologist and CARL E. MCLEMORE is a fisheries technician at the Forestry Sciences Laboratory, Pacific Northwest Forest and Range Experiment Station, 3200 Jefferson Way, Corvallis, Oregon 97331.

Description of Channels

The channels are oval shaped, measuring 14 by 16 feet (ft) (fig. 1). They are 2.5 ft wide and 2 ft deep, with a total volume of 1,550 gallons.

Each channel consists of eight pieces constructed separately and bolted together (fig. 1). There are four corner pieces 10.3 ft long on the outside and 6.4 ft on the inside and four straight sections, two 2 ft long and two 4 ft long. The bottom of each section is 0.75-inch-thick plywood. The back is 0.25-inch-thick plywood. All wood surfaces are covered with fiberglass and painted with an epoxy paint. Cross supports and uprights were made with 1.5-inch and 1.25-inch angle iron, respectively, and arc-welded together.

The open inner center of the channel is a viewing chamber. Walls of each section are single panes of 0.25-inch-thick plexiglass. A layer of silicone rubber was placed between the glass and the angle iron. The glass was then bolted to the angle iron.

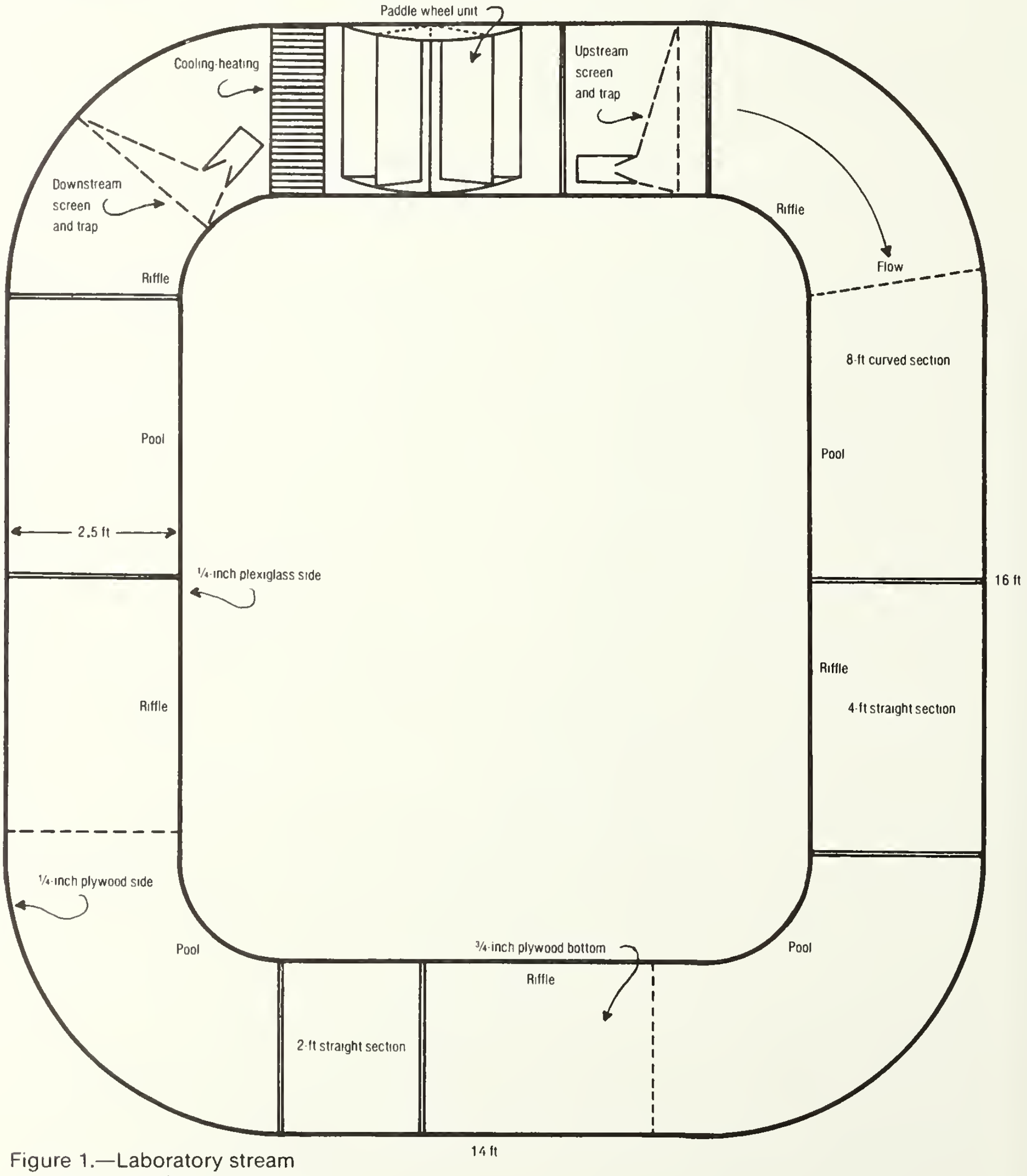

Figure 1.—Laboratory stream channel and major components.

Black polyethylene curtains are suspended around the inside and outside of the channels to eliminate undesired light and other disturbances. The curtains are hung on curtain hooks from a cable attached to the ceiling. This allows the curtains, which extend to the floor, to be moved for easy access to the channels. Slots for observation are cut in the inner curtain at various intervals.

The support structure for the channels is made from Dexion® metal.[1] The channels are set one above the other. The bottom of the lower channel is 16 inches from the floor, vertical distance between channels is 18 inches, and the bottom of the upper channel is 58 inches above the floor. Access to the viewing area is by a stairway over the top of the upper channel. The frame is set on a 1-percent grade (from back to front) to facilitate complete drainage of each channel.

Each channel has independent systems for controlling velocity, lighting, cooling, heating, filtering, feeding, and ultraviolet sterilizing of water. The water depth and the physical structure of habitat, such as riffles, pools, substrate, and cover, within the channel can also be altered.

Two Muskin® model FH40 swimming pool pumps, with a 15-gallon-per-minute capacity, are used to pump water to the filters and feeding boxes. The filter is a stainless steel barrel containing sand. All pipes are 1-inch inside diameter, polyvinyl chloride (PVC).

Water is from the city of Corvallis water supply. Once a channel is filled, only enough water is added continuously to maintain the desired level. Water level is controlled by standpipes of desired height.

The feeding system for each channel consists of a plexiglass box connected to a 5-ft length of pipe. The food box for each channel is installed so that the water level in the box is 48 inches above the water level in the channel. Water pressure from the food box forces brine shrimp (*Artemia* spp.) through small holes in the PVC pipe on the bottom of the channel. The feeding system simulates the natural invertebrate drift food resource of small streams.

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[1] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.

The triangular-shaped food box is made from 0.25-inch plexiglass (fig. 2). The boxes are held in a single frame attached to the ceiling. The bottom of each box is about 24 inches above the top of each channel. The box is divided into two compartments by a piece of 0.25-inch plexiglass. Frozen brine shrimp are placed in the smaller compartment. A small hole, placed slightly above the water level of the front compartment, allows water and thawed brine shrimp to flow from the back to the front compartment. The amount of water flowing to each compartment is controlled by separate valves. An airstone is placed in each compartment to keep the brine shrimp in suspension and increase dispersal time. Water and shrimp from the large compartment flow down to the feeder pipes in the channel. Any excess water drains to the channel via an overflow pipe positioned near the top of the box.

The feeding pipe runs at right angles across the head, diagonally across the length, and at right angles across the tail of riffles. The pipe runs diagonally across pools. It stops 4 ft from the downstream screen to prevent loss of food into the systems control areas of the channels that are not accessible to fish.

Holes one-sixteenth inch in diameter are drilled in the feeding pipe to allow brine shrimp to escape and simulate drifting insects. Pipe in riffles in the upstream half of the channel contains a hole every 6 inches. Holes are every 3 inches in the downstream half and 12 inches in the pools. This arrangement was found to give the best distribution of shrimp throughout the channel.

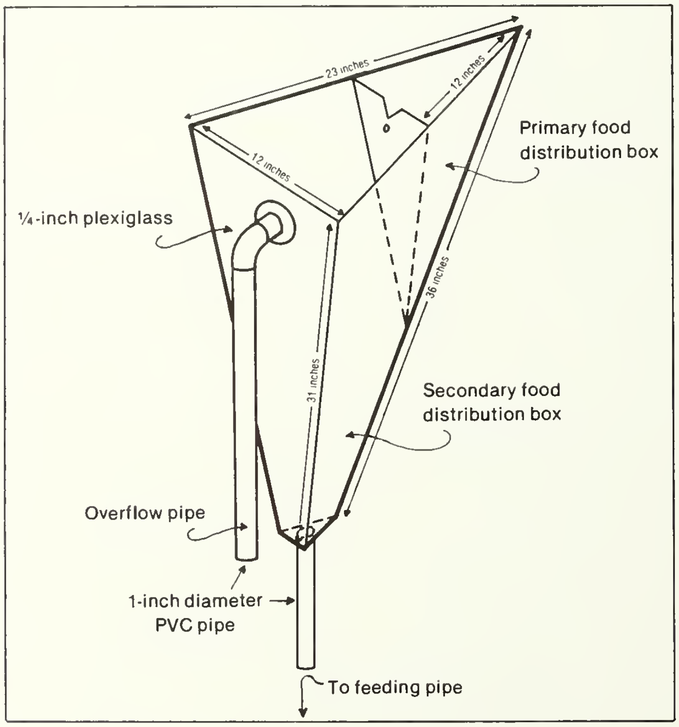

Figure 2.—Dimensions of food boxes for laboratory stream channels.

Water velocity is controlled by a paddle wheel located in each channel. The wheels are made from 0.25-inch-thick plexiglass and are 30 inches in diameter on the ends. There are eight blades, 14 by 26 inches, glued to the end plates; the blades are spaced an equal distance apart. A metal faceplate is mounted on each end of the paddle wheel to support the center shaft. The shaft with bearings is attached to each side of the channel.

Both wheels are belt-driven by a single gear-motor located between the channels. A set of four pulleys on each wheel allows water velocities to be changed. A single idler pulley is used to maintain spring tension on each drive belt. The rotation speed of the paddle wheels can be set to produce a maximum velocity of about 1.5 ft per second, with a volume of flow of about 3 ft^3 per second.

Aquafine® ultraviolet water sterilizers are used to sterilize the water in the channels. Ultraviolet radiation also effectively dechlorinates the water (Seegert and Brooks 1978).

Low temperatures are maintained by a single 3-ton-capacity compressor. Each channel has a chrome- and nickel-plated copper cooling coil controlled by a separate thermostat. Each coil is set directly upstream from the paddle wheel to insure maximum flow over it. High temperatures are maintained by 1500-watt thermostatically controlled immersion heating elements. The controlled temperature capability of the channels ranges from about 33° F to 85° F.

The electrical systems have a total demand of 83 amperes:

Electrical system	Power required (Amperes)
Paddle wheels	4
Filters	10
Ultraviolet sterilizers	2
Lights	12
Refrigeration	24
Heaters (immersion)	26
Miscellaneous valves, timers, aerators	5
Total	83

The electrical power supply is protected with ground-fault interrupters.

The lighting system consists of nine 60-watt bulbs with 12-inch reflectors equally spaced over the area of each channel available to fish. Lights are controlled by a timer device described in detail by Everest and Rodgers (1982) (fig. 3). The device provides a natural diel cycle of sunrise-day-sunset-night.

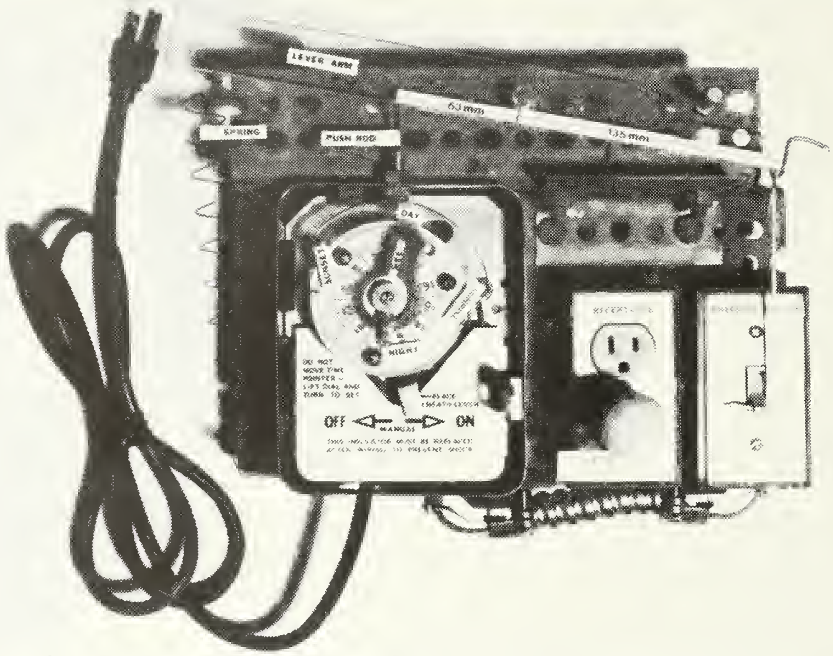

Figure 3.—Light control device simulates natural diel cycle of sunrise-day-sunset-night.

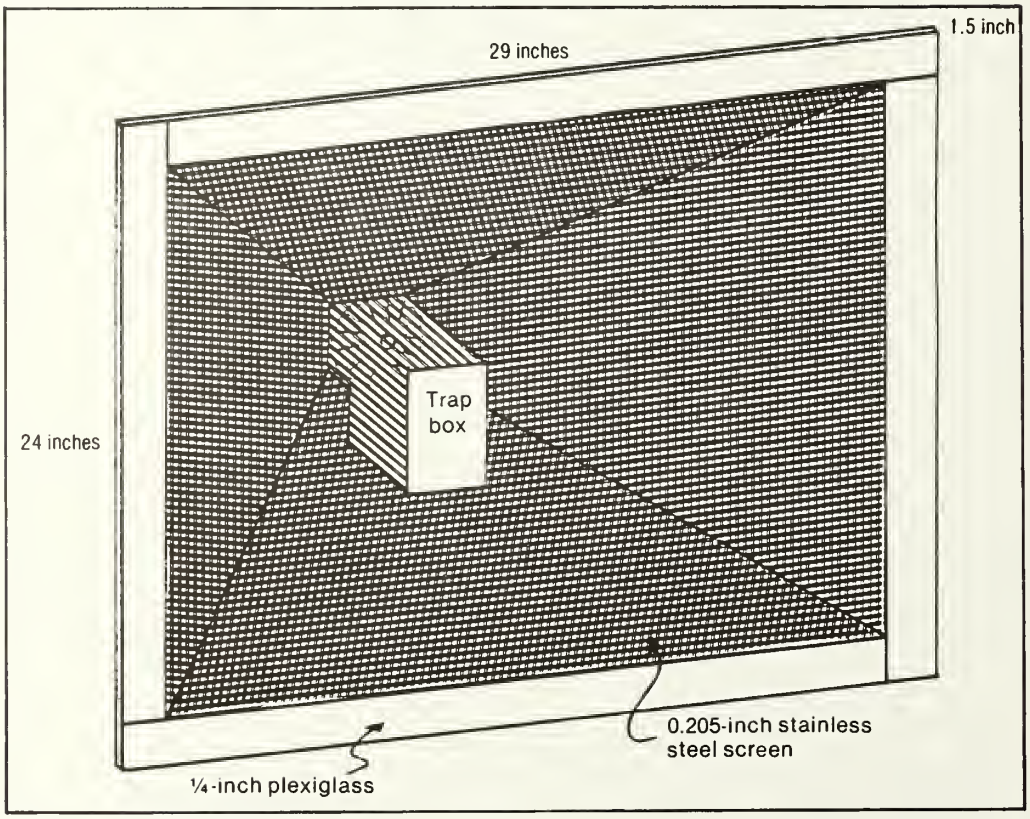

Figure 4.—Screen and trap box
used in laboratory streams.

Two screens prevent movement of fish into the area of each channel where the cooling coil and paddle wheel are located (about 8 ft of space). The screens are designed to direct fish attempting to leave the channels into either upstream or downstream trap boxes. The screens are 0.205-inch-mesh stainless steel attached to a 0.25-inch plexiglass frame (fig. 4). They are set in slots formed by plexiglass mounted on the side of the channels. This allows the screens to be removed during cleaning or rearranging the substrate.

A trap box, also made from stainless steel screen, is attached to the back of each screen. The front of the box has a one-eighth-inch plexiglass frame that slides in and out of slots of a plexiglass adapter attached to each screen. A piece of plastic screening forms a narrow fyke at the box opening, through which fish pass to the holding area. The back of the box is plexiglass and is detachable for removing fish.

The bottom configuration of each channel consists of 50 percent pools and 50 percent riffles. Each pool and riffle is about 4 ft long. The pools are 18 inches deep and the riffles 12 to 14 inches. Pools contain sand and some rocks ($<$2 inches in diameter). Riffles contain rocks 2 to 3 inches in diameter and a few larger rocks. Gravel the size of peas was also placed in the riffles to decrease the amount of intergravel space.

Substrate was placed on platforms made from 0.75-inch plywood to reduce the amount and weight of substrate materials on the riffles. The platforms are 4 inches high by 36 inches long by 29 inches wide and covered with fiberglass resin. A 12-inch-long slope at each end of the platform creates a gradual transition between pools and riffles.

Total cost for the two channels, excluding labor, was about $7,700:

Category	Cost
	(Dollars)
Channel construction	2,646
Refrigeration and heating	2,099
Electrical lighting, etc.	739
Plumbing	625
Filters and pumps	800
Ultraviolet system	800
Total	7,709

Carrying Capacity of Channels

The channels were designed to represent small stream environments and, consequently, primarily are suitable habitat for small fish. Depths, velocities, and cover characteristics of the channels are marginal for salmonids more than 6 inches long, but conditions are excellent for salmonid fry and fingerlings. The carrying capacity of the channels depends on the size of fish introduced. Each channel can accommodate 80 to 100 recently emerged salmonid fry but only 12 to 15 salmonids 5 to 6 inches long. Larger numbers of small, nonterritorial fish with less rigid spatial demands can be accommodated.

Research Opportunities

The channels provide the opportunity for conducting a wide spectrum of research dealing with the ecological behavior of small fishes in a controlled environment. Broad areas of research suitable for the channels include habitat requirements of fishes, the effects of human activities on habitats, fish responses, rehabilitation and enhancement of fish habitat, and studies of interspecific and intraspecific interactions, such as competition or predation.

Metric Equivalents

To convert:	to:	multiply by:
feet	centimeters	30.40
inches	centimeters	2.540
gallons	liters	3.785
(°F)-32	°C	5/9

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Pacific Northwest Forest and Range
Experiment Station
809 NE Sixth Avenue
Portland, Oregon 97232

United States Department of Agriculture

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Pacific Northwest Forest and Range Experiment Station

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Growth of Suppressed Grand Fir and Shasta Red Fir in Central Oregon After Release and Thinning — 10-Year Results

Kenneth W. Seidel

Abstract

A 43-year-old, even-aged stand of advance reproduction of grand fir and Shasta red fir in central Oregon responded to release and thinning with diameter and height growth two to three times the prerelease rate. The response began immediately after the overstory was killed with 2,4-D. Diameter growth during the second 5 years after release increased significantly over that of the first 5 years. Differences in spacing had no effect on growth. Increased growth after release suggests that saving advance true fir reproduction is desirable under certain conditions.

Keywords: Growth response, thinning effects, even-aged stands, release, central Oregon, grand fir, *Abies grandis*, Shasta red fir, *Abies magnifica*.

Introduction

Many mixed conifer forests in eastern Oregon and Washington consist of a mature or overmature overstory and a suppressed understory of saplings and poles. Although true firs are an important component of these mixed conifer forests, no information is available on their long-term growth and yield under various spacing and thinning regimes.

In 1970, a study was begun in a suppressed, even-aged stand of grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.) and Shasta red fir (*A. magnifica* var. *shastensis* Lemm.) in central Oregon. The purpose was to obtain data on growth of the two species at several initial spacings and under a progressive thinning schedule. This paper reports study results after 10 years. It supplements an earlier report of results for the first 5 years (Seidel 1977).

Study Area and Methods

The study site is on the Pringle Falls Experimental Forest in the Deschutes National Forest near Bend, Oregon; the site and the timber stand are described in an earlier report (Seidel 1977).

The study consists of two closely related parts. One is an initial spacing experiment, testing growth at four spacings (6-, 12-, 18-, and 24-feet) in variable-area plots created by thinning in 1970. Each spacing is replicated twice, making a total of eight plots. Twenty-four trees were selected for measurements in each plot; plot size, including buffer strips, ranged from 0.14 acre to 0.64 acre, depending on spacing. No additional thinning will be done in these plots.

KENNETH W. SEIDEL is a research forester with the Silviculture Laboratory, 1027 NW Trenton Avenue, Bend, OR 97701.

The second part is a progressive thinning experiment with fixed-area plots similar to O'Conner's design (1935). Eight 0.25-acre plots were thinned to 6-foot spacing in 1970. The plan calls for subsequent thinning based on diameter growth. When diameter growth of 10 percent of trees on all eight plots is 0.1 inch or less than growth the previous year, six of the eight plots will be thinned to 12-foot spacing. When growth on the plots with 12-foot spacing slows to the same degree, four plots of the six will be thinned to 18-foot spacing. Thinning will continue on this pattern until there are two plots at each of the four spacings in variable-area plots. This plan will eventually permit comparison of volume growth and yield between the initial spacing, variable-area plots and progressively thinned, fixed-area plots. After 10 years, the fixed-area plots remain at 6-foot spacing.

The lodgepole pine overstory was killed in 1970 with 2,4-D ((2,4-dichlorophenoxy) acetic acid) to release the fir understory without logging damage and provide partial shade for a few years after release. Two-hundred-fifty fir seedlings near the plots were transplanted onto the fixed-area plots to improve spacing.

Height of all plot trees was measured to the nearest 0.1 foot and diameter at breast height (d.b.h.) of trees 0.6 inch or larger to the nearest 0.1 inch in 1971, 1975, and 1980. Diameter was measured annually on a 10-percent random sample of trees on the fixed-area plots. In 1976, 50 trees of each species were randomly chosen from the buffer strips and cut at the groundline for measurements of diameter growth during the 5 years before release and the 5 years after release. In 1976, the 5-year prerelease height growth was measured by counting whorls of all trees in the variable-area plots and the 10-percent sample in the fixed-area plots. Crown diameter and height to live crown were measured on 10 trees per plot on the variable-area plots in 1971, 1975, and 1980.

Average height of trees on the eight fixed-area plots was 4.6 feet after thinning and ranged from 3.8 to 5.6 feet on the variable-area plots (table 1). Average d.b.h. of trees of measurable size was about 1 inch. Of the trees in the fixed-area plots, 59 percent were grand fir compared with 81 percent in the variable-area plots.

Differences in diameter and height growth between species, periods, and initial spacings were analyzed using split-plot analyses of variance in a completely randomized design at the 0.05 probability level. Height growth was also subjected to analysis, using height before release and thinning and 5-year prerelease height growth as covariates. No analyses were applied to data from the fixed-area plots because they are all at the same 6-foot spacing.

Table 1 — Characteristics of grand fir — Shasta red fir plots after thinning in 1970 and 5 and 10 years later

Plots and spacing	Species composition: Grand fir	Species composition: Red fir	Number of trees	Trees less than 0.6-inch d.b.h.		Quadratic mean diameter[1]	Average height	Basal area	Total volume
Feet	*---Percent---*		*Per acre*	*Number per acre*	*Percent*	*Inches*	*Feet*	*Square feet per acre*	*Cubic feet per acre*
After thinning, 1970:									
Fixed-area plots —									
6 x 6	59	41	1,169	817	70	1.2	4.6	2.8	20.6
Variable-area plots —									
6 x 6	81	19	1,200	975	81	1.2	3.8	1.7	11.5
12 x 12	79	21	304	158	52	1.2	5.6	1.2	7.7
18 x 18	92	8	134	103	77	0.9	4.3	0.2	1.1
24 x 24	71	29	76	63	83	1.0	4.1	0.1	0.5
1975:									
Fixed-area plots—									
6 x 6	59	41	1,114	498	45	1.5	6.7	8.5	65.4
Variable-area plots —									
6 x 6	81	19	1,200	800	67	1.5	5.3	5.4	38.3
12 x 12	79	21	304	95	31	1.8	8.0	3.6	25.4
18 x 18	92	8	134	61	46	1.4	6.5	0.8	5.6
24 x 24	71	29	76	33	43	1.3	6.0	0.4	2.5
1980:									
Fixed-area plots —									
6 x 6	60	40	1,039	280	27	2.2	8.4	19.9	173.6
Variable-area plots —									
6 x 6	81	19	1,200	550	46	1.9	6.5	12.8	100.5
12 x 12	80	20	298	44	15	2.6	10.1	9.3	81.8
18 x 18	92	8	132	11	8	2.1	9.1	3.0	24.8
24 x 24	69	31	76	11	15	2.0	8.3	1.4	10.2

[1] All trees 0.6-inch d.b.h. and larger.

Results

Diameter Growth

Release had a marked effect on rate of diameter growth of the fir understory. The average growth of both species during the 5 years before release (measured on trees cut in buffer strips) was about 0.04 inch per year. Growth increased nearly threefold, to 0.11 inch per year, in the 5 years after release. The response occurred during the first year, averaging 0.13 inch.

During the first 5-year period diameter growth was not affected by variations in spacing. Annual growth averaged 0.16 inch on the 12-, 18-, and 24-foot spacings and 0.15 inch on the 6-foot spacing (table 2). On the eight fixed-area plots, which remained at 6-foot spacing, periodic annual diameter growth averaged 0.15 inch, and there was no significant difference between grand fir (0.14 inch per year) and red fir (0.16 inch per year).

During the second 5-year period, diameter growth increased significantly ($P<0.05$) above that of the first period. Increases ranged from 20 percent at the 6-foot spacing to 44 percent at the 18-foot spacing. Differences among spacings were still not significant, although growth at the 12- and 18-foot spacings was 0.22 to 0.23 inch per year compared to 0.18 inch at the 6-foot spacing (table 2). Diameter growth in table 2 may not agree with differences between mean diameters at the beginning and end of growth periods shown in table 1 because average diameters at each measurement are based on trees 0.6 inches d.b.h. or larger at the time, but growth is based only on trees of measurable size in 1970 and 1975. Differences between the two species again were not significant.

Table 2 — Periodic annual increment and mortality of grand fir and Shasta red fir saplings during two 5-year measurement periods after release and thinning in 1970 when trees were 43 years old

Plots and spacing	Diameter growth[1]	Basal area growth			Total volume growth		
		Net	Mortality	Gross	Net	Mortality	Gross
Feet	*Inches*	*— Square feet per acre —*			*— Cubic feet per acre —*		
From age 43 to 48 (1971-75):							
Fixed-area plots —							
6 x 6	0.15	1.13	0.01	1.14	8.9	0.1	9.0
Variable-area plots —							
6 x 6	.15	.74	—	.74	5.4	—	5.4
12 x 12	.16	.50	—	.50	3.6	—	3.6
18 x 18	.16	.14	—	.14	.9	—	.9
24 x 24	.16	.06	—	.06	.4	—	.4
From age 48 to 53 (1976-80):							
Fixed-area plots —							
6 x 6	.17	2.28	.08	2.36	21.6	.7	22.3
Variable area plots —							
6 x 6	.18	1.47	—	1.47	12.4	—	12.4
12 x 12	.22	1.14	.03	1.17	11.3	.2	11.5
18 x 18	.23	.44	—	.44	3.9	—	3.9
24 x 24	.20	.20	—	.20	1.6	—	1.6

[1]Arithmetic mean diameter growth of trees 0.6-inch d.b.h. or larger at beginning of each 5-year period and living through the period.

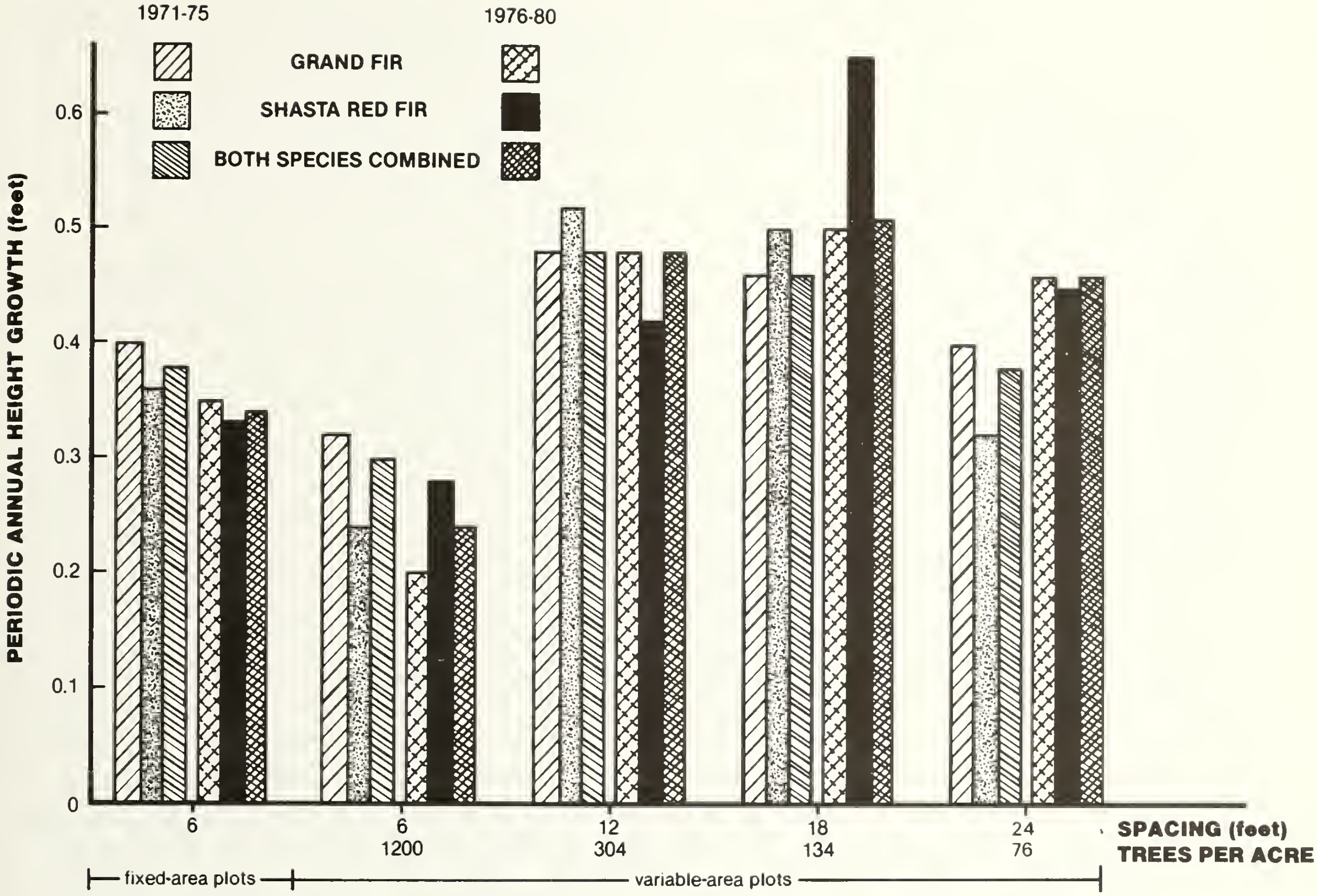

Figure 1. — Periodic annual height increment after release, by species, spacing, and growth period, based on growth of all trees living through each 5-year period. The number of trees per acre in the fixed-area plots varied over time because of mortality but was not more than 1,200.

Height Growth

Height growth did not differ significantly according to species or spacing, or between the two 5-year periods. Use of initial height and prerelease height growth as covariates did not produce any significant differences among spacings. Average annual growth was slowest at the 6-foot spacing during both periods and fastest at the 12- and 18-foot spacings (fig. 1). During the second period, height growth at the 6-foot spacing was slightly less than in the first period, while growth at the wider spacings was somewhat greater. Height growth of individual trees varied widely, ranging from 0 to 7 feet during the 10 years.

The trees responded to release the first growing season after release, in contrast to a delay of 5 years for suppressed red firs in California (Gordon 1973). The growth rate doubled from about 0.2 foot annually before release to about 0.4 foot per year after release.

Growth in Basal Area and Volume

Growth in both basal area and total cubic volume was small during the first 5 years but increased significantly ($P<0.05$) during the second 5 years as more trees reached measurable size. Annual volume increment more than doubled, from 9.0 to 22.3 cubic feet per acre, on the fixed-area plots during the second period (table 2). Average volume and basal area growth in the 6-foot-spaced variable-area plots was much less than growth in the fixed-area plots because one variable-area plot had only 33 percent trees of measurable size compared to 73 percent on the fixed-area plots.

Mortality

Much of the mortality was transplanted seedlings. All but 8 of the 111 that died during the first 5 years were transplanted trees. During the second period, 70 additional trees died; most were less than 3 feet tall. No snow damage was observed after release and thinning, except for a few trees with small crowns that were growing in dense clumps before thinning.

Discussion

The large and rapid response to release, in terms of both diameter and height growth, may have been because most of the trees in this study were vigorous, with live crown ratios greater than 40 percent. Basal area and volume increment more than doubled during the second 5-year period on the fixed-area plots and can be expected to increase rapidly during the next 10 to 20 years as average stand diameter and height increase and all trees attain measurable size.

Because of their shade tolerance, many true fir seedlings and saplings retain relatively full crowns, even though they are suppressed, and thus can respond rapidly to increased growing space as did the trees in this study. Results of another study in central Oregon (Seidel 1980a) indicate that suppressed advance reproduction with live crown ratios of at least 50 percent, showing rapid height growth before release are best able to respond to release. The height advantage of advance reproduction can be determined if average heights and height-growth rates of both planted seedlings and advance reproduction are known (Seidel 1980b). In addition, using a two-stage overstory removal, with about 5 years between cuttings, on hot, dry sites, as suggested by Ferguson and Adams (1979), enables trees to adjust to their new environment.

When deciding whether to save advance reproduction or clearcut and plant, managers should also consider the possibility of animal damage to seedlings and the probability that heart rots will cause decay in the future. There is still some uncertainty that heart-rotting fungi will be reactivated by wounds in advance reproduction of true fir, but Filip and Aho (1978) have identified conditions where a high risk of future decay exists for white fir (*Abies concolor*) in the Fremont National Forest. These conditions are: (1) white fir overstory infected with Indian paint fungus (*Echinodontium tinctorium*), (2) advance white fir regeneration that has been suppressed for more than 50 years, (3) advance reproduction that has numerous wounds, and (4) advance reproduction of low vigor because of poor site. They feel if three or more of these conditions are present in a stand, the advance white fir regeneration has a high potential for developing serious decay.

A decision to save and manage the advance reproduction requires the use of logging methods and slash disposal techniques designed to reduce loss and damage to the understory. Barrett and others (1976) have shown that it is possible to preserve adequate numbers of understory ponderosa pine (*Pinus ponderosa*) saplings by marking the potential crop trees before logging and by using unconventional slash disposal equipment, such as a front-end grapple mounted on a rubber-tired tractor. Similar techniques should be applicable to mixed conifer stands where topography permits tractor logging.

Metric Equivalents

1 acre = 0.405 hectare
1 foot = 0.3048 meter
1 inch = 2.54 centimeters
1 mile = 1.61 kilometers
1 square foot = 0.0929 square meter
1 square foot/acre = 0.2296 square meter/hectare
1 tree/acre = 2.47 trees/hectare
1 cubic foot = 0.0293 cubic meter
1 cubic foot/acre = 0.0700 cubic meter/hectare

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PNW-405
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Water Quality and Streamflow in the Caribou-Poker Creeks Research Watershed, Central Alaska, 1978

Jerry W. Hilgert and
Charles W. Slaughter

Abstract

Baseline data from 1978 are presented on precipitation, streamflow, and chemical and biological water quality in a subarctic, taiga watershed. First-, second-, and third-order streams that drain undisturbed catchments embracing permafrost-underlain and permafrost-free landscapes were monitored; results are being used in analysis of the natural, undisturbed condition of the research watershed.

Keywords: Water quality, stream environment, streamflow, stream analysis, subarctic environment, watershed management, hydrology, taiga, Alaska.

Introduction

Study sites embracing representative ecosystems and amenable to observation, measurement, and experimentation are valuable for developing basic understanding of environmental properties and processes, as well as for developing and testing techniques for resource management. For such a research site to be most useful, baseline site information such as stream flow regime, local climate, and stream quality must be available. This report presents basic data and initial analyses for undisturbed streams within a formally established, subarctic environmental-research site.

JERRY W. HILGERT is an aquatic biologist and CHARLES W. SLAUGHTER is a research hydrologist, Institute of Northern Forestry, Pacific Northwest Forest and Range Experiment Station, 308 Tanana Drive, Fairbanks, Alaska 99701.

Objectives

Baseline data on water quality from four monitoring stations in the Caribou-Poker Creeks Research Watershed were acquired during a segment of the 1978 summer (open-water) season. Weekly field sampling was conducted on two first-order streams, one second-order stream, and one third-order stream. The two first-order streams were chosen because they differ in proportion of permafrost (permanently frozen ground). The stream draining a permafrost-dominated basin was expected to have a more pronounced response to storm events, resulting in greater discharge peaks, higher turbidity and sediment production, and lower water temperatures than a relatively permafrost-free watershed. The third-order stream was expected to have higher annual discharge and higher turbidity, sediment production, and water temperatures than the second-order stream.

A weekly schedule for water-quality sampling was adopted, to evaluate applicability of that schedule to monitoring storm events during the ice-free season. Discharge characteristics of the streams were compared to determine whether a more intensive, storm-oriented sampling scheme would be necessary for adequate monitoring of sediment production during high flows.

Results of this partial-season study provide a basis for more intensive investigations of stream quality. This information is being used to develop a better understanding of the current environmental functioning of the site, and in planning for experimental manipulation of selected landscapes.

The Study Area

The Caribou-Poker Creeks Research Watershed (fig. 1) encompasses 106 km^2 in the subarctic taiga of central Alaska.[1/] The research watershed, 49 km north of Fairbanks, was established in 1969 under sponsorship of the Inter-Agency Hydrology Committee for Alaska (formerly Inter-Agency Technical Committee for Alaska).

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[1] The Institute of Northern Forestry currently administers two other major field study areas: Bonanza Creek Experimental Forest and Washington Creek Fire Study Area.

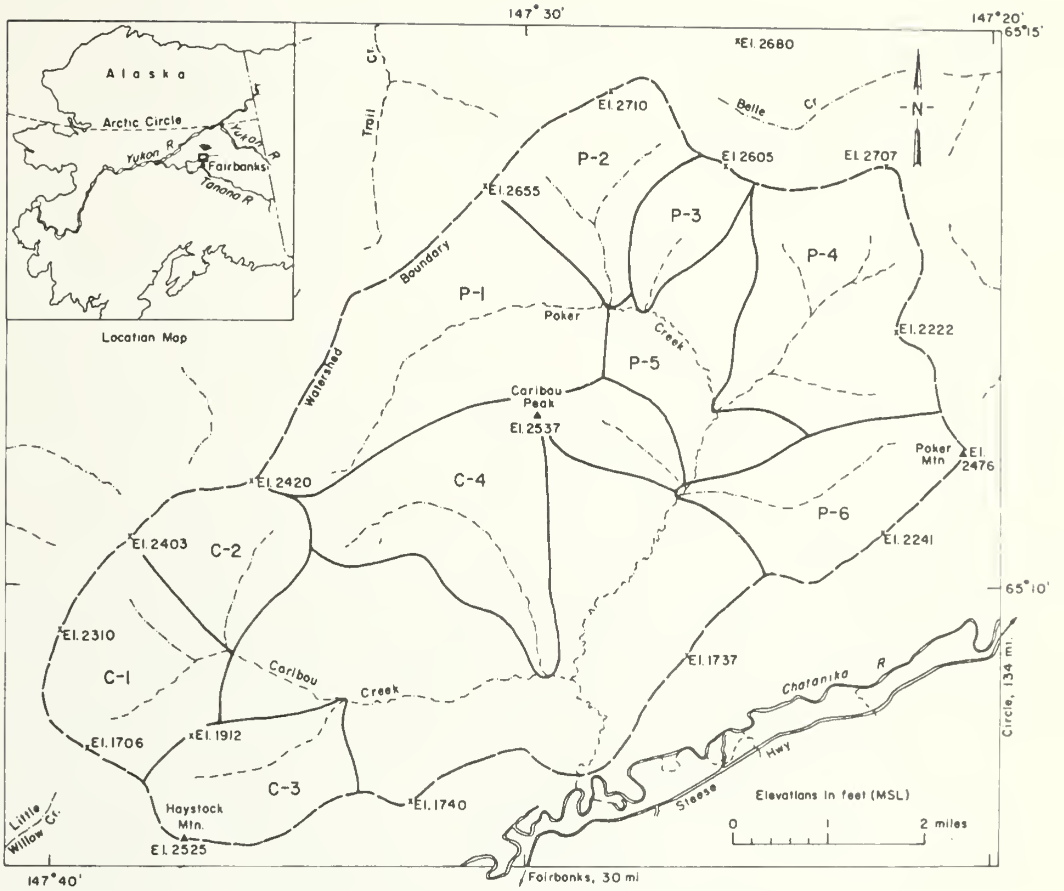

Figure 1.--Caribou-Poker Creeks Research Watershed.

The dendritic drainage pattern of Caribou and Poker Creeks is developed in the Precambrian Birch Creek schist of the Yukon-Tánana Uplands (Wahrhaftig 1965). The watershed has moderate relief, with elevations from 210 m above mean sea level (m.s.l.) to 826 m above m.s.l., and is almost entirely forested. Vegetation patterns are typical of the discontinuous-permafrost taiga; valleys and north-facing slopes are underlain by permafrost and support slow-growing stands of black spruce (<u>Picea mariana</u> (Mill.) B.S.P.) and a deep, virtually continuous organic ground cover (sphagnum and feather mosses, as well as accumulated litter). South-facing slopes are generally free from permafrost and support heterogeneous and sometimes almost pure stands of birch (<u>Betula papyrifera</u> Marsh.), aspen (<u>Populus tremuloides</u> Michx.), white spruce (<u>Picea glauca</u> (Moench) Voss), and alder (<u>Alnus crispa</u> Ait.) Pursh. Streamside zones are commonly dominated by a shrub complex of dwarf birch (<u>Betula glandulosa</u> Michx.), willow (<u>Salix</u> spp.), blueberry (<u>Vaccinium uliginosum</u> L.), and associated species.

The climate is typically continental with short, warm summers (May through mid-September) and long, cold winters. Precipitation is low, averaging about 50 cm/year at upper elevations (compared with 29 cm/year at Fairbanks). Winter snowfall has averaged 17.5 cm (water equivalent) over the past 7 years.

Most effort so far in Caribou-Poker Creeks has been to establish and maintain sites for acquiring hydrologic and climatologic data. Shifting agency responsibilities, funding, and personnel has produced discontinuities in the basic data set. With designation in 1977 of the research watershed as an Experimental Ecological Reserve (Institute of Ecology 1977), renewed emphasis has been placed on reliable, long-term environmental monitoring; this report of baseline data in part reflects that emphasis.

We also decided in 1977 to place greater emphasis on analysis of upland stream systems, particularly the physical, chemical, and biological quality of undisturbed first- and second-order streams draining permafrost and nonpermafrost catchments. This report includes recent data on stream quality, building on earlier water-quality sampling by Jinkinson et al. (1973) and Lotspeich et al. (1976). Biological characteristics of the watershed will be addressed in a subsequent report.

A general description of the study area and objectives is given by Slaughter and Lotspeich (1977). More specific information is available for many aspects of Caribou-Poker Creeks Research Watershed, including geology (Koutz and Slaughter 1972), soils (Reiger et al. 1972), vegetation (Vogel and Slaughter 1972; Troth et al. 1975, 1976), and hydrology (Carlson 1972, Ford 1973, Kane and Slaughter 1973, Slaughter and Long 1974, Santeford 1978). Several earlier reports of basic hydrometeorology data are also available (Slaughter 1970a, 1970b, 1972; Hobgood and Slaughter 1974; Lotspeich et al. 1976; Bredthauer 1977; Slaughter and Bredthauer 1977).

Methods

Precipitation

Summer precipitation was measured at the confluence of Caribou and Poker Creeks with a Weather-Measure tipping-bucket precipitation gage (Model P-501), linked to a Weather-Measure event recorder (Model P-522). At three sites (Helmers Ridge, and at the 487- and 640-m elevations on the Caribou Peak trail), precipitation was measured with Fisher-Porter weighing precipitation gages (Model 1559). A large storage gage equipped with a Leupold & Stevens A-71 level recorder was used to measure precipitation on Caribou Peak at 768 m. Snowfall data will be reported in another paper.

Streamflow

Streamflow data for Caribou and Poker Creeks (CJ and PJ) were acquired by personnel of the U.S. Geological Survey (1979), using water-level recorders at natural-control cross sections. Streamflow from subdrainage C2 was monitored with a Fisher-Porter 1542 water-level recorder with a fiberglass Parshall flume. Streamflow from subdrainage C3 was measured with a similar flume, equipped with a Leupold & Stevens Type F water-level recorder.

Water Quality

Four primary stream-sampling stations were established for the 1978 summer and fall field season. All sampling was conducted near midday, and we tried to sample all the stations in as short a time as access and travel allowed. No more than 3 hours elapsed between the first and last station sampling. Each station was sampled weekly for chemical constituents. Two 125-ml samples were taken and filtered through Gelman microquartz glass fiber filters (0.45 μm). Samples for Na, K, Ca, Mg, As, Fe, and Mn were acidified to pH 2 and stored in the dark at 5°C until analyzed by atomic absorption spectrophotometry (American Public Health Association 1975). Samples for NO_2, $NO_2 + NO_3$, NH_3, PO_4, and Si were filtered as above, stored frozen, and later analyzed with a Technicon Auto-Analyzer (U.S. Environmental Protection Agency 1976). A 500-ml sample was collected and filtered through a tared Gelman microquartz glass fiber filter (0.45 μm) for quantification of nonfilterable residue (suspended sediment) (American Public Health Association 1975).

Ambient air and water temperature, turbidity, pH, and alkalinity were measured by portable field apparatus on the sites. Specific conductance was measured with a calibrated Beckman Solubridge meter.

Biological sampling for macroinvertebrate populations (tri-replicate Surber sampling at nine stations), and preliminary evalution of periphyton sampling methods for analysis of standing-crop biomass and accumulation rates on various artificial substrates will be presented in a separate publication.

Subdrainages C2 and C3 were chosen for detailed monitoring because they differ in occurrence of permafrost. The proportion of permafrost was determined from soil maps (Reiger et al. 1972). The C2 catchment is predominantly nonpermafrost (only 3 percent by area) and is characterized by south-facing slopes, with relatively deep soils supporting aspen, paper birch, white spruce, and some black spruce. The C3 subbasin has a greater proportion of permafrost (53 percent by area) than C2 because of its generally northeast aspect. Soils are shallow, overlain by a moss/lichen ground cover and generally open overstory dominated by black spruce (Slaughter and Kane 1979). Striking dissimilarities in local climate (Slaughter and Long 1974) and hydrologic response between the two subdrainages have been documented.

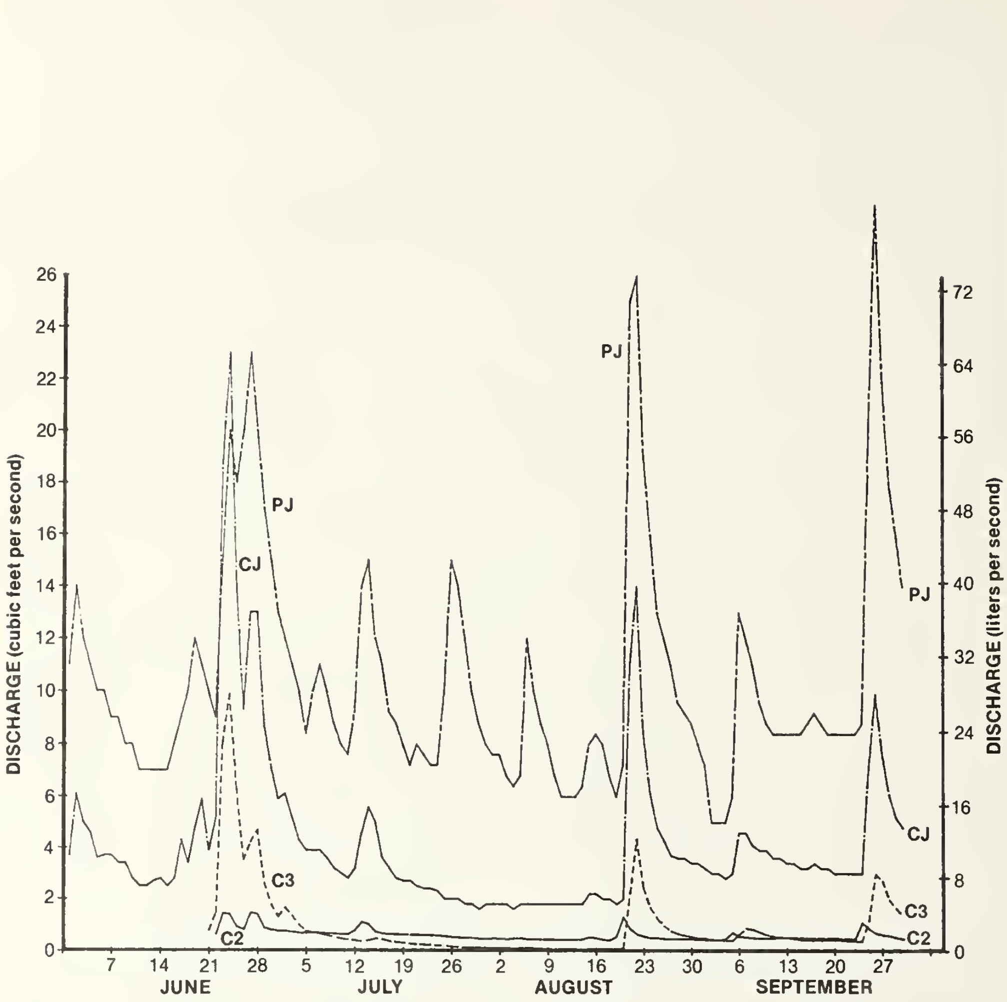

Figure 2.--Summer 1978 hydrographs of C2, C3, CJ (Caribou Creek), and PJ (Poker Creek).

Results and Discussion

Hydrology

Precipitation data for the ice-free season of 1978 are given in appendix tables 9 and 10. Mean daily streamflow data for the four stations are summarized in appendix tables 11 through 14. Hydrographs from all four stations over the ice-free season are presented as figure 2. Poker Creek exhibited higher flows than Caribou Creek throughout the season. Of special interest in the subarctic is a comparison of the response to summer storms of a stream draining a permafrost-dominated basin (C3) with a stream draining a relatively permafrost-free basin (C2). Cumulative precipitation measured at the junction of Poker and Caribou Creeks is compared hourly with C2 and C3 hydrographs for storms that occurred in June, August, and September 1978 (figs. 3, 4, and 5). Response in all three events was much more pronounced in C3 (permafrost-dominated) than in C2 (comparatively permafrost-free).

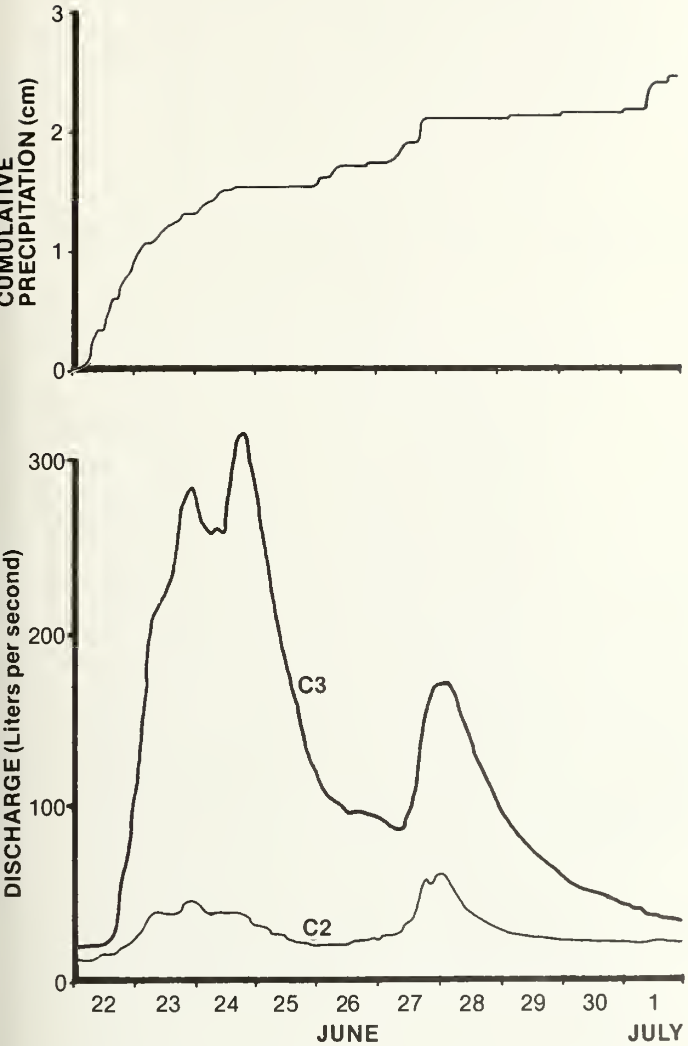

Figure 3.--Hydrographs of C2 and C3 and cumulative storm precipitation at junction of Poker and Caribou Creeks, June 22 to July 1, 1978.

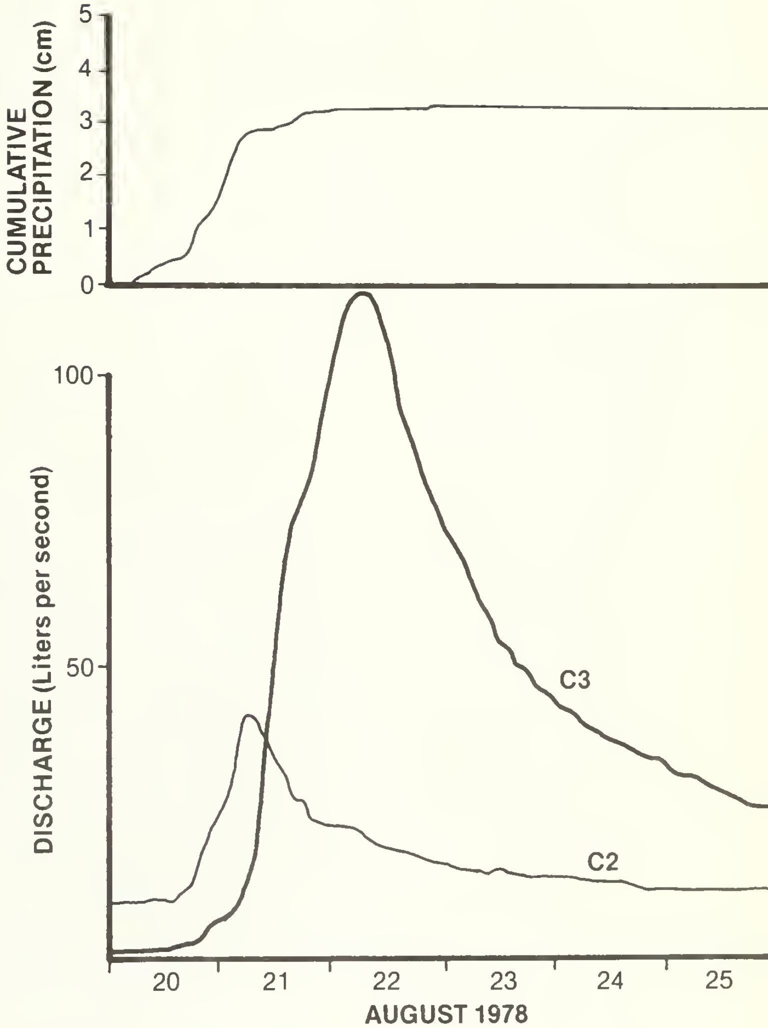

Figure 4.--Hydrographs of C2 and C3 and cumulative storm precipitation at junction of Poker and Caribou Creeks, August 20 to 25, 1978.

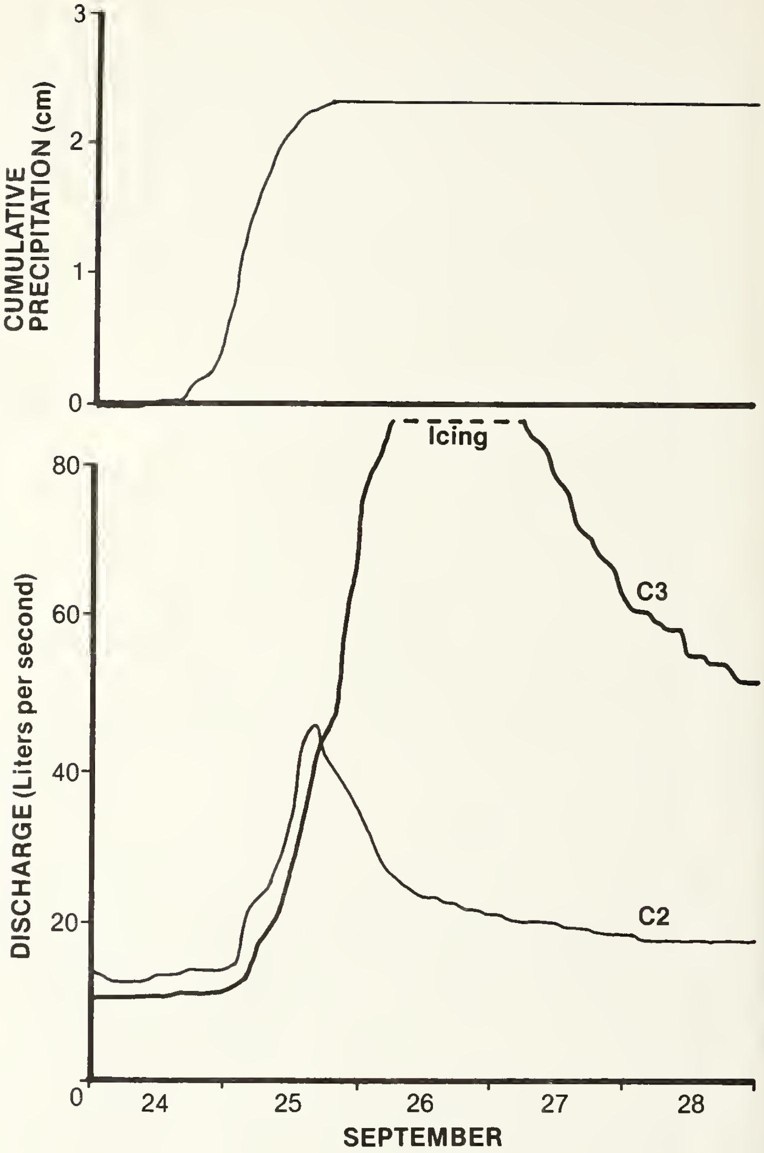

Figure 5.--Hydrographs of C2 and C3 and cumulative precipitation at junction of Poker and Caribou Creeks, September 24 to 28, 1978.

Water Quality

Physical and chemical characteristics (air and water temperature, pH, alkalinity, and specific conductance) are presented in appendix table 15. Concentrations of nonfilterable residue, turbidity, and point discharge are given in appendix table 16.

Water temperatures appeared slightly lower in the C3 (permafrost-dominated) drainage than in the C2 (low-permafrost) drainage. Mean temperatures (based on weekly point measurements) for the ice-free study period (7-26 through 9-28) were 3.2°C in C3 and 4.25°C in C2. Mean water temperatures (weekly point measurements) for the ice-free period were 3.5°C for Caribou Creek and 4.9°C for Poker Creek, possibly reflecting higher mean water temperatures with increasing drainage area.

Figure 6 shows weekly sampling-time water temperatures at the four stations and midday air temperature at the confluence of Poker and Caribou Creeks.

Figure 6.--Air and water temperatures in Caribou-Poker Creeks.

The mean values of nonfilterable residue (measured weekly) for the period 5-16-78 to 10-4-78 (fig. 7) were 0.24 mg/l for C2 (N=21) and 0.23 mg/l for C3 (N=20); standard deviations were 0.42 (C2) and 0.41 (C3). A t-test for the difference of the two means indicated no significant difference ($P>0.05$). Nonfilterable residues for the period 6-21-78 through 12-8-78 (fig. 8) were higher in Poker Creek (PJ), with a mean of 10.66 mg/l (N=32), than in Caribou Creek (CJ), with a mean of 3.64 mg/l (N=31). Standard deviations were 14.19 (PJ) and 10.86 (CJ). A t-test indicated a significant difference between the means of CJ and PJ ($P<0.05$).

Mean turbidity values for weekly samples from 7-26-78 through 10-4-78 (N=11) were 2.18 Formazin turbidity units (FTU) in C2 (standard deviation = 3.03) and 2.09 FTU in C3 (standard deviation = 2.26). Mean turbidity values for weekly samples from 7-26-78 through 12-8-78 (N=15) were 5.40 FTU in Caribou Creek (standard deviation = 5.08) and 4.73 FTU in Poker Creek (standard deviation = 3.59). The t-tests revealed no significant difference ($P>0.05$) between the means of C2 and C3 and likewise no significant difference ($P>0.05$) between the means of CJ and PJ. Relation of turbidity to discharge for C2 and C3, and CJ and PJ are presented in figures 9 and 10.

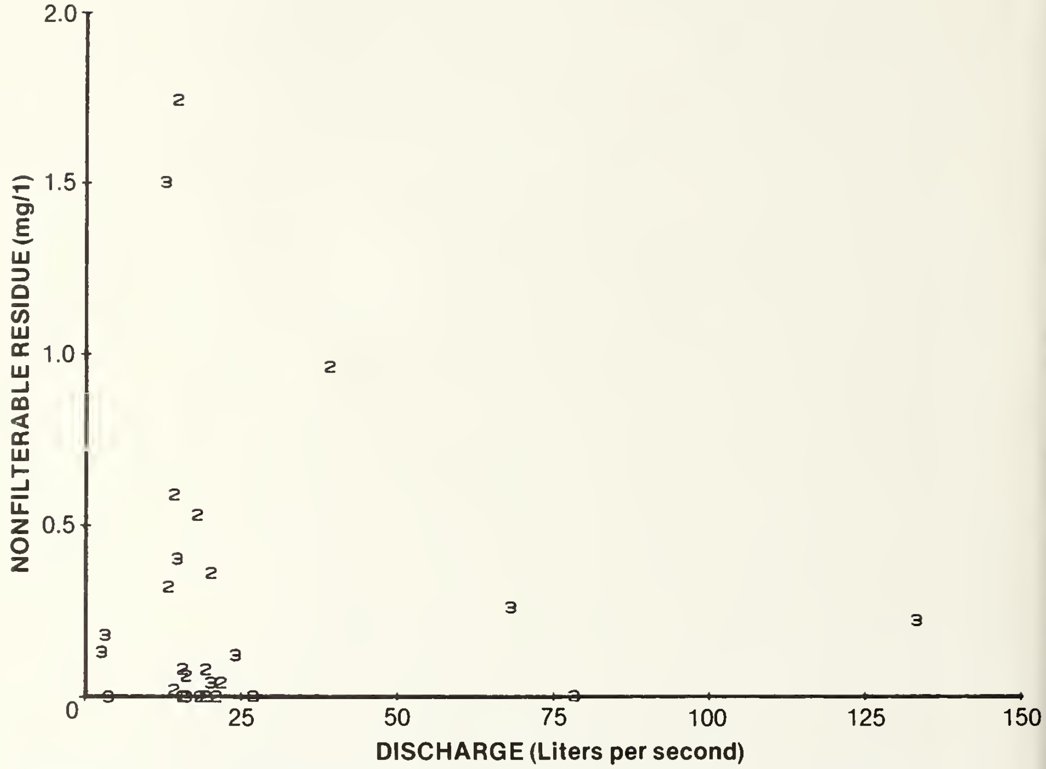

Figure 7.--Relation of nonfilterable residue to discharge, C2 (2) and C3 (3).

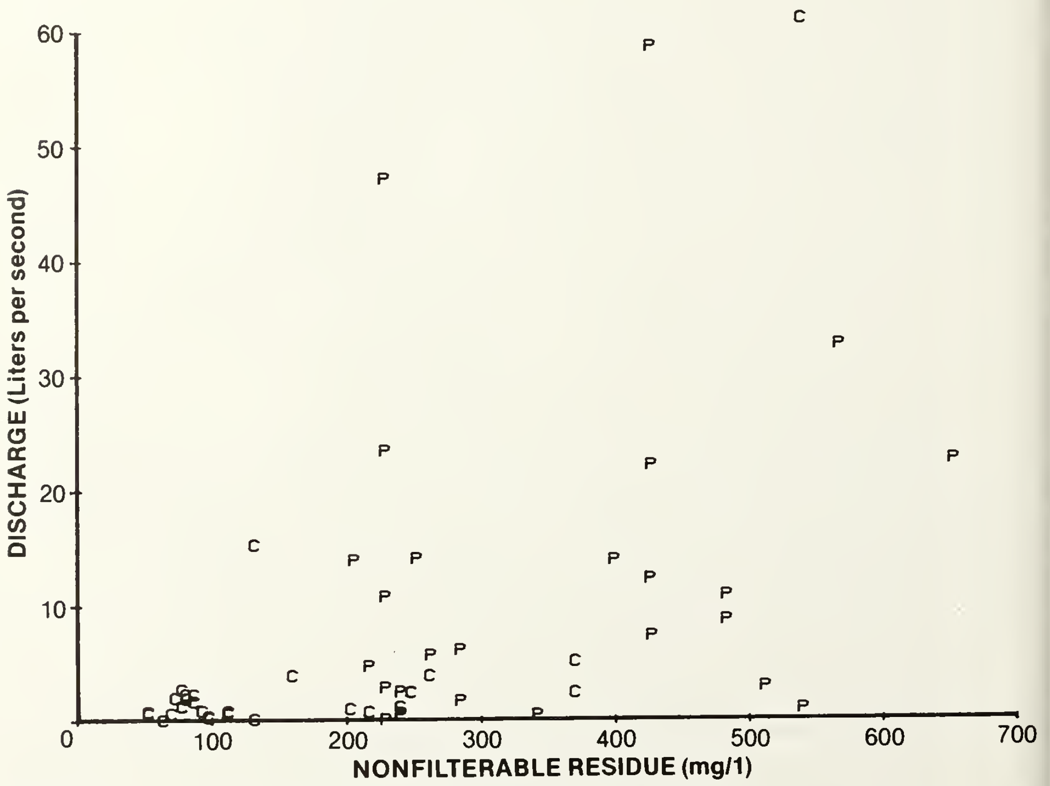

Figure 8.--Relation of nonfilterable residue to discharge, Caribou (CJ) and Poker (PJ) Creeks.

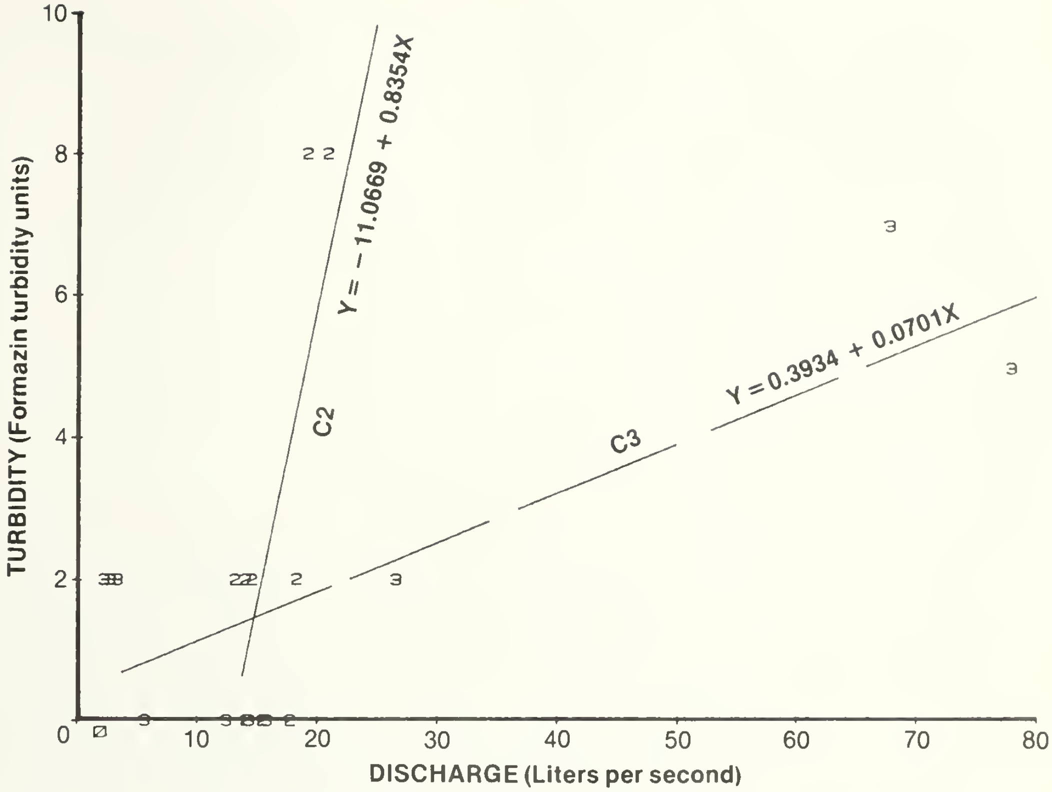

Figure 9.--Relation of turbidity to discharge in C2 and C3.

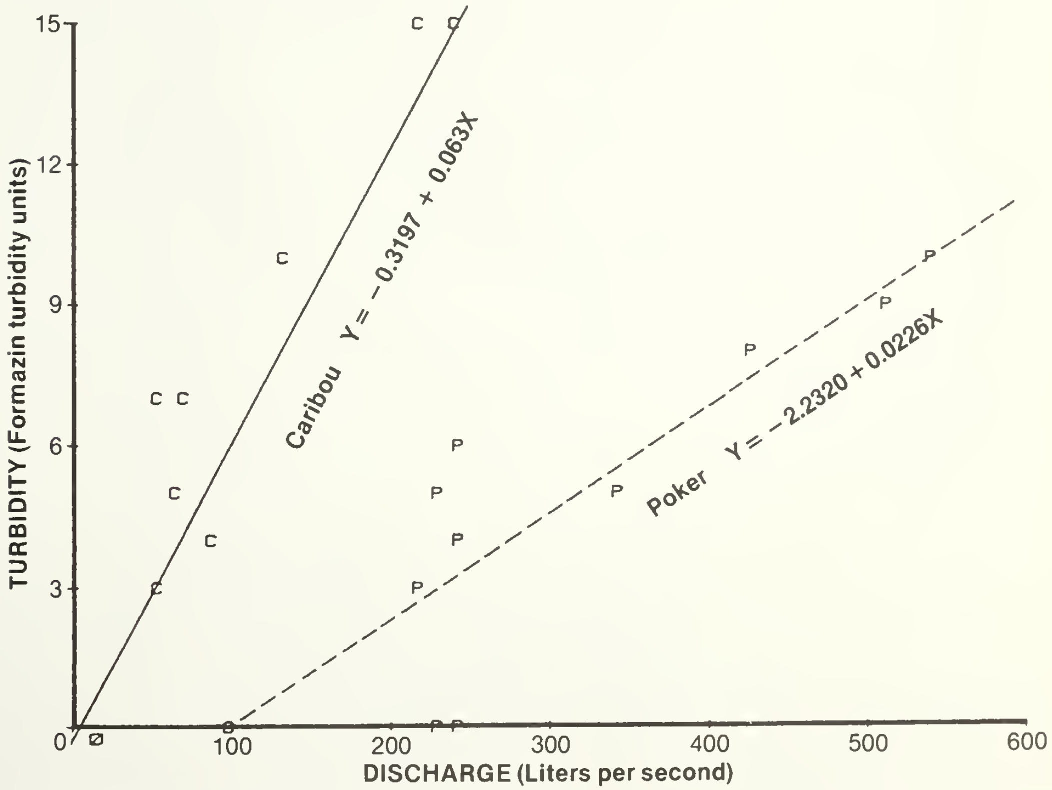

Figure 10.--Relation of turbidity to discharge in Caribou (C) and Poker (P) Creeks.

Calculated correlation coefficients among discharge, nonfilterable residue, turbidity, and water temperature are listed in table 1.

Table 1--Correlation coefficients for 4 stream-sampling stations, Caribou-Poker Creeks Research Watershed

Station	Correlation coefficient	Sample size
Turbidity to discharge:		
C2	0.693*	10
C3	.325	10
CJ	.780*	10
PJ	.833*	10
Nonfilterable residue to discharge:		
C2	0.189	15
C3	-.165	14
CJ	.672*	27
PJ	-.077	26
Nonfilterable residue to turbidity:		
C2	-.116	11
C3	-.295	11
CJ	.205	15
PJ	.300	15
Water temperature to discharge:		
C2	.361	10
C3	.690*	10
CJ	-.436	7
PJ	-.416	7

* = significant at the 5-percent level.

Turbidity generally was significantly correlated ($P<0.05$) with discharge. Only the permafrost-dominated C3 basin did not exhibit this correlation. Nonfilterable residue (suspended sediment) generally was not significantly correlated with discharge; only the Caribou Creek (CJ) samples showed a significant correlation ($P<0.05$) between these parameters.

Turbidity was not significantly correlated ($P>0.05$) with nonfilterable residue at any of the stations sampled. This may be attributed to heavy loadings of organic leachates (often referred to as "tea-colored water") into low-order streams during high-flow periods. Such loadings can increase turbidity without increase in associated sediment concentrations in the stream. Development of a predictive residue:turbidity regression is precluded, when few samples are collected during a single season and concentration of suspended sediment is low.

Based on these preliminary data and others using infrequent sampling, predicting concentration of nonfilterable residues by using turbidity or streamflow for these streams would not be justified.

Failure of the permafrost-dominated C3 basin to show strong correlation between discharge and turbidity may be related to temperature and ground cover (reflections of the microclimate of colder, north-facing slopes). Permafrost-underlain landscapes have cold soils, typically overlain by thick, virtually continuous organic mats that may be highly acidic (pH as low as 3.5). Leaching processes and rates that affect the input of lignins and tannins into streams may thus differ markedly from warmer settings. Such stream responses, if characteristic of permafrost-dominated catchments, should "average out" as water is progressively incorporated into higher order channels downstream, reflective of a composite of varying permafrost/non-permafrost conditions.

Mean values of alkalinity, pH, and specific conductance are summarized in tables 2, 3, and 4. Mean pH values appeared slightly higher in the two main creeks (7.8) than in the two first-order streams (7.6). Specific conductance, pH, and bicarbonate alkalinity appeared to increase slightly during periods of early winter ice cover and reduced discharge.

A listing of concentrations of nitrogen, phosphorus, and silicon is presented as appendix table 17.

Table 2--Mean alkalinity of 4 streams, Caribou-Poker Creeks Research Watershed

Station	Season (1978) Open-water (7-26 to 10-5) (N=11)	Ice-cover (11-9 to 12-9) (N=4)	Total (7-26 to 12-9) (N=15)
	Milligrams per liter of bicarbonates		
C2	38.9	--	--
C3	29.1	--	--
CJ	47.1	52.5	49.1
PJ	55.7	64.0	58.7

Table 3--Mean pH of 4 streams, Caribou-Poker Creeks Research Watershed

Station	Season (1978) Open-water (7-26 to 10-5) (N=11)	Ice-cover (11-9 to 12-9) (N=4)	Total (7-26 to 12-9) (N=15)
C2	7.76	--	--
C3	7.79	--	--
CJ	7.88	7.98	7.91
PJ	7.91	8.00	7.94

Table 4--Mean specific conductance of 4 streams, Caribou-Poker Creeks Research Watershed

Station	Season (1978) Open-water (7-26 to 10-5) (N=11)	Ice-cover (11-9 to 12-9) (N=4)	Total (7-26 to 12-9) (N=15)
	Micromhos per centimeter		
C2	79	--	--
C3	73	--	--
CJ	91	122	91
PJ	114	127	117

Table 5--Mean values of nitrogen and phosphorus compounds and silicon in 4 streams, Caribou-Poker Creeks Research Watershed, 7-26-78 to 11-29-78[1]

Station and sample size	NO_2	$NO_2 + NO_3 - N$	$NH_3 - N$	$PO_4 - P$	Si
	- - - - - - - - - - Micrograms per liter			- - - - - - - - - -	Milligrams per liter
C2, N=10	0.55 (0.62)	245.71 (159.95)	40.75 (28.29)	8.49 (7.17)	2.18 (1.76)
C3, N=11	.41 (.52)	286.25 (153.86)	16.04 (11.76)	2.34 (2.16)	1.96 (1.34)
CJ, N=12	.85 (.92)	236.79 (104.99)	35.58 (38.01)	3.36 (3.51)	2.18 (1.24)
PJ, N=14	.84 (.89)	255.71 (119.87)	28.23 (22.27)	4.38 (5.40)	2.17 (1.02)

[1]Standard deviations in parentheses.

Mean phosphate concentrations from C2 appeared to be nearly four times that of C3 and twice the levels in Caribou (CJ) and Poker Creeks (PJ). Small sample sizes from this data set precluded valid statistical testing. Nitrate plus nitrite levels appeared similar at all stations. The low concentrations of nitrite may be attributed to the high dissolved-oxygen content and cold temperatures of the basin (Lotspeich et al. 1976).

Silicon concentrations appeared negtively correlated with discharge at C2, C3, and CJ, but not in Poker Creek. Additional high-discharge measurements will be required to test these relationships further in subsequent study years.

Nitrogen to phosphorus ratios (N/P) are an important consideration in determining limitation of prime nutrients for algal and aquatic plant productivity. N/P ratios were calculated by the formula (Zison et al. 1977):

$$N/P = \frac{\text{Total N}}{\text{Ortho-}PO_4} .$$

N/P ratios greater than 15 are indicative of phosphorus-limited conditions and less than 15 are indicative of nitrogen limitation (Uttormark et al. 1974). Calculated N/P ratios are summarized in table 6. Only two instances of possible nitrogen limitation were evident from the Caribou Creek collections: C2 on 8-9-78 (N/P = 6.5) and 8-16-78 (N/P = 5.6). One case of slight nitrogen limitation occurred in the Poker Creek sampling on 8-9-78 (N/P = 13.2).

Table 6--Nitrogen to phosphorus ratios for 4 streams, Caribou-Poker Creeks Research Watershed

	Station			
Date (1978)	C2	C3	CJ	PJ
7-26	--	27.1	59.5	69.0
8-1	15.3	46.9	--	42.2
8-9	6.5*	166.4	16.1	13.2*
8-16	5.6*	70.8	78.8	18.1
8-23	18.1	108.8	63.4	122.9
8-31	64.5	213.0	104.7	+
9-7	+	+	143.9	+
9-13	143.6	96.1	31.5	60.5
9-20	97.3	820.8	686.8	58.0
9-28	16.6	107.6	--	24.0
10-4	397.4	+	181.2	+
11-7	--	--	187.1	474.3
11-21	--	--	+	+
11-28	--	--	81.2	212.7

* = Nitrogen limited; + = PO_4 - P less than 1.0 milligram per liter.

Consideration of N/P ratios and phosphorus limitation could become relevant if impoundments were proposed on a subarctic lotic system. Examination of these limited data suggest that impounded water from these streams might be phosphorus-limited and thus have a low potential for disruptive or toxic algal blooms, unless landscape disturbance contributed additional phosphorus compounds. Addition of phosphorus from activities such as residential development, roadbuilding, fire, timber harvest, or other manipulations could conceivably supply adequate phosphorus for excessive algal or aquatic plant growth.

Preliminary analyses of these data indicate that assignment of nutrient and sediment loadings will require several years more observations at a greater number of sites with extended sampling frequency. Characterization of high-flow regimes and greater resolution of the relation of discharge to sediment are required. Future efforts should incorporate 9 to 11 stations, and emphasize breakup processes and hydrologic extremes (high and low flows).

Analysis of Elements

Dissolved ionic constituents are presented in appendix table 18. Mean concentrations of dissolved ionic constituents appeared lower in the two first-order streams (C2 and C3) than in the higher order streams (PJ and CJ) (table 7). Ionic concentrations in Poker and Caribou Creeks tended to increase in the autumn after an ice cover had formed; this relationship was also observed in the total hardness concentrations (table 8). Total hardness values are presented in appendix table 19. More samples from higher discharge periods are required to explore further the relation of hardness to discharge.

Table 7--Mean concentrations of elements in 4 streams, Caribou-Poker Creeks Research Watershed

Season (1978), sample size, and station	Na	K	Ca	Mg	As	Fe	Mn
	Milligrams per liter						
Open-water (8-16 to 10-5) (N=7):							
C2	1.49	0.47	8.85	2.80	<0.04	0.016	<0.005
C3	1.52	.43	9.81	1.53	<.04	.56	<.005
CJ	2.01	.72	15.05	3.03	<.04	.105	.015
PJ	2.10	.80	21.51	4.02	.04	.059	.028
Ice-cover (11-9 to 12-9) (N=4):							
CJ	2.01	.77	17.60	3.62	<.04	.056	.022
PJ	1.95	.82	24.00	4.53	.04	.024	.031
Total (8-16 to 12-9) (N=11):							
CJ	2.01	.72	15.05	3.03	<.04	.088	.018
PJ	2.05	.81	22.34	4.19	<.04	.047	.029

Table 8--Mean total hardness of water in 4 streams, Caribou-Poker Creeks Research Watershed[1]

Station	Season (1978) Open-water (8-16 to 10-5) (N=7)	Ice-cover (11-7 to 12-9) (N=4)	Total (8-16 to 12-9) (N=11)
		Milligrams per liter	
C2	33.63 (16.99)	--	--
C3	30.87 (14.58)	--	--
CJ	45.88 (7.56)	59.03 (1.93)	50.26 (8.90)
PJ	70.44 (7.21)	78.65 (2.59)	73.18 (7.16)

[1]Standard deviation in parentheses.

Conclusions

Differences in both quantity and quality of water were observed between the streams. The permafrost-dominated (C3) basin exhibited a more pronounced hydrologic response to the three summer storm events than did the relatively permafrost-free (C2) basin. The third-order stream Poker Creek (PJ) had a higher total discharge than did the second-order stream Caribou Creek (CJ). Water temperatures appeared slightly lower in the C3 basin than in the C2 basin and higher in the third-order Poker Creek than in the second-order Caribou Creek. Poker Creek was found to have a significantly ($P<0.05$) higher mean nonfilterable residue than did Caribou Creek, but no significant difference was observed between C2 and C3. No significant differences in turbidity were observed in either Poker Creek vs. Caribou Creek or C2 vs. C3.

Examination of the water-quality data from a partial season indicates that a weekly sampling schedule will provide an adequate general understanding of gross water-quality characteristics under minimum flow conditions. Major hydrologic events, such as spring breakup and summer storm episodes, evidently are the dominant contributors of sediment to the streams (Aldrich and Johnson 1979). Future efforts should focus on these events.

Access to the basins during spring breakup and major storm events is a major problem. A network of automated samplers would permit simultaneous, timed sampling, a sample schedule dependent on discharge conditions, or both (for example, sampling could commence when discharge increases to a predetermined level).

Greater resolution of suspended-sediment concentrations on the rising and falling limbs of a hydrograph is necessary to calculate sediment-discharge relations accurately. Calculation of annual sediment yields also necessitates more intensive episodic monitoring, especially during spring breakup.

Previous efforts to sample stream quality throughout the winter (Lotspeich et al. 1976) indicated that relatively little sediment is produced and that water-quality characteristics are comparatively stable and predictable under an extensive ice cover. Lotspeich et al. (1976) concluded: "It does not appear necessary to continuously monitor water quality parameters from freezing to breakup unless there is some special reason to justify the effort." Grab samples should be collected monthly in winter, when obtainable; however, extensive aufeis in the C3 and, to a lesser extent, the C2 and C4 valleys commonly precludes periodic sampling past January. Time-lapse photography and automated sampling should be attempted to estimate discharge and associated sediment loadings during spring breakup.

Addition of stations at subdrainage C4, the bridge over upper Caribou Creek upstream from the influx of C3, and at "Caribou Main" (the USGS stream-gaging station) will provide a wider data base for the study of the stream continuum from first- through third-order, and of processes associated with increasing stream order. This more comprehensive sampling scheme should provide the strong comparative data set of "baseline" conditions necessary before experimental landscape manipulations are initiated.

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Conversions

U.S. customary units used in this report may be converted to metric units as follows:

Multiply	By	To obtain
foot	0.3048	meter
mile	1.609	kilometer
pound	.4536	kilogram
square mile	2.589	square kilometer
gallon	3.785	liter
cubic foot	.02831	cubic meter

Metric units used in this report may be converted to U.S. customary units as follows:

Multiply	By	To obtain
meter	3.281	foot
kilometer	.6214	mile
kilogram	2.205	pound
square kilometer	.3861	square mile
liter	.2641	gallon
cubic meter	35.31	cubic foot

Appendix

Table 9--Monthly summaries of precipitation, Caribou-Poker Creeks Research Watershed, May-September 1978

Month	Caribou-project (elevation, 230 m)	Caribou Peak trail (elevation, 487 m)	Caribou Peak trail (elevation, 640 m)	Caribou Peak (elevation, 768 m)	Helmers Ridge (elevation, 630 m)
			Millimeters		
May	2.3	2.5	2.5	--	7.6
June	34.6	53.3	63.5	64	45.6
July	33.4	88.9	78.7	35	12.7
August	54.4	66.0	78.7	50	35.5
September	50.5	60.9	58.4	10	58.4

Table 10--Daily precipitation, summer 1978, Caribou-Poker Creeks junction [using Weather-Measure P-501 tipping-bucket gage]

Date	Precipitation: Increment	Precipitation: Cumulative total	Date	Precipitation: Increment	Precipitation: Cumulative total
	Millimeters			Millimeters	
4-7	--	--	7-11	1.78	70.33
4-15	0.76	0.76	7-12	13.46	83.79
4-26	2.29	3.05	7-14	.76	84.55
5-1	.25	3.30	7-22	.25	84.80
5-16	1.52	4.82	7-25	6.10	90.90
5-17	.25	5.07	7-26	.25	91.15
5-26	.25	5.32	8-12	.76	91.91
6-1	7.11	12.43	8-14	1.52	93.43
6-6	1.27	13.70	8-15	8.13	101.56
6-10	.25	13.95	8-16	.25	101.81
6-12	.76	14.71	8-20	16.00	117.81
6-13	9.65	24.36	8-21	17.78	135.59
6-15	.76	25.12	8-22	1.02	136.61
6-16	5.59	30.71	8-31	.25	136.86
6-18	.25	30.96	9-5	6.10	142.96
6-19	4.32	35.28	9-6	10.41	153.37
6-20	.25	35.53	9-7	.25	153.62
6-21	2.03	37.56	9-9	.25	153.87
6-22	9.14	46.70	9-12	.25	154.12
6-23	4.32	51.02	9-14	.25	154.37
6-24	2.29	53.31	9-16	2.29	156.66
6-26	2.03	55.34	9-20	1.27	157.93
6-27	3.81	59.15	9-21	2.29	160.22
6-29	.25	59.40	9-22	.25	160.47
6-30	.51	59.91	9-23	1.02	161.49
7-1	2.79	62.70	9-24	5.59	167.08
7-6	4.83	67.53	9-25	18.54	185.62
7-7	1.02	68.55	9-28	1.02	186.64

Table 11--Mean daily streamflow, summer 1978, subdrainage C-2 of Caribou-Poker Creeks Research Watershed [monitored by Parshall flume, Fisher-Porter water-level recorder]

Date	Mean daily streamflow[1]	Date	Mean daily streamflow[1]
	Cubic feet per second[2]		Cubic feet per second[2]
6-22	0.65	7-22	0.62
6-23	1.45	7-23	.61
6-24	1.41	7-24	.60
6-25	.93	7-25	.59
6-26	.82	7-26	.57
6-2	[3]1.47	7-27	.54
6-28	1.41	7-28	.52
6-29	.88	7-29	.51
6-30	.80	7-30	.50
7-1	.77	7-31	.48
7-2	.76	8-1	.48
7-3	.73	8-2	.49
7-4	.69	8-3	.47
7-5	.68	8-4	.46
7-6	.72	8-5	.49
7-7	.69	8-6	.50
7-8	.68	8-7	.46
7-9	.66	8-8	.46
7-10	.64	8-9	.45
7-11	.64	8-10	.45
7-12	.80	8-11	.44
7-13	[4]1.12	8-12	.44
7-14	1.02	8-13	.45
7-15	.81	8-14	.44
7-16	.73	8-15	.46
7-17	.67	8-16	.54
7-18	.64	8-17	.50
7-19	.64	8-18	.44
7-20	.62	8-19	.42
7-21	.62	8-20	.57

Table 11--Mean daily streamflow, summer 1978, subdrainage C-2 of Caribou-Poker Creeks Research Watershed [monitored by Parshall flume, Fisher-Porter water-level recorder] (continued)

Date	Mean daily streamflow[1]	Date	Mean daily streamflow[1]
	Cubic feet per second[2]		Cubic feet per second[2]
8-21	1.31	9-11	0.50
8-22	.86	9-12	.51
8-23	.65	9-13	.53
8-24	.57	9-14	.53
8-25	.51	9-15	.53
8-26	.51	9-16	.53
8-27	.48	9-17	.52
8-28	.47	9-18	.51
8-29	.47	9-19	.51
8-30	.47	9-20	.51
8-31	.47	9-21	.52
9-1	.46	9-22	.49
9-2	.45	9-23	.49
9-3	.44	9-24	.49
9-4	.44	9-25	[5]1.11
9-5	.48	9-26	.88
9-6	.72	9-27	.71
9-7	.57	9-28	.64
9-8	.55	9-29	.61
9-9	.52	9-30	.54
9-10	.51	10-1	.49
		10-2	[6]--

[1] Each mean daily flow is the mean of 24 hourly values.
[2] For conversion to metric units, 1.0 cubic foot per second equals 28.32 liters per second.
[3] Instantaneous peak was 2.18 cubic feet per second.
[4] Instantaneous peak was 1.63 cubic feet per second.
[5] Instantaneous peak was 1.66 cubic feet per second.
[6] Flume and stilling well frozen.

Table 12--Mean daily streamflow, summer 1978, subdrainage C-3 of Caribou-Poker Creeks Research Watershed [monitored by Parshall flume, Fisher-Porter water-level recorder]

Date	Mean daily streamflow[1]	Date	Mean daily streamflow[1]
	Cubic feet per second[2]		Cubic feet per second[2]
6-21	[3] 0.80	7-16	.44
6-22	1.48	7-17	.37
6-23	8.05	7-18	.33
6-24	[4] 9.89	7-19	.31
6-25	6.31	7-20	.27
6-26	3.52	7-21	.25
6-27	4.23	7-22	.24
6-28	4.70	7-23	.23
6-29	2.61	7-24	.21
6-30	1.78	7-25	.20
7-1	1.31	7-26	.17
7-2	1.66	7-27	.15
7-3	1.35	7-28	.14
7-4	1.00	7-29	.13
7-5	.76	7-30	.12
7-6	.70	8-1	.12
7-7	.66	8-2	.13
7-8	.59	8-3	.12
7-9	.53	8-4	.11
7-10	.47	8-5	.12
7-11	.44	8-6	.13
7-12	.40	8-7	.11
7-13	.37	8-8	.10
7-14	.41	8-9	.09
7-15	.48	8-10	.08
		8-11	.08

Table 12--Mean daily streamflow, summer 1978, subdrainage C-3 of Caribou-Poker Creeks Research Watershed [monitored by Parshall flume, Fisher-Porter water-level recorder] (continued)

Date	Mean daily streamflow[1]	Date	Mean daily streamflow[1]
	Cubic feet per second[2]		Cubic feet per second[2]
8-12	0.08	9-6	0.65
8-13	.08	9-7	.89
8-14	.07	9-8	.84
8-15	.09	9-9	.74
8-16	.10	9-10	.64
8-17	.09	9-11	.58
8-18	.08	9-12	.56
8-19	.08	9-13	.53
8-20	.12	9-14	.50
8-21	2.25	9-15	.46
8-22	4.35	9-16	.44
8-23	2.42	9-17	.44
8-24	1.66	9-18	.44
8-25	1.25	9-19	.44
8-26	.97	9-20	.44
8-27	.77	9-21	.44
8-28	.68	9-22	.41
8-29	.61	9-23	.40
8-30	.56	9-24	.40
8-31	.51	9-25	.18
9-1	.49	9-26	2.98
9-2	.46	9-27	2.70
9-3	.45	9-28	1.98
9-4	.42	9-29	1.60
9-5	.42	9-30	1.35
		10-1	2.12
		10-2	[5]--

[1] Each mean daily flow is the mean of 24 hourly values.
[2] For conversion to metric units, 1.0 cubic foot per second equals 28.32 liters per second.
[3] Half-day record, from 1400 hours 21 June.
[4] Instantaneous peak was 11.13 cubic feet per second.
[5] Flume and stilling well frozen.

Table 13--Mean daily streamflow, Caribou Creek[1]

DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1977 TO SEPTEMBER 1978[2] MEAN VALUES												
DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	12	7.4	5.6	3.5	2.5	2.5	1.5	1.5	3.7	5.9	1.8	3.2
2	11	7.4	5.6	3.5	2.5	2.5	1.5	1.5	6.1	6.1	1.8	3.0
3	10	7.2	5.6	3.5	2.5	2.5	1.5	1.5	5.0	5.2	1.8	3.0
4	11	7.2	5.4	3.5	2.5	2.5	1.5	1.5	4.6	4.3	1.6	2.8
5	11	7.2	5.2	3.5	2.5	2.5	1.5	1.5	3.6	3.9	1.8	3.0
6	10	7.2	5.2	3.0	2.5	2.0	1.5	1.7	3.7	3.9	1.8	4.6
7	9.3	7.0	5.2	3.0	2.5	2.0	1.5	1.9	3.7	3.9	1.8	4.6
8	9.0	7.0	5.0	3.0	2.5	2.0	1.5	2.0	3.4	3.6	1.8	4.1
9	8.4	7.0	5.0	3.0	2.5	2.0	1.5	2.0	3.4	3.2	1.8	3.9
10	8.4	6.8	5.0	3.0	2.5	2.0	1.5	1.6	2.8	3.0	1.8	3.9
11	8.4	6.8	5.0	3.0	2.5	2.0	1.5	1.6	2.5	2.8	1.8	3.6
12	8.2	6.8	5.0	3.0	2.5	2.0	1.5	1.7	2.5	3.2	1.8	3.6
13	8.2	6.6	4.5	3.0	2.5	2.0	1.5	2.0	2.7	4.6	1.8	3.4
14	8.2	6.6	4.5	3.0	2.5	2.0	1.5	2.2	2.8	5.6	1.8	3.4
15	8.2	6.6	4.5	3.0	2.5	2.0	1.5	2.5	2.5	5.0	2.2	3.2
16	8.0	6.6	4.5	3.0	2.5	2.0	1.5	2.4	2.8	3.6	2.2	3.2
17	8.0	6.4	4.5	3.0	2.5	2.0	1.5	2.0	4.3	3.2	2.0	3.4
18	8.0	6.4	4.0	3.0	2.5	2.0	1.5	2.0	3.4	2.8	2.0	3.2
19	8.0	6.4	4.0	3.0	2.5	2.0	1.5	2.0	4.8	2.7	1.8	3.2
20	8.0	6.4	4.0	3.0	2.5	2.0	1.5	2.1	5.9	2.7	2.4	3.0
21	7.8	6.2	4.0	3.0	2.5	2.0	1.5	2.2	3.9	2.5	11	3.0
22	7.8	6.2	4.0	3.0	2.5	2.0	1.5	2.6	5.2	2.4	14	3.0
23	7.8	6.2	4.0	2.5	2.5	2.0	1.5	3.0	19	2.4	8.4	3.0
24	7.8	6.0	4.0	2.5	2.5	2.0	1.5	3.2	23	2.3	6.1	3.0
25	7.8	6.0	4.0	2.5	2.5	2.0	1.5	3.2	14	2.0	4.8	7.1
26	7.6	6.0	4.0	2.5	2.5	1.5	1.5	3.0	9.3	2.0	4.3	9.9
27	7.6	5.8	4.0	2.5	2.5	1.5	1.5	3.0	13	2.0	3.7	7.6
28	7.6	5.8	3.5	2.5	2.5	1.5	1.5	3.2	13	1.8	3.6	6.1
29	7.4	5.8	3.5	2.5	---	1.5	1.5	3.0	8.7	1.8	3.6	5.2
30	7.4	5.8	3.5	2.5	---	1.5	1.5	2.8	7.1	1.6	3.4	4.8
31	7.4	---	3.5	2.5	---	1.5	---	2.8	---	1.8	3.4	---
TOTAL	265.3	196.8	139.3	91.0	70.0	61.5	45.0	69.2	190.4	101.8	103.9	122.0
MEAN	8.56	6.56	4.49	2.94	2.50	1.98	1.50	2.23	6.35	3.28	3.35	4.07
MAX	12	7.4	5.6	3.5	2.5	2.5	1.5	3.2	23	6.1	14	9.9
MIN	7.4	5.8	3.5	2.5	2.5	1.5	1.5	1.5	2.5	1.6	1.6	2.8
CFSM	.93	.71	.49	.32	.27	.22	.16	.24	.69	.36	.37	.44
IN.	1.07	.80	.56	.37	.28	.25	.18	.28	.77	.41	.42	.49
AC-FT	526	390	276	180	139	122	89	137	378	202	206	242

CAL YR 1977 TOTAL 1911.30 MEAN 5.24 MAX 60 MIN .20 CFSM .57 IN 7.74 AC-FT 3790
WTR YR 1978 TOTAL 1456.20 MEAN 3.99 MAX 23 MIN 1.5 CFSM .43 IN 5.89 AC-FT 2890

NOTE.--No gage-height record October 7 to May 23.

[1] From U.S. Geological Survey (1979).
[2] For conversion to metric units, 1.0 cubic foot per second = 28.32 liters per second.

Table 14--Mean daily streamflow, Poker Creek[1]

DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1977 TO SEPTEMBER 1978[2]
MEAN VALUES

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	28	10	6.0	5.0	4.0	3.5	3.0	18	11	13	7.6	7.2
2	26	10	6.0	5.0	4.0	3.5	3.0	19	14	12	7.6	5.0
3	25	10	6.0	5.0	4.0	3.5	3.0	19	12	11	6.8	5.0
4	24	10	6.0	5.0	4.0	3.5	3.0	20	11	10	6.4	5.0
5	23	9.0	6.0	5.0	4.0	3.5	4.0	20	10	8.4	6.8	6.0
6	22	9.0	6.0	5.0	4.0	3.5	4.0	19	10	10	12	13
7	21	9.0	6.0	5.0	4.0	3.5	5.0	19	9.0	11	10	12
8	20	9.0	6.0	5.0	4.0	3.5	5.0	18	9.0	10	8.8	11
9	20	9.0	6.0	5.0	4.0	3.0	6.0	17	8.0	8.8	8.0	9.6
10	19	9.0	6.0	5.0	4.0	3.0	7.0	16	8.0	8.0	6.8	8.8
11	19	8.0	5.5	4.5	4.0	3.0	7.0	15	7.0	7.6	6.0	8.4
12	18	8.0	5.5	4.5	4.0	3.0	7.0	14	7.0	9.2	6.0	8.4
13	18	8.0	5.5	4.5	3.5	3.0	7.0	13	7.0	14	6.0	8.4
14	17	8.0	5.5	4.5	3.5	3.0	8.0	13	7.0	15	6.4	8.4
15	17	8.0	5.5	4.5	3.5	3.0	8.0	14	7.0	12	8.0	8.4
16	16	8.0	5.5	4.5	3.5	3.0	8.0	16	8.0	11	8.4	8.8
17	16	8.0	5.5	4.5	3.5	3.0	8.0	17	9.0	9.2	8.0	9.2
18	15	7.0	5.5	4.5	3.5	3.0	8.0	16	10	8.8	6.8	8.8
19	15	7.0	5.5	4.5	3.5	3.0	8.0	15	12	8.0	6.0	8.4
20	14	7.0	5.5	4.5	3.5	3.0	8.0	15	11	7.2	7.2	8.4
21	14	7.0	5.5	4.5	3.5	3.0	9.0	14	10	8.0	25	8.4
22	13	7.0	5.5	4.5	3.5	3.0	9.0	14	9.0	7.6	26	8.4
23	13	7.0	5.5	4.5	3.5	3.0	10	13	15	7.2	19	8.4
24	12	7.0	5.0	4.5	3.5	3.0	10	13	20	7.2	16	8.8
25	12	7.0	5.0	4.5	3.5	3.0	11	12	18	10	13	20
26	12	6.0	5.0	4.0	3.5	3.0	12	12	20	15	12	29
27	11	6.0	5.0	4.0	3.5	3.0	14	13	23	14	11	22
28	11	6.0	5.0	4.0	3.5	3.0	15	12	20	12	9.6	18
29	11	6.0	5.0	4.0	---	3.0	16	11	17	10	9.2	16
30	10	6.0	5.0	4.0	---	3.0	17	10	15	8.8	8.8	14
31	10	---	5.0	4.0	---	3.0	---	10	---	8.0	8.0	---
TOTAL	522	236.0	171.5	141.5	104.0	97.0	243.0	467	354.0	312.0	307.2	321.2
MEAN	16.8	7.87	5.53	4.56	3.71	3.13	8.10	15.1	11.8	10.1	9.91	10.7
MAX	28	10	6.0	5.0	4.0	3.5	17	20	23	15	26	29
MIN	10	6.0	5.0	4.0	3.5	3.0	3.0	10	7.0	7.2	6.0	5.0
CFSM	.73	.34	.24	.20	.16	.14	.35	.65	.51	.44	.43	.46
IN.	.84	.38	.28	.23	.17	.16	.39	.75	.57	.50	.49	.52
AC-FT	1040	468	340	281	206	192	482	926	702	619	609	637

CAL YR 1977 TOTAL 4142.70 MEAN 11.3 MAX 70 MIN .70 CFSM .49 IN 6.67 AC-FT 8220
WTR YR 1978 TOTAL 3276.40 MEAN 8.98 MAX 29 MIN 3.0 CFSM .39 IN 5.28 AC-FT 6500

NOTE.--No gage-height record Oct. 5 to June 28.

[1] From U. S. Geological Survey (1979).
[2] For conversion to metric units, 1.0 cubic foot per second = 28.32 liters per second.

Table 15--Air and water temperature, pH, alkalinity, and specific conductance for streamwater-monitoring stations, Caribou-Poker Creeks Research Watershed, 1978

Station	Date	Time	Air temperature	Water temperature	pH	Bicarbonate alkalinity	Specific conductance
			- - - - - - °C	- - - - - -		Milligrams per liter	Micromhos per square centimeter
C1	9-12	1200	3	3.5	7.6	35	46
C2	7-26	1220	24	5	7.8	--	86
	8-1	1200	25	5	7.6	--	80
	8-9	1200	28	6.5	7.0	--	83
	8-16	1145	21	5	7.0	--	73
	8-23	1130	12	4	7.1	35	82
	8-31	1130	22	4	8.2	35	86
	9-7	1130	17.5	4	7.9	35	77
	9-13	1100	3	4	7.7	35	73
	9-20	1200	2	2.5	7.9	39	74
	9-28	1150	12	2.5	7.5	39	77
	10-4	1100	-7	0	8.0	54	82
C3	7-26	1325	23	3.5	7.9	--	95
	8-1	1230	25	4.5	7.7	--	93
	8-9	1230	28	5.5	7.0	--	--
	8-16	1215	21	5	7.1	--	84
	8-23	1200	12	2.5	7.1	18	53
	8-31	1200	20	3	8.2	38	73
	9-7	1200	18	2.5	7.9	32	69
	9-13	1300	4	3	7.6	27	65
	9-20	1230	2	1.5	8.2	32	73
	9-28	1230	12	1	7.6	26	52
	10-4	1130	-7	0	7.6	31	77
C4	9-13	1445	4	3	8.0	56	95
	11-21	1100	-6	0	8.0	55	108
CJ	7-26	1500	21	6	8.0	--	97
	8-1	1315	25	--	7.4	--	108
	8-9	1315	27	7	7.9	--	99
	8-16	1300	18	7	7.2	--	92
	8-23	1100	12	3	7.1	35	69
	8-31	1245	19	3.5	8.0	76	95
	9-7	1130	17	2	8.0	58	86
	9-14	0930	3	2	8.1	46	86
	9-20	1200	5	2	7.8	50	95
	9-27	1145	12	1.5	8.2	20	82
	10-4	1300	-7	0	7.7	45	95
	11-9	1345	-19	0	7.9	60	112
	11-21	1200	-6	0	8.2	49	112
	11-28	1200	-10	0	8.1	45	120
	12-8	1200	-6	0	7.3	56	142
P1	9-12	1430	4	4	7.9	62	112
P2	9-12	1500	4	4	8.1	48	112
P4	9-12	1630	3	2	7.9	55	86
P6	9-12	1830	3	3	7.8	55	120
PJ	7-26	1555	--	--	8.3	--	112
	8-1	1330	25	--	7.3	--	129
	8-9	1330	27	10	7.8	--	116
	8-16	1315	18	7	7.2	--	116
	8-23	1130	12	4	7.0	50	103
	8-31	1300	19	6	7.9	62	112
	9-7	1200	17	4	8.1	62	112
	9-14	1015	3	3	8.0	60	120
	9-20	1215	5	3	8.1	54	116
	9-27	1200	12	2.5	8.0	44	95
	10-4	1300	-7	0	7.8	58	120
	11-9	1400	-19	0	7.8	62	146
	11-21	1230	-6	0	8.2	72	108
	11-28	1230	-10	0	8.2	63	97
	12-8	1200	-6	0	7.2	59	155

Table 16--Nonfilterable residue, turbidity, and point discharge, for streamwater-monitoring stations, Caribou-Poker Creeks Research Watershed, 1978

Date	Nonfilterable residue	Turbidity	Discharge	Nonfilterable residue	Turbidity	Discharge
	Milligrams per liter	Formazin turbidity units	Cubic feet per second	Milligrams per liter	Formazin turbidity units	Cubic feet per second
		STATION C2			STATION C3	
5-16	0.16			0.12		
5-22	.08			1.24		
5-30	.04			.08		
6-9	.08			.16		
6-14	0			.08		
6-21	.06		0.56	.12		0.84
6-28	.96		1.37	.22		4.69
7-6	.04		.76	.04		.70
7-12	.36		.70	0		.39
7-18	.08		.67	--		.35
7-26	.53	0	.62	.10	0	.20
8-1	.59	2	.49	0	2	.12
8-9	.32	2	.46	.13	2	.08
8-16	0	8	.67	.18	2	.10
8-23	0	2	.64	.26	7	2.39
8-31	.02	0	.49	.40	0	.51
9-7	.08	0	.54	0	2	.94
9-13	0	0	.54	0	0	.56
9-20	1.74	2	.51	1.50	0	.44
9-28	0	8	.73	0	5	2.75
10-4	0	0	1/--	0	3	1/--
		STATION C1			STATION C4	
9-13	--	0	--	--	0	.9
11-21	--	--	--	--	7	--
		STATION P1			STATION P2	
9-12	--	0	3.0	--	0	.9
		STATION P4			STATION P6	
9-12	--	0	1.35	--	0	--
		STATION CJ			STATION PJ	
6-21	.80		3.9	1.72		10
6-23	61.20		19	58.73		15
6-26	3.92		9.2	32.68		20
6-27	2.40		13	22.72		23
6-28	5.16		13	10.92		17
6-29	2.44		8.7	8.76		17
6-30	1.00		7.1	--		15
7-6	.60		3.9	7.36		15
7-10	1.64		3.0	6.20		10
7-11	2.28		2.8	23.52		8.0
7-12	.83		3.2	5.70		9.2
7-13	15.28		4.6	14.12		14
7-14	3.88		5.6	13.28		15
7-18	1.93		2.8	14.12		8.8
7-19	2.69		2.7	47.16		8.0
7-20	1.24		2.7	14.02		7.2
7-21	1.97		2.5	10.84		8.0
7-26	.59	7	2.0	22.24	8	15
8-1	.74	3	1.8	4.75	3	7.6
8-9	.61	7	1.8	2.87	5	8.0
8-16	.02	5	2.2	.66	4	8.4
8-23	1.14	15	8.4	.94	10	19
8-31	.24	0	3.4	.12	0	8.0
9-7	.09	10	4.6	.47	5	12
9-14	.32	0	3.4	.54	0	8.4
9-20	2.26	4	3.0	2.50	6	8.4
9-27	.71	15	7.6	2.95	9	18
10-4	.04	4	2/--	.24	4	2/--
11-9	.26	0		.08	0	
11-21	.32	2		.04	8	
11-28	0	9		0	9	
12-8	0	0		.20	0	

1/Frozen.
2/Terminated.

Table 17--Water chemistry data for streamwater-monitoring stations, Caribou-Poker Creeks Research Watershed, 1978

Station	Date	NO_2 - N	NO_2+NO_3 - N	NH_3 - N	PO_4 - P	Si
		Micrograms per liter				Milligrams per liter
C2	7-26	--	--	--	--	--
	8-1	1.3	220.5	20.7	15.8	3.75
	8-9	1.3	32.2	34.5	10.2	.40
	8-16	<1.0	32.2	77.0	19.5	.37
	8-23	<1.0	130.3	26.3	8.7	<.01
	8-31	1.4	212.1	27.7	3.7	3.71
	9-7	<1.0	432.1	98.5	<1.0	3.75
	9-13	<1.0	453.1	36.4	3.4	3.62
	9-20	<1.0	460.7	25.8	5.0	3.83
	9-28	<1.0	242.6	55.4	18.0	.02
	10-4	<1.0	241.3	5.0	<1.0	2.37
C3	7-26	<1.0	141.8	43.0	6.8	2.54
	8-1	<1.0	140.1	5.2	3.1	3.27
	8-9	<1.0	139.0	15.8	<1.0	3.27
	8-16	<1.0	134.6	19.0	2.2	1.20
	8-23	<1.0	329.2	8.3	3.1	.04
	8-31	1.4	182.8	15.3	<1.0	1.51
	9-7	<1.0	542.2	21.4	<1.0	3.60
	9-13	<1.0	460.7	16.1	5.0	.40
	9-20	<1.0	482.8	26.1	<1.0	3.50
	9-28	<1.0	332.4	1.3	3.1	.48
	10-4	<1.0	263.3	5.0	<1.0	1.79
CJ	7-26	2.4	118.9	10.2	2.2	4.20
	8-1	--	--	--	--	--
	8-9	<1.0	143.0	21.8	10.2	4.22
	8-16	<1.0	134.9	11.8	1.9	2.59
	8-23	1.1	174.4	22.1	3.1	.55
	8-31	<1.0	122.1	40.2	1.5	3.40
	9-7	<1.0	275.0	37.4	2.2	1.53
	9-14	<1.0	315.4	16.5	10.5	.82
	9-20	2.8	276.4	149.5	<1.0	1.01
	9-27	--	--	--	--	--
	10-4	<1.0	161.2	7.3	<1.0	2.15
	11-7	<1.0	361.1	44.8	2.2	1.41
	11-21	<1.0	383.4	38.1	<1.0	2.33
	11-28	<1.0	375.7	27.2	5.0	1.95
PJ	7-26	2.0	138.5	11.2	2.2	3.71
	8-1	2.4	117.0	24.1	3.4	3.60
	8-9	<1.0	161.2	38.9	15.2	1.01
	8-16	1.8	125.4	15.0	7.7	1.31
	8-23	1.1	174.2	16.2	1.5	2.61
	8-31	<1.0	138.9	10.2	<1.0	1.08
	9-7	<1.0	294.3	19.5	<1.0	3.60
	9-14	<1.0	313.6	23.8	5.6	2.37
	9-20	<1.0	335.3	41.7	6.5	2.82
	9-27	2.0	292.6	93.6	16.1	2.67
	10-4	<1.0	197.5	7.4	<1.0	1.01
	11-7	<1.0	423.9	17.2	<1.0	1.02
	11-21	<1.0	437.6	44.7	<1.0	1.77
	11-28	<1.0	429.9	31.7	2.2	1.79

Table 18--Dissolved ionic constitutents for streamwater-monitoring stations, Caribou-Poker Creeks Research Watershed, 1978

Station	Date	Na	K	Ca	Mg	As	Fe	Mn
				Milligrams per liter				
C2	8-16	1.1	0.4	7.5	1.6	<0.04	0.005	0.007
	8-23	<.1	<.1	<.1	<.1	<.04	<.005	<.005
	8-31	3.0	.8	11.3	3.7	<.04	<.005	<.005
	9-7	.8	.2	4.8	1.6	<.04	<.005	<.005
	9-13	1.2	.6	11.9	3.9	<.04	.013	<.005
	9-20	1.4	.7	11.8	3.9	<.04	.020	<.005
	9-28	2.2	.5	11.7	3.8	<.04	.007	<.005
	10-4	2.1	.5	11.7	3.8	<.04	.005	<.005
C3	8-16	.4	.2	4.1	<.1	<.04	<.005	<.005
	8-23	.2	<.1	2.1	<.1	<.04	<.005	<.005
	9-7	2.3	.5	11.2	1.9	<.04	.170	<.005
	9-13	1.4	.6	12.5	2.0	<.04	.090	<.005
	9-20	1.6	.6	13.1	2.2	<.04	.130	<.005
	9-28	2.1	.4	9.6	1.6	<.04	.037	<.005
	10-4	1.6	.4	12.6	2.1	<.04	.005	<.005
CJ	8-16	1.1	.4	11.9	1.6	<.04	.030	.013
	8-23	2.4	.6	11.5	2.4	<.04	.202	.016
	8-31	2.6	.8	15.3	3.1	<.04	.078	.017
	9-7	2.4	.8	13.6	2.9	<.04	.135	.020
	9-14	1.6	.8	15.5	3.2	<.04	.074	.011
	9-20	2.2	1.1	15.8	3.2	<.04	.089	.020
	9-27	2.2	.5	10.6	2.3	<.04	.151	.007
	10-4	1.8	.5	16.0	3.2	<.04	.078	.020
	11-9	2.0	.9	16.7	3.5	<.04	.049	.025
	11-21	2.0	.8	18.0	3.6	<.04	.055	.013
	11-28	2.0	.7	17.7	3.6	<.04	.062	.026
	12-8	1.8	.7	18.0	3.8	<.04	.058	.025
PJ	8-16	3.3	1.2	23.0	4.4	<.04	.057	.042
	8-31	2.4	.8	21.5	4.0	<.04	.037	.033
	9-7	2.4	.8	21.4	4.0	<.04	.079	.031
	9-12	1.6	.8	25.0	3.9	<.04	.030	.007
	9-14	1.5	.8	22.0	4.2	<.04	.058	.028
	9-20	1.6	.8	22.0	4.3	<.04	.045	.035
	9-27	2.2	.6	16.4	3.2	<.04	.114	.008
	10-4	1.8	.6	20.8	4.2	<.04	.053	.038
	11-9	1.7	.7	24.0	4.6	<.04	.018	.032
	11-21	2.0	.8	23.0	4.3	<.04	.023	.024
	11-28	1.8	.8	24.0	4.6	<.04	.018	.032
	12-8	2.3	1.0	25.0	4.6	<.04	.037	.037
C1	9-13	1.0	.5	9.0	1.9	<.04	.220	<.005
C4	9-13	1.6	.8	17.6	3.3	<.04	.012	.007
C4	11-21	2.0	.8	18.1	3.5	<.04	.015	<.005
P1	9-12	1.2	.8	24.0	4.7	<.04	.030	.006
P2	9-12	1.1	.6	17.9	4.8	<.04	.005	<.005
P4	9-12	1.5	.7	16.2	2.5	<.04	.077	.016

Table 19--Calculated total hardness for streamwater-monitoring stations, Caribou-Poker Creeks Research Watershed, 1978

	Station			
Date	C2	C3	CJ	PJ
	Milligrams per liter			
8-16	25.34	10.65	36.37	75.72
8-23	.56	6.65	38.99	70.28
8-31	43.45	42.28	51.13	70.10
9-7	18.58	36.09	46.18	78.54
9-13	45.78	39.60	52.02	72.37
9-20	45.55	42.00	62.82	72.77
9-28	44.86	30.63	36.22	54.33
10-4	44.85	40.10	53.30	69.39
11-9	--	--	56.25	78.95
11-21	--	--	59.89	75.21
11-28	--	--	59.18	78.95
12-8	--	--	60.74	81.50

Research Note PNW-406
is available on microfiche
located on third level in
cabinets behind the information
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Pacific Northwest Forest and Range Experiment Station

Research Note PNW-407

September 1983

Evaluation of Blown Down Alaska Spruce and Hemlock Trees for Pulp

Donald J. Fahey and James M. Cahill

Abstract

Chips from Alaska hemlock and spruce trees blown down more than 10 years produced usable grades of viscose pulp. Yields of pulp from both species were about 2 percent lower for blowdown material than for control trees. Ash content was slightly higher in the pulp manufactured from blowdown timber than in pulp from control trees.

Keywords: Residues, pulp manufacture, mill residues, Alaska, wood utilization, blowdown.

Introduction

Wind damage to Sitka spruce and western hemlock trees is common in the coastal forests of southeast Alaska. Approximately 27 percent of trees lost to timber production are broken or uprooted by wind (Harris 1974). Exceptionally severe storms sweep through the area about every 8 years. In the Thanksgiving day storm of 1968, for example, more than a billion board feet of commercial sawtimber was blown down by hurricane-force winds.

This study examined the quality of pulp produced from mill residues generated from blowdown spruce and hemlock logs. Pulp producers and forest managers should find this information useful in evaluating blowdown timber as a raw material.

DONALD J. FAHEY is a Research Forest Products Technologist, Forest Products Laboratory, Madison, Wisconsin. JAMES M. CAHILL is a Research Forester, Pacific Northwest Forest and Range Experiment Station, P.O. Box 3890, Portland, Oregon 97208.

Methods

Log Selection

Study logs were selected from trees blown down in 1968, and during the years 1974 through 1976. Live trees were also selected for a control. All sample trees were from the Tongass National Forest. The study logs were divided into 5 categories (table 1) by species and blowdown date. Age of the blowdown was determined from local records and on-the-ground observations.

The higher percent of defect (table 1) in the older blowdown is the result of log scale deductions made for sap decay. Sap decay is caused by fungi that enter the logs through insect galleries and wood exposed by breakage. At the time of sampling, trees in the older blowdown category (1968) had lost all fine branches in crowns and were covered with 1 to 2 inches (25 to 51 mm) of forest litter. Hemlock seedlings, 2 to 3 years old, were growing from the surface of some 1968 blowdown.

Table 1--Number of logs and scale information by log category

Log category	Years since blowdown	Logs	Scaling defect[1]	Average scaling diameter	
		Number	Percent	Inches	Millimeters
Hemlock, 1968	11	49	32	12	305
Hemlock, 1974-76	3-5	153	19	14	355
Hemlock, live	--	77	10	11	280
Spruce, 1974-76	3-5	50	16	14	355
Spruce, live	--	25	4	11	280

[1]Defect based on a long-log Scribner scale taken by USDA Forest Service check scalers.

Harvesting and Processing

Blowdown trees and the control trees (77 hemlock and 25 spruce) were logged during the summer of 1979, using conventional ground-skidding equipment and following customary industry practices. The logs were stored in water, then towed to a sawmill, where they were sorted by species and blowdown date into five categories (table 1), and sawn into dimension lumber and cants. During sawing, chips produced from the slabs, edgings, and trim ends were sampled periodically. About 60 pounds (27.3 kg) of green chips for each category of blowdown and control logs were sent to the Forest Products Laboratory, in Madison, Wisconsin, to test their suitability for pulp. At the Laboratory, samples were screened and those chips measuring 1/4 inch (6.3 mm) to 1 inch (25 mm) were used for the pulping experiments.

Pulp and Bleaching

The pulping experiments were conducted in a stationary stainless steel digester of 0.8 ft^3 (0.023 m^3) capacity, using cooking liquor with an acid bisulfite magnesium base. The same cooking conditions were used in digesting all chips: liquor-to-wood ratio of 4-to-1, the total sulfur dioxide content was 8.4 percent, the digester pressurized with nitrogen gas to 80 lb/in^2 (550 kPa), and 3 1/4 hours' rise to maximum temperature of 148°C. The time at maximum temperature was varied to yield screened pulps with viscosity of 75 ± 3 cP (mPa s).

Before bleaching, the pulps were screened and cleaned in a centrifuge. Bleaching experiments were conducted with one 0.25 lb (0.11 kg) sample of cleaned viscose pulp from each category of logs. Samples were treated with chlorination, extraction, two stages of hypochlorite, and one stage of sulfur dioxide.

Alkali solubility of the purified pulps was measured at sodium hydroxide concentrations of 10 percent and 18 percent.

Results

Chips from the blowdown trees were 6 to 10 percentage points dryer than the chips from control trees. Dryness did not appear to affect the size of spruce chips. Hemlock chips of acceptable size, however, were 3 percent fewer than the spruce chips. Percent of bark and rot was not determined, but bark made up a large proportion of the material that went through the 1/4-inch (6.3 mm) screen and was rejected. Some bark pieces from both species remained with the accepted material.

The yield of unbleached pulp from both species was about 2 percent lower for the blowdown material than for material from control trees. The blowdown material required slightly longer cooking time to reach the same viscosity as the control material. This may have been caused by the difference in moisture content of the chips.

The pulp was bleached to 93-percent brightness and no difference in pulp from different age categories was observed.

The alpha-cellulose values of the pulp from control trees averaged about 1 percent higher than pulp from blowdown trees; beta-cellulose, however, was lower. There was no difference in gamma-cellulose values. The pulp from blowdown spruce had fewer alcohol benzene solubles than pulp from the control spruce; no difference was noted for hemlock.

Chemical evaluations indicate that chips from blowdown trees show promise as a source of viscose pulp (table 2). The slightly higher ash content in pulp from the older blowdown trees indicates there would be more difficulty in removing the dirt, silica, and other contaminants from the pulp of those trees than pulp from younger blowdown or control trees. The amount of pulp from older blowdown trees used in blends with pulp from trees cut live requires careful control, particularly for pulps used in bleached papers and other products in which contaminants are undesirable.

Table 2--Properties of bleached pulps from 5 categories of logs

Log category	Solubility: Alcohol benzene	Solubility: 10-percent cold NaOH, Beta	Solubility: 10-percent cold NaOH, Gamma	Solubility: 18-percent cold NaOH, Alpha	Solubility: 10-percent hot KOH	Ash	Disperse viscosity[1]	Brightness (Elrepho)	Drainage time (British)
	Percent						cP	Percent	Seconds
Hemlock, 1968	0.30	2.9	5.2	91.9	9.0	.32	23.7	93.2	5.1
Hemlock, 1974-76	.32	2.7	5.0	92.3	8.9	.27	25.0	92.6	4.9
Hemlock, live	.31	2.0	5.0	93.0	8.7	.29	24.6	93.5	4.6
Spruce, 1974-76	.35	3.5	5.5	90.9	9.3	.31	23.5	93.2	4.9
Spruce, live	.48	2.6	5.7	91.7	10.8	.27	24.3	93.1	4.7

[1]Two percent concentration in cupriethylenediamine.

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United States Department of Agriculture

Forest Service

Pacific Northwest Forest and Range Experiment Station

Research Note PNW-408

January 1984

Day-to-Day Survival of Late-Instar Western Spruce Budworm Larvae and Pupae

Robert W. Campbell and Nilima Srivastava

Abstract

For the western spruce budworm populations studied, day-to-day survival rates were close to constant in the interval from instar IV to residual pupae. In any given crown stratum, host-tree species, and site, day-to-day changes across this interval could be approximated very closely by the Malthusian equation $N_t = N_o e^{\alpha t}$.

Keywords: Insect populations, western spruce budworm, *Choristoneura occidentalis.*

Introduction

Survival from instar III to pupae was shown (Watt 1963) to be important in determining generation survival in populations of the spruce budworm, *Choristoneura fumiferana* (Clemens). Similarly, survival from instar IV to residual pupae (pupae remaining after predation) appears to be important in determining generation survival in populations of the western spruce budworm, *C. occidentalis* Freeman. For this reason, a model relating relevant habitat characteristics to budworm survival during this crucial interval would be useful to both researchers and managers.

In this paper, we suggest a simple analytical form for describing day-to-day changes in populations of the western spruce budworm from instar IV to adults. This form may prove to be useful in the subsequent development of a model relating habitat characteristics to the survival of the western spruce budworm and similar species.

Observations of day-to-day changes in budworm populations are labor intensive and may require special equipment. We have accumulated only two such observation sets on the western spruce budworm. Both sets represent the interval from just before pupation until all remaining insects had either died or become adults. From these data, we developed a model of day-to-day survival. Its behavior suggests that the model form is appropriate for a considerably longer budworm interval—the interval from instar IV to residual pupae.

Our objectives are: to describe day-to-day survival rates of several western spruce budworm populations from just before the onset of pupation until they either died or became adults; to show how these survival rates might be modeled to reflect relevant environmental characteristics; to show that day-to-day survival rates in these populations were approximately equal across the interval between instar IV and adult emergence; and to suggest that further investigation of how environmental factors influence the parameter α in the equation $N_t = N_o e^{\alpha t}$ may prove exceptionally useful in understanding the population dynamics of the western spruce budworm.

ROBERT W. CAMPBELL is a research entomologist, Pacific Northwest Forest and Range Experiment Station, U.S. Department of Agriculture, Forest Service, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, Oregon 97331. NILIMA SRIVASTAVA is a research associate, College of Forestry, Wildlife and Range Sciences, University of Idaho, Moscow, Idaho 83843.

Methods

In 1979, branch tips representing the upper, mid, and lower crown thirds of about 12-m-tall Douglas-fir, *Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco, were selected for day-to-day observations of their resident budworm cohorts. Four branch tips about 60 cm long were observed in each crown stratum of each of six trees in a site in the Okanogan highlands of north-central Washington. A truck-mounted, 8.5-m hydraulic lift was used as a platform to observe the cohorts in the mid and upper crowns. In 1980, similar budworm cohorts were studied on both Douglas-fir and grand fir, *Abies grandis* (Dougl.) Lindl., in a site in central Idaho. For each host species, we used the same number and vertical pattern of branch tips used in Washington.

Visits to each tree began shortly before the insects started to pupate. During each visit, all budworm larvae, pupae, and pupal exuviae on each labeled branch were recorded. For each site, host species, and crown stratum, an observation was defined as the larvae and pupae found on that day, plus all pupal exuviae found on that day and earlier.

Densities of instar IV (N_L) and of pupae remaining after predation (N_{P2}) per square meter of foliage were determined by destructively sampling branch tips from nearby host trees with a basket and pole pruner.

Standard graphic and multiple-regression techniques were used to determine relations between variables.

Results

Day-to-day numerical changes in the budworm cohort in each crown third are shown for the population in the north-central Washington site in figure 1. Similar changes are shown for the population in central Idaho in figures 2 and 3. As previously noted, counts commenced just before pupation and continued until all insects had died or emerged.

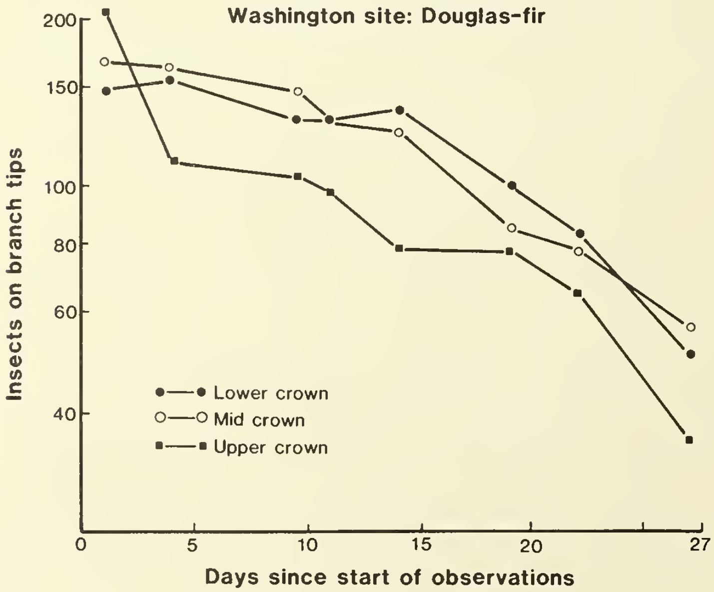

Figure 1.—Day-to-day budworm changes on Douglas-fir in the north-central Washington site (late-stage larvae to residual pupae).

Apparently, α can be approximated for any given site, host-tree species, crown stratum, and budworm generation from estimates of densities of instar IV and residual pupae, together with the dates of the two density estimates. In turn, α may prove to be a function of the underlying environmental processes that determine budworm survival during this critical interval.

Acknowledgments

We thank Clinton E. Carlson, Forestry Sciences Laboratory, Missoula, Montana, and Max W. McFadden, Forest Insect Research, USDA Forest Service, Washington, D.C., for their careful reviews of an earlier draft of this manuscript. Work leading to this publication was funded by the U.S. Department of Agriculture, Forest Service, Canada/United States Spruce Budworms Program, Washington, D.C.

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Inspection suggested—and analyses confirmed—that successive budworm counts could be approximated by the famous Malthusian equation for population growth (Pielou 1977), $N_t = N_o e^{\alpha t}$; that changes in the mid and upper crown were very similar for both sites and species; and that changes in the lower crown differed both from site to site and between the cohorts on Douglas-fir and grand fir. We determined that:

- For mid and upper crown,
$N_t = N_o e^{-0.039t}$; $r^2 = .88$, $n = 44$.

- For lower crown,

$$\left.\begin{array}{l} N_t = N_o e^{-0.061t} \text{ if Washington} \\ N_t = N_o e^{-0.050t} \text{ if Idaho Douglas-fir;} \\ N_t = N_o e^{-0.102t} \text{ if Idaho grand fir.} \end{array}\right\} R^2 = .96, n = 22.$$

Starting from observed instar IV per square meter of foliage, we used the above equations to project the density of residual pupae per square meter of foliage on each host species and in each crown stratum and site. The relation between predicted and observed densities of residual pupae is shown in figure 4.

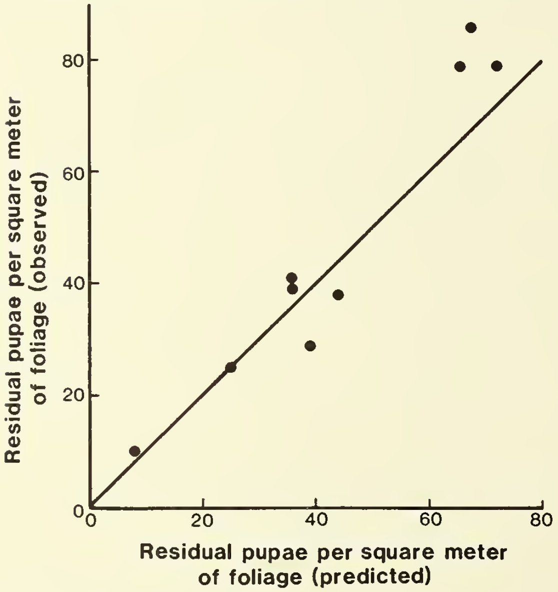

Figure 4.—Observed residual pupae per square meter of foliage and residual pupae predicted from observed instar IV.

Discussion

Numerical changes in the western spruce budworm in the interval from just before pupation until the insects had either died or emerged could be approximated very closely by the Malthusian equation. For the two sites studied, day-to-day changes in any given crown stratum, host-tree species, and site depended only on the value of the parameter α in the equation $N_t = N_o e^{\alpha t}$. Further, for any given environmental stratum, this equation accurately projected the density of residual pupae from observed density at instar IV. For these populations, budworm survival rates from day to day appear to have been relatively constant across the entire interval from instar IV to residual pupae.

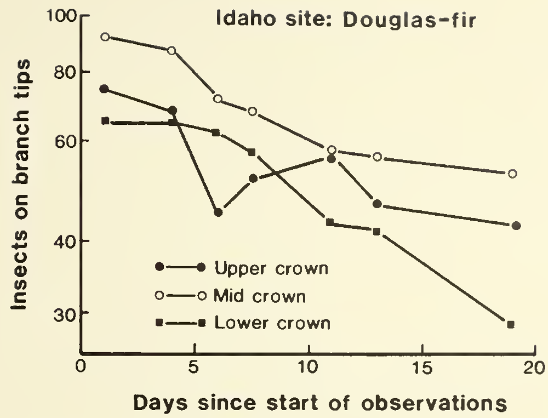

Figure 2.—Day-to-day budworm changes on Douglas-fir in the central Idaho site (late-stage larvae to residual pupae).

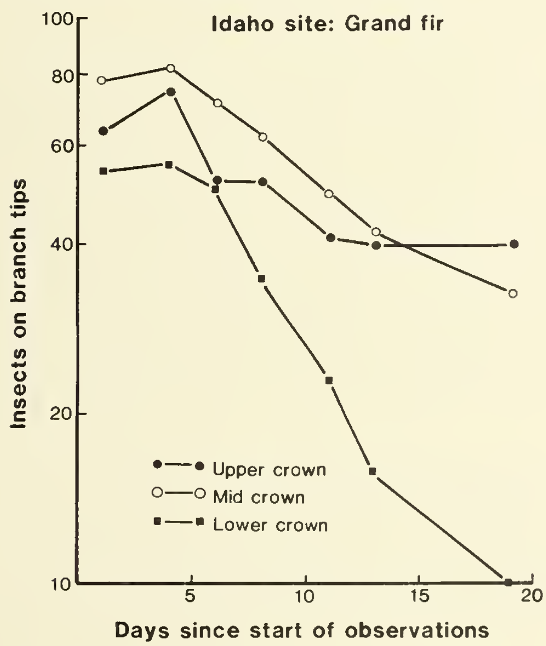

Figure 3.—Day-to-day budworm changes on grand fir in the central Idaho site (late-stage larvae to residual pupae).

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Research Note
PNW-409
February 1984

A Western Larch-Engelmann Spruce Spacing Study in Eastern Oregon: Results After 10 Years

K. W. Seidel

Abstract

The 10-year growth response from a spacing study in an even-aged stand of western larch (*Larix occidentalis* Nutt.) and Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), thinned at age 10 to 9- and 15-foot spacings, was measured in eastern Oregon. Both basal area and total cubic volume increment per acre increased at the narrower spacing while diameter growth per tree was less than at the wider spacing. Height growth was not affected by spacings. Larch grew about twice as fast as spruce in height and diameter resulting in the development of a stratified two-storied stand.

Keywords: Growth response, thinnings (-stand volume,), spacing thinnings, thinning effects, western larch, *Larix occidentalis,* Engelmann spruce, *Picea engelmannii*, eastern Oregon.

Introduction

Spacing and thinning studies located in stands of various ages and species or on different sites provide information on long-term growth and yield of managed stands that is useful in developing and verifying simulation models and designing thinning schedules to meet land management objectives. Considerable information is available on the growth response of pure, even-aged stands to thinning but little is known about the response of mixed species stands, especially those containing species that differ greatly in tolerance to shade.

In 1971, a small spacing study was begun in a young, even-aged stand of western larch (*Larix occidentalis* Nutt.) and Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) in northeastern Oregon. The purpose of this study was to compare diameter, height, basal area, and volume growth for these species at two spacings. This paper reports results from the first 10 years of the study consisting of two 5-year growth periods (1972-76 and 1977-81).

Study Area and Methods

The study is located in the La Grande District of the Wallowa-Whitman National Forest in the Anthony Lakes burn which occurred in 1960. The study is on a northwest-facing, 15-percent slope at an elevation of about 6,000 feet. The soil is a moderately deep and well-drained Typic Vitrandept (Olot series) that developed in volcanic ash and colluvium and residuum weathered from basalt. It consists of about 15 inches of silty loam ash overlaying 20 to 25 inches of silty loam residual soil.[1]

[1] Personal communication from Dan Harkenrider, Union Ranger District, Wallowa-Whitman National Forest, Union, Oregon.

K. W. SEIDEL is a silviculturist with the Silviculture Laboratory, 1027 NW Trenton Avenue, Pacific Northwest Forest and Range Experiment Station, Bend, Oregon 97701.

Table 1—Characteristics of western larch-Engelmann spruce plots in 1971, 1976, 1981

Spacing	Species composition		Number of trees	Trees 0.6-inch d.b.h. or greater		Quadratic mean diameter1/			Average height2/			Basal area1/			Total volume1/		
	Larch	Spruce		Number per acre	Percent	Larch	Spruce	Combined	Larch	Spruce	Combined	Larch	Spruce	Combined	Larch	Spruce	Combined
Feet	--Percent--		Per acre			--------Inches-------			--------Feet----------			-Square feet per acre-			--Cubic feet per acre--		
1971:																	
9 x 9	50	50	538	46	9	1.0	--	1.0	5.1	2.5	3.7	0.2	--	0.2	2.0	--	2.0
15 x 15	53	47	193	16	8	1.3	--	1.3	5.1	2.6	3.9	.1	--	.1	1.1	--	1.1
1976:																	
9 x 9	49	51	531	300	56	1.7	1.0	1.6	11.4	5.1	8.1	3.6	0.3	3.9	31.0	2.7	33.7
15 x 15	53	47	193	124	64	1.7	0.9	1.6	10.8	5.4	8.3	1.6	.1	1.7	13.7	1.3	15.0
1981:																	
9 x 9	49	51	531	508	96	2.9	1.3	2.3	16.7	7.9	12.2	11.7	2.2	13.9	102.3	16.9	119.2
15 x 15	53	47	193	185	96	3.0	1.7	2.5	16.2	8.8	12.9	5.1	1.2	6.3	44.3	8.5	52.8

1/ All trees 0.6-inch d.b.h. and larger.

2/ All trees.

The study area is located in an *Abies lasiocarpa*/*Vaccinium scoparium* plant community (Hall 1973). Typical ground cover in this community consists primarily of grouse huckleberry (*Vaccinium scoparium* Leib.) and small amounts of species such as boxwood (*Pachistima myrsinites* (Pursh) Raf.), side-flowered mitrewort (*Mitella stauropetala* Piper), and sidebells pyrola (*Pyrola secunda* L.). Site index, based on Schmidt and others (1976) curves, of older larch in the area indicates a height of 45 feet at age 50.

The study was installed in a naturally regenerated young stand of larch, spruce, and lodgepole pine (*Pinus contorta* Dougl. ex Loud.) that was about 10 years old when the study began in 1971. It is an initial spacing experiment testing two spacings (9 by 9 and 15 by 15 feet) created by thinning. Each spacing was replicated two times for a total of four plots. All lodgepole pine were removed from the plots. Thirty-five trees were measured in each plot. The goal was an alternate arrangement of larch and spruce. Plot size including buffer strips thus depended upon spacing. Plots at the 9-foot spacing are 0.19 acre in size and those at the 15-foot spacing are 0.29 acre. No further thinning will be done in these plots.

Total height of all plot trees was measured to the nearest 0.1 foot, and diameter at breast height (d.b.h.) of trees 0.6 inch or larger was measured to the nearest 0.1 inch in 1971, 1976, and 1981. In 1976, diameter and bark thickness were measured at several points on the boles for 12 trees per plot. Data from all plots were used to construct a combined equation for both species expressing total cubic volume inside bark as a function of diameter^2 x height (D^2H). This equation was used for volume estimation at each measurement.

After thinning, average height of larch at both spacings was 5.1 feet, about twice as tall as the spruce on these plots which were 2.5 feet (table 1). Average d.b.h. of larch of measureable size was 1.0 inch at the 9-foot spacing and 1.3 inches at the 15-foot spacing. Species composition at each spacing was about equal; 50 percent larch and 50 percent spruce.

Analyses of variance were used to compare spacings, species, and growth periods for diameter, height, basal area, and volume growth. The experiment was a split-split plot: Whole-plot treatments were spacings; split-plot treatments were species; and split-split-plot treatments were time periods.

Basal Area and Volume Growth

Both basal area and total cubic volume growth per acre showed the same response to spacing, among species, and between periods. Annual volume increment, for example, more than doubled from 10.4 to 23.5 cubic feet per acre as spacing decreased from 15 to 9 feet (table 2). This difference was significant ($P<0.05$). Because of the more rapid diameter and height growth of the larch, volume increment of this species was more than five times greater than that of spruce (averaged over both spacings and periods) and the difference was highly significant ($P<0.01$). Larch accounted for about 85 percent of the total volume and basal area growth during the 10 years of the study. This difference in growth rate between larch and spruce should continue but is expected to decline as the spruce become larger. Basal area and volume increment increased significantly ($P<0.01$) during the second 5-year period as more trees reached 0.6-inch d.b.h. (ingrowth) and diameter and height were greater.

In addition to the relationships just described, significant interactions ($P<0.05$) were also found between spacings and periods and between species and periods. The species-period interaction for volume growth is shown in figure 2. Although growth of both species increased during the second period, growth of larch relative to spruce was considerably greater during the second period. This resulted in a growth differential between the species of about 8 cubic feet per acre per year during the second period compared to only 3.8 cubic feet during the first period.

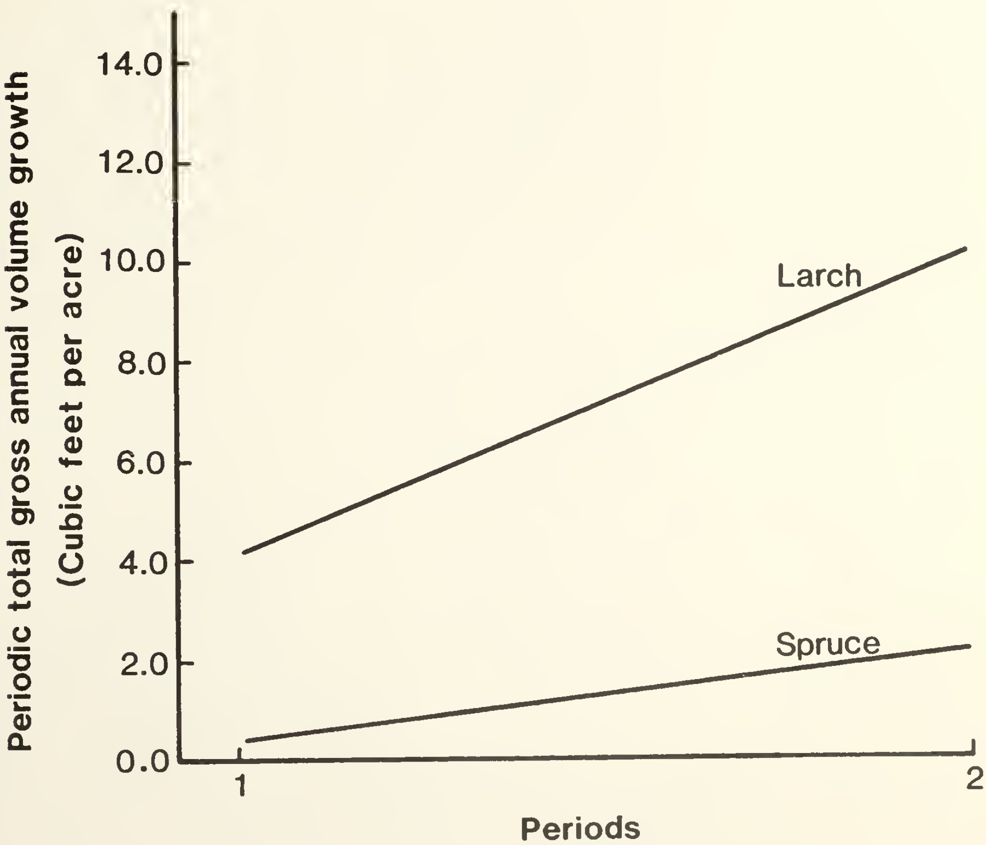

Figure 2.—Periodic total gross annual cubic volume increment of larch and spruce during first and second 5-year periods averaged over both spacings.

Figure 1.—Comparison of larch and spruce saplings showing difference in total height after 20 years.

Table 2—Periodic annual increment of western larch and Engelmann spruce saplings during two 5-year measurement periods from 1972 to 1981

	Diameter growth1/			Height growth			Gross basal area growth			Gross total volume growth		
Spacing	Larch	Spruce	Combined	Larch	Spruce	Combined	Larch	Spruce	Combined	Larch	Spruce	Combined
Feet	-------Inches--------			-------Feet----------			-Square feet per acre-			-Cubic feet per acre-		
From age 10 to 15 (1972-76)												
9 x 9	0.34	--	0.34	1.3	0.5	0.9	0.68	0.06	0.74	5.8	0.5	6.3
15 x 15	.33	--	.33	1.1	.6	.9	.30	.03	.33	2.5	.3	2.8
From age 15 to 20 (1977-81)												
9 x 9	.26	0.17	.22	1.1	.6	.9	1.63	.37	2.00	14.3	2.9	17.2
15 x 15	.28	.24	.26	1.1	.7	.9	.70	.21	.91	6.1	1.5	7.6

1/ Arithmetic mean diameter growth of trees 0.6-inch d.b.h. or larger at beginning of each 5-year period and living through the period.

Results

Diameter Growth

Significant differences (P<0.05) in periodic annual diameter growth existed between spacings with trees at the wider spacing growing at an average rate of 0.26 inch compared to 0.22 inch at the closer spacing during the second 5-year period (table 2). Larch grew significantly faster in diameter (P<0.01) than spruce: Larch averaged 0.27 inch per year over both spacings compared to an average of 0.21 inch per year for spruce.

At the beginning of the first 5-year period, none of the spruce had reached 0.6-inch d.b.h. and only six larch in the 9-foot plots and six in the 15-foot plots were that size. During the second period, ingrowth resulted in more trees (both larch and spruce) reaching 0.6-inch d.b.h. Diameter growth in table 2 may not agree with differences between mean diameters at the beginning and end of growth periods shown in table 1. This is because average diameters at each measurement are based on trees 0.6-inch d.b.h. or larger at the time, but growth is based only on trees of that size in 1971 and 1976.

Height Growth

Larch grew about twice as fast in height as spruce at both spacings and during both periods, averaging about 1.2 feet per year compared to about 0.6 foot for spruce (table 2). This difference was significant (P<0.01). Only small differences in height growth were found between spacings or periods and thus there were no significant interactions. Height growth of individual trees varied greatly and ranged from 3.5 to 17.9 feet for larch and from 1.9 to 10.2 feet for spruce during the 10-year study period. After 20 years of growth, larch were about twice as tall as spruce because of the more rapid early height growth of larch (fig. 1).

Mortality

Mortality was light during the 10 years of this study. Only one tree (a larch) died on a plot having a 9-foot spacing during the first 5-year period, and none died during the second period.

Discussion

The stand where these plots are located is a classic example of the development of a stratified, two-storied, even-aged stand consisting of a fast growing, intolerant overstory species and a slower growing, more tolerant understory species. Twenty years after both larch and spruce became established in the burned area, average height and diameter of the larch is about double that of the spruce (table 1). The growth rate of larch should continue to exceed that of spruce for at least 50 years resulting in a more pronounced stratification in height and diameter between the two species. As time goes by, this stand should take on the appearance of an uneven-aged stand even though this structure is due to differences in growth rate rather than time of establishment.

Although data on stand response to spacing are limited because only two spacings were tested, the typical pattern of greater diameter growth per tree and less volume growth per acre with wider spacing is evident after 10 years of stocking regulation. Perhaps the most valuable aspect of this study is the opportunity to document the development of a two-storied, even-aged stand from time of origin.

Acknowledgment

WALTER G. DAHMS, formerly with the Pacific Northwest Forest and Range Experiment Station and now retired, was responsible for the design and installation of this study.

Metric Equivalents

1 foot = 0.3048 meter
1 inch = 2.54 centimeters
1 acre = 0.4047 hectare
1 square foot per acre = 0.2296 square meter per hectare
1 cubic foot per acre = 0.0700 cubic meter per hectare
1 tree per acre = 2.47 trees per hectare

Literature Cited

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Botanical Reconnaissance of Silver Lake Research Natural Area, North Cascades National Park, Washington

Robin Lesher

Abstract

A botanical survey of Silver Lake Research Natural Area in the North Cascade National Park in northern Washington recorded 109 vascular plant taxa representing 27 families, including 2 sensitive species. This research note provides baseline information on the distribution, habitats, and abundance of vascular plants within the Silver Lake Research Natural Area.

Keywords: Plant communities, natural areas (research), scientific reserves, Silver Lake Res. Nat. Area--Washington, Washington (Silver Lake Res. Nat. Area), north Cascades, checklists (vascular plants).

Environment

Silver Lake Research Natural Area (RNA) covers 682.7 hectares (ha) in the northeastern portion of North Cascades National Park (lat. 48°59'05" N., long. 121°13'45" W.). This RNA is administered by the superintendent, North Cascades National Park. The rugged and steep topography has been extensively modified by glaciers. Twelve active glaciers remain, covering about 320 ha. Silver Lake, elevation 2063 meters (m), occupies a cirque basin and is fed by the large glacier on the north slope of Mount Spickard, the highest point in the RNA, 2737 m. This alpine lake covers 65 ha, and its known maximum depth is about 159 m.[1]

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[1]Personal communication (1980) from Robert Wasem, Management Biologist, North Cascades National Park, Sedro Woolley, Washington.

ROBIN LESHER was a graduate student in Biology at Western Washington University at the time this research was done; her address is 8700 S.W. Hillview Terrace, Portland, Oregon 97225. This research was supported by a contract with the Pacific Northwest Forest and Range Experiment Station.

According to Shideler (1965), the lake basin was formed by alpine ice controlled by the continental ice sheet; the apparent level of the alpine glacier can be seen as a break in the slope of the ridge sides around Silver Lake. The lower ridges were rounded by glacial action contrasting with the sharp and precipitous ridges at higher elevations. The size of the active glacier southwest of Silver Lake has changed since the area was mapped in 1904 and 1905 (Shideler 1965). At that time Silver Lake did not exist, and the ice extended to the northeastern end of the present lake.

The north shore of Silver Lake is characterized by moderate to steep talus slopes composed of intrusive granite. The south rim, upper slopes of the cirque, and exposed ridges are composed of Skagit Volcanics, probably of Oligocene age (Shideler 1965). Generally, soil in the entire basin is poorly developed.

Silver Lake RNA is located along the eastern portion of the western north Cascade Range. The climate of the north Cascades varies considerably from maritime on the western slopes to more continental on the eastern slopes. Within the Cascade Range, elevation has a primary effect on the local climate. Precipitation and snowfall increase and temperatures decrease rapidly with increasing elevation (Franklin and Dyrness 1973). Most of the precipitation at higher elevations in the region falls as snow or sleet during the fall and winter; the summer is relatively dry. Showers, however, are frequent during the summer (Douglas 1972).

Methods

A botanical reconnaissance of the Research Natural Area was conducted from August 12 to 14, 1980. The main emphasis was on the alpine vegetation of the lake basin, inlet, east rim, and lower northern cirque walls up to 2320 m. The eastern slope of the outlet stream was also surveyed, but only to the lower subalpine areas, about 1830 m. The south rim was inaccessible because of extensive cliffs, glaciers, and steep talus slopes. The only visible vegetation on the south rim was on bluff sites of cliffs that had stable soils and better water retention. All distinct habitats were visited in the RNA, except the montane forest.

The RNA is divided into seven locations (fig. 1) for easier discussion. Descriptive information regarding habitats and vegetation is provided for each location. A total of 109 vascular plant taxa, representing 27 families, were recorded. A checklist of these species is included with notations about relative abundance, habitats, range of elevation, and associated species. Abundance of species was estimated in the field as rare, infrequent, occasional, frequent, or abundant. Families are arranged alphabetically, as are genera and species. Table 1 is a list of families with number of representative species indicated. Table 2 is a list of species with notations about locations and habitat.

Botanical nomenclature follows Hitchcock and Cronquist (1973). Most species were identified in the field and were not collected so as to minimize the impact on this fragile ecosystem. Questionable specimens were collected and identified by consulting Hitchcock and others (1955, 1959, 1961, 1964, 1969), and were verified by use of herbarium specimens at Western Washington University, Bellingham, Washington. Voucher specimens are deposited in the herbarium at North Cascades National Park Headquarters, Sedro Woolley, Washington.

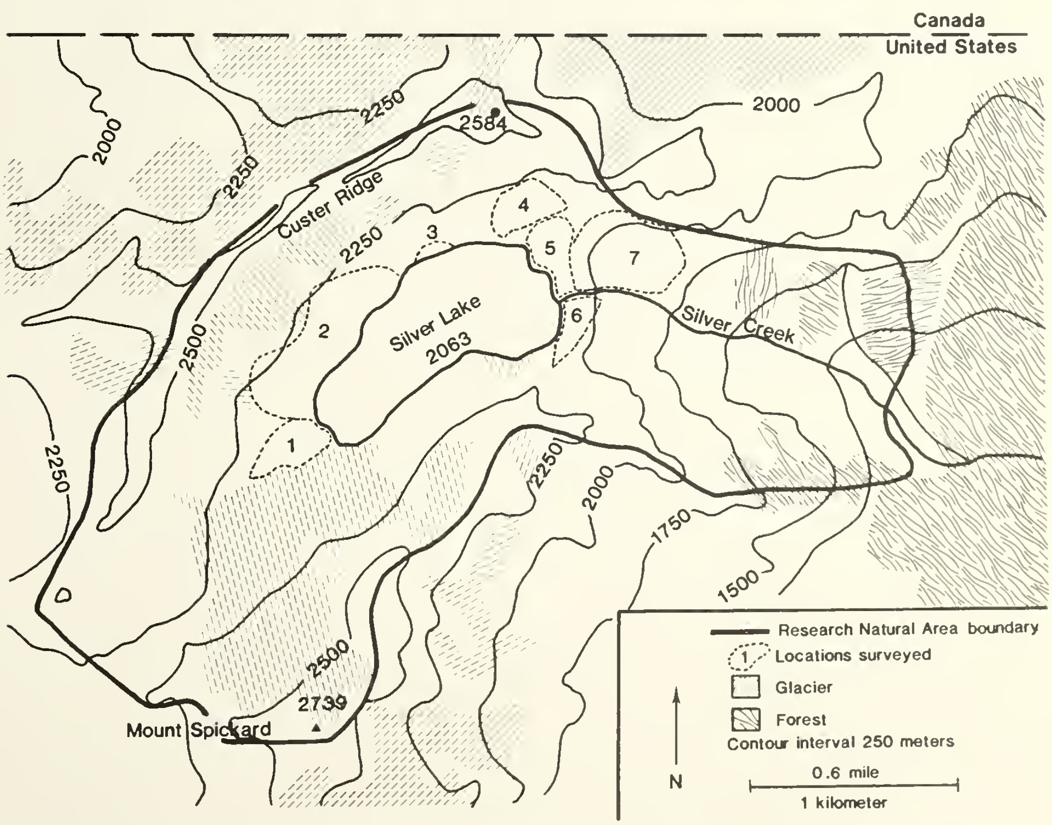

Figure 1.--Silver Lake Research Natural Area, with locations of glaciers, forests, and areas sampled.

Table 1—Vascular plant families in Silver Lake Research Natural Area, North Cascades National Park, Washington

Family	Number of taxa
Campanulaceae	1
Caryophyllaceae	4
Compositae	14
Crassulaceae	1
Cruciferae	3
Cupressaceae	2
Cyperaceae	7
Empetraceae	1
Ericaceae	9
Gramineae	17
Hydrophyllaceae	2
Juncaceae	4
Lentibulariaceae	1
Liliaceae	2
Lycopodiaceae	1
Onagraceae	3
Orchidaceae	1
Pinaceae	4
Polemoniaceae	2
Polygonaceae	2
Polypodiaceae	3
Ranunculaceae	2
Rosaceae	5
Salicaceae	2
Saxifragaceae	9
Scrophulariaceae	6
Valerianaceae	1

Table 2--Distribution and habitat of plant taxa in Silver Lake Research Natural Area, North Cascades National Park, Washington

Taxa	Location 1/	Habitat 2/									
		R	T	SC	FF	H	SM	VM	K	SEEP	MOSS
Abies lasiocarpa	5,6,7	X			X				X		
Achillea millefolium lanulosa alpicola	2,4	X	X			X	X			X	
Agrostis humilus	2									X	X
Agrostis scabra	1,2,6	X			X					X	X
Agrostis thurberiana	7	X				X			X		
Agrostis variabilis	2									X	X
Antennaria alpina media	1,2,4,5,6,7	X		X	X	X		X			
Antennaria lanata	5,6,7	X				X			X		
Antennaria umbrinella	2		X								
Arabis lyallii	4		X								
Arabis microphylla microphylla	2		X								
Arctostophylos uva-ursi	5,6	X			X						
Arenaria capillaris americana	7	X				X					
Arenaria macrophylla	1	X		X							X
Arnica latifolia gracilis	7					X					X
Arnica mollis	2									X	
Calamagrostis canadensis canadensis	6				X						
Calamagrostis purpurascens	6				X						
Caltha biflora biflora	7					X				X	
Campanula rotundifolia	2,4		X			X	X	X		X	
Carex nardina	2,5,7	X									
Carex nigricans	2,6,7	X				X	X			X	X
Carex phaeocephala	1,2,4,5	X	X	X	X					X	
Carex pyrenaica	2,7	X	X							X	
Carex scirpoidea pseudoscirpoidea	4		X					X			
Carex scirpoidea stenochlaena	2	X									
Carex spectabilis	1,2,4,6,7	X	X	X	X	X	X	X		X	X
Cassiope mertensiana mertensiana	2,5,6,7	X	X			X	X		X	X	X
Cassiope tetragona saximontana	2,6	X				X					X
Castilleja parviflora albida	7					X					
Castilleja rupicola	3,4,5	X	X		X			X			
Chamaecyparis nootkatensis	7	X							X		
Cryptogramma crispa acrostichoides	7	X									
Cystopteris fragilis	7	X									
Danthonia intermedia	7	X							X		
Deschampsia atropurpurea	2,7		X			X				X	
Empetrum nigrum	5,6	X			X	X					
Epilobium alpinum clavatum	1,2,7	X		X						X	X
Epilobium alpinum lactiflorum	7	X							X		
Epilobium latifolium	1,2,4	X	X	X		X	X			X	
Erigeron aureus	2,3,4,5,6	X	X		X			X			
Erigeron compositus glabratus	5	X			X						
Erigeron peregrinus callianthemus scaposus	2,7	X				X				X	
Erigeron peregrinus peregrinus dawsonii	2,3	X								X	
Festuca ovina brevifolia	1,2,4,5,6	X	X	X	X			X			
Haplopappus lyallii	1,2,6	X	X	X							
Hieracium gracile	2,7	X	X			X					
Juncus drummondii subtriflorus	1,2,7	X	X	X							X
Juncus mertensianus	1,2,4,7	X	X	X		X	X			X	X
Juniperus communis montana	2 5,6,7	X	X						X		
Kalmia microphylla	4,7					X		X		X	
Ledum glandulosum glandulosum	7								X		
Leptarrhena pyrolifolia	7									X	X
Luetkea pectinata	2,4,5,6,7	X	X			X	X			X	
Luzula piperi	1,2,4,7	X	X	X					X	X	X
Luzula spicata	1,2,5,6,7	X		X	X						X
Lycopodium sitchense	2,4,6,7	X	X			X				X	
Mimulus tilingii caespitosus	7									X	
Mitella pentandra	7									X	
Oxyria digyna	1,2,6	X	X	X	X						

1/See text for description of locations.
2/R=rock, T=talus, SC=scree, FF=fell-field, H=heather community, SM=sedge meadow, VM=vegetation mats, K=krummholz, SEEP=seepage, MOSS=moss mats.

Table 2--Distribution and habitat of plant taxa in Silver Lake Research Natural Area, North Cascades National Park, Washington (continued)

Taxa	Location 1/	Habitat 2/									
		R	T	SC	FF	H	SM	VM	K	SEEP	MOSS
Parnassia fimbriata fimbriata	7									X	
Penstemon davidsonii menziesii	1,2,5,6	X		X	X						
Penstemon procerus tolmiei	2,4,7		X			X	X				
Phacelia sericea sericea	1,2		X	X							
Phleum alpinum	4,7		X			X					
Phlox diffusa longistylis	2,4,5.6,7	X	X		X	X		X			
Phyllodoce empetriformis	2,4,5,6,7	X	X		X	X	X	X	X	X	X
Phyllodoce glanduliflora	2 4,5,6,7	X	X		X	X	X	X	X	X	X
Picea engelmannii	2,5,6,7	X	X		X				X		
Pinguicula vulgaris	2							X		X	
Pinus albicaulis	2,5,6,7	X	X		X				X		
Poa alpina	1,2,4,7	X	X			X		X		X	
Poa cusickii epilis	4,7		X			X	X				
Poa grayana	4,6				X			X			
Poa incurva	1,2	X								X	X
Poa leptocoma paucispicula	2	X								X	X
Poa lettermannii	1,2	X									
Polemonium elegans	1,2,4,5	X	X	X	X						X
Polygonum viviparum	2,6	X			X						
Polystichum lonchitis	2	X								X	
Potentilla flabellifolia	4,7		X			X					X
Potentilla fruticosa	2,4,5	X	X		X	X	X	X		X	
Potentilla villosa parviflora	2,6	X									
Ranunculus verecundus	2	X								X	
Romanzoffia sitchensis	1			X						X	X
Salix cascadensis	2,6	X	X		X	X		X			
Salix nivalis nivalis	2,4,6	X	X		X	X		X		X	
Saxifraga bronchialis austromontana	5,6	X			X						
Saxifraga debilis	1			X						X	
Saxifraga ferruginea macounii	1,2,6,7	X	X							X	X
Saxifraga oppositifolia	2	X									
Saxifraga punctata cascadensis	2,7	X									X
Saxifraga tolmiei tolmiei	1,2,6,7	X	X	X						X	X
Sedum lanceolatum lanceolatum	2		X					X			
Senecio fremontii	1,2,4	X	X								
Sibbaldia procumbens	2,4,6,7	X	X			X				X	
Silene acaulis	1,2,4,5,6	X	X		X			X			
Smelowskia ovalis	1,2,4,5,6	X	X	X	X						
Solidago multiradiata	2,4,5,6	X	X		X			X			
Spiranthes romanzoffiana romanzoffiana	2									X	
Stellaria longipes	6	X									
Tofieldia glutinosa brevistyla	4,7		X					X		X	X
Trisetum spicatum	1,2,4,6	X	X		X			X		X	
Tsuga mertensiana	7	X							X		
Vaccinium caespitosum	2,4,6,7		X		X	X		X			
Vaccinium deliciosum	4,5,6,7	X	X			X			X		
Valeriana sitchensis	7									X	
Veratrum viride	7									X	
Veronica wormskjoldii	2,4,7	X	X			X				X	

1/ See text for description of locations.
2/ R=rock, T=talus, SC=scree, FF=fell-field, H=heather community, SM=sedge meadow, VM=vegetatinn mats, K=krummholz, SEEP=seepage, MOSS=moss mats.

Taxa of Special Interest

Several species of special interest occur within the Silver Lake Research Natural Area. An extension of the range of *Carex scirpoidea* var. *pseudoscirpoidea* has been documented in the RNA, as this is the farthest west occurrence known for this taxon in Washington. *Saxifraga debilis* and *Poa grayana* are listed as sensitive in "Endangered, Threatened and Sensitive Vascular Plants of Washington" (Washington Natural Heritage Program 1982): a vascular plant taxon with small populations or localized distribution within the State, that is not presently endangered or threatened, but whose populations and habitats will be jeopardized if current land use practices continue. Regional herbaria (Washington State University, University of Washington, Western Washington University, and University of British Columbia) and the Washington Natural Heritage Program provided information on collections and localities of these three taxa in Washington.

The primary range of *Poa grayana* is British Columbia to southwest Alberta, south in the Rocky Mountain States to Utah and New Mexico (Hitchcock and Cronquist 1973). *Poa grayana* approaches the geographical limits of its continuous range in Washington and is known from two sites in Okanogan County and from two sites in the Olympic Mountains in Clallam and Jefferson Counties. This documentation of *Poa grayana* at Silver Lake RNA represents the farthest west occurrence of this taxon in the north Cascades. *Poa grayana* occurs in a fell-field on the east rim of Silver Lake and is an occasional grass in vegetation mats on talus slopes.

Saxifraga debilis is widely distributed outside Washington, occurring in British Columbia south to the Cascades of Washington, the Blue and Wallowa Mountains of northeastern Oregon, the Sierra Nevada of California, the San Francisco Mountains of northern Arizona; east in British Columbia to the Rocky Mountains; and south through Montana to eastern Utah and Colorado (Hitchcock and others 1961). *Saxifraga debilis* is sporadically distributed across part of Washington, with reported sightings in the Olympic Mountains, the north Cascades south to Glacier Peak and Mount Rainier, and in Okanogan County. This distribution is probably due to habitat specialization within the alpine zone, favoring damp cliffs, rock crevices, and talus near snowbanks (Washington Natural Heritage Program 1981). *Saxifraga debilis* is rare in the RNA and is restricted to the outwash area of the inlet stream; only a few plants are found in moist, mossy sites of glacial silt and scree.

Carex scirpoidea var. pseudoscirpoidea is the common variety in the southern Rocky Mountains, occasionally west to California, and north to the Little Belt Mountains of Montana, and the mountains of central Idaho and southeastern Oregon (Hitchcock and others 1969). According to Taylor and others (1973), Carex scirpoidea var. pseudoscirpoidea was not reported for the Cascade Range until it was collected by George W. Douglas in Okanogan County. Early botanists in Washington, however, found Carex scirpoidea var. pseudoscirpoidea in the Cascade Range; the Marion Ownbey Herbarium at Washington State University has two collections of this taxon from Stuart Pass in Chelan County made by Harold St. John and L. A. Thayer in 1925. Carex scirpoidea var. pseudoscirpoidea was infrequent in the Silver Lake RNA; the only sighting was in a vegetation mat on a moderately steep talus slope, elevation 2160 m. This taxon is not included on the Washington list (Washington Natural Heritage Program 1982), although it is apparently rare in Washington.

Another species of interest at Silver Lake is Ranunculus verecundus. According to Taylor and others (1973), there have been only two collections of this taxon in Washington: Crater Mountain in the western portion of the Pasayten Wilderness Area east of Ross Lake and Mount Adams in southern Washington. Although distributed from Alaska to the Cascades in southern Washington (Hitchcock and others 1964), this species has rarely been collected in Washington. This taxon is rare in the Silver Lake basin; occasional plants occur along a rocky seepage area just above the north shore of Silver Lake, elevation 2065 m.

Poa leptocoma var. paucispicula and Cassiope tetragona var. saximontana are on the "monitor list" (Washington Natural Heritage Program 1982), a list of taxa that are more abundant or are less threatened in Washington than was previously assumed. Taxa on this list are not used by the Washington Natural Heritage Program in environmental assessment or impact analysis, but data on these plants are stored to monitor any changes in population size, threats to habitat, or future changes in status.

Habitats and Vegetation

Location 1 (Fig. 1)

The lake inlet (fig. 1) is a rocky outwash area of north-northeast aspect that supports sparse vegetation (table 2). Glacial silt and scree adjacent to the inlet stream retain a great deal of water. Several meters from the stream the substrate is coarser and drainage is better, allowing a greater diversity of plant species, although plant cover is still sparse. Large rocks carried downslope by glacial action, runoff, and slides provide microsites for the establishment of seedlings. Vegetation in the inlet region occurs in moist areas and in sites protected from outwash during peak runoff periods. Graminoids are dominant, including such bunchgrasses as *Festuca ovina* var. *brevifolia*, *Trisetum spicatum*, *Poa alpina*, *Juncus mertensianus*, *J. drummondii* var. *subtriflorus*, *Carex spectabilis*, and *C. phaeocephala*. The rare *Saxifraga debilis* occurs adjacent to the inlet stream.

In the valley above the delta, little vegetation is found. The north slope of Mount Spickard is covered by glacier, and snowfields persist in the ravine. The east-facing slope of Custer Ridge is characterized by glacier, cliffs, and steep talus slopes. Vegetation is found in seepage areas adjacent to rock outcrops and cliff faces.

Location 2 (Fig. 1)

Above the northwest shore of Silver Lake are moderate to steep talus slopes, extending to 2350 m. At this elevation, precipitous cliffs blackened with lichen growth rise to Custer Ridge which forms the northern boundary of the RNA (fig. 1). Persistent snowfields cover the steep slope below the cliffs. Vegetation is sparse because runoff and erosion prevent plant establishment.

The talus slopes from lakeshore to 2320 m were extensively surveyed (fig. 1, table 2). Large outcrops that interrupt the slope provide sites of greater stability and are colonized by plants. Outcrops protect vegetation from rockslides and avalanches, function as barriers to erosion, and allow soil and moisture to accumulate; thus, they support different flora than do adjacent talus slopes. Different communities occupy the bluff and base of outcrops because of differences in the moisture regime resulting from snow accumulation and time of snowmelt. The bluff supports mats of *Salix cascadensis*, *Phyllodoce glanduliflora*, and occasionally *Cassiope tetragona* var. *saximontana*. Winter snow accumulates at the base of outcrops which results in late season snowmelt. These sites support lush communities dominated by *Carex spectabilis* and *C. nigricans*, along with *P. glanduliflora*, various graminoids, and herbs.

Moisture is limited on talus slopes, and the vegetation generally follows seepage and streams. Senecio fremontii and Phacelia sericea var. sericea, however, are commonly scattered on talus, occupying pockets of soil among the rocks. Communities of Epilobium latifolium colonize sites of early season seepage and are abundant in some locations.

Occasional rocky plateaus support lush meadows dominated by Potentilla fruticosa and associated species: Epilobium latifolium, Phyllodoce glanduliflora, and Carex spectabilis. Snow melts early in the season on these gently sloping sites.

A Phyllodoce glanduliflora community occurs in areas of slight slope that accumulate soil and retain water. This community occupies sites that become free from snow later in the season than sites supporting the Potentilla fruticosa community. Carex spectabilis and P. fruticosa are important associates of P. glanduliflora.

Location 3 (Fig. 1)

The eastern section of the north rim of Silver Lake is extremely rugged and inaccessible. Steep slopes are composed primarily of shear cliffs and talus. Only rock ledges along the lakeshore were sampled (fig. 1).

Vegetation follows drainage patterns and occupies stable sites where landslides and avalanches are less likely to occur. These sites were dominated by shrubs. Infrequent krummholz clumps are established in sites of stable substrate where moisture is retained. Textured rock, cracks, ledges, and microsites of less extreme relief also support plant growth. Vegetated areas extend to about 2290 m.

Location 4 (Fig. 1)

This location occupies the south-facing slope above the east rim of Silver Lake (fig. 1). Talus slopes of moderate to steep relief were surveyed from 2130 to 2230 m (table 2). Extensive vegetation mats are established in stable sites where soil and water accumulate. These mats are composed of a diversity of species, commonly Potentilla fruticosa, Carex spectabilis, Salix nivalis var. nivalis, and Silene acaulis, as well as various graminoids and herbaceous perennials. Seepage sites support a lush growth of moss, Pinguicula vulgaris, Tofieldia glutinosa var. brevistyla, Kalmia microphylla, Spiranthes romanzoffiana var. romanzoffiana, and Phyllodoce glanduliflora. Communities of Carex spectabilis and Potentilla fruticosa also occur in this area.

Location 5 (Fig. 1)

This location encompasses the bench along the east rim of Silver Lake, north of the outlet stream (fig. 1). A fell-field habitat with frequent boulders occupies the crest of the bench, and an extensive boulder field covers the west slope to the lakeshore.

The fell-field is characterized by sprawling, low-growing shrubs: *Juniperus communis* var. *montana*, *Arctostaphylos uva-ursi*, *Penstemon davidsonii* var. *menziesii*, and *Potentilla fruticosa*, and occasional graminoids and herbaceous perennials (table 2). Krummholz trees of *Pinus albicaulis*, *Abies lasiocarpa*, and *Picea engelmannii* occur along the eastern flank of the bench and in sites protected by large boulders.

The extensive growth of lichen along the east rim is impressive; no rock is left bare. *Umbilicaria* is the dominant lichen and is responsible for the blackened appearance of the boulder field on the western slope and along the bench. Crustose lichens inhabit rock where they can successfully compete with *Umbilicaria*. *Thamnolia* and *Cetraria* are common fruticose forms in the fell-field.

Location 6 (Fig. 1)

The east rim of Silver Lake south of the outlet stream is sparsely vegetated (table 2). Boulder- and fell-field habitats predominate on the bench; to the east are barren talus slopes and on the western slope, terraced cliffs extend to the lakeshore.

Empetrum nigrum is an important shrub in rocky exposed sites and is often associated with *Arctostaphylos uva-ursi* and *Salix nivalis* var. *nivalis*. *Salix nivalis* var. *nivalis* also forms vegetation mats in sites that are rockier and more exposed than those inhabited by *E. nigrum*.

A *Phyllodoce glanduliflora* community occurs in concave, less rocky areas of the fell-field, where soil accumulates and moisture is more abundant. Occasional mats of *Salix cascadensis* are associated with this community. On the eastern slope below the crest of the bench are protected basins that support heather communities of *P. empetriformis* and *Cassiope mertensiana* var. *mertensiana*.

Location 7 (Fig. 1)

This location covers the east-facing slope of Silver Lake north of the outlet stream, from 2040 to 1830 m (fig. 1). The upper slopes are predominantly barren talus; yet creeks, seepage areas, basins, rock outcrops and stable sites are favorable for establishment of vegetation (table 2). Frequent avalanches and rock slides perpetuate the barren nature of this slope.

The vegetation is dramatically influenced by topography, microrelief, snowpack, and seepage. Heather communities predominate in sites on higher ground and of better drainage. *Cassiope mertensiana* var. *mertensiana* and *Phyllodoce empetriformis* are dominants, with *Phyllodoce glanduliflora* as a codominant species at higher elevations. Sites of late snowmelt support sedge meadows of *Carex spectabilis*, *C. nigricans*, or both. *Saxifraga tolmiei* var. *tolmiei* and *Luzula piperi* occur in thick moss mats in seepage areas at higher elevations, whereas at lower elevations a greater diversity of species is found (table 2).

Extensive krummholz stands of *Abies lasiocarpa* sprawl along steeper parts of the slope in well-drained sites of stable rock. *Ledum glandulosum* is often associated with *A. lasiocarpa*. *Tsuga mertensiana* may also occur in these krummholz stands. Dense stands of krummholz--composed of *A. lasiocarpa*, *T. mertensiana*, *Pinus albicaulis*, and *Chamaecyparis nootkatensis*--occur near Silver Creek.

Summary

Generally, the flora of Silver Lake Research Natural Area is typical of the western and central north Cascades; however, several species occur primarily in the eastern north Cascades: *Carex scirpoidea* var. *pseudoscirpoidea*, *Poa grayana*, *Cassiope tetragona* var. *saximontana*, *Calamagrostis purpurescens*, *Carex nardina*, and *Salix nivalis* var. *nivalis* (Douglas and Bliss 1977, Taylor and Douglas 1978).

Vegetation in the Silver Lake basin is sparse. Except for occasional vegetated sites, a large portion of the basin is inhospitable for seedling establishment and plant colonization. Silver Lake basin is characterized by rugged topography, glaciers, cliffs, rock outcrops, steep and unstable talus slopes with frequent avalanches and rock slides, and poor soil development. These factors are important in preventing plant establishment. Because of the extensive glacial disturbance of this area in recent geologic time, the flora of Silver Lake RNA appears relatively young.

Partial Checklist of Vascular Plants

CAMPANULACEAE

Campanula rotundifolia L., bellflower--occasional plant, common in some sites at elevations of 2070 to 2260 m; found on talus, vegetation mats on talus slope, drier sites above and in meadows of Carex spectabilis, and in seepage areas associated with C. nigricans, C. spectabilis, Phyllodoce glanduliflora, and P. empetriformis.

CARYOPHYLLACEAE

Arenaria capillaris Poir. var. americana (Mag.) Davis, mountain sandwort--occasional plant, commonly associated with Phyllodoce glanduliflora and Luetkea pectinata; 1980-2040 m.

Arenaria macrophylla Hook. (L263),[2] bigleaf sandwort--found at only two restricted locations near lake inlet--on a moist level site among rocks with moss, and under ledges of rock outcrop associated with liverworts.

Silene acaulis L., moss campion--occasional to frequent cushion plant in rocky sites at elevations of 2070 to 2200 m; rock outcrops, ledges on cliff face associated with Saxifraga oppositifolia, talus, lake inlet, fell-field, and vegetation mats on talus slope.

Stellaria longipes Goldie, longstalk starwort--infrequent, found at only one location on top of rock cliff (2070 m), associated with Antennaria alpina var. media and Saxifraga bronchialis var. austromontana.

COMPOSITAE (ASTERACEAE)

Achillea millefolium L. ssp. lanulosa (Nutt.) Piper var. alpicola (Rydb.) Garrett (L264), yarrow--occasional on talus, seepage sites, and communities dominated by Phyllodoce glanduliflora; common in sedge meadow dominated by Carex spectabilis and Potentilla fruticosa; north side of lake at elevations of 2070 to 2260 m.

Antennaria alpina (L.) Gaertn. var media (Greene) Jeps., alpine pussy-toes--occasional plant throughout area; scree in drier sites near lake inlet, fell-field, rock cliffs, vegetation mats on moderately steep talus slope, and heather communities; 1890-2160 m.

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[2]Letters and numbers in parentheses after the taxon are collection numbers that correspond to the voucher specimens deposited in the herbarium at North Cascades National Park Headquarters, Sedro Woolley, Washington.

Antennaria lanata (Hook.) Greene, woolly pussy-toes--occasional on east rim of lake and down east slope of outlet stream, mostly in drier sites of heather community dominated by *Phyllodoce glanduliflora* and *Cassiope mertensiana* var. *mertensiana*; rare occurrence in fell-field along north exposure above outlet stream.

Antennaria umbrinella Rydb. (L232), umber pussy-toes--infrequent along north lakeshore in moist sites, rocky and gravelly soil, and talus; 2070 m.

Arnica latifolia Bong. var. *gracilis* (Rydb.) Cronq. (L256), mountain arnica--infrequent on moss mats in community dominated by *Phyllodoce empetriformis* and *Carex spectabilis*; 2010 m.

Arnica mollis Hook. (L240), hairy arnica--occasional in rocky seepage areas and moist sites along north lakeshore, associated with *Poa alpina*, *P. incurva*, and *Erigeron peregrinus*; 2070 m.

Erigeron aureus Green (L239), golden fleabane--common in rocky sites of lake basin, such as fell-fields, rock outcrops, and boulder fields; also found on talus slopes in areas of soil accumulation, vegetation mats, and along periphery of *Salix nivalis* mats.

Erigeron compositus Pursh var. *glabratus* Macoun, dwarf mountain fleabane--occasional in fell-field and rockier sites on east bench.

Erigeron peregrinus (Pursh) Greene ssp. *callianthemus* (Greene) Cronq. var. *scaposus* (T. & G.) Cronq. (L241, L258), subalpine daisy--occasional plant in protected sites on rock cliffs associated with *Cystopteris fragilis*, moist protected sites under rock along creek, and heather community; 1830-2260 m. (L241 approaches var. *angustifolius* regarding narrow basal leaves.)

Erigeron peregrinus (Pursh) Greene ssp. *peregrinus* var. *dawsonii* Greene (L253, L254), subalpine daisy--occasional plant found at only two locations--ledge of rock outcrop along north lakeshore at 2070 m, and rocky seepage site at base of large rock outcrop. (L254 possesses involucral and ray characteristics that more closely fit var. *thompsonii*, yet range and habitat are incompatible.)

Haplopappus lyallii Gray, Lyall's goldenweed--occasional to frequent plant scattered on north lakeshore, nestled among rocks in areas of soil development, also common on unstable talus with *Senecio fremontii*, scree sites near lake inlet, and rock outcrops on east bench of lake; 2070 m.

Hieracium gracile Hook., alpine hawkweed--occasional plant on talus slope in sites of soil accumulation, and among rocks in heather community; 1980-2320 m.

Senecio fremontii T. & G., dwarf mountain groundsel--abundant, one of the most common plants scattered on open talus slopes, nestled among rocks in areas of slight soil development, associated with Epilobium latifolium and Carex phaeocephala; 2070-2260 m.

Solidago multiradiata Ait., northern goldenrod--occasional to frequent plant in rocky sites with some soil accumulation, fell-field, and vegetation mats on moderately steep talus slope; 2070-2160 m.

CRASSULACEAE

Sedum lanceolatum Torr. var. lanceolatum, lanceleaved stonecrop--infrequent, found at only one location in large mats of Salix nivalis var. nivalis on talus slope; 2100 m.

CRUCIFERAE (BRASSICACEAE)

Arabis lyallii Wats. (L243), Lyall's rockcress--rare, found at only one site on steep unstable, rocky slope (2230 m), associated with Phlox diffusa var. longistylis.

Arabis microphylla Nutt. var. microphylla (L242), littleleaf rockcress--rare plant in rocky sites of slight soil development (2260 m), associated with Epilobium latifolium and Potentilla fruticosa.

Smelowskia ovalis Jones (L237), shortfruit Smelowskia--occasional to frequent plant in rocky sites; fell-field, talus, boulder fields, from lake inlet to open slopes, and east bench of lake; 2063-2200 m.

CUPRESSACEAE

Chamaecyparis nootkatensis (D. Don) Spach, Alaska yellow cedar--frequent in dense stands of krummholz near Silver Creek on north side of drainage (elevation up to 1950 m), associated with Abies lasiocarpa, Tsuga mertensiana, and Pinus albicaulis.

Juniperus communis L. var. montana Ait., mountain juniper--occasional to frequent sprawling shrub in rocky sites; rock outcrops, ledges, fell-field, commonly associated with Pinus albicaulis, Picea engelmannii, and Penstemon davidsonii var. menziesii; 2070-2130 m.

CYPERACEAE

Carex nardina Fries, spikenard sedge--occasional plant in rocky sites above 1950 m.

Carex nigricans Retz., black alpine sedge--frequent to abundant in moist sites and seepage areas, from rocky slopes to moss mats, and heather community dominated by Phyllodoce empetriformis and Carex spectabilis. This sedge forms dense stands in snow bed areas where snow melts late in the season, 1890-2260 m.

Carex phaeocephala Piper (L262), mountain hare sedge--frequent sedge in rocky sites of lake basin, scattered on talus slopes in areas of soil development, ledges of rock outcrop, fell-field, and scree near lake inlet, occasionally found along seepage areas; above 2070 m.

Carex pyrenaica Wahl., Pyrenaean sedge--infrequent, found at only two locations: moist site on talus slope along creek (2260 m), and protected site on rock cliff (1890 m).

Carex scirpoidea Michx. var. pseudoscirpoidea (Rydb.) Cronq. (L212), single-spike sedge--infrequent, found only in vegetation mat on moderately steep talus slope; 2160 m.

Carex scirpoidea Michx. var. stenochlaena Holm (L226), single-spike sedge--infrequent, found at only one location on terraces of large rock outcrop (2100 m), associated with Salix cascadensis.

Carex spectabilis Dewey, showy sedge--locally abundant and found in most habitats throughout the area; 1890-2260 m. Common in moist sites on talus, rock outcrops, scree of lake inlet, and fell-field; abundant in sites contiguous with rock outcrops where soil and moisture accumulate, mossy sites, and vegetation mats on steep talus slope. Carex spectabilis dominates localized communities, primarily seepage sites on talus, is a common associate in communities dominated by Phyllodoce glanduliflora, P. empetriformis, or Cassiope mertensiana var. mertensiana, and is associated with Carex nigricans along creeks and seepage and in basins.

EMPETRACEAE

Empetrum nigrum L., crowberry--occasional to frequent in rocky sites, fell-field, rock bluffs, and outcrops along east bench; often associated with Arctostaphylos uva-ursi. Dominant shrub in fell-field in sites less rocky and exposed than sites inhabited by Salix nivalis; also found in higher heather meadows at 2100 m in association with Phyllodoce glanduliflora and Salix cascadensis.

ERICACEAE

Arctostaphylos uva-ursi (L.) Spreng., kinnikinnick--occasional to frequent sprawling shrub in rocky sites and fell-field on east rim of lake.

Cassiope mertensiana (Bong.) G. Don var. mertensiana, white mountain heather--occasional to abundant throughout most areas; 1830-2130 m. Occurs on talus in stable sites of soil accumulation, moist sites in fell-field, along seepage areas, and associated with krummholz. Dominant shrub in heather communities in certain locations, usually associated with Phyllodoce empetriformis and P. glanduliflora.

Cassiope tetragona (L.) D. Don var. saximontana (Small) Hitchc. (L227), four-angled mountain heather--limited in distribution to three known sites: frequent plant in lush, moist sites with moss buildup on large rock outcrop, associated with Potentilla fruticosa and Phyllodoce glanduliflora, east aspect, 2100 m; occasional plant on small ledges of rock wall along east rim of lake south of outlet; also upslope in heather meadow, associated with P. glanduliflora, Empetrum nigrum, and Salix cascadensis, north aspect, 2070-2100 m.

Kalmia microphylla (Hook.) Heller, alpine Kalmia--occasional plant in seepage site on talus slope above east rim, also in areas of greater stability where soil and water accumulate and support vegetation mats (2160 m); locally common in heather community on east slope (2070 m).

Ledum glandulosum Nutt. var. glandulosum, mountain labrador tea--dominant understory in krummholz stands of Abies lasiocarpa, with common associates Phyllodoce glanduliflora and P. empetriformis. This community covers extensive areas on steeper parts of the slope and in sites of better drainage.

Phyllodoce empetriformis (Sw.) D. Don, pink mountain heather--occasional to abundant throughout area; on talus among rocks in pockets of water retention, in basins on exposed rocky benches, understory of krummholz Abies lasiocarpa, moss mats, and along seepage areas. Dominant shrub in heather communities, associated with Cassiope mertensiana var. mertensiana and P. glanduliflora; 1830-2160 m.

Phyllodoce glanduliflora (Hook.) Cov., yellow mountain heather--occasional to abundant throughout area; seepage areas, sites of soil accumulation on talus slopes, lush sites with moss buildup, moist sites on rock outcrops, fell-field, and understory of krummholz Abies lasiocarpa. Dominant plant in heather community, associated with Potentilla fruticosa and Carex spectabilis from 2100 to 2230 m, and Cassiope mertensiana var. mertensiana and Phyllodoce empetriformis below 2070 m.

Vaccinium caespitosum Michx., dwarf huckleberry--occasional to frequent on talus slopes associated with Phyllodoce glanduliflora, and on higher, drier ground of heather communities, fell-field, and vegetation mats on moderately steep talus slope, up to 2160 m.

Vaccinium deliciosum Piper, Cascade huckleberry--occasional to frequent in heather communities on east slope of outlet stream, among rocks, on unstable talus slope, and understory of krummholz stands; up to 2230 m.

GRAMINEAE (POACEAE)

Agrostis humilus Vasey (L224), alpine bentgrass--rare, found at only one location in moss mat along seepage area, east slope; 2320 m.

Agrostis scabra Willd. (L220, L221, L245, L246, L255, L257, L259), winter bentgrass--occasional grass at higher elevations from lakeshore to 2320 m. Found in rocky sites along seepage areas, moist sites with moss mats on rock cliffs, scree near lake inlet, and fell-field on east bench. This species proved to be taxonomically difficult in this area, especially collections L220, L246, L255, L257, L259. The specimens are not clearly distinct from Agrostis borealis, and they exhibit overlapping characteristics. These specimens were not as robust as typical specimens of A. scabra, and the panicle was somewhat congested. Measurements of the glumes, lemma, and anthers of A. borealis and A. scabra overlap; however, the awn was not "consistently" strong and geniculate, which was the major characteristic favoring A. scabra over A. borealis. I made the only known collection of A. borealis in Washington in 1978 from Chapoka Peak. Therefore, I have been conservative and have classified these specimens as A. scabra, yet mention their close affinity with A. borealis.

Agrostis thurberiana Hitchc. (L265, L266), Thurber bentgrass--infrequent in heather community dominated by Phyllodoce empetriformis and Carex spectabilis (2010 m); also found on moist site of rock cliff beneath krummholz; (1890 m).

Agrostis variabilis Rydb. (L244), variant bentgrass--rare, found at only one location on moss mat of seepage area, east slope; 2320 m.

Calamagrostis canadensis (Michx.) Beauv. var. canadensis (L213), bluejoint reedgrass--infrequent in fell-field; 2070 m.

Calamagrostis purpurascens R. Br. (L214), pinegrass--infrequent in rocky site of fell-field, east aspect; 2070 m.

Danthonia intermedia Vasey (L267), timber oatgrass--infrequent, found at only one location in moist site on east-facing rock cliff beneath krummholz; 1890 m.

Deschampsia atropurpurea (Wahl.) Scheele (L236), mountain hairgrass--occasional in community dominated by Phyllodoce empetriformis and Carex spectabilis (2010 m); also in moist site along creek on talus slope (2260 m).

Festuca ovina L. var. brevifolia (R. Br.) Wats (L219, L268), alpine fescue--frequent at higher elevations (above 2070 m) throughout lake basin, and a common bunchgrass at lake inlet. Occurs in rocky sites, fell-field, talus, and vegetation mats on steep talus slope.

Phleum alpinum L., alpine timothy--occasional plant in community dominated by Phyllodoce empetriformis and Carex spectabilis (2010 m); also found at 2230 m on steep unstable rocky slope, associated with Epilobium latifolium and C. phaeocephala.

Poa alpina L. (L261), alpine bluegrass--occasional to frequent plant from upper subalpine slopes to lake basin (2010-2160 m); in moist sites on talus and rock outcrops, seepage, vegetation mats on talus slope, common bunchgrass at lake inlet, and in heather community dominated by Phyllodoce empetriformis.

Poa cusickii Vasey var. epilis (Scribn.) Hitchc. (L269), skyline bluegrass--occasional plant in meadows of Carex spectabilis on gentle sloping talus (2160 m), and in community dominated by Phyllodoce empetriformis and Luetkea pectinata (2010 m).

Poa grayana Vasey (L215, L218, L225), Gray's bluegrass--occasional grass in vegetation mats on moderately steep talus slopes of south aspect (2160 m) and in fell-field habitat on east rim of lake.

Poa incurva Scribn. & Will. (L260, L261), curly bluegrass--occasional plant in wet, mossy seepage site just above north lakeshore; also found at rocky site near lake inlet.

Poa leptocoma Trin. var. paucispicula (Scribn. & Merr.) Hitchc. (L247, L250), bog bluegrass--infrequent plant in moist sites of upper lake basin (2100-2320 m), found on moss mat of seepage area, with moss on rock face, and along creek.

Poa lettermannii Vasey (L248, L249), Letterman's bluegrass--infrequent grass in rocky site at lake inlet, and on terraces of large rock outcrop (2070 m); associated with Salix cascadensis, Polygonum viviparum, and Carex scirpoidea var. stenochlaena.

Trisetum spicatum (L.) Richter, spike Trisetum--frequent grass in rocky sites of lake basin, and a common bunchgrass at lake inlet. Occurs in seepage site at base of rock outcrop, vegetated areas of talus slope, rock outcrops in microsites of soil buildup, and fell-field; 2070-2160 m.

HYDROPHYLLACEAE

Phacelia sericea (Grah.) Gray var. sericea, silky Phacelia--occasional to frequent on talus and on drier sites near lake inlet; associated with Senecio fremontii and Epilobium latifolium.

Romanzoffia sitchensis Bong. (L231), Sitka mistmaiden--rare, only a few plants in outwash area of inlet stream and in moist, mossy sites of glacial silt and scree.

JUNCACEAE

Juncus drummondii E. Meyer var. subtriflorus (Meyer) Hitchc. (L270), Drummond's rush--occasional to frequent in moist sites along creeks, rocky seepage areas, and lake inlet (1950-2260 m); able to colonize more stable, moist sites near lakeshore with Juncus mertensianus.

Juncus mertensianus Bong. (L271), Merten's rush--occasional to frequent rush (2010-2160 m): near lake inlet; in rocky seepage sites with moss, Carex nigricans and Juncus drummondii var. subtriflorus; and in community dominated by Phyllodoce empetriformis and Carex spectabilis.

Luzula piperi (Cov.) Jones, Piper's woodrush--frequent in seepage areas, often associated with Saxifraga tolmiei var. tolmiei (1950-2260 m); on talus, thick moss mats, snow bed areas, and lake inlet.

Luzula spicata (L.) DC. (L272), spiked woodrush--occasional plant in rocky sites and seepage areas from 1950 to 2130 m; moist sites on rock outcrops, lake inlet, and fell-field.

LENTIBULARIACEAE

Pinguicula vulgaris L. (L217), common butterwort--occasional to frequent in seepage areas on moderately steep talus slope above east rim of lake, also growing in moist vegetation mats on talus (2160 m); associated with Tofieldia glutinosa var. brevistyla and Spiranthes romanzoffiana var. romanzoffiana.

LILIACEAE

Tofieldia glutinosa (Michx.) Pers. var. brevistyla Hitchc. (L222), sticky Tofieldia--occasional plant in seepage areas and vegetation mats on talus slope above east rim of lake (2160-2230 m), associated with Pinguicula vulgaris and Spiranthes romanzoffiana var. romanzoffiana; also found in moist mossy sites (1890-1950 m), associated with Phyllodoce empetriformis and Carex spectabilis.

Veratrum viride Ait., false hellebore--occasional plant in moist seepage sites along creek below 1890 m.

LYCOPODIACEAE

Lycopodium sitchense Rupr., Alaska clubmoss--infrequent to occasional clubmoss on talus slopes in areas of stability and soil accumulation, associated with Phyllodoce glanduliflora; terraces on rock outcrop, rock cliffs, drier sites of heather communities, and fringes of seepage site associated with Salix nivalis var. nivalis.

ONAGRACEAE

Epilobium alpinum L. var. clavatum (Trel.) Hitchc. (L234), alpine willow-herb--occasional plant in rocky seepage sites, and scree of lake inlet (2010-2100 m).

Epilobium alpinum L. var. lactiflorum (Hausskn.) Hitchc. (L273), alpine willow-herb--occasional plant found at only one location, a moist site on east-facing rock cliff beneath krummholz; 1890 m.

Epilobium latifolium L., red willow-herb--common and abundant on talus slopes of lake basin (2070-2260 m), dominant in sites of early season seepage; occurs in Phyllodoce glanduliflora/Potentilla fruticosa community, on steep unstable slopes, seepage areas along creeks associated with Phyllodoce empetriformis, Carex spectabilis, C. nigricans, and in dry rocky sites and scree of lake inlet.

ORCHIDACEAE

Spiranthes romanzoffiana Cham. var. romanzoffiana, hooded pearl-twist--occasional plant found at only one location; seepage site on moderately steep talus slope above east rim of lake (2160 m), associated with Tofieldia glutinosa var. brevistyla and Pinguicula vulgaris.

PINACEAE

Abies lasiocarpa (Hook.) Nutt., subalpine fir--occasional to abundant, occurring as krummholz species up to 2100 m. Occurs in protected sites on east rim of lake and down east slope of outlet stream, forming extensive stands on steeper slope in sites of better drainage; often associated with Tsuga mertensiana and also occurs with Chamaecyparis nootkatensis, Picea engelmannii, and Pinus albicaulis.

Picea engelmannii Parry, Engelmann spruce--occasional krummholz species up to 2100 m; occurs on rock outcrops of north lakeshore, protected sites on east rim, and down east slope of outlet stream; associated with Abies lasiocarpa and Pinus albicaulis.

Pinus albicaulis Engelm., white bark pine--occasional krummholz species up to 2100 m; occurs on rock outcrops of north lakeshore, along east rim in fell-field and protected sites adjacent to large boulders, and down east slope of outlet stream to 1830 m; associated with Juniperus communis var. montana (above 2070 m), Abies lasiocarpa, and Picea engelmannii.

Tsuga mertensiana (Bong.) Carr., mountain hemlock--occasional to frequent krummholz species on east slope of outlet stream below 2040 m; commonly associated with Abies lasiocarpa on steeper slopes in sites of better drainage, moist sites on rock cliff, and in dense stands of krummholz species near Silver Creek; also associated with Chamaecyparis nootkatensis and Pinus albicaulis.

POLEMONIACEAE

Phlox diffusa Benth. var. longistylis (Wherry) Peck (L233), spreading phlox--occasional plant in rocky sites of lake basin and upper slopes of outlet stream (2040-2230 m); rock outcrops, fell-field, talus slope, vegetation mats on talus, and also in rockier sites of Phyllodoce glanduliflora community.

Polemonium elegans Greene (L223), elegant sky-pilot--occasional to frequent plant in rocky sites of lake basin (2063-2320 m); common on talus and dominant in some sites, fell-field, among rocks and scree near lake inlet, and moist, mossy sites on rock cliffs.

POLYGONACEAE

Oxyria digyna (L.) Hill., mountain sorrel--occasional plant from lakeshore to 2100 m; in protected sites among rocks, talus, scree of lake inlet, and fell-field on east rim.

Polygonum viviparum L. (L238), alpine bistort--infrequent in moist sites (2070-2100 m); terraces of large rock outcrop, and fell-field on east rim of lake.

POLYPODIACEAE

Cryptogramma crispa (L.) R. Br. var. acrostichoides (R. Br.) Clarke (L228), parsley fern--infrequent plant in protected sites on rock cliff; 1920 m.

Cystopteris fragilis (L.) Bernh. (L257), brittle bladder fern--occasional plant in protected sites on rock cliffs; 1890-1920 m.

Polystichum lonchitis (L.) Roth, mountain sword fern--rare, found at only one location in moist, protected site under rock, along small creek; 2290 m.

RANUNCULACEAE

Caltha biflora DC. var. biflora, marshmarigold--occasional to frequent in moist sites associated with Phyllodoce empetriformis, and along seepage areas; 1890 m.

Ranunculus verecundus Robins. (L235), modest buttercup--occasional plant found at only one location, along a rocky seepage area, just above the north lakeshore; 2065 m.

ROSACEAE

Luetkea pectinata (Pursh) Kuntze., partridgefoot--occasional to abundant throughout area (2010-2320 m); on talus and rocky sites in areas of seepage or soil development, commonly found in heather communities dominated by Cassiope mertensiana var. mertensiana, Phyllodoce empetriformis, P. glanduliflora, and in moist sedge meadows with Carex spectabilis and C. nigricans.

Potentilla flabellifolia Hook., fanleaf cinquefoil--occasional in moss mats of community dominated by Phyllodoce empetriformis and Carex spectabilis (2010 m); also found on moderately steep talus slope in sites of soil accumulation, associated with P. glanduliflora and P. empetriformis (2230 m).

Potentilla fruticosa L., shrubby cinquefoil--locally abundant and important dominant in communities on stabilized talus slope in areas of soil accumulation and early season snowmelt, also found in seepage sites and fell-fields (2100-2260 m); an important associate in Phyllodoce glanduliflora communities on talus slopes, common in drier sites of Carex spectabilis meadows, and scattered on talus with Epilobium latifolium.

Potentilla villosa Pall. var. parviflora Hitchc. (L216), villous cinquefoil--rare in lake basin, a few plants found at two locations: rocky site with soil development below large rock outcrop, associated with Salix cascadensis and Poa alpina; and on rock wall of north aspect on east rim of lake, associated with Cassiope tetragona var. saximontana; 2070 m.

Sibbaldia procumbens L., creeping Sibbaldia--occasional in moist sites from 2070 to 2160 m; seepage on talus, base of large rock outcrop, and in community dominated by Cassiope mertensiana var. mertensiana and Phyllodoce empetriformis, sometimes forming extensive mats.

SALICACEAE

Salix cascadensis Cockerell (L274), Cascade willow--locally abundant, forming extensive mats in rocky sites, and important in stabilizing soil of rock slopes (2070-2130 m); moist areas of rock outcrops, fell-field, and rockier sites on fringe of Phyllodoce glanduliflora community.

Salix nivalis Hook. var. nivalis (L275), snow willow--locally abundant, forming extensive mats in rocky sites (2070-2230 m); talus--fringe of seepage or sites of soil accumulation; fell-field--common in rockier and more exposed sites than inhabited by Empetrum nigrum, and rocky sites on periphery of Phyllodoce glanduliflora community.

SAXIFRAGACEAE

Leptarrhena pyrolifolia (D. Don) R. Br., leatherleaf saxifrage--occasional plant in moist, mossy sites along seepage; 1860 m.

Mitella pentandra Hook. (L229), alpine mitrewort--occasional plant in seepage along creek, associated with Cassiope mertensiana var. mertensiana and Phyllodoce empetriformis; 1830 m.

Parnassia fimbriata Konig. var. fimbriata, fringed grass-of-parnassus--occasional plant in seepage sites along creek, associated with Mimulus tilingii var. caespitosus; 1830 m.

Saxifraga bronchialis L. var. austromontana (Wieg.) Jones, spotted saxifrage--occasional to frequent plant in rockier sites of fell-field, and rock cliff, east rim of lake; 2070-2100 m.

Saxifraga debilis Engelm. (L230), pygmy saxifrage--rare, restricted to outwash area of inlet stream, found in moist, mossy sites of glacial silt and scree.

Saxifraga ferruginea Grah. var. macounii Engl. & Irmsch., rusty saxifrage--abundant in seepage areas on talus slopes, moss ledges, and moist sites of rock outcrops; 2010-2100 m.

Saxifraga oppositifolia L., purple saxifrage--rare, only a few plants found on terraces of rock cliff near west end of lake; 2070 m.

Saxifraga punctata L. var. cascadensis (Calder & Savile) Hitchc. (L276), dotted saxifrage--occasional plant in moist sites on rock cliff, also on moss mats, associated with Phyllodoce empetriformis and Carex spectabilis; 1890-2070 m.

Saxifraga tolmiei T. & G. var. tolmiei, alpine saxifrage--frequent to abundant in seepage sites on talus, rock faces, moss mats, and glacial silt and scree at lake inlet; 1890-2130 m.

SCROPHULARIACEAE

Castilleja parviflora Bong. var. albida (Pennell) Ownbey, small-flowered paintbrush--occasional plant in moist subalpine areas, associated with Phyllodoce empetriformis and Carex spectabilis; 1890 m.

Castilleja rupicola Piper, cliff paintbrush--infrequent in rocky sites of lake basin (2070-2160 m); fell-field on east rim, rock ledges and cliffs above north shore of lake; more common on higher talus slope in vegetation mats, occasional in Phyllodoce glanduliflora community.

Mimulus tilingii Regel var. caespitosus (Greene) Grant, large mountain monkeyflower--occasional in seepage sites along creek, associated with Parnassia fimbriata var. fimbriata; 1830 m.

Penstemon davidsonii Greene var. menziesii (Keck) Cronq., Davidson's penstemon--occasional to frequent in rocky sites, fell-field, rock faces, and lake inlet; 2070-2260 m.

Penstemon procerus Dougl. var. tolmiei (Hook.) Cronq., small-flowered penstemon--occasional plant in areas of stability on talus slope (2230-2320 m); associated with Carex spectabilis or Phyllodoce glanduliflora; also occurs in heather community dominated by P. empetriformis and P. glanduliflora (2010 m).

Veronica wormskjoldii Roem. & Schult., alpine speedwell--frequent in certain locations along seepage and creeks, and on talus slope in communities of *Phyllodoce glanduliflora* and *P. empetriformis*; 2010-2260 m.

VALERIANACEAE

Valeriana sitchensis Bong., Sitka valerian--occasional in moist sites along creek below 1860 m.

Acknowledgments

I gratefully acknowledge the logistic support of the North Cascades National Park Service, along with Robert Wasem and Jonathan Bjorklund, whose assistance enabled me to conduct this botanical survey. I also thank Dr. Ronald J. Taylor who helped verify difficult taxa.

English Equivalents

1 hectare (ha) = 2.471 acres
1 meter (m) = 3.281 feet
1 kilometer (km) = 0.621 mile

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Pacific Northwest Forest and Range
Experiment Station
809 N.E. Sixth Avenue
P.O. Box 3890
Portland, Oregon 97208

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Pacific Northwest Forest and Range Experiment Station

Research Note PNW-411
April 1984

Effect of Lauricidin and Ethylenediaminetetraacetic Acid on Growth of Nine Hymenomycetous Fungi

C. Y. Li and Paul E. Aho

Abstract

Growth of nine wood-decaying basidiomycetes was measured on media containing 10, 100, and 1,000 parts per million (p/m) Lauricidin with or without 0.1 percent ethylenediaminetetraacetic acid (EDTA). EDTA alone significantly reduced the growth of all fungi tested. Lauricidin at 1,000 p/m significantly retarded the growth of all fungi except two: *Ganoderma applanatum* and *Armillariella mellea*. The addition of EDTA to 1,000 p/m Lauricidin completely inhibited *Echinodontium tinctorium, Fomitopsis officinalis*, and *Perenniporia subacida*. These compounds show promise as constituents of tree-wound dressings.

Keywords: Decay fungi (wood), lipids, fatty acids, wounds, tree injury.

Introduction

Lauricidin[1/] is the trade name of monolaurin with more than 90-percent monoester attached to the first glycerol hydroxyl group. This compound has shown remarkably high activity against oral streptococci and actinomycetes and has been incorporated into products used to prevent dental caries in humans (Kabara and others 1978). In vitro growth of *Heterobasidion annosum* (Fr.) Bref. and *Phellinus weirii* (Murr.) Gilb. was inhibited by Lauricidin (Li and Kabara 1978). A preliminary field test indicated that Lauricidin applied on stump surfaces of western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) could prevent colonization by *H. annosum* (Nelson and Li 1980).

[1/] Lauricidin is a compound available from Med-Chem Laboratories, Monroe, Michigan. Trade names are included for information only and do not imply endorsement by the U. S. Department of Agriculture.

C. Y. LI is microbiologist and PAUL E. AHO is research plant pathologist, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, Oregon 97331.

Intensive forest management usually requires repeated stand entries with logging equipment. Aho and others (1983) have shown that up to 50 percent or more of the residual (crop) trees were injured during thinning in young true fir stands in northern California. About 14 percent of the board-foot volume of the wounded trees was lost to decay after only 13 years. Wounds on trees in recreation and urban areas may lead to extensive decay and tree failure, resulting in property damage and injury or death to people.

Recent studies have shown that commonly used wound dressings do not prevent invasion by bacteria and fungi that cause discoloration and decay (Shigo and Wilson 1977). Shigo and Wilson (1971) suggested that an effective dressing should protect wounds not only from invasion by decay fungi, but also from the bacteria and nondecay fungi that are often the pioneer invaders of exposed wood and contribute to discoloration and decay. Because Lauricidin is relatively inexpensive, is not toxic to animals and higher plants, and inhibits both bacteria and fungi, it is a potential component of tree-wound dressings. We tested the inhibitory effects of Lauricidin alone and combined with EDTA in vitro on nine hymenomycetous fungi. EDTA was added because it increases the solubility of Lauricidin and the permeability of microbial cells to Lauricidin (Shibasaki and Kato 1978).

Materials and Methods

The fungi used in this experiment were *Armillariella mellea* (Fr.) Karst., *Coniophora puteana* (Fr.) Karst., *Echinodontium tinctorium* E. and E., *Fomitopsis pinicola* (Fr.) Karst., *F. officinalis* (Vill. ex Fr.) Bond. et Sing., *Ganoderma applanatum* (Pers. ex Wallr.) Pat., *G. tsugae* Murr., *Phellinus pini* (Fr.) Pilát, and *Perenniporia subacida* (Pk.) Donk. Cultures of these fungi were provided by the Center for Mycology Research, Forest Products Laboratory, Madison, Wisconsin. Cultures had been maintained on malt or potato dextrose agar since 1968. Inocula of the fungi obtained were from colonies grown on malt agar in petri plates at 25 °C until they reached 25 to 30 mm in diameter.

Lauricidin was added to malt agar and malt agar containing 0.1 percent EDTA to give concentrations of 10, 100, and 1,000 p/m. Controls were malt agar and malt agar containing 0.1 percent EDTA. The media were autoclaved at 15 lb pressure for 15 minutes, then adjusted to pH 5.4 with sterile 0.1 N NaOH. Petri dishes, 90 mm in diameter, were filled with 20 ml of medium. Four replicate plates were inoculated with *F. officinalis, G. applanatum, G. tsugae*, and *Phellinus pini*; five replicate plates were inoculated with *C. puteana, E. tinctorium, F. pinicola*, and *Perenniporia subacida*. Radial growth of *A. mellea* mycelia was difficult to measure because irregularly shaped colonies developed. We therefore measured the dry-weight gain of *A. mellea* after growing it in tubes 25 mm outside diameter x 200 mm, each containing 80 ml of medium. A plug of inoculum 4 mm in diameter was taken from the edge of colonies of each fungus and inverted in the center of each agar plate or tube. Inoculated plates and tubes were incubated at room temperature (22 to 24 °C). Because of variations in growth rate, radial mycelial growth was measured at three intervals: 12 days for *C. puteana, F. pinicola* and *Perenniporia subacida*; 27 days for *Phellinus pini, F. officinalis, G. applanatum* and *G. tsugae*; and 37 days for *E. tinctorium.* Dry weight of *A. mellea* colonies was determined after incubation for 26 days. Colonies were removed from warm agar, washed in water, and ovendried at 80 °C for 48 hours.

The experiment had a completely random factorial design. Unfortunately, some of the fungi grew quickly to the maximum size permitted by the petri dishes; thus, potential growth beyond this size was unknown. Data for these cultures were eliminated from the analyses. A one-way analysis of variance was used for the unbalanced data. The remaining fungi were analyzed in the prescribed manner. Individual differences in both formats were analyzed using Tukey's multiple comparison technique.

Results and Discussion

The effects of Lauricidin and EDTA on radial mycelial growth are shown in figure 1. Growth of *C. puteana, F. pinicola*, and *Perrenniporia subacida* on media with 10 p/m Lauricidin was significantly lower than for controls, and growth was further significantly decreased on concentrations of 100 and 1,000 p/m. Growth of *F. officinalis* in 10 p/m Lauricidin did not differ significantly from the control but was significantly less on 100 and 1,000 p/m than on controls or 10 p/m Lauricidin. *Ganoderma applanatum, G. tsugae*, and *Phellinus pini* on 1,000 p/m Lauricidin grew significantly less than on controls and on 10 and 100 p/m Lauricidin. Growth of *Echinodontium tinctorium* did not differ on 10, 100, and 1,000 p/m Lauricidin. Except for *P. pini* at 1,000 p/m Lauricidin combined with EDTA, the other Lauricidin-EDTA combinations significantly decreased growth of all fungi compared to Lauricidin alone. Lauricidin at 1,000 p/m plus EDTA significantly reduced mycelial growth of *F. pinicola* and *G. applanatum*, and completely inhibited the growth of *E. tinctorium, F. officinalis*, and *Perenniporia subacida*. *Ganoderma tsugae* failed to grow on media with EDTA or EDTA-Lauricidin combinations. EDTA alone significantly reduced the growth of all fungi. Lauricidin alone, however, increased the growth of *A. mellea*.

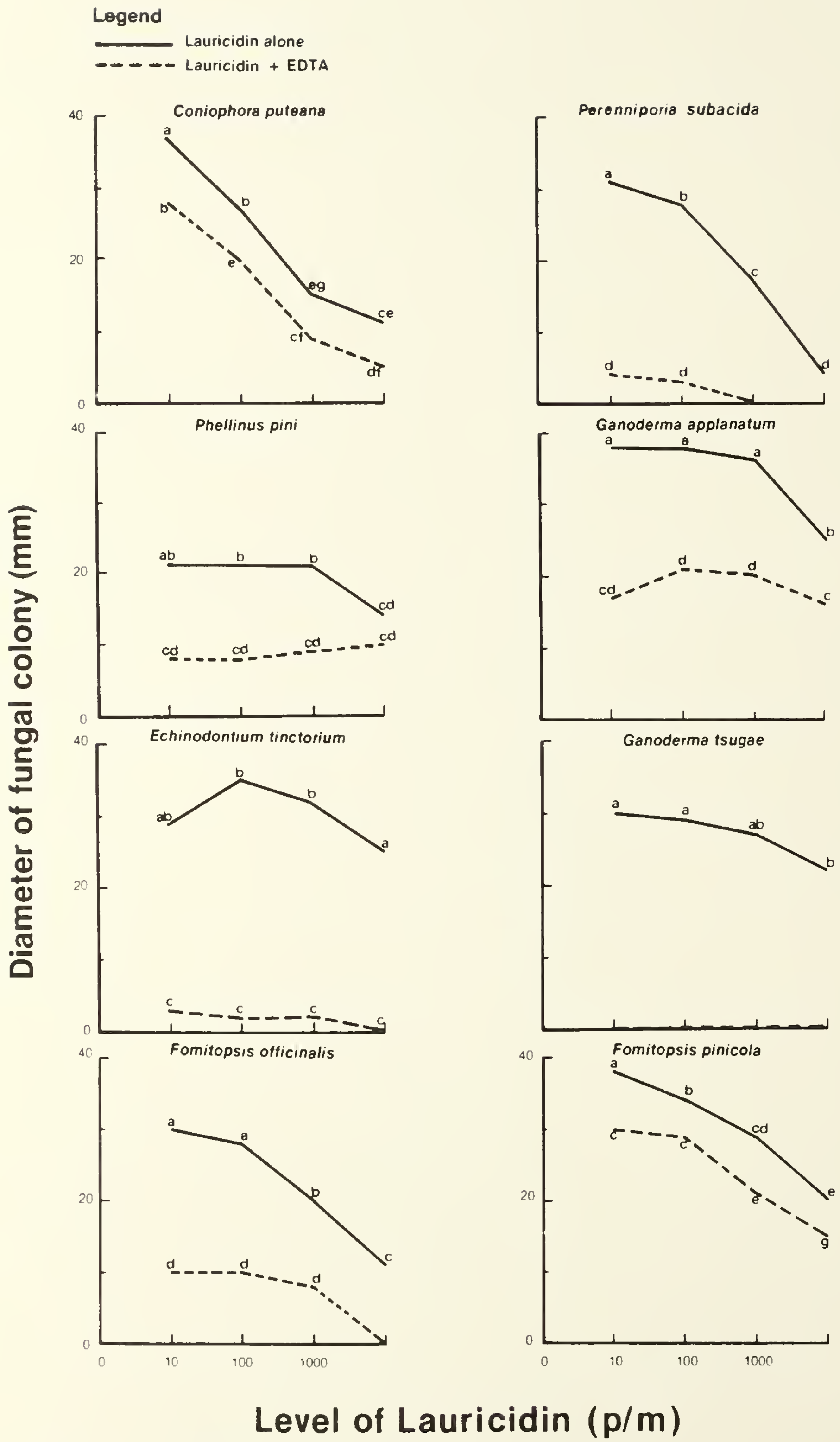

Figure 1. Effect of Lauricidin and EDTA on mycelial growth of eight hymenomycetous fungi. Means not sharing a common letter significantly differ at the 95-percent confidence level with the Tukey test.

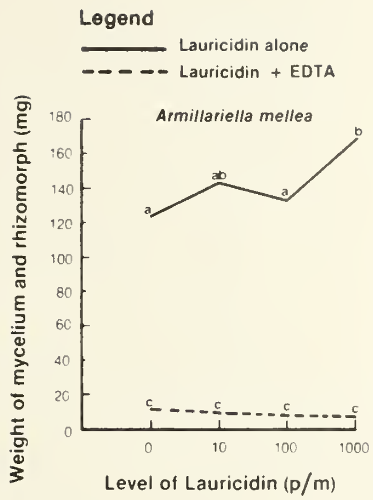

Figure 2.--Effect of Lauricidin and EDTA on growth of Armillariella mellea. Means differ significantly at the 95-percent confidence level with the Tukey test.

These data indicate that EDTA enhances the antifungal activity of Lauricidin on *C. puteana, E. tinctorium, F. pinicola, F. officinalis* and *Perenniporia subacida*, as was shown for *Phellinus weirii* and *Heterobasidion annosum* in earlier studies (Li and Kabara 1978). EDTA either inhibited or reduced fungal growth. The mechanism by which these compounds inhibit growth of fungi is unknown. Shibasaki and Kato (1978) reported that bacterial cells treated with EDTA released lipopolysaccharides from the outer cell membrane, allowing monolaurin to penetrate easily into the inner membrane, a primary site for its antibacterial action. Some wood-destroying fungi were reportedly inhibited by metal-complexing agents, such as EDTA, because essential elements are not available for metal-requiring fungal enzymes (Highley 1975, Mandels and Reese 1963). Bohne (1973) reported that chelation of metal elements by EDTA can inhibit deoxyribonucleic acid synthesis.

Our study indicates that growth of most test fungi was reduced significantly, and four were completely inhibited by one or more of the treatments. Two important invaders of tree wounds, *G. applanatum* and *F. pinicola*, are the least affected by Lauricidin and EDTA. Their growth was unaffected or only delayed. Malt agar is an excellent growth medium for these fungi, however, and the size and type of inoculum used is probably more effective than that found under natural conditions.

Lauricidin and EDTA show promise for interfering with the growth of decay fungi. These compounds may also effectively inhibit germination of basidiospores on the surface of wounds (Nelson and Li 1980). Further testing in combination with other chemicals or at higher concentrations is necessary, however, to establish these compounds as attractive alternatives to the use of petrochemicals in forest or urban environments. Field tests on wounds are also needed to establish what works in practice.

Metric Equivalents

1 millimeter (mm) = 0.039 inch
1 millimeter (mm) = 0.001056 quart (U.S. liquid)

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Experiment Station
319 S.W. Pine St.
P.O. Box 3890
Portland, Oregon 97208

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Research Note
PNW-412
May 1984

Foliar Nitrogen Content and Tree Growth After Prescribed Fire in Ponderosa Pine

J. D. Landsberg, P. H. Cochran,
M. M. Finck, and R. E. Martin

Abstract

This initial study of prescribed burning in ponderosa pine *(Pinus ponderosa* Dougl. ex Laws.) stands in central Oregon showed that all periodic annual growth increments were reduced for trees alive four growing seasons later. Height growth was reduced 8 percent in areas burned by fires with moderate fuel consumption and 18 percent in areas with high fuel consumption. Basal area growth was reduced 16 percent in the moderate fuel consumption areas and 28 percent in the high fuel consumption areas; volume growth declined 23 percent at both levels of fuel consumption.

Foliar nitrogen (N) concentration was not affected by the prescribed fires; however, total foliar N content was reduced immediately after burning, and it remained depressed four growing seasons later after the burned areas had recovered from crown scorch. Foliar N content was significantly correlated with the observed reductions in periodic annual increments. Prescribed fire needs additional evaluation for a longer period and in additional ponderosa pine communities to determine long-term effects.

Keywords: Prescribed burning, fire effects, foliar analysis, increment (height), increment (basal area), increment (volume), ponderosa pine, *Pinus ponderosa*.

Introduction

The use of prescribed fire as a silvicultural tool has been questioned because of the potential loss of volatile nutrients from the site, especially nitrogen (N), and the subsequent effect of lower N content—less tree growth. A linear relationship between foliar N concentration and growth in forest-grown trees has been demonstrated (Leyton 1954, Leyton and Armson 1955, Wright 1959).

Research shows that the N content of the duff layer of a soil in western Washington was reduced to 33 percent of the original value by a severe fire (Isaac and Hopkins 1937). Laboratory experiments by Knight (1966) indicated a 25- to 64-percent loss of N from the forest floor at temperatures of 575 to 1300 °F. A loss of 10 to 30 percent of the N in the forest floor was produced by light surface burning in central Oregon ponderosa pine *(Pinus ponderosa* Dougl. ex Laws.) (Nissley 1978). DeBell and Ralston (1970) found that 62 percent

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J. D. LANDSBERG is a research chemist, P. H. COCHRAN is a soil scientist, and M. M. FINCK is a physical science technician at the Silviculture Laboratory, Pacific Northwest Forest and Range Experiment Station, 1027 N.W. Trenton Avenue, Bend, Oregon 97701. R. E. MARTIN was a research forester at the Silviculture Laboratory at the time of this study. He is now Professor, Wildland Fire Management, Department of Forestry and Resource Management, University of California, Berkeley, California 94702.

of the N contained in pine litter and leaf materials was released by burning, and a major portion was volatilized as N_2 gas. Fire, which volatilizes N, has the short-term effect of increasing N stress in fire-dominated ecosystems (Raison 1979, Vitousek and others 1982). These losses of N through fire could be expected to reduce tree growth.

Second-growth ponderosa pine covers a large area of central Oregon. These stands were established after railroad logging of the area in the 1920's, and they have developed during a period of fire exclusion. Prescribed fire is now being implemented as a silvicultural option for reducing fuel and fire hazard, stimulating nutrient release, increasing forage production, and improving wildlife habitat. Questions remain concerning the effect of prescribed fire on tree stem growth in ponderosa pine.

Objectives

This study investigated the effects of prescribed fire on foliar N concentration and content and on tree growth in central Oregon ponderosa pine. Prescribed fires at two levels of fuel consumption and a no-burn control were established. Specific objectives were to determine changes in fuel load, duff depth, foliar N concentration and content, and stem growth with treatment.

Methods

Research Location

The study site is representative of natural regeneration, second-growth ponderosa pine stands found over large areas of central Oregon. The community type is ponderosa pine/bitterbrush/needlegrass *(P. ponderosa/Purshia tridentata* (Pursh) Oc./*Stipa occidentalis* Thurb. ex Wats.). Community type designation is CP-S2-12 (Volland 1982).

The site is 10 miles south of Bend near Lava Butte in the Fort Rock District of the Deschutes National Forest. The research area covers 42 acres at an elevation of 4,750 feet and has less than 2 percent slope to the north and west. The area receives about 20 inches of precipitation annually, mainly as snow; summers are normally hot and dry.

The stand is on a Typic Cryorthent (Shanahan- and Klawhop-like series) soil developing on Mazama pumice and ash. A sandy loam A1 horizon 2 inches thick and a sandy loam AC horizon 22 inches thick overlie older buried material. The stand was precommercially thinned in 1961, and the thinning slash was not treated before burning. Average dead and down woody fuel load ranged from 12.2 to 17.8 tons per acre and the duff layer from 2.5 to 4.6 inches in depth.[1]

Site index of the area is 108 feet (100-year basis) (Barrett 1978). When the study was installed in the spring of 1979, the stand had a basal area of 124 square feet per acre on 240 stems. The quadratic mean diameter (diameter of tree of average basal area) was 9.7 inches, and the stand age at breast height was 45 years. The average height was 54 feet, and the average live crown ratio was 0.68.

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[1] In this paper dead and down woody fuel refers to the stems, branches, and twigs lying above the continuous duff layers (organic horizons 01 and 02).

Treatments

This research was designed to test the effect of prescribed fire at two levels of fuel consumption on foliar N concentration and content and on growth of tree stems. The three treatments were: (1) a prescribed burn with high fuel consumption, (2) a prescribed burn with moderate fuel consumption, and (3) a no-burn control. Each treatment was applied twice. The moderate fuel consumption burns were prescribed to remove 80 percent of the dead and down woody fuel less than or equal to 1 inch in diameter and to leave 50 percent of the duff and woody fuel greater than or equal to 3 inches in diameter. The high fuel consumption burns were prescribed to remove 85 percent of all dead and down woody fuel and duff. Before each prescribed fire, a small test area was burned to assure that consumption was within the limits of the objectives.

The 42-acre area was divided into six units of 4.0 to 11.9 acres each. Each treatment was randomly assigned to two units. Each unit contained four to six 1/5-acre plots surrounded by a half-chain buffer strip. The plots were selected to be representative of the area and to provide a treatment response for each unit.

Statistical Design

The statistical design was completely randomized with the successive dates of foliage sampling treated as a split plot in time and crown position treated as a split plot in space. Periodic annual basal area and volume growth were analyzed by analysis of variance for unequal sample size (Steel and Torrie 1960a). Analysis of covariance for basal area and volume growth was rejected because of a lack of correlation between initial basal area and subsequent increments. Height growth, foliar N concentration and content, and crown biomass were also analyzed by analysis of variance. The whole plot experimental errors in these analyses have only a few degrees of freedom; therefore, differences in means must be substantial to be significantly different. Tukey's *w*-procedure was used to isolate differences among treatment means (Steel and Torrie 1960b). The level of significance is 5 percent unless otherwise given.

Measurement

The diameter of all trees was measured to the nearest 0.1 inch. On each 1/5-acre plot, 12 to 15 trees were measured with optical dendrometers so a volume table could be constructed for that plot. These trees encompassed the range of size on each plot but were selected to sample a higher proportion of the larger trees since larger trees have the most volume. Height of the remaining trees was measured to the nearest 0.5 foot.

Volumes (V) for trees not measured with a dendrometer were calculated by use of diameters (d) and heights (h) from equations of the form,

$$\ln V = a + b (\ln d) + c (\ln h);$$

where ln is the symbol for natural logarithms. The constant a and coefficients b and c were determined separately for each plot by fitting a stepwise regression to the values for the trees measured with a dendrometer. Measurements were made before the start of the first growing season. Four growing seasons later, the same trees were remeasured with optical dendrometers. All remaining trees were measured for diameter and height, and volumes were calculated from new volume equations for each plot by the above procedure. Periodic annual height, basal area, and volume growth were determined from differences in height, basal area, and volume based on trees that were alive when the second measurements were made.

Dead and down woody fuel loads were measured by size class with the planar intersect technique (Brown 1974). Before and after burning, the duff depth at 12 points and four 49-foot planar intersect lines were measured on each plot.

During the burns, samples for moisture content were collected hourly from the dead and down fuel classes at locations within the treatment areas. These samples were sealed in metal cans and weighed immediately after transport to the laboratory. Samples were then dried to constant weight at 160 °F, and moisture levels were calculated as percent dry weight. Average moisture for the duff layers is given in table 1.

Flame characteristics were observed at 5- to 10-minute intervals, and weather conditions were recorded every 30 minutes during the burning period (table 2).

Table 1—Average duff moisture and standard deviation during prescribed burns in ponderosa pine in central Oregon

Treatment	Date	Upper duff	Lower duff
		Percent	
Moderate fuel consumption:			
1st burn	May 15, 1979	23.5 ± 21.6	63.8 ± 46.9
2d burn	May 16, 1979	13.0 ± 6.8	20.3 ± 2.1
High fuel consumption:			
1st burn	June 12, 1979	8.6 ± 2.6	11.4 ± 2.7
2d burn	June 12, 1979	11.3 ± 1.9	9.4 ± 1.2

Table 2—Weather and fire behavior during prescribed burns in ponderosa pine in central Oregon

Treatment	Temperature	Relative humidity	Wind-speed[1]	Flame length	Flame height	Rate of spread
	°F	*Percent*	*Miles per hour*	*Inches*	*Inches*	*Feet per minute*
Moderate fuel consumption:						
1st burn	72-47	33-74	0-7	12	9	2.0
2d burn	59-45	38-67	0-8	22	18	4.6
High fuel consumption:						
1st burn	51-46	53-67	2-7	24	16	2.0
2d burn	40-36	50-84	0-3	41	31	1.0

[1]Measured 4.5 feet above the ground.

Samples for foliar N analysis were obtained from one dominant or codominant tree on each plot. Foliage was sampled from the upper, middle, and lower crowns. A composite sample across all needle ages was obtained from each crown section to access changes within the entire crown. Samples were taken at about 3-week intervals during the first and second growing seasons and once at the end of the fourth growing season after burning. Foliar N concentration was determined in duplicate on 1979 and 1980 foliage by semimicro Kjeldahl procedure (American Society of Agronomy 1965) on air-dry samples ground in a Wiley mill to pass through a 40-mesh sieve.[2] The Kjeldahl procedure was not modified to include nitrate or nitrite because these forms were not found in measurable amounts in these samples. The 1982 samples were analyzed by a lithium sulfate-hydrogen peroxide-sulfuric acid digestion procedure (Parkinson and Allen 1975), followed by segmented flow colorimetry on a Technicon AutoAnalyzer II (1978).

Needle mass and N content of the foliage were calculated for the first growing season after the fire (Landsberg and Cochran 1980). Those calculations were repeated at the end of the fourth growing season with new measurements for height, diameter, height to live crown, and foliar N concentration.

Results and Discussion

Woody Fuel Consumption

Dead and down woody fuel was significantly reduced in both burn treatments (table 3). Reductions in woody fuel averaged 34 and 37 percent for the two moderate fuel consumption units; a mean fuel load of 7.9 tons/acre remained after the fire. The high fuel consumption units had much greater fuel reductions; 68 and 70 percent of all dead and down woody fuel was consumed, leaving an average fuel load of 4.7 tons/acre.

Table 3—Woody fuel load, depth of duff, and standard deviation before prescribed burning and average reduction after burning in ponderosa pine in central Oregon

	Woody fuel load		Depth of duff	
Treatment	Before burning	Reduction after burning	Before burning	Reduction after burning
	Tons per acre	*Percent*	*Inches*	*Percent*
Control	17.8 ± 3.7	—	4.6 ± 0.9	—
Moderate fuel consumption	12.2 ± 7.0	35	2.5 ± .7	49
High fuel consumption	15.0 ± 5.8	69	3.9 ± 1.6	88

[2]Mention of trade names does not imply endorsement by the U.S. Department of Agriculture.

Duff Consumption

Duff consumption ranged from 28 to 68 percent in the moderate fuel consumption burns, and from 76 to 93 percent in the high fuel consumption burns. Duff depths after burning were 0.6 to 1.7 inches for the moderate fuel consumption units and 0.3 to 0.8 inch for the high fuel consumption units. These reductions and depths were significantly different ($P \leq 0.01$).

Moisture content of lower duff on the moderate fuel consumption plots was 20 to 68 percent, and the reductions we obtained were similar to the 42-percent reduction in surface and ground fuels obtained by Sackett (1980) while burning in ponderosa pine stands at night with a duff moisture of 28 percent. In contrast, lower duff moisture content on the high fuel consumption units averaged 9 and 11 percent, and reductions were comparable to those obtained in other studies. Sackett (1980) obtained a reduction of 63 percent in surface and ground fuels when ground fuels averaged 10 to 19 percent moisture. Harrington (1981) obtained needle and humus reductions of 33 to 77 percent in open and closed ponderosa pine canopies with lower duff moistures of 21 to 88 percent.

Reductions of all dead and down fuels, including duff, were close to the objectives set forth in the study plan.

Foliar Nitrogen Concentration

There were no differences in foliar N concentration among the control, the moderate fuel consumption areas, and the high fuel consumption areas during the study period. If there had been changes in the amount or availability of N to the trees, changes would be expected in foliar N levels (van den Driessche 1974). Generally, foliar N concentrations were low, falling to 0.8 percent during needle elongation and rising to 1.2 percent at the end of the growing seasons. These concentrations of foliar N during needle elongation are below the critical level of 0.9 percent (Powers 1980), but they are uniform throughout the treatment areas. If the different needle ages had been analyzed separately, subtle differences might have been detected. For this research, however, composite sampling of all needle ages was used to access changes within the entire crown.

Significant differences were found in foliar N concentration for both crown position and date of sampling (table 4). Generally, lower crown foliage was expected to have lower concentrations of N. This was true in 1979 ($P \leq 0.01$). In 1980, however, the N concentration in each position was significantly different from that in every other crown position ($P \leq 0.01$); the midcrown foliage had the lowest concentration. In 1982, there were no significant differences in foliar N concentration with crown position.

A composite curve and its equation giving foliar N concentration in the midcrown on the sampling date were developed earlier (Landsberg and Cochran 1980). That curve and a curve developed from 1980 midcrown samples are shown in figure 1. Because there was no significant difference with treatment, all treatments were pooled; however, there could be differences that are not apparent because of the limited number of degrees of freedom. The curves are similar in form, and they show the rapid decline in foliar N concentrations that occurs concurrently with bud burst and needle elongation, and an increase in N toward the end of the growing season.

Table 4—Foliar nitrogen concentration by date and crown position[1] in ponderosa pine in central Oregon

Date	Upper crown	Midcrown	Lower crown
		Weight percent	
1979:			
May 7	1.04 a	1.01 a	0.89 b
June 5	—	.83 a	.95 b
June 20	.89 a	.92 a	.84 b
July 5	—	.86 a	.97 b
July 27	.98 a	1.02 a	.87 b
August 10	.97 a	1.02 a	.84 b
September 20	—	1.15 a	1.11 b
1980:			
May 20	1.05 c	.97 d	.99 e
June 19	.99 c	.89 d	.94 e
July 23	1.06 c	.92 d	.97 e
August 14	1.05 c	.94 d	1.01 e
September 17	1.04 c	.99 d	1.01 e
1982:			
October 6	1.09 f	1.08 f	1.06 f

[1]Crown positions with different letters are significantly different ($P \leq 0.01$) from other crown positions within that year.

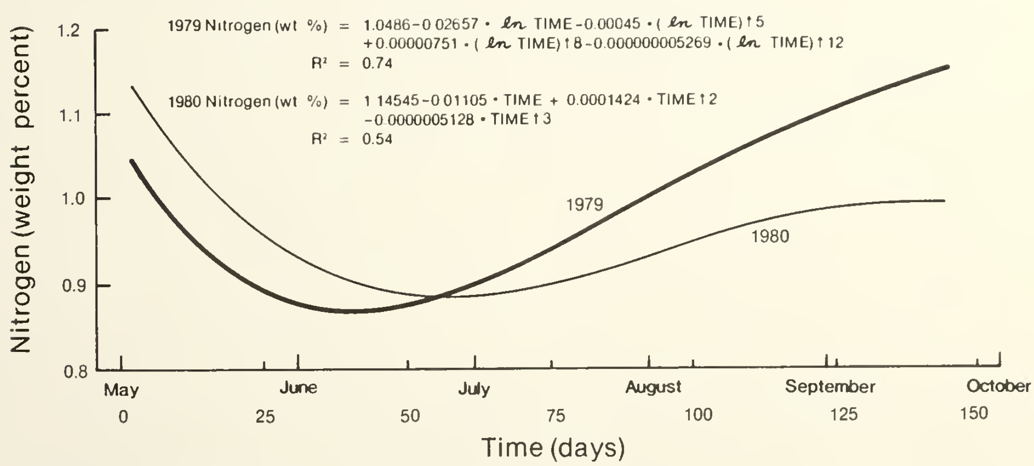

Figure 1.—Midcrown foliar nitrogen concentrations in 1979 and 1980.

Foliar Nitrogen Content

Landsberg and Cochran (1980) reported 4- and 20-percent reductions in crown needle mass in the moderate fuel consumption and high fuel consumption areas, respectively, because of crown scorch. This reduction in lower crown would be similar to that caused by pruning. Dahms (1954), Gordon (1959), and Barrett (1968) found no effect of pruning in ponderosa pine when less than 25 percent of the live crown was removed. Therefore, this reduction in lower crown caused by scorching probably would not affect tree growth to any great extent.

At the end of the fourth growing season, however, there was still significantly less needle mass in the burned areas (table 5). A small part of this may be a residual effect of crown scorch in the high fuel consumption units, but height growth in the moderate fuel consumption units would have increased the crown ratio to the preburn value. This loss of needle mass produced a concomitant reduction in foliar N content. Foliar N content was reduced 14 percent in the moderate fuel consumption area and 33 percent in the high fuel consumption area. Foliar needle mass and foliar N content four growing seasons after burning both correlate with postburn reductions in duff depth (fig. 2).

Table 5—Needle mass and nitrogen content of ponderosa pine foliage at end of 1st and 4th growing seasons after prescribed burning, central Oregon

Treatment	Needle mass		Foliar nitrogen	
	First growing season	Fourth growing season	First growing season	Fourth growing season
	Pounds per acre			
Control	8,800	9,600	96	105
Moderate fuel consumption	8,500	8,600	94	90
High fuel consumption	7,100	6,500	79	70

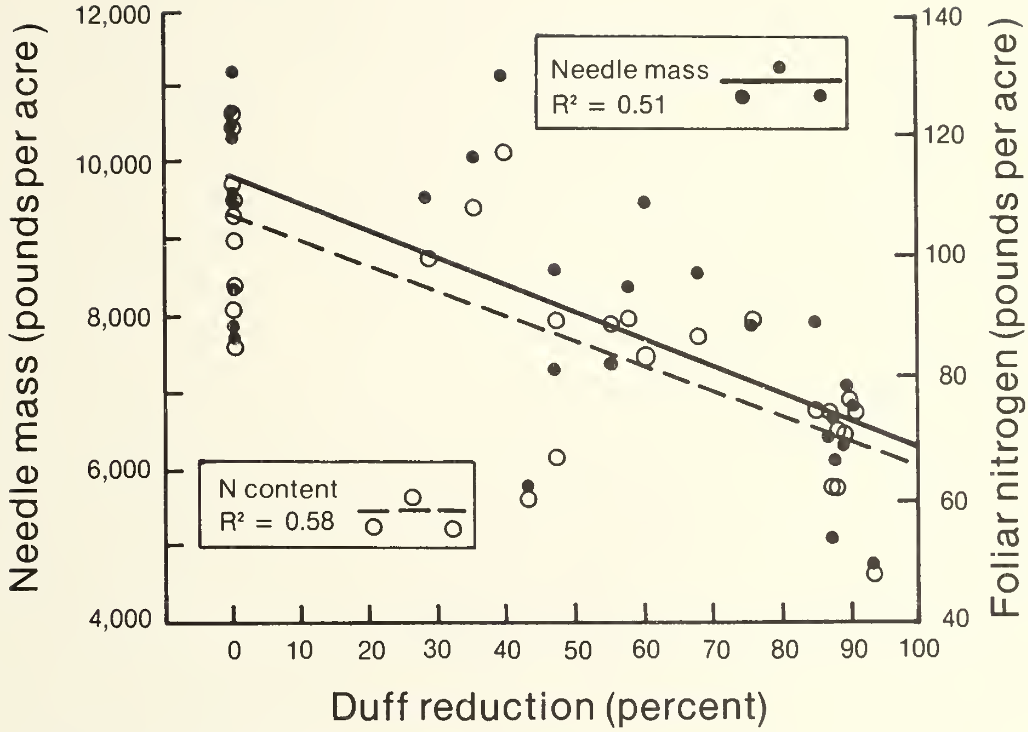

Figure 2.—Foliar needle mass and foliar nitrogen content four growing seasons after burning correlate with duff reduction.

Growth and Yield

A significant ($P \leq 0.10$) reduction was found in all periodic annual growth increments: height, basal area, and volume (table 6). Height growth was depressed 8 percent in the moderate fuel consumption area and 18 percent in the high fuel consumption area for trees alive four growing seasons after burning. Basal area growth was reduced by 16 percent in the moderate fuel consumption area and 28 percent in the high fuel consumption area, and volume growth was reduced by

Table 6—Periodic annual increments for ponderosa pine over 4 growing seasons, central Oregon

Treatment	Height growth	Basal area growth per acre	Volume growth per acre
	Feet	*Square feet*	*Cubic feet*
Control	1.2	3.2	117
Moderate fuel consumption	1.1	2.7	91
High fuel consumption	1.0	2.3	91

23 percent in both areas. Periodic annual increments are significantly correlated with reductions in duff depth (fig. 3) and with reductions in foliar N content (fig. 4). As duff depth was reduced, periodic annual increments declined; and as foliar N content declined, periodic annual increments were reduced. Reduction of duff depth and the concomitant reduction of foliar N content play a part in the reduction of periodic annual increments. The volume growth reduction in the moderate fuel consumption area is the same as that in the high fuel consumption area.

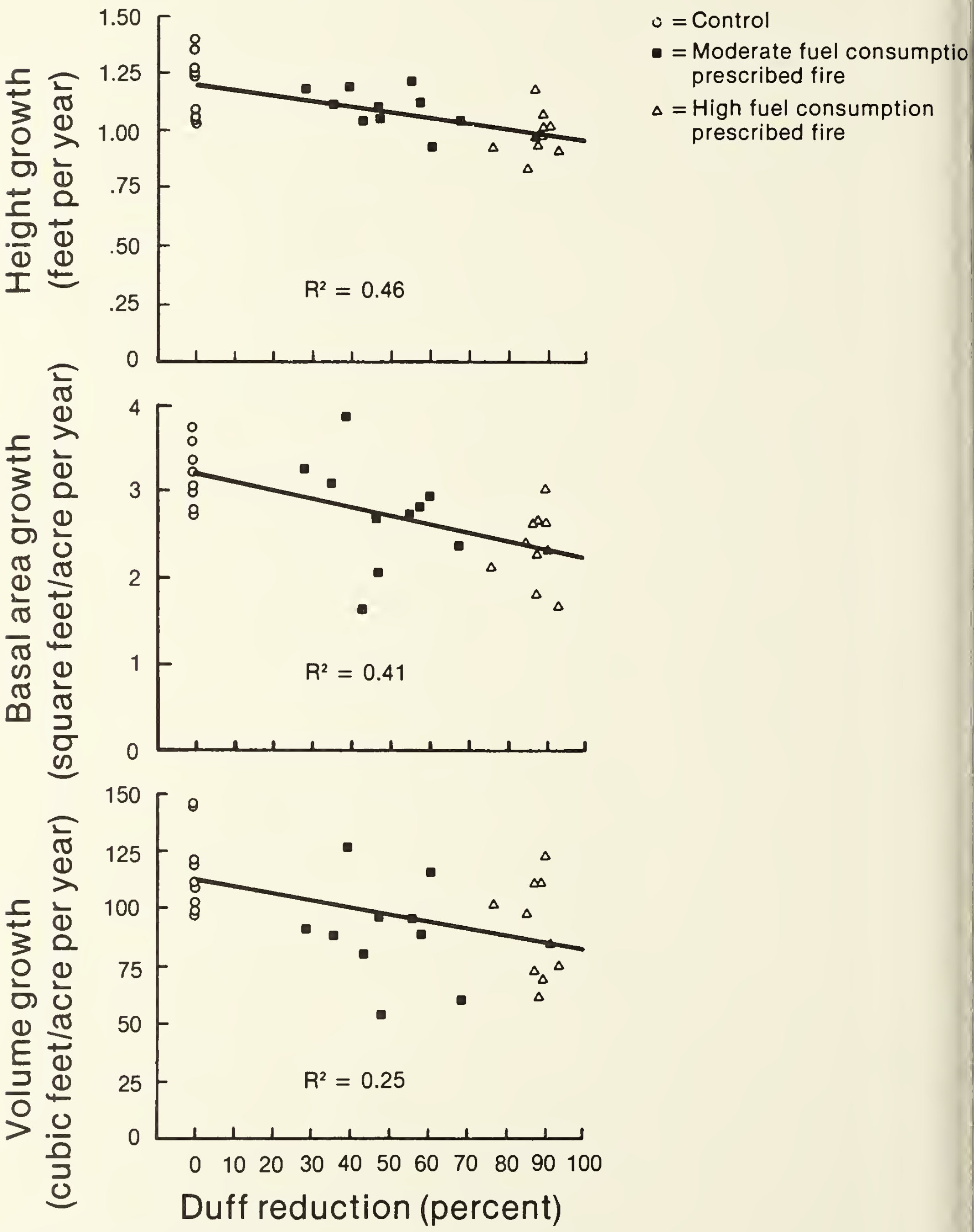

Figure 3.—Periodic annual growth in height, basal area, and volume were reduced four growing seasons after burning as duff reduction increased.

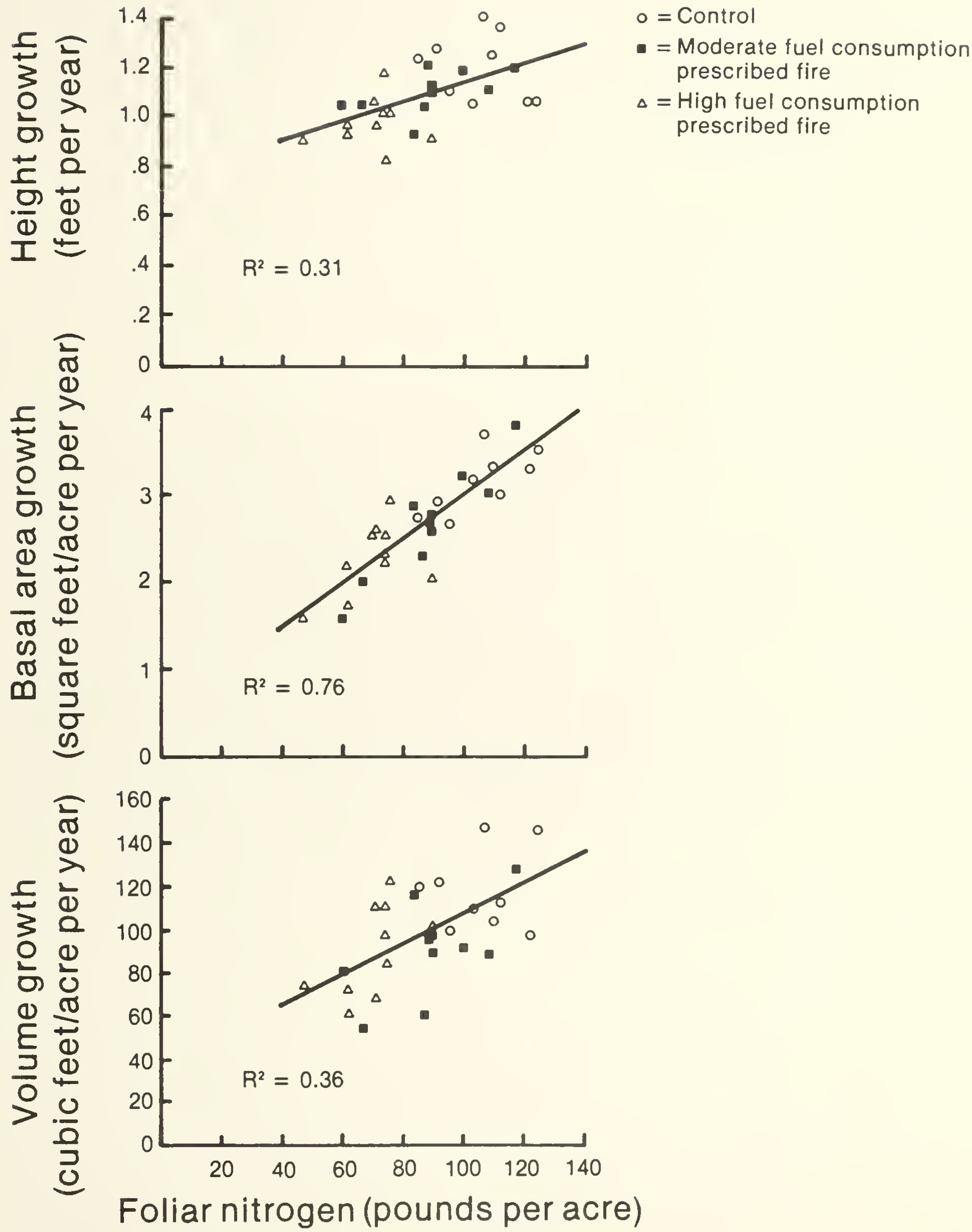

Figure 4.—Periodic annual growth in height, basal area, and volume correlates with foliar nitrogen content four growing seasons after burning

Other research on the effects of prescribed fire on growth of ponderosa pine has produced conflicting results. Some researchers have reported increases in growth with burning; others have found reductions as we did. Lynch (1959) found reductions in diameter growth of 30 to 50 percent in trees that had 50 percent crown scorch after burning, but height growth was not affected.

In contrast, increases in both height and diameter growth were found in northeast Washington ponderosa pine six growing seasons after burning that produced 46 percent crown scorch (Morris and Mowat 1958). The diameter growth of trees on burned areas exceeded that on unburned areas by 36 percent after six growing seasons when results were adjusted to initial diameter through analysis of covariance, whereas the height growth on burned areas exceeded that on unburned areas by 7 percent.

The results of Morris and Mowat (1958) seem to contradict our results, but the differences may be due to the drastic reduction in competition resulting from their prescribed fires. Their work was done in a ponderosa pine thicket with 2,550 stems/acre before burning and 830 stems/acre six growing seasons later, and the numbers of stems in the unburned areas dropped from 3,260 stems/acre to 2,900 over the 6-year period. Our research area had 240 stems/acre.

Mortality

Mortality at the end of the fourth growing season was 1.1 and 3.7 percent of the initial basal area in the moderate fuel consumption and the high fuel consumption units, respectively. Mortality was a result of burning and was confined to the smaller trees. The area was overstocked so some mortality was acceptable. No mortality occurred on the control plots. Some of the cambium on one side of some trees in the burn units, principally the high fuel consumption units, died. This may produce additional mortality or a reduction in volume in the future.

Conclusions

Two distinct levels of fuel consumption were obtained by prescribed fire. Burning with appropriate fuel moisture conditions produced an average reduction of 35 percent in woody fuel and an average reduction of 49 percent in duff depth in the moderate fuel consumption units, whereas in the high fuel consumption burns the woody fuel load was reduced 69 percent and the duff depth 88 percent.

No differences were found in foliar N concentrations after burning.

Crown needle mass and foliar N content were significantly reduced by the fires and declined to even lower levels four growing seasons later.

Periodic annual growth in height, basal area, and volume was significantly reduced by the prescribed fires.

Prescribed burning needs further evaluation in larger studies conducted over a longer time in a variety of ponderosa pine communities to determine long-term effects on tree growth.

Metric Conversion Factors

°F = (°C × 9/5) + 32
1 mile = 1.61 kilometers
1 acre = 0.405 hectare
1 foot = 0.3048 meter
1 inch = 2.54 centimeters
1 ton/acre = 0.445 tonne/hectare
1 square foot/acre = 0.229568 square meter/hectare
1 cubic foot/acre = 0.069972 cubic meter/hectare
1 chain = 20.1168 meters

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Pacific Northwest Forest and Range
Experiment Station
809 N.E. Sixth Avenue
P.O. Box 3890
Portland, Oregon 97208

United States Department of Agriculture

Forest Service

Pacific Northwest Forest and Range Experiment Station

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Environment and Forest Regeneration in the Illinois Valley Area of Southwestern Oregon

Don Minore, Joseph N. Graham, and Edward W. Murray

Abstract

Multiple regression analyses were used to relate environmental factors to forest regeneration on clearcut and partial cut areas managed by the Bureau of Land Management in the Illinois Valley area southwest of Grants Pass, Oregon. Difficulty of regenerating clearcuttings at elevations between 3,000 and 4,900 feet (914 and 1 494 m) increased with increases in soil coarse fragments, solar radiation, and slash burning. Difficulty of regenerating clearcuttings at elevations between 1,500 and 2,900 feet (457 and 884 m) increased as solar radiation, shrub cover, grass cover, and surface rock plus gravel increased. Difficulty of regenerating partial cuts increased as moisture, slope, soil silt plus clay, and density of canopy increased.

Keywords: Regeneration (natural), regeneration (artificial), environment, southwest Oregon.

Introduction

Southwestern Oregon is a diverse region with many climates, soils, and floras that form complex environments and vary by locality. Forest regeneration is a problem throughout the region, but it also varies by locality. Research personnel with the Pacific Northwest Forest and Range Experiment Station have been relating environment to forest regeneration in southwestern Oregon since 1970 by studying relatively small, reasonably coherent portions of the region (Carkin and Minore 1974; Graham and others 1982; Minore and Carkin 1978; Minore and others 1977, 1982; Stein 1981). The Illinois Valley area located southwest of Grants Pass, Oregon, is one of those portions.

Average annual precipitation ranges from 35 to 90 inches (89 to 229 cm) in the Illinois Valley area (Froelich and others 1982), with only 4 to 9 inches (10 to 23 cm) of this precipitation occurring during the dry season of May through September (McNabb and others 1982). Air temperatures monitored at 35 shaded locations in the Illinois Valley ranged from 17 °F (-8 °C) in January to 104 °F (40 °C) in August 1980. Elevations range from 1,000 to 5,500 feet (304 to 1 676 m). A large flora, complex geology, and diverse topography characterize most of southwest Oregon, but the Illinois Valley area is particularly noteworthy for its endemic plant species and serpentine intrusions. Local vegetation and geology are well described by Atzet (1979).

DON MINORE is a plant ecologist at the Forestry Sciences Laboratory, Pacific Northwest Forest and Range Experiment Station, 3200 Jefferson Way, Corvallis, Oregon 97331. JOSEPH N. GRAHAM and EDWARD W. MURRAY were research foresters at the Forestry Sciences Laboratory when the research was conducted.

We studied the Illinois Valley area to derive functional relationships between selected environmental factors and forest regeneration following timber harvest in clearcut and partial cut areas. These relationships were developed for public land managed by the Bureau of Land Management, U.S. Department of the Interior, but they should apply on land of all ownerships in the study area. Our objective was to compare forested sites in terms of relative difficulty of regeneration.

Methods

Clearcuttings

The 62 clearcut units sampled during 1980 were selected to include as many different combinations of aspect and elevation as possible and to provide a good geographic distribution (fig. 1; table 7, appendix). All were 3 to 9 years old and

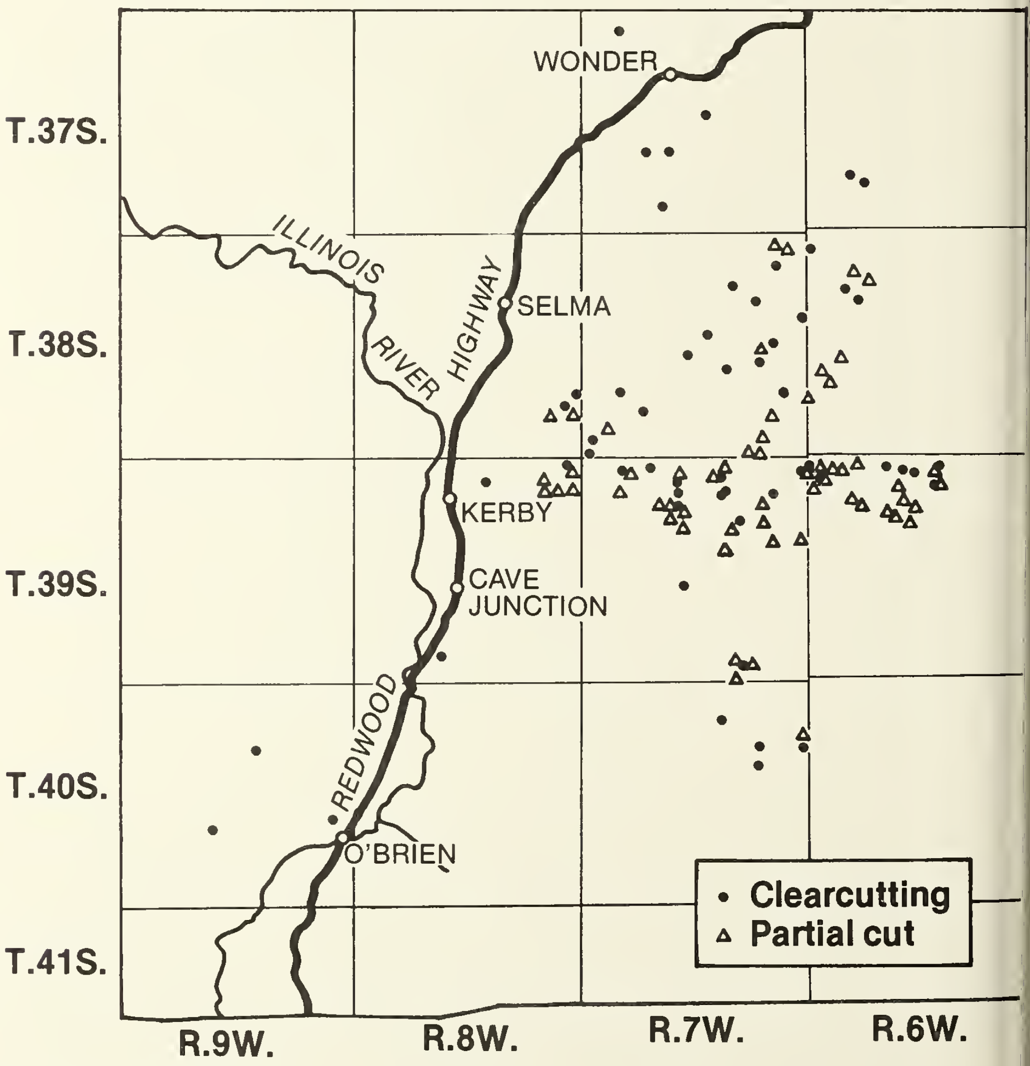

Figure 1.—Study plots in the Illinois Valley area.

had a nearby uncut stand with similar slope, aspect, soil, and elevation to represent preharvest vegetation and environment.[1] A grid of 30 subplots spaced 33 feet (10 m) apart was established on a relatively uniform area in each sample clearcutting.[2] Beginning from a randomly located starting point, we systematically located the equally spaced subplots but did not sample near road fills or edges of adjacent stands. Each subplot consisted of a circle with an area of 1/250 acre (0.0016 ha). Percent slope, degree aspect, number of established postharvest seedlings (by species), and the number of vigorous preharvest seedlings were recorded on each subplot.[3] Subplots supporting one or more established seedlings were considered stocked.[4] Average elevation and the dominant shrub, forb, and grass species were recorded for each clearcut plot. Soil depth was recorded as shallow (less than 20 inches or 50 cm), moderate (20-40 inches or 50-100 cm), or deep (greater than 40 inches or 100 cm).

An uncut stand near each clearcut unit was sampled with 10 subplots spaced 33 feet (10 m) apart. Each subplot consisted of two concentric circles with areas of 1/250 and 1/60 acre (0.0016 and 0.0067 ha). We tallied the number of conifer seedlings less than 4.5 feet (1.4 m) tall, the number of conifer saplings 4 inches (10.2 cm) or less in diameter at breast height, and the percent crown cover of every forb and grass species that occurred on each 1/250-acre (0.0016-ha) circle. Crown cover of every shrub species and understory tree species was recorded for each 1/60-acre (0.0067-ha) circle in the uncut stand. The basal areas of overstory tree species were tallied with a 20-factor prism by diameter class.[5]

Depth of duff, percent cover of surface rock plus gravel on small duff-cleared areas, and percent moss cover were estimated at each of the 10 subplots in the uncut stand. Percent of coarse fragments was estimated in the top 10 inches (25.4 cm) of soil at pits dug on subplots 1, 4, 7, and 10.

Samples of equal volume from a depth of 4 inches (10 cm) in each of the four pits were combined and blended to yield a single soil sample for each plot. All soil samples were air dried immediately and analyzed for cation exchange capacity (ammonium acetate method) and total carbon content (Walkley and Black 1934). Soil texture was determined by using a modified hydrometer technique.

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[1]The uncut stands contained differences no greater than 30 percent in slope, 35° in azimuth, and 200 feet in elevation from the clearcut unit.

[2]Uniform was defined as being within a range of 30 percent for slope and 35° for azimuth.

[3]Seedlings of *Pseudotsuga menziesii* and *Abies* sp. were considered established if they had branched before 1980. Establishment of other conifers was determined by size and vigor.

[4]Stocking percentage was calculated for each plot by dividing the number of stocked subplots by 30 and multiplying the result by 100.

[5]Diameter classes were 4-10 inches (10-27 cm), 11-20 inches (28-52 cm), 21-30 inches (53-77 cm), 31-40 inches (78-103 cm) and 41+ inches (104+ cm).

The percent slope, degree aspect, depth of duff, percent moss cover, and percent cover of surface gravel plus rock recorded on the subplots were averaged to obtain values for each clearcut sample plot. We used average slope, average aspect, and the tables of Frank and Lee (1966) to generate a radiation index for each plot. The optimum aspect for regeneration and indexes for slope-adjusted aspect were computed by using the method described by Stage (1976).[6] Slash burning was included in the multiple regression equation by using dummy variables (1 for burned, 0 for unburned).

Plant indicators of relative regeneration success after clearcutting were selected and weighted by using the method described by Minore and Carkin (1978). These indicators were then used to calculate a clearcut regeneration index for each clearcut sample plot. Plant indicators were also used to calculate moisture indexes for the clearcut plots. Data on moisture stress and species present required to select and weight those plant indicators were obtained on 68 additional plots established in relatively undisturbed stands throughout the Illinois Valley area. Each 1/5-acre (0.08-ha) moisture plot contained at least two Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) saplings between 5 and 10 feet (1.5 and 3.1 m) tall. We used a pressure bomb and the technique described by Waring and Cleary (1967) to measure nocturnal plant moisture stress in those saplings during August 1980.

The clearcut plots were stratified by elevation after preliminary examination of the field data: low elevation (1,500 to 2,900 feet or 457 to 884 m) and high elevation (3,000 to 4,900 feet or 914 to 1 494 m). Stepwise multiple regression was then used with each elevation group to correlate environmental variables and indexes to percent stocking and number of seedlings per acre. We excluded variables with coefficients that were not significant ($P < .05$) in these regression analyses. Multiple regression equations with less than seven variables that accounted for the most variation were used as mathematical models for comparing sites in terms of regeneration after clearcutting.

Partial Cuts

We sampled 56 partial cut stands (fig. 1; table 7, appendix) by using the same selection criteria and subplot design used with the clearcuts. Similar measurements were also made of percent slope, degree aspect, depth of duff, percent cover of surface gravel plus rock, soil texture, and regeneration. Plant species present and soil parameters were assumed to be the same after partial cutting as before logging, however, so data on indicator plants and soil were recorded in the sampled partial cuts rather than in adjacent uncut stands. Species present were recorded on subplots 2, 5, 8, 11, 14, 17, 20, 23, 26, and 29. Soil samples and estimates of percent coarse fragments were obtained from pits on subplots 6, 12, 18, and 24.

Density of canopy, basal area of the residual overstory, and basal area of the preharvest stand (stumps plus standing timber) were recorded for each partial cut subplot. Density of canopy was measured in two ways: we dot-counted the

[6]An optimum aspect was empirically determined from our data on regeneration. Indexes for slope-adjusted aspect were then calculated by using sine and cosine of azimuth and percent slope in a multiple regression equation.

reflected image of the canopy with a spherical densiometer and estimated overhead density of canopy by sighting through a 4- by 2.6-inch (10- by 6.5-cm) tube formed by a 10-3/4-oz. (305-g) soup can. The partial cut plots were stratified by timber type: mixed conifer (true fir regeneration absent or subordinate) and true fir (true fir regeneration predominant). All but seven of the plots occurred in the mixed conifer type, however, and only the mixed conifer plots were subjected to the multiple regression analyses used in correlating environment with regeneration.

Results

Clearcuttings

Stocking of postharvest seedlings ranged from 20 percent to 100 percent on the clearcut sample plots. It was similar in the low and high elevation strata, but more seedlings per acre occurred on the high elevation plots, where regeneration tended to be clumpy.

Major competing species on the low elevation clearcuttings were tanoak (*Lithocarpus densiflorus* (H. & A.) Rehd.), canyon live oak (*Quercus chrysolepis* Liebm.), Pacific madrone (*Arbutus menziesii* Pursh), California black oak (*Quercus kelloggii* Newb.), deerbrush ceanothus (*Ceanothus integerrimus* H. & A.), California hazel (*Corylus cornuta* (DC.) Sharp), poison oak (*Rhus diversiloba* T. & G.), hairy honeysuckle (*Lonicera hispidula* (Lind.) Dougl.), creambush rockspirea (*Holodiscus discolor* (Pursh) Maxim.), box blueberry (*Vaccinium ovatum* Pursh), western bracken fern (*Pteridium aquilinum* var. *pubescens* Underw.), modest whipplea (*Whipplea modesta* Torr.), and fescues (*Festuca* spp. L.).[7] Major competitors on the high elevation clearcuttings included golden chinkapin (*Castanopsis chrysophylla* (Dougl.) A.DC.), vine maple (*Acer circinatum* Pursh), Pacific rhododendron (*Rhododendron macrophyllum* G. Don), Sadler oak (*Quercus sadleriana* R. Br.), huckleberry oak (*Quercus vaccinifolia* Kell.), and manzanitas (*Arctostaphylos* spp. Adans.). Most (81 percent) of the clearcuttings dominated by golden chinkapin, California hazel, Pacific madrone, or bracken fern were adequately stocked with postharvest conifer regeneration. Most (73 percent) of the clearcuttings dominated by deerbrush ceanothus were poorly stocked.

Postharvest regeneration at elevations between 3,000 and 4,900 feet (914 and 1 494 m) increased with increases in the indexes for slope-adjusted aspect listed in table 1. Regeneration decreased as radiation indexes increased on clearcuttings at all elevations. Both of these trends were statistically significant ($P < .05$). Regeneration was best on northerly aspects and poorest on southwestern aspects at all elevations. Postharvest regeneration was positively correlated ($r = 0.33$) with moss cover at elevations between 1,500 and 2,900 feet (457 and 884 m) and negatively correlated ($r = -0.42$) with slash burning at elevations between 3,000 and 4,900 feet (915 and 1 494 m). The clearcut regeneration indexes derived from plant indicator species were also significantly correlated with regeneration when appropriate indicator species and values were used for the high and low elevation plots (tables 2 and 3).

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[7]Nomenclature is according to Garrison and others (1976).

Table 1—Indexes for slope-adjusted aspect for clearcuttings at elevations between 3,000 and 4,900 feet (914 and 1 494 m)[1/]

Aspect azimuth	Percent slope							
	10	20	30	40	50	60	70	80
Degrees								
10	79	83	87	91	95	99	104	108
20	78	81	84	88	91	94	98	101
30	76	79	80	83	84	86	89	90
40	75	75	75	76	76	77	77	78
50	73	72	70	69	68	66	65	64
60	71	69	65	62	59	56	54	50
70	70	65	61	56	52	47	43	38
80	69	63	57	51	45	39	34	28
90	68	61	54	48	40	34	27	20
100	67	59	53	45	38	30	24	16
110	67	59	52	44	37	29	22	14
120	67	59	52	44	37	29	22	14
130	67	60	53	45	38	30	24	16
140	68	60	54	46	39	32	25	18
150	68	60	54	47	40	33	26	19
160	68	60	54	47	40	33	26	19
170	67	60	53	46	39	32	24	17
180	67	59	52	44	36	29	21	14
190	66	58	49	41	33	24	16	8
200	65	56	47	38	29	19	9	0
210	64	54	44	34	24	14	4	-5
220	64	53	41	30	19	9	-1	-12
230	63	51	39	28	16	4	-5	-17
240	63	50	39	26	14	3	-8	-19
250	63	51	39	27	15	3	-7	-19
260	64	52	40	29	18	7	-3	-14
270	64	54	44	34	24	14	4	-4
280	66	58	49	40	32	24	14	6
290	68	61	54	48	42	35	29	22
300	70	66	61	57	53	48	44	39
310	73	70	68	66	64	62	59	58
320	74	74	74	74	74	74	74	74
330	76	79	80	82	84	86	88	89
340	78	81	84	88	91	94	98	101
350	79	83	87	91	95	99	104	108
360	79	84	88	92	97	101	106	110

1/ Index = 74.89 + 0.60(percent slope)(cos azimuth) + 0.17(percent slope)(sin azimuth) + 0.34(percent slope)(cos 2 azimuth) - 0.09(percent slope)(sin 2 azimuth) - 0.50(percent slope). These indexes reflect the relative difficulty of regenerating clearcuts with respect to their slopes and aspects. High values indicate better regeneration than low values.

Table 2—Indicator species and values used in computing regeneration indexes for clearcuttings at elevations between 3,000 and 4,900 feet (914 and 1 494 m)[1]

Species	Indicator value 2/
Clintonia uniflora (Schult.) Kunth	9
Smilacina racemosa Wats.	9
Lonicera hispidula (Lind.) Dougl.	9
Acer circinatum Pursh	8
Rhododendron macrophyllum G. Don	8
Rubus parviflorus Nutt.	8
Vaccinium membranaceum Dougl. ex. Hook.	8
Lilium spp. L.	8
Pyrola spp. L.	8
Trillium spp. L.	8
Veratrum spp.	8
Vaccinium parvifolium Smith	7
Quercus Kelloggii Newb.	2
Arctostaphylos patula Greene	2
Pteridium aquilinum var. *pubescens* Underw.	2
Quercus vaccinifolia Kell.	1
Polystichum munitum (Kaulf.) Presl.	1
Viola spp. L.	1

1/ A regeneration index for clearcuttings may be obtained by averaging the values of all species present in a given uncut stand.
2/ High values indicate better regeneration than low values.

Table 3—Indicator species and values used in computing regeneration indexes for clearcuttings at elevations between 1,500 and 2,900 feet (457 and 884 m)[1]

Species	Indicator value 2/
Erythronium spp. L.	12
Acer circinatum	11
Melica spp. L.	11
Asarum hartwegi Wats.	11
Campanula scouleri Hook. ex A. DC.	11
Disporum hookeri (Torr.) Nicholson	11
Iris spp. L.	11
Montia spp. L.	11
Viola spp. L.	11
Sanicula spp. L.	3
Smilacina spp. Desf.	1

1/ A regeneration index for clearcuttings may be obtained by averaging the values of all species present in a given uncut stand.
2/ High values indicate better regeneration than low values.

Multiple regression analyses with number of seedlings per acre as the dependent variable accounted for more variation than those with percent stocking as the dependent variable, so we used the number of seedlings per acre as a measure of regeneration success for the clearcut plots. Number of seedlings per acre is expressed as the relative number of seedlings (R#S) in the following equations to emphasize the relative, comparative nature of our results.

At elevations between 3,000 and 4,900 feet (914 and 1 494 m):

$$R\#S = 55.4RI - 7.8CF - 241.1B + 11.6S + 11.4A - 366.3; \qquad (1)$$

where:

R#S = relative number of seedlings,
RI = regeneration index (table 2),
CF = percent of soil coarse fragments (top 10 inches or 25.4 cm),
B = slash burning (0 if absent, 1 if present),
S = percent slope,
A = aspect index (table 1);

n = 30,
$R^2 = 0.70$.

During the winter months, when regeneration indexes are more difficult to obtain, a less precise multiple regression equation may be used:

$$R\#S = 11.2S + 14.6A - 10.0CF - 249.7B - 94.7; \qquad (2)$$

n = 30,
$R^2 = 0.66$.

At elevations between 1,500 and 2,900 feet (457 and 884 m):

$$R\#S = 138.3RI + 178.9C + 0.24E - 9.8(R+G) - 19.6G + 5.2M - 920.2; \qquad (3)$$

where:

RI = regeneration index (table 3),
C = percent soil carbon,
E = elevation (in feet),
(R+G) = percent rock plus gravel cover,
G = percent grass cover,
M = percent moss cover;

n = 32,
$R^2 = 0.77$.

If percent soil carbon cannot be determined in the laboratory:

$$R\#S = 108.2RI - 573.3RAD + 214.3DS - 109.6SS - 6.4SH - 39.6G + 75.3; \quad (4)$$

where:
RAD = Radiation index (table 4),
DS = soil more than 40 inches (102 cm) deep (0 if absent, 1 if present),
SS = soil less than 20 inches (51 cm) deep (0 if absent, 1 if present),
SH = shrub cover (in percent);

n = 32,
R^2 = 0.61.

If both percent soil carbon and regeneration index are difficult or impossible to obtain:

$$R\#S = 805.2RAD + 327.5DS - 249.9SS - 6.4SH - 30.4G + 5.4M + 680.9; \quad (5)$$

n = 32,
R^2 = 0.51.

The regeneration indexes, percent soil carbon, and data on rock plus gravel cover, grass cover, moss cover, and shrub cover used in equations (1) through (5) were all collected in relatively undisturbed stands representative of preharvest conditions. Data on preharvest conditions from undisturbed stands will be essential for valid use of those equations.

The relative, imprecise nature of the results from the equations is illustrated by the observed and predicted values shown in table 11, appendix. Exact numbers of seedlings cannot be calculated in advance, but a comparison of regression results from areas to be harvested should be useful in assessing relative difficulty of regeneration in those areas.

Table 4—Radiation indexes for lat. 42° N.

	Aspect								
Slope	N.	S	NNE., NNW.	SSE., SSW.	NE., NW.	SE., SW.	ENE., WNW.	ESE., WSW.	E., W.
Percent									
0	0.4704	0.4704	0.4704	0.4704	0.4704	0.4704	0.4704	0.4704	0.4704
10	.4329	.5039	.4359	.5014	.4442	.4942	.4562	.4833	.4700
20	.3930	.5323	.3994	.5278	.4168	.5148	.4416	.4944	.4689
30	.3524	.5553	.3625	.5492	.3898	.5314	.4271	.5032	.4670
40	.3133	.5728	.3270	.5656	.3640	.5441	.4133	.5096	.4644
50	.2786	.5854	.2943	.5773	.3403	.5531	.4005	.5136	.4611
60	.2496	.5935	.2662	.5849	.3191	.5588	.3887	.5156	.4573
70	.2246	.5981	.2424	.5891	.3006	.5617	.3781	.5158	.4530
80	.2030	.5998	.2219	.5906	.2847	.5624	.3685	.5146	.4484
90	.1839	.5993	.2042	.5901	.2710	.5615	.3599	.5124	.4436
100	.1677	.5972	.1887	.5880	.2593	.5593	.3520	.5094	.4388

Source: Frank and Lee (1966).

Partial Cuts

Most (about 90 percent) of the partial cut plots had been cut once in a three-stage shelterwood system, and they probably had not been harvested with the intent of establishing regeneration. All were cut 3 to 21 years before sampling, and all were on sloping terrain. The only regeneration present was of natural origin.

Stocking of postharvest regeneration ranged from 3 to 100 percent in the 49 partial cut stands sampled in the mixed conifer type. It ranged from 17 to 93 percent in the seven stands sampled in the true fir type. Most (72 percent) of the mixed conifer partial cuts with California black oak, canyon live oak, or tanoak as major stand components were poorly stocked with postharvest conifer regeneration. Most (67 percent) of the partial cuts containing California hazel were well stocked, as were half of the stands with prominent Pacific madrone.

Regeneration after partial cutting in the mixed conifer type increased with increasing percent soil carbon and cation exchange capacity. Regeneration decreased with increasing percent silt plus clay. Postharvest regeneration in the true fir type was positively correlated with depth of duff and the amount of moss cover.

Percent stocking was used as the dependent variable in our multiple regression analyses of the mixed conifer partial cuts. It is expressed as percent relative stocking (RS%) in the best regression equation, which accounted for 58 percent of the total variation:

$$RS\% = 11.35507RI - 4.26223MI - 0.38616S - 0.94832(S+C) + 9.99730DS - 0.54080CA + 53.50416; \quad (6)$$

where:

RS% = percent relative stocking,
RI = regeneration index (table 5),
MI = moisture index (table 6),
S = percent slope,
(S+C) = percent soil silt plus clay,
DS = soil more than 40 inches (102+ cm) deep (0 if absent, 1 if present),
CA = percent overhead canopy;

n = 49,
R^2 = 0.58.

None of the partial cuts included in our analyses had soils less than 20 inches (51 cm) deep, and none were on flat terrain, so equation (6) may not be reliable where very shallow soils occur or where the land is level.

Multiple regression analyses of our limited data on partial cuts in the true fir type were not practical.

Equation (6) does not yield precise results, and it should not be relied upon to provide absolute percentages of partial cut stocking. Its imprecision is illustrated by the observed and predicted values shown in table 12, appendix: predicted values vary from observed values by 12 or less for 51 percent of the plots, but the difference between observed and predicted values exceeds 20 for 18 percent of the sampled partial cuts. Equation (6) does provide estimates that should be useful in comparing areas to be partial cut, however, for the observed and predicted values shown in table 12, appendix, vary similarly when the sample

Table 5—Indicator species and values used in computing regeneration indexes for partial cuts in the mixed conifer type[1]

Species	Indicator value 2/
Rubus parviflorus	16
Cornus nuttallii Aud. ex T. & G.	14
Berberis nervosa Pursh	14
Vaccinium parvifolium	14
Pyrola picta Smith	14
Gaultheria shallon Pursh	13
Lonicera ciliosa (Pursh) DC.	13
Pteridium aquilinum var. pubescens	13
Lithocarpus densiflorus	5
Libocedrus decurrens Torr.	5
Quercus chrysolepis	5
Rhus diversiloba T. & G.	5
Ceanothus integerrimus H. & A.	4
Berberis aquifolium Pursh	4

1/ A regeneration index for partial cuts may be obtained by averaging the values of all species present in a given stand.
2/ High values indicate better regeneration than low values.

Table 6—Indicator species and values used in computing moisture indexes[1]

Species	Indicator value 2/
Rubus spp. L.	23
Castanopsis chrysophylla (Dougl.) A. DC.	21
Berberis nervosa	21
Pyrola spp.	19
Pinus ponderosa Dougl. ex Loud.	5
Rhus diversiloba	4
Quercus Kelloggii	3
Lonicera hispidula	3

1/ A moisture index may be obtained by averaging the values of all species present in a given stand.
2/ High values indicate more moist conditions than low values.

plots are compared. Plots with high predicted values have high observed values, and plots with low predicted values have low observed values.

Regeneration after clearcutting in the Illinois Valley study area was quite good. Only 25 percent of our sampled clearcut plots were less than 60 percent stocked. Poorly stocked plots occurred with equal frequency at elevations below and above 3,000 feet (914 m), but regeneration problems appeared to differ with elevation. Depth of soil, steepness of slope, and percent cover of surface rock plus gravel were the most important environmental variables correlated with regeneration below 3,000 feet (914 m); slash burning was the most important variable between 3,000 and 4,900 feet (914 and 1 494 m). None of the sampled clearcuttings were above 5,000 feet (1 524 m), where data compiled by Wolfson (n.d.) indicate that clearcutting is impractical.

Most of the low elevation clearcuttings with poor regeneration had shallow soils, steeper than average slopes, more than the average amount of surface rock plus gravel, and higher than average radiation indexes. Slash burning was not correlated with regeneration below 3,000 feet (914 m). Aspect did not seem to be important, but this is uncertain because most of the lower elevation clearcuttings occurred on north and east aspects.

Aspect seemed to be important at high elevations, where 82 percent of the clearcuttings with poor regeneration occurred on southerly aspects. Most of the poorly regenerating high elevation clearcuts had been burned. This correlation of slash burning with poor regeneration does not prove that burning caused poor regeneration at high elevations, however, for regression correlations are not appropriate for determining relationships between cause and effect. Some unmeasured variable associated with both burning and regeneration may have been responsible, or an interacting combination of several factors may have had different effects on the burned and unburned clearcut units.

Dense brush cover was more common on the burned clearcuttings than on unburned clearcuttings, and dominance by *Ceanothus* sp. tended to be associated with slash burning at all elevations. Our data and field observations indicate that deerbrush ceanothus, tanoak, canyon live oak, huckleberry oak, and manzanita adversely affected regeneration on clearcuttings. Those species appeared to be less important than the environmental variables found to be correlated with regeneration, but they should be considered whenever clearcutting is planned.

Natural regeneration was adequate but clumpy in most of the partial cut stands sampled. It was poor on many south and southwest aspects and at elevations below 1,800 feet (549 m) in the mixed conifer type, however, especially where slopes were steep. Partial cut regeneration improved on the south and southwest aspects above 1,800 feet as overstory basal area increased, but only the amount of madrone in that overstory seemed to be positively correlated with better regeneration below 1,800 feet. Advance regeneration was not included in deriving our predictive equations. Therefore, the estimates of relative success of regeneration provided by those equations may be quite conservative on sites where preharvest seedlings and saplings exist.

Site preparation, planting techniques, and condition of the planting stock were important factors influencing the clearcut regeneration measured in this study, but they could not be evaluated in our regression analyses. Consequently, these silvicultural variables constitute unmeasured sources of error in our correlations for clearcuttings. The correlations for partial cuts were less affected by unmeasured variables, for the partial cuts were not planted. We assumed that the effects of environment were not obscured by site preparation or planting treatments and that differences in regeneration related to environmental factors were still evident among the plots sampled.

Our results reflect practices in effect 3 to 21 years before the beginning of this study, and modern regeneration techniques or improved planting stock may result in better regeneration than that indicated by our regression equations. If the new technology is applied on all sites, however, the relative differences among areas should not change with improvements in reforestation. Sites with low regression estimates should still be more difficult to regenerate than those with high regression estimates. The regression equations presented here are not intended to serve as precise, absolute indicators of numbers of future seedlings or percentages of stocking. Their purpose is to indicate where special techniques and additional effort should be considered in planning reforestation procedures.

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Appendix

Table 7—Plot summary, Illinois Valley area, southwest Oregon

(Number of plots)

Plot type	Elevation			Aspect				Slope		Soil depth			Soil coarse fragments		Brush cover			Slash burned	Density of overstory canopy		
	<1,500 ft (457 m)	1,500 3,000 ft (457-914 m)	>3,000 ft (914 m)	N	S	E	W	<40%	40%+	<20 in (51 cm)	20-40 in (51-102 cm)	>40 in (102 cm)	<35%	35%+	Sparse	Moderate	Dense		<35%	35-54%	55%+
Clearcut:																					
3,000 ft-(914-m) elevation and above			30	11	5	8	6	9	21	7	10	13	3	27	12	15	3	17	--	--	--
Below 3,000-ft (914-m) elevation	--	32		15	4	11	2	8	24	4	15	13	14	18	10	17	5	14	--	--	--
Partial cut:																					
Mixed conifer	4	40	5	16	11	12	10	15	34	--	21	28	18	31	30	16	3	--	9	28	12
True fir	--	--	7	--	1	4	2	3	4	1	1	5	--	7	4	3	--	--	2	3	2

Table 8—Pertinent data for clearcuttings at elevations between 3,000 and 4,900 feet (914 and 1 494 m), Illinois Valley Area, southwest Oregon[1]

Plot number	Location (T.R.S.)	Elevation	Slope	Aspect azimuth	Aspect index	Regeneration index 2/	Slash burned	Soil coarse fragments 2/
		Feet 3/	Percent	Degrees				Percent
19	38-7-1	3,100	48	78	48	5.60	No	50
21	39-6-19	3,200	45	53	50	6.83	No	70
22	38-7-25	3,250	57	347	97	5.60	Yes	85
27	39-7-11	3,650	55	188	30	4.75	No	46
28	39-7-15	3,200	64	107	27	4.00	Yes	45
30	39-7-9	3,000	54	204	20	2.00	Yes	20
32	39-7-9	3,100	37	308	67	5.40	No	65
34	39-7-9	3,100	45	158	43	1.50	Yes	49
36	39-7-3	3,350	30	350	87	7.00	No	55
39	39-7-11	4,100	54	119	33	4.00	No	54
40	39-7-11	4,300	54	105	34	6.60	Yes	60
41	39-7-13	3,350	36	160	50	7.00	No	20
45	39-6-4	3,650	56	215	15	5.00	Yes	38
46	39-6-9	4,000	61	273	18	4.00	Yes	55
47	39-6-6	4,000	35	360	90	7.14	Yes	84
48	39-6-6	3,750	58	93	34	7.75	Yes	38
49	39-6-3	4,800	41	291	48	8.00	Yes	38
50	39-6-3	4,800	46	321	74	8.00	No	44
51	39-6-9	4,750	42	309	65	6.17	Yes	24
52	39-6-9	4,800	27	351	84	8.50	No	40
53	39-6-9	4,200	38	321	74	8.00	No	51
54	39-6-9	4,100	25	303	66	7.83	No	59
55	39-6-8	4,200	45	17	91	8.13	Yes	59
56	39-6-8	4,100	40	131	46	3.80	Yes	75
57	39-6-6	4,600	56	100	34	2.80	Yes	64
58	39-6-6	4,700	38	16	89	6.86	Yes	61
59	39-6-5	4,000	51	305	64	4.50	No	59
60	39-6-6	4,150	35	325	78	5.50	Yes	66
61	39-6-6	4,600	45	116	40	1.33	No	60
62	39-6-6	4,900	55	102	34	3.33	Yes	64

1/ Variables used in the regression equations.
2/ Data from adjacent undisturbed stands representing preharvest conditions.
3/ To obtain elevation in meters, multiply by 0.3048.

Table 9—Pertinent data for clearcuttings at elevations between 1,500 and 2,900 feet (457 and 884 m), Illinois Valley Area, southwest Oregon[1/]

Plot number	Location (T.R.S.)	Elevation	Radiation index	Regeneration index	Shrub cover 2/	Grass cover 2/	Moss cover 2/	Rock plus gravel cover 2/	Soil carbon 2/	Soil depth class 3/
		Feet 4/			- - - - -	- - - - -	-Percent-	- - - - -	- - - - -	
1	38-7-31	1,500	0.4703	7.14	15	1	26	17	1.06	D
2	39-8-1	1,850	.3491	4.20	8	1	24	51	1.40	S
3	39-7-35	2,650	.2841	6.17	8	5	20	35	1.61	M
4	39-8-1	1,900	.3670	4.20	41	1	12	41	2.22	M
5	39-8-1	2,650	.4678	8.50	2	0	2	31	1.79	D
6	39-8-1	2,750	.5058	5.50	3	2	1	50	1.58	D
7	39-8-1	2,450	.2606	6.71	5	0	4	47	1.82	D
8	39-7-35	2,500	.2491	7.86	2	1	10	49	1.34	M
9	39-7-35	2,900	.2618	6.67	6	4	17	49	1.51	M
10	38-8-25	1,900	.4271	7.25	4	14	3	35	1.20	D
11	38-8-25	1,950	.5138	6.78	8	1	10	40	1.61	M
12	38-6-8	2,400	.2563	7.00	3	1	22	63	1.46	M
13	38-6-8	2,300	.4272	4.83	36	0	1	30	1.62	M
14	39-7-5	2,050	.3503	7.25	68	0	9	60	1.52	D
15	39-7-5	2,450	.5333	6.33	1	0	1	12	1.73	D
16	38-7-35	2,700	.3246	7.83	5	1	24	29	2.07	D
17	38-7-35	2,900	.2821	7.57	2	1	31	67	2.46	M
18	38-7-1	2,800	.2819	5.40	2	1	21	70	3.20	S
20	38-6-19	2,500	.3365	7.75	5	1	15	45	1.37	M
23	38-6-19	2,900	.2706	6.40	7	1	62	73	1.95	M
24	38-7-25	2,800	.3914	5.40	2	1	36	85	2.19	S
25	38-7-25	2,800	.3654	6.00	11	0	52	83	1.34	M
26	28-7-23	2,800	.2667	4.17	1	2	5	50	1.92	S
29	39-7-9	2,800	.5891	1.50	1	1	1	53	1.86	M
31	39-7-9	2,800	.5714	2.50	4	0	1	42	2.54	M
33	38-7-35	2,700	.2389	6.90	3	1	44	21	1.73	D
35	39-7-4	2,550	.2073	5.80	7	0	8	18	1.55	D
37	39-7-3	2,550	.2720	6.14	8	1	24	75	4.86	D
38	39-7-3	2,400	.3162	6.50	12	1	31	52	5.15	D
42	39-7-13	2,600	.5685	7.25	13	0	9	57	2.20	M
43	40-7-12	2,200	.5096	5.40	5	1	13	22	0.58	D
44	40-7-12	2,200	.3573	7.38	14	0	71	39	1.34	M

1/ Variables used in the regression equations.
2/ Data from adjacent undisturbed stands representing preharvest conditions.
3/ D = deep (more than 40 inches or 102 cm); M = moderate (20-40 inches or 51-102 cm); S = shallow (<20 inches or <51 cm).
4/ To obtain elevation in meters, multiply by 0.3048.

Table 10—Pertinent data for partial cuts in the mixed conifer type, Illinois Valley area, southwest Oregon[1]

Plot number	Location (T.R.S.)	Slope	Regeneration index	Moisture index	Overhead canopy	Soil depth class 2/	Silt plus clay cover
		Percent			Percent		Percent
1	38-7-11	19	6.80	9.33	64	D	20
2	39-8-3	50	8.25	9.50	53	D	23
3	38-8-25	52	7.25	7.67	45	M	35
4	38-6-7	60	10.40	8.89	51	M	17
5	38-7-11	28	8.25	7.29	68	D	17
6	38-7-1	53	12.50	9.00	40	D	20
7	38-6-6	46	17.40	11.00	49	D	24
8	38-6-8	70	13.43	11.75	18	M	17
9	38-7-29	57	7.60	7.14	61	D	30
10	38-7-31	38	8.25	6.00	34	M	25
11	39-7-3	46	21.00	12.10	47	D	5
12	39-7-3	58	17.25	10.75	41	M	21
13	38-7-22	74	13.71	9.89	31	M	16
14	38-7-23	60	3.75	7.00	32	M	34
15	38-7-21	39	9.33	6.88	66	D	27
16	39-7-21	23	7.60	6.88	56	M	19
18	40-7-11	19	14.40	10.89	46	D	28
19	39-8-33	10	11.20	7.00	57	D	6
20	40-7-14	27	12.83	6.33	48	D	32
21	37-7-33	37	8.25	8.20	62	M	31
22	40-8-10	40	7.60	9.00	67	D	9
23	39-7-11	51	21.00	12.00	14	M	8
27	39-7-35	71	12.50	8.57	41	M	21
28	38-7-29	58	15.17	9.50	48	M	16
29	38-7-25	61	12.50	9.89	44	M	26
30	39-7-4	48	14.40	9.40	35	D	16
31	39-7-5	51	13.43	7.14	35	D	29
32	40-7-12	25	17.40	9.38	44	D	25
33	38-7-13	15	8.25	6.00	58	M	26
34	38-7-29	32	7.60	6.17	50	D	29
35	40-8-21	25	7.60	10.60	70	D	23
36	38-7-13	66	11.43	10.29	39	M	41
37	39-6-4	44	17.40	13.75	38	D	20
38	37-7-15	46	8.25	7.67	52	D	12
39	37-6-29	58	17.60	11.75	43	D	8
40	37-7-5	50	8.25	7.14	53	D	13
41	38-7-2	68	17.00	9.86	34	D	16
42	37-7-20	56	12.50	9.13	47	M	16
43	39-8-1	54	7.60	7.67	38	M	30
44	37-6-29	54	10.80	9.50	43	M	21
45	37-7-21	46	3.33	6.75	48	M	11
46	38-7-31	39	10.60	10.00	31	D	37
47	39-7-5	58	14.40	9.25	28	D	35
48	39-7-4	79	12.75	11.00	23	M	10
49	40-7-3	44	8.25	4.80	51	M	23
51	39-6-4	13	21.00	12.20	53	D	17
52	40-8-24	56	7.60	5.00	55	D	23
53	38-7-15	48	14.40	9.50	55	D	35
56	38-8-25	50	7.75	6.40	36	M	32

1/ Variables used in the regression equation.
2/ D = deep (more than 40 inches or 102 cm); M = moderate (20-40 inches or 51-102 cm).

Table 11—Observed and predicted values for the number of postharvest seedlings on clearcut plots, Illinois Valley area, southwest Oregon

			Predicted value				
Plot number	Elevation	Observed value	Equation (1)	Equation (2)	Equation (3)	Equation (4)	Equation (5)
	Feet 1/	Number of seedlings per acre 2/					
1	1,500	242	--	--	526	649	643
2	1,850	200	--	--	0	125	198
3	2,650	417	--	--	520	324	357
4	1,900	142	--	--	154	16	156
5	2,650	1,250	--	--	918	925	629
6	2,750	325	--	--	258	491	526
7	2,450	591	--	--	481	833	788
8	2,500	458	--	--	558	725	491
9	2,900	375	--	--	497	449	402
10	1,900	258	--	--	151	250	229
11	1,950	392	--	--	413	416	239
12	2,400	650	--	--	361	624	544
13	2,300	142	--	--	300	116	110
14	2,050	409	--	--	303	433	337
15	2,450	658	--	--	741	658	577
16	2,700	1,250	--	--	1,002	876	814
17	2,900	783	--	--	746	675	578
18	2,800	417	--	--	473	333	274
19	3,100	475	666	649	--	--	--
20	2,500	566	--	--	613	649	28
21	3,200	458	750	683	--	--	--
22	3,250	758	816	874	--	--	--
23	2,900	491	--	--	595	524	724
24	2,800	242	--	--	222	266	267
25	2,800	150	--	--	276	441	598
26	2,800	58	--	--	168	175	176
27	3,650	375	525	500	--	--	--
28	3,200	508	316	317	--	--	--
29	2,800	50	--	--	0	0	175
30	3,000	108	242	399	--	--	--
31	2,800	92	--	--	145	0	200
32	3,100	292	608	633	--	--	--
33	2,700	1,250	--	--	995	833	1,005
34	3,100	125	123	317	--	--	--
35	2,550	317	--	--	637	749	839
36	3,350	1,250	950	974	--	--	--
37	2,550	601	--	--	776	699	837
38	2,400	1,250	--	--	1,107	691	814
39	4,100	475	458	475	--	--	--
40	4,300	200	316	175	--	--	--
41	3,350	1,116	858	849	--	--	--
42	2,600	325	--	--	587	449	188
43	2,200	283	--	--	291	508	606
44	2,200	850	--	--	854	574	688
45	3,650	108	200	133	--	--	--
46	4,000	392	75	21	--	--	--
47	4,000	641	574	533	--	--	--
48	3,750	725	591	433	--	--	--
49	4,800	367	574	449	--	--	--
50	4,800	1,250	1,133	1,091	--	--	--
51	4,750	433	775	841	--	--	--
52	4,800	1,250	1,091	1,074	--	--	--
53	4,200	1,175	991	933	--	--	--
54	4,100	550	650	558	--	--	--
55	4,200	775	950	908	--	--	--
56	4,100	167	12	28	--	--	--
57	4,600	167	92	142	--	--	--
58	4,700	1,250	758	774	--	--	--
59	4,000	641	683	741	--	--	--
60	4,150	150	483	541	--	--	--
61	4,600	317	233	408	--	--	--
62	4,900	192	108	133	--	--	--

1/ To obtain elevation in meters, multiply by 0.3048.
2/ To obtain number of seedlings per hectare, multiply by 2.47105.

Table 12—Observed and predicted values for percent stocking of postharvest seedlings on partial cut plots in the mixed conifer type, Illinois Valley area, southwest Oregon

Plot number	Observed value	Predicted value
	- - - Percent stocking	- - -
1	97	80
2	70	66
3	43	32
4	50	43
5	53	47
6	43	51
7	63	47
8	43	76
9	40	28
10	20	29
11	73	63
12	30	37
13	67	46
14	63	44
15	13	25
16	70	42
18	50	67
19	67	54
20	23	13
21	20	34
22	60	73
23	83	65
27	10	28
28	3	33
29	7	40
30	50	56
31	37	21
32	43	38
33	17	24
34	30	34
35	100	82
36	60	36
37	80	88
38	30	58
39	87	68
40	30	49
41	50	43
42	70	41
43	30	38
44	77	51
45	57	61
46	53	64
47	47	36
48	77	71
49	7	6
51	43	62
52	17	14
53	17	28
56	7	24

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Equations for Total, Wood, and Saw-Log Volume for Thirteen California Hardwoods

Norman H. Pillsbury and Michael L. Kirkley

Abstract

Volume equations for thirteen species of California hardwoods were developed from measurements of 766 sample trees from all parts of the state. The species included: bigleaf maple (*Acer macrophyllum* Pursh), Pacific madrone (*Arbutus menziesii* Pursh), giant chinkapin (*Castanopsis chrysophylla* (Dougl.) A. DC.), tanoak (*Lithocarpus densiflorus* (Hook. & Arn.) Rehd.), coast live oak (*Quercus agrifolia* Née), canyon live oak (*Quercus chrysolepis* Liebm.), blue oak (*Quercus douglasii* Hook. & Arn.), Engelmann oak (*Quercus engelmannii* Greene), Oregon white oak (*Quercus garryana* Dougl. ex Hook), California black oak (*Quercus kelloggii* Newb.), California white oak or valley Oak (*Quercus lobata* Née), interior live oak (*Quercus wislizeni* A. DC.), and California-laurel (*Umbellularia californica* (Hook. & Arn.) Nutt.).

Measurements were taken of standing trees using a Spiegel Relaskop. English and metric equations for three utilization standards were developed for each species: (1) total tree volume (all stem and branch wood plus stump and bark); (2) wood volume (all wood inside bark from stump to 10 cm (4 in) top outside bark); and (3) saw-log volume for trees 28 cm (11 in) diameter at breast height and larger (straight sections from stump to 23 cm (9 in) top outside bark). Diameter and height were found to be good predictors of total volume and wood volume. An indicator variable representing whether or not the first segment was merchantable, in addition to diameter and height, was found to be a good predictor of saw-log volume for eight of the species.

Keywords: Volume equations, volume measurement, hardwoods, California.

NORMAN H. PILLSBURY is head of the Department of Natural Resources Management, School of Agriculture and Natural Resources, California Polytechnic State University, San Luis Obispo, 93407.

MICHAEL L. KIRKLEY is an instructor in forestry at Modesto Junior College, Modesto, California 95350. At the time the research was done he was a graduate research assistant at California Polytechnic State University, San Luis Obispo.

Introduction

There is a vast hardwood resource in California. It is estimated[1] that together all hardwood species occupy 5-6 million hectares (12-15 million acres). Hardwood forest types cover 1.1 million hectares (2.8 million acres) of the 6.6 million hectares (16.3 million acres) of commercial forest lands (excluding parks and wilderness areas) in California. In addition, hardwood trees account for 10 percent or more of the stocking on 1.1 million hectares (2.7 million acres) of commercial conifer types (Bolsinger 1979). In a recent study the gross volume of hardwoods in the hardwood forests and woodlands in four central coast counties alone was estimated at 24.7 million cords or 56 million cubic meters of wood (two billion cubic feet at 80 cubic feet of wood per standard cord) (Pillsbury and Brockhaus 1981). We have estimated that hardwoods amount to about 26 percent of the total wood volume in California's forests (approximately 18 billion cubic feet).

In the past, little has been done to manage native California hardwoods because of the limited market for most hardwood products. The selective cutting of conifers in mixed stands has led to a 34-percent increase in cubic-foot volume of oaks and a 29-percent decrease in conifers since 1953 (Bolsinger 1979).

With the increasing demand for hardwood for fuel, energy, wood fiber, lumber, and noncohsumptive uses such as wildlife, watershed protection, and aesthetics (Asher,[2] Barrett, 1979, Bolsinger 1979, Crail, [3]Smith 1981, Tillman 1978, Verner 1979), information on the distribution and volume of California's hardwoods is needed to manage the resource. Estimates of standing tree volumes are needed to inventory forests for management purposes, forest valuation, and taxation.

Background

Only a few volume equations have been published for native California hardwoods and all have been developed for local or regional use. Existing equations have been reported by several authors: Wiant and Berry (1965)—tanoak; Hornibrook and others (1950)—California black oak, Oregon white oak, Pacific madrone, and tanoak; Pillsbury and Stephens (1978)—coast live oak, blue oak, and tanoak; Harrington and others (1979)—California white oak. Local volume equations have been developed by McDonald (1983) for Pacific madrone, tanoak, and California black oak. Pillsbury and Stephens (1978) developed a methodology to estimate volume in standing trees with multiple stems and irregular forms.

Reliable volume equations already exist for red alder (*Alnus rubra* Bong.), a commercial hardwood in California and the Pacific Northwest (Browne 1962, Curtis and others 1968, Johnson and others 1949, Skinner 1959, Turnbull and others 1963). Volume equations for bigleaf maple also exist, but were developed for use in British Columbia (Browne 1962).

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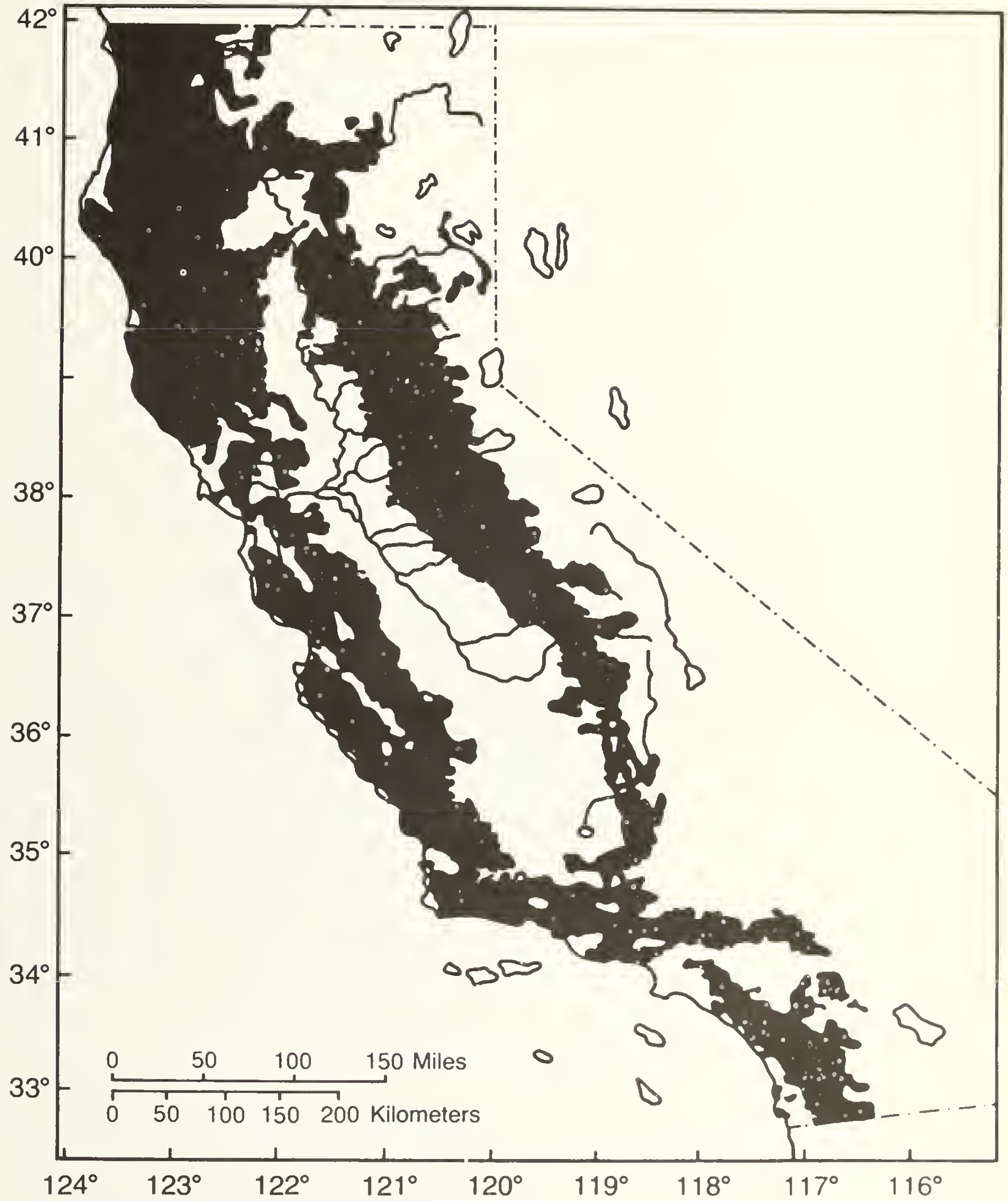
[1] Personal communication, 1982, Charles L. Bolsinger, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

[2] Presentation at the Hardwood Inventory and Utilization workshop, 1982, "Hardwood utilization and marketing in southern California," by James E. Asher, Natural Resources Management Department, California Polytechnic State University, San Luis Obispo.

[3] Presentation at the Hardwood Inventory and Utilization workshop, 1982. "Demand for hardwoods as a raw material for pulping processes," by Miles Crail, Natural Resources Management Department, California Polytechnic State University, San Luis Obispo

Figure 1.—Geographic range of the thirteen hardwood species in California (after Plumb 1979 and Griffin and Critchfield 1972).



None of the equations, except those for red alder, are considered suitable for a statewide forest inventory because of the inconsistency in measurement standards and the possibility that they may be unreliable outside of the area for which they were developed. In this study, volume equations for thirteen major hardwood species were developed (fig. 1) from data collected on sample trees distributed throughout their natural ranges in California. Equations were developed for: (1) total tree volume (all stem and branch wood plus stump and bark); (2) wood volume (wood inside bark from stump to 10 cm (4 in) top outside bark); and (3) saw-log volume for trees 28 cm (11 in) diameter at breast height (d.b.h.) and larger.[4]

[4] All measurements were taken in metric units. English units shown in the text are rounded to the nearest unit.

The species included in this study are:

Scientific name/author	Common name
Acer macrophyllum Pursh	Bigleaf maple
Arbutus menziesii Pursh	Pacific madrone
Castanopsis chrysophylla (Dougl.) A. DC.	Giant chinkapin
Lithocarpus densiflorus (Hook. & Arn.) Rehd.	Tanoak
Quercus agrifolia Née	Coast live oak
Quercus chrysolepis Liebm.	Canyon live oak
Quercus douglasii Hook. & Arn.	Blue oak
Quercus engelmannii Greene	Engelmann oak
Quercus garryana Dougl. ex Hook.	Oregon white oak
Quercus kelloggii Newb.	California black oak
Quercus lobata Née	California white oak (valley oak)
Quercus wislizeni A. DC.	Interior live oak
Umbellularia californica (Hook. & Arn.) Nutt.	California-laurel

Methodology

Utilization Standards and Measured Variables

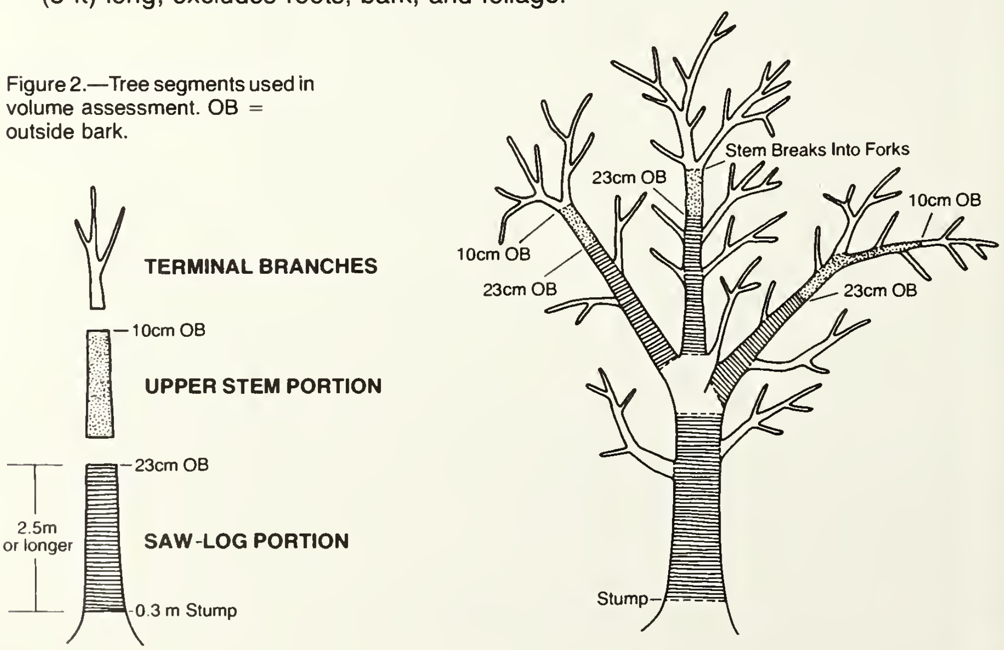
The volume equations developed for each species are expressed in cubic feet and cubic meters for three utilization standards (fig. 2).

1. Total volume: includes all stem and branch wood plus stump and bark; excludes roots and foliage.

2. Wood volume: computed from stump height (0.3 m (1 ft)) to a 10-cm (4-in) top outside bark; excludes roots, bark, and foliage.

3. Saw-log volume: computed for trees 28 cm (11 in) d.b.h. and larger; volume computed from stump height to a 23-cm (9-in) top outside bark for straight sections 2.5 m (8 ft) long; excludes roots, bark, and foliage.

Figure 2.—Tree segments used in volume assessment. OB = outside bark.



Sample Design

Each species was sampled throughout its natural range in California based on maps developed by Griffin and Critchfield (1972). The state was divided into six geographic regions: northern coast, northern interior, central coast, central interior, southern coast, and southern interior.[5] The percentage of trees sampled in each region was proportional to the approximate area each species occupies in the region.

Trees were sampled in areas of varying site qualities, stand densities, and topography. Trees were not sampled east of the Sierra Nevada and Cascade Range because few hardwoods occur there.

A desirable sample size for each species was 60 trees, for a total of approximately 780 trees to be measured statewide for the 13 species studied. Experience has shown that a sample of this size is normally satisfactory for estimating regression coefficients and testing for adequacy of the model for the three utilization standards.

Sample Tree Selection

In sample areas, trees were selected to represent a range of diameters, heights, growth forms, stand structures, and topography. Sound trees 12.7 cm (5 in) in diameter, or larger, at breast height were selected. Decadent trees and trees with major defects were avoided.

Tree and Site Measurements

Sample tree variables measured in the field are summarized in table 1. Total height was measured from ground level to the tip of the tree. Habit class ratings developed by Pillsbury and Stephens (1978) were assigned to each tree sampled (fig. 3). A numerical

[5] Unpublished Master's Thesis, 1982, Michael L. Kirkley, California Polytechnic State University, San Luis Obispo.

Table 1—Summary and measurement description of sample tree variables

Variable	Units	Measurement description
Diameter at breast height	cm	Diameter of main stem at 1.37 meters (4.5 ft) measured to the nearest tenth with a D-tape.
Stump diameter	cm	Diameter of main stem at 0.3 meters (1 ft) measured to the nearest tenth with a D-tape.
Height	m	To the terminal-most leader determined by Relaskop on the uphill side to the nearest tenth.
Single bark thickness	cm	Measured to the nearest tenth at breast height (1.37 m) (4.5 ft) with a ruler.
Habit class	class 1-5	Defined by branching pattern. 1 = conifer-like form; 5 = multi-branching form with many forks (fig. 3).
Stand density	m^2/ha	Cross-sectional area of trees at d b h measured using a Relaskop (basal area factor of 4).
Site quality	class	H = high; M = medium, L = low

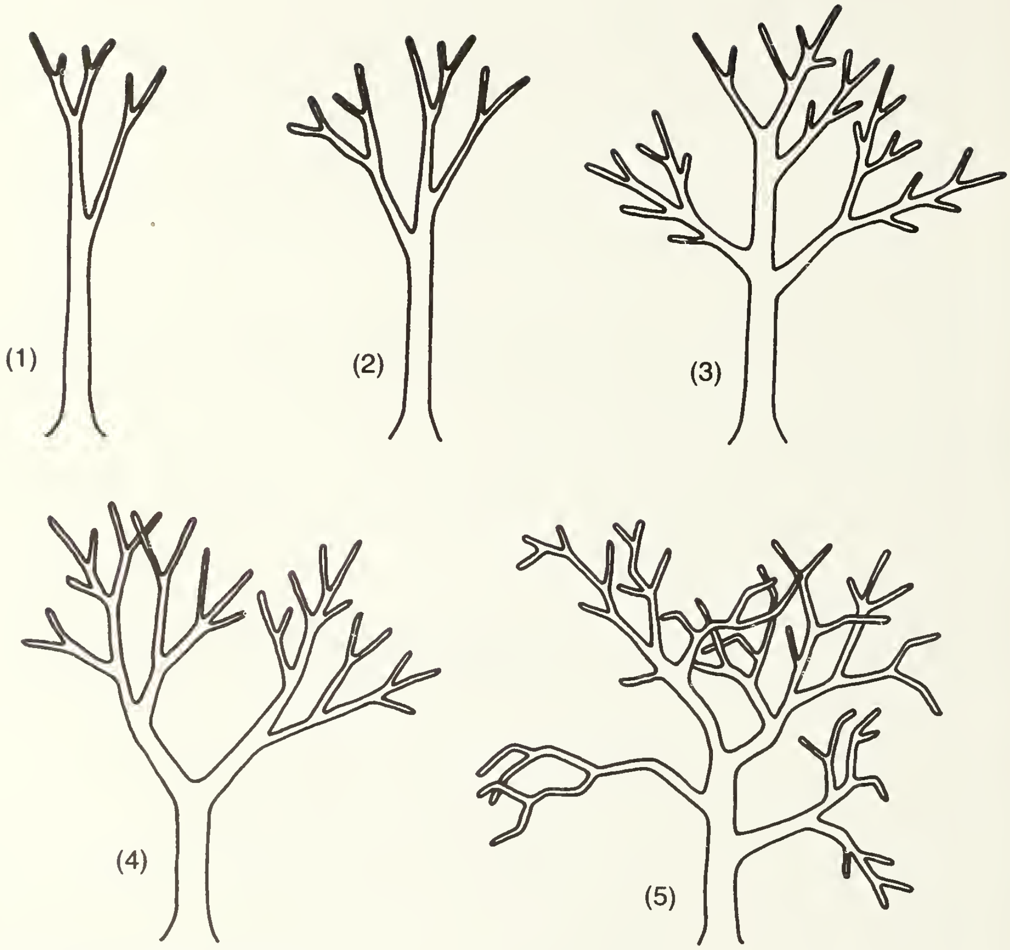


Figure 3.—Five habit classes were used for evaluating tree form and branching complexity (from Pillsbury and Stephens 1978).

rating of one to five was recorded to indicate the complexity of branching: a rating of one indicated an excurrent growth form with one main bole and one or two lateral branches, and a rating of five indicated a deliquescent growth form with complex branching (fig. 3). Stump diameters were measured to compute the volume of the first segment; bark thickness was measured to develop relationships between diameter at inside bark (d.i.b.) and diameter at outside bark (d.o.b.) for computing underbark volume and developing wood and saw-log volume equations.

Basal area per hectare and site quality data were recorded to describe the range of stand densities and sites of the sample trees. In areas with recent logging activity basal area was computed by counting both standing trees and stumps to estimate basal area prior to timber harvesting. Site quality was a subjective rating of high, medium, and low. Stand density, associated vegetation, soil depth, and tree form were used as guides to estimate site quality.

Tree Volume Measurement

For volume measurement, the branching pattern was defined on a segment basis Segment length and the diameters at each end were measured using a Spiegel Relaskop (Dilworth 1981). Segment length was determined from coordinates measured at both ends of each segment. Each tree was divided into segments based on four criteria

1. Segments were defined as the distance from fork to fork in trees with very complex branching pattern such as segment 11, figure 4.

2. If a branch had sweep or crook, segments were meaured to obtain a straight log length such as in segments 3 and 5.

3. Segments were defined if abrupt changes in taper were apparent such as in segments 16 and 17.

4. If a tree had an excurrent growth form the maximum segment length was approximately 3 m (10 ft).

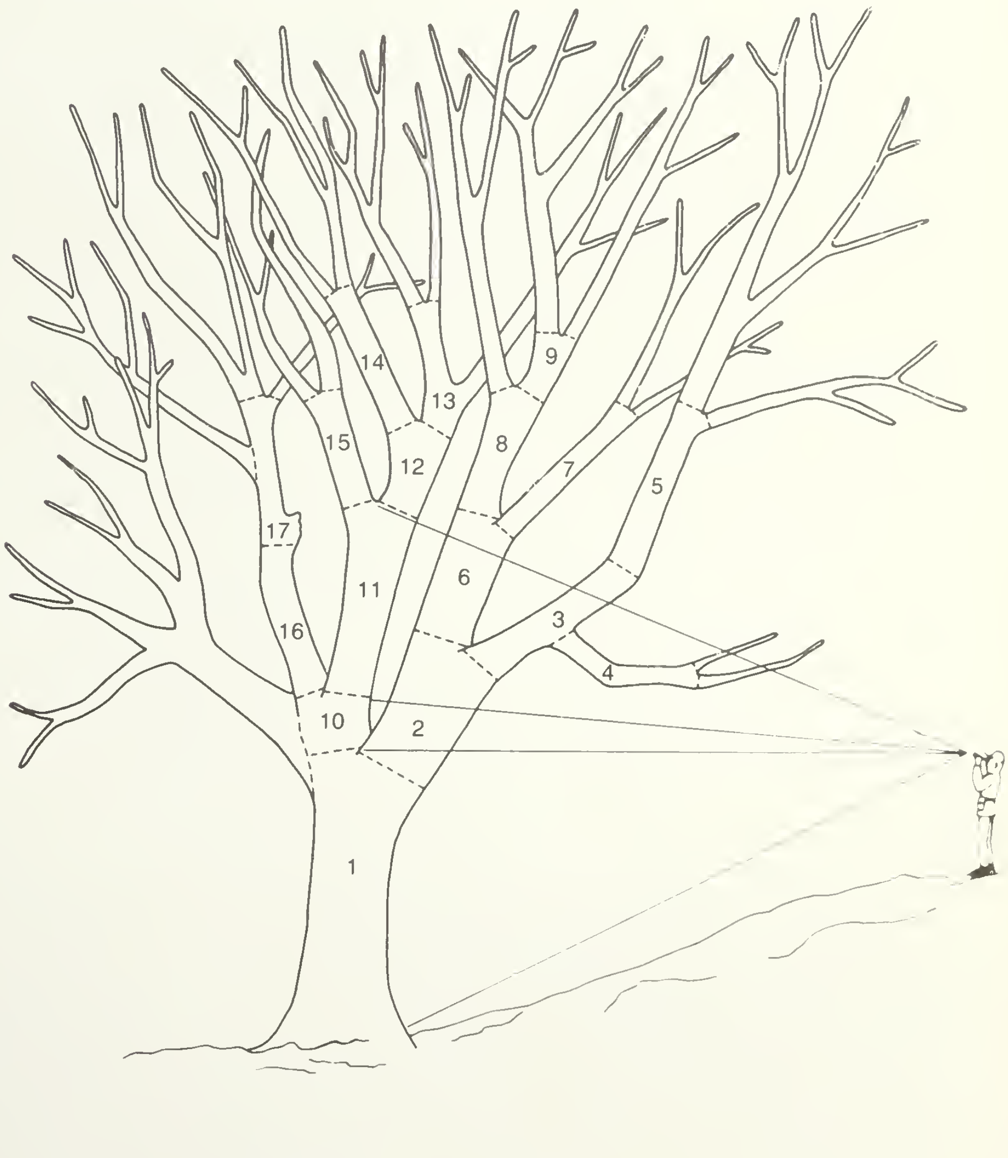


Figure 4.—Tree volumes were calculated from segment lengths and diameters.

Saw-log tree segments had to be at least 2.5 m (8 ft) long, with a small end diameter of 23 cm (9 in). If swelling was present on the stem, diameter measurements were taken slightly above or below the abnormality. Branches not growing vertically were assigned an angle (estimated to the nearest 5 degrees from horizontal) and segment length was calculated. Segments growing less than 30 degrees from horizontal were measured by projecting their length to the ground and measuring with a cloth tape held parallel to the branch angle. Terminal branches were measured from a 10-cm (4-in) diameter to the tip. All terminal branches were tallied and an average length to the nearest 0.5 m (20 in) was recorded.

Computation of Sample Tree Data

Segment volumes were computed from Relaskop coordinate and diameter measurements in cubic meters using Smalian's formula. Segment volumes were summed to obtain gross volume for each tree up to a 10-cm (4-in) top. Terminal branch volume was computed as a paraboloid.

Regression equations estimating d.i.b. from d.o.b. were developed for each species using bark thickness sample data (table 2). With the exception of tanoak, it was assumed that the d.i.b.: d.o.b. ratio remained constant at all heights in upper stem diameters. Previous work by Pillsbury and Stephens (1978) showed that this relationship did not hold with tanoak. A separate study was done to examine how the d.i.b.: d.o.b. ratio changed at increasing heights in tanoak. A sample of 50 trees was measured in Santa Cruz and Monterey Counties. Bark thickness and d.o.b. measurements were made at 0.3 m (1 ft), 1.37 m (4.5 ft), 2.74 m (9 ft), and 5.18 m (17 ft) on standing trees. The results of the study show that the wood tapers more with height than the bark does. A multiple regression equation was developed for tanoak to estimate d.i.b. at any height (DIB_h) using DOB_h and its height above ground (H):

$$DIB_h = -4.36852 + 0.95354\,(DOB_h) + 0.18307\,(H)$$

N = 201 height points on 50 trees; $R^2 = 0.962$; SE = 1.16.

Error and Outlier Analysis

A simple linear regression model using tree basal area times height (volume of a cylinder) to estimate volume was computed and plotted to analyze the data for linearity and detect any outliers. Also, d.b.h. was plotted against both volume and total height, and total height was plotted against volume to detect possible errors in the data sets. This was necessary to guard against compensation errors (for example, a case where basal area is too small and height too large, but basal area times height appears normal).

Extreme values were analyzed using a t-test. Lund's (1975) standardized residuals were computed and compared to tables for an approximate test for outliers. A total of 13 trees out of 779 trees sampled (1.7 percent) was determined to be outliers and were dropped from the analyses.

Table 2—Equations for estimating diameter inside bark based on measured diameter outside bark for 13 California hardwoods

	N	R^2	SE
BIGLEAF MAPLE			
DIB = 0.21235 + 0.94782 (DOB)	61	0.995	0.94
CALIFORNIA BLACK OAK			
DIB = -0.68133 + 0.95767 (DOB)	60	.997	1.20
BLUE OAK			
DIB = -0.44003 + 0.94403 (DOB)	60	.995	.99
CANYON LIVE OAK			
DIB = -0.48584 + 0.96147 (DOB)	57	.996	.81
GIANT CHINKAPIN			
DIB = 0.39534 + 0.90182 (DOB)	60	.986	1.53
COAST LIVE OAK			
DIB = -1.92379 + 0.93475 (DOB)	60	.992	1.47
ENGLEMANN OAK			
DIB = -1.99573 + 0.92472 (DOB)	61	.992	1.23
INTERIOR LIVE OAK			
DIB = 0.12237 + 0.92953 (DOB)	58	.995	1.27
CALIFORNIA-LAUREL			
DIB = -0.32491 + 0.96579 (DOB)	60	.998	.67
PACIFIC MADRONE			
DIB = -0.03425 + 0.98155 (DOB)	60	.999	.46
OREGON WHITE OAK			
DIB = -0.78034 + 0.95956 (DOB)	60	.995	1.19
CALIFORNIA WHITE OAK			
DIB = -0.97254 + 0.93545 (DOB)	60	.995	1.35
TANOAK			
DIB_h = -4.36852 + 0.95354 (DOB_h) + 0.18307 (H)			
N = 201 height points on 50 trees; R^2 = 0.962; SE = 1.16			

SE = Standard error of estimate in cm.
DIB = diameter inside bark (cm).
DOB = diameter outside bark (cm).
DIB_h = diameter inside bark at any height.
DOB_h = diameter outside bark at any height.
H = height above ground.

Analysis

Development of Volume Equations

Multiple regression equations were developed for total, wood, and saw-log volume from sample tree variables. Volume equations were developed for the 13 species in units of cubic feet and cubic meters. A $\log_{10}$ transformation of volume and tree variables was used in developing the regression model to linearize the data and equalize the variation about the regression line.

Total and wood volume equations.—Tree volume was tested as a function of diameter at breast height, total height, stand density, and habit class. Diameter at breast height and total tree height were found to be the best predictors of total volume and wood volume. Stand density and habit class contributed little to the prediction of total and wood volume and were dropped from the model.

Multiple coefficient of determination (R^2) values exceeded 0.92 in all total and wood volume equations, indicating a strong relationship (tables 3 and 4).

Table 3—English equations for total, wood, and saw-log volumes for California hardwoods

Species	Equation	R^2	N	SE
BIGLEAF MAPLE	TVOL = .0101786350 $(DBH^{2.22462})(HT^{0.57561})$	0.944	61	45.4
	WVOL = .0034214162 $(DBH^{2.35347})(HT^{0.69586})$	.924	61	48.4
	SVOL = .0004236332 $(DBH^{2.10316})(HT^{1.08584})(IV^{0.40017})$	.767	26	53.7
CALIFORNIA BLACK OAK	TVOL = .0070538108 $(DBH^{1.97437})(HT^{0.85034})$	.971	59	43.1
	WVOL = .0036795695 $(DBH^{2.12635})(HT^{0.83339})$	.962	60	45.2
	SVOL = .0012478663 $(DBH^{2.68099})(HT^{0.42441})(IV^{0.28385})$	.929	38	47.7
BLUE OAK	TVOL = .0125103008 $(DBH^{2.33089})(HT^{0.46100})$	.971	60	43.0
	WVOL = .0042324071 $(DBH^{2.53987})(HT^{0.50591})$	.970	60	44.1
	SVOL = .0036912408 $(DBH^{1.79732})(HT^{0.83884})(IV^{0.15958})$	.826	32	46.0
CANYON LIVE OAK	TVOL = .0097438611 $(DBH^{2.20527})(HT^{0.61190})$	.978	58	41.8
	WVOL = .0031670596 $(DBH^{2.32519})(HT^{0.74348})$	.980	58	42.0
	* SVOL = .0006540144 $(DBH^{2.24437})(HT^{0.81358})(IV^{0.43381})$	.884	68	48.4
GIANT CHINKAPIN	TVOL = .0120372263 $(DBH^{2.02232})(HT^{0.68638})$	.960	60	44.4
	WVOL = .0055212937 $(DBH^{2.07202})(HT^{0.77467})$	.958	60	45.0
	SVOL = .0018985111 $(DBH^{2.38285})(HT^{0.77105})$	.880	40	46.2
COAST LIVE OAK	TVOL = .0065261029 $(DBH^{2.31958})(HT^{0.62528})$	.968	60	44.1
	WVOL = .0024574847 $(DBH^{2.53284})(HT^{0.60764})$	.971	59	44.1
	* SVOL = .0006540144 $(DBH^{2.24437})(HT^{0.81358})(IV^{0.43381})$	.884	68	48.4
ENGELMANN OAK	TVOL = .0191453191 $(DBH^{2.40248})(HT^{0.28060})$	.965	61	43.4
	WVOL = .0053866353 $(DBH^{2.61268})(HT^{0.31103})$	.966	61	43.9

Table 3—English equations for total, wood, and saw-log volumes for California hardwoods, continued

Species		Equation	R^2	N	SE
INTERIOR LIVE OAK		TVOL = $.0136818837\,(DBH^{2.02989})\,(HT^{0.63257})$	0.971	58	42.7
		WVOL = $.0041192264\,(DBH^{2.14915})\,(HT^{0.77843})$	.967	58	44.0
	*	SVOL = $.0006540144\,(DBH^{2.24437})\,(HT^{0.81358})\,(IV^{0.43381})$	.884	68	48.4
CALIFORNIA LAUREL		TVOL = $.0057821322\,(DBH^{1.94553})\,(HT^{0.88389})$	.967	60	43.8
		WVOL = $.0016380753\,(DBH^{2.05910})\,(HT^{1.05293})$	.959	60	46.0
		SVOL = $.0007741517\,(DBH^{2.23009})\,(HT^{1.03700})$	.913	30	45.1
PACIFIC MADRONE		TVOL = $.0067322665\,(DBH^{1.96628})\,(HT^{0.83458})$	.967	60	43.4
		WVOL = $.0025616425\,(DBH^{1.99295})\,(HT^{1.01532})$	.959	58	44.8
		SVOL = $.0006181530\,(DBH^{1.72635})\,(HT^{1.26462})\,(IV^{0.37867})$	.905	32	45.9
OREGON WHITE OAK		TVOL = $.0072695058\,(DBH^{2.14321})\,(HT^{0.74220})$	.961	60	44.6
		WVOL = $.0024277027\,(DBH^{2.25575})\,(HT^{0.87108})$	.958	60	44.6
		SVOL = $.0008281647\,(DBH^{2.10651})\,(HT^{0.91215})\,(IV^{0.32652})$	.838	32	49.6
TANOAK		TVOL = $.0058870024\,(DBH^{1.94165})\,(HT^{0.86562})$	.973	60	42.9
		WVOL = $.0005774970\,(DBH^{2.19576})\,(HT^{1.14078})$	.961	59	46.3
		SVOL = $.0002526443\,(DBH^{2.30949})\,(HT^{1.21069})$	.906	37	48.0
CALIFORNIA WHITE OAK		TVOL = $.0042870077\,(DBH^{2.33631})\,(HT^{0.74872})$	.990	59	40.6
		WVOL = $.0009684363\,(DBH^{2.39565})\,(HT^{0.98878})$	.990	59	41.0
		SVOL = $.0001880044\,(DBH^{1.87346})\,(HT^{1.62443})$	.929	37	47.0

SE = the standard error of the estimate in cubic feet.
TVOL = total tree volume in cubic feet.
WVOL = wood volume in cubic feet.
SVOL = saw-log volume in cubic feet.
DBH = diameter at breast height in inches.
HT = total height in feet.
IV = an indicator variable (1 = non-merchantable first segment; 10 = merchantable first segment).
* Combined equation for sawlog volumes for canyon live oak, interior live oak, and coast live oak.

Table 4—Metric equations for total, wood, and saw-log volumes for California hardwoods

Species		Equation	R^2	N	SE
BIGLEAF MAPLE	TVOL	$= .0000718042\,(DBH^{2.22462})\,(HT^{0.57561})$	0.944	61	1.29
	WVOL	$= .0000246916\,(DBH^{2.35347})\,(HT^{0.69586})$	.924	61	1.37
	SVOL	$= .0000061361\,(DBH^{2.10316})\,(HT^{1.08584})\,(IV^{0.40017})$	.767	26	1.52
CALIFORNIA BLACK OAK	TVOL	$= .0000870843\,(DBH^{1.97437})\,(HT^{0.85034})$	.971	59	1.22
	WVOL	$= .0000386403\,(DBH^{2.12635})\,(HT^{0.83339})$	.962	60	1.28
	SVOL	$= .0000048067\,(DBH^{2.68099})\,(HT^{0.42441})\,(IV^{0.28385})$	.929	38	1.35
BLUE OAK	TVOL	$= .0000697541\,(DBH^{2.33089})\,(HT^{0.46100})$	.971	60	1.22
	WVOL	$= .0000204861\,(DBH^{2.53987})\,(HT^{0.50591})$	.970	60	1.25
	SVOL	$= .0000530200\,(DBH^{1.79732})\,(HT^{0.83884})\,(IV^{0.15958})$	.826	32	1.31
CANYON LIVE OAK	TVOL	$= .0000730718\,(DBH^{2.20527})\,(HT^{0.61190})$	.978	58	1.18
	WVOL	$= .0000248325\,(DBH^{2.32519})\,(HT^{0.74348})$	.980	58	1.19
	* SVOL	$= .0000060095(DBH^{2.24437})\,(HT^{0.81358})\,(IV^{0.43381})$	.884	68	1.37
GIANT CHINKAPIN	TVOL	$= .0001169607\,(DBH^{2.02232})\,(HT^{0.68638})$	.960	60	1.26
	WVOL	$= .0000568840\,(DBH^{2.07202})\,(HT^{0.77467})$	.958	60	1.27
	SVOL	$= .0000145764\,(DBH^{2.38285})\,(HT^{0.77105})$	.880	40	1.31
COAST LIVE OAK	TVOL	$= .0000446992\,(DBH^{2.31958})\,(HT^{0.62528})$	.968	60	1.25
	WVOL	$= .0000135114\,(DBH^{2.53284})\,(HT^{0.60764})$	.971	59	1.25
	* SVOL	$= .0000060095\,(DBH^{2.24437})\,(HT^{0.81358})\,(IV^{0.43381})$	.884	68	1.37
ENGELMANN OAK	TVOL	$= .0000805935\,(DBH^{2.40248})\,(HT^{0.28060})$	.965	61	1.23
	WVOL	$= .0000193268\,(DBH^{2.61268})\,(HT^{0.31103})$	.966	61	1.24

Table 4—Metric equations for total, wood, and saw-log volumes for California hardwoods, continued

Species		Equation	R^2	N	SE
INTERIOR		TVOL = $.0001238312 (DBH^{2.02989}) (HT^{0.63257})$	0.971	58	1.21
LIVE OAK		WVOL = $.0000396716 (DBH^{2.14915}) (HT^{0.77843})$	.967	58	1.24
	*	SVOL = $.0000060095 (DBH^{2.24437}) (HT^{0.81358}) (IV^{0.43381})$	.884	68	1.37
CALIFORNIA		TVOL = $.0000763133 (DBH^{1.94553}) (HT^{0.88389})$	.967	60	1.24
LAUREL		WVOL = $.0000237733 (DBH^{2.05910}) (HT^{1.05293})$	.959	60	1.30
		SVOL = $.0000094003 (DBH^{2.23009}) (HT^{1.03700})$	.913	30	1.28
PACIFIC		TVOL = $.0000821921 (DBH^{1.96628}) (HT^{0.83458})$	.967	60	1.23
MADRONE		WVOL = $.0000378129 (DBH^{1.99295}) (HT^{1.01532})$	.959	58	1.27
		SVOL = $.0000157319 (DBH^{1.72635}) (HT^{1.26462}) (IV^{0.37867})$	.905	32	1.30
OREGON		TVOL = $.0000674342 (DBH^{2.14321}) (HT^{0.74220})$	.961	60	1.26
WHITE OAK		WVOL = $.0000236325 (DBH^{2.25575}) (HT^{0.87108})$	.958	60	1.30
		SVOL = $.0000097284 (DBH^{2.10651}) (HT^{0.91215}) (IV^{0.32652})$	.838	32	1.41
TANOAK		TVOL = $.0000763045 (DBH^{1.94165}) (HT^{0.86562})$	.973	60	1.22
		WVOL = $.0000081905 (DBH^{2.19576}) (HT^{1.14078})$	.961	59	1.31
		SVOL = $.0000035019 (DBH^{2.30949}) (HT^{1.21069})$	.906	37	1.36
CALIFORNIA		TVOL = $.0000334750 (DBH^{2.33631}) (HT^{0.74872})$	.990	59	1.15
WHITE OAK		WVOL = $.0000095166 (DBH^{2.39565}) (HT^{0.98878})$	.990	59	1.16
		SVOL = $.0000063968 (DBH^{1.87346}) (HT^{1.62443})$	.929	37	1.33

SE = the standard error of the estimate in cubic meters.
TVOL = total tree volume in cubic meters.
WVOL = wood volume in cubic meters.
SVOL = saw-log volume in cubic meters.
DBH = diameter at breast height in centimeters.
HT = total height in meters.
IV = an indicator variable (1 = non-merchantable first segment; 10 = merchantable first segment).
* Combined equation for sawlog volumes for canyon live oak, interior live oak, and coast live oak.

Saw-log volume equations.—A qualitative indicator variable was used to break the saw-log data into two subsets: trees with a merchantable (straight, at least 2.5 m (8 ft) long, and free of defect) first segment, and trees without a merchantable first segment. A code of "1" means the first segment in nonmerchantable and a code of "10" means it is merchantable. The addition of the indicator variable helped reduce the variation in saw-log equations for 8 of the 13 species (tables 3 and 4). This improved the precision of the saw-log volume equation. Species that forked below 2.5 m (8 ft) commonly had sweep, crook, and a multiple branching pattern, resulting in segment lengths shorter than 2.5 m (8 ft) and an overall lower proportion of saw-log volume.

Of the eight species where an indicator variable was included in the model, trees with a merchantable first segment had an average of 2.3 times more volume than trees without a merchantable first segment. The regression model incorporating the indicator variable was not used for tanoak, chinkapin, and California-laurel because these species usually have merchantable first logs. Also it was not used for California white oak because the indicator variable added little to reduce variation in predicting saw-log volume.

Saw-log equations were not developed for Engelmann oak, which has a very complex growth form with few straight sections. Little or no saw-log volume can be expected in unmanaged native stands of this species.

Test To Combine Regression Lines

Because of the size and irregular form of the live oak species (canyon, coast, and interior), many trees measured did not have any saw-log volume. As a result the sample size for developing saw-log equations for the live oak species was small. These species were observed to have similar growth forms and an F-test supported combining the data sets. The three live oak data sets were therefore combined to produce one equation for saw-log volume (tables 3 and 4).

Verification of Tree Volume

Most of the sample trees were on private property and were not felled at the time of Relaskop measurement. Pillsbury and Stephens' (1978) method was used to check tree volumes. They cut and measured 61 trees to check the accuracy of the volumes based on Relaskop measurements of standing trees. They developed a simple linear regression equation ($\log_{10}$ transformation) relating standing tree volume to cut tree volume and obtained a multiple coefficient of determination of 0.990 (SE = 1.17). To validate their equation for use in this study, 10 additional sample trees spanning the range of diameters at breast height were measured. Standing tree measurements were made by the techniques previously discussed in this report. Then each tree was felled and measured with tape and caliper. A simple linear regression ($\log_{10}$ transformation) was developed relating standing tree volume to cut tree volume and compared to the Pillsbury and Stephens (1978) equation. An F-test supported combining the two data sets as one population at the 0.99 probability level. All standing volumes were corrected using the Pillsbury and Stephens (1978) equation:

$$\text{Corrected Volume } (M^3) = 1.166\ (\text{Standing Volume } (M^3))^{0.9947}$$

The standing tree volumes are increased by approximately 15 percent using this equation, indicating that the technique used to measure standing tree volume tends to underestimate tree volume.

Reliability of the Equations

The average aggregate difference in percent is -2.1 for total volume, -2.8 for wood volume, and -5.8 for saw-log volume. An independent test was made using total volume of 76 felled trees in three central coast counties. The average aggregate difference for the 76 trees is 17.0 percent.

The reliability of the equations can be measured by the relative deviation of individu tree volumes from the regression surface (MacLean and Berger 1976). A measure this residual variation is the root mean squared error; that is, the root of the mean squared difference between the predicted and actual values. This comparison, expressed as a percent of the mean volume, is shown in table 5. The root mean squared error difference for 76 trees of known volume in three central coast counties is sho in table 6. The root mean squared errors range from about 20 to 55 for the various utilization standards shown in tables 5 and 6. These values are higher than those reported for conifers (MacLean and Berger 1976) and illustrate the greater variability in volume that occurs for a given diameter and height for many hardwoods.

Table 5—Root mean squared errors of standard volume equations for total, wood, and saw-log utilization standards

Species	Root mean squared error					
	Total volume		Wood volume		Sawlog volum	
	N	*Percent*	*N*	*Percent*	*N*	*Percen*
Bigleaf maple	61	36	61	46	24	31
California black oak	59	50	60	56	38	21
Blue oak	60	27	60	30	32	36
Canyon live oak	58	52	58	53	—n/a—	
Giant chinkapin	60	45	60	46	40	20
Coast live oak	60	36	59	39	—n/a—	
Engelmann oak	61	30	61	34	—n/a—	
Interior live oak	58	28	58	38	—n/a—	
California-laurel	60	24	60	26	30	20
Pacific madrone	60	38	58	39	32	24
Oregon white oak	60	41	60	47	32	36
Tanoak	60	38	59	54	37	27
California white oak	59	20	59	22	37	22
Combined: Canyon, interior and coast live oaks	—n/a—		—n/a—		65	64

n/a = not applicable.

Table 6—Results of a test of equations for 76 trees of known total volume from Monterey, San Luis Obispo, and Santa Cruz Counties

Species	Root mean squared error	
	Number of trees	*Percent*
Blue oak	26	42
Coast live oak	35	50
Tanoak	15	24

Use of the Equations

Following is an example showing calculations in English units of total, wood, and saw-log volumes for a blue oak tree with these dimensions: d.b.h. = 25.5 inches; and total height = 47 feet. It has a merchantable first segment:

TVOL = $.0125103008\ (25.5^{2.33089}) \times (47^{0.46100}) = 140$ cubic feet;

WVOL = $.0042324071\ (25.5^{2.53987}) \times (47^{0.50591}) = 110$ cubic feet; and

SVOL = $.0036912408\ (25.5^{1.79732}) \times (47^{0.83884}) \times (10^{0.15958}) = 45$ cubic feet.

Although other hardwood volume equations are available, most have been developed for regional or local use and incorporate various utilization standards. Volume equations developed for local areas may provide better estimates of tree volumes in those areas than the equations for the entire state. Field checking may be necessary to compare the accuracy of the statewide equations to local or regional sites if this use is desired.

Volume Tables and Range of Data

In the appendix are tables showing calculated volumes for selected diameters and heights for each of the 13 hardwood species studied. The range of measurements used to develop the equations is shown on each table.

Literature Cited

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Appendix

Tables 7 through 19 are in English measurement; tables 20 through 32 are in metric measurement.

Table 7--Total tree, wood, and saw-log volume for giant chinkapin

DIAMETER AT BREAST HEIGHT OUTSIDE BARK 1/	TOTAL HEIGHT (FEET) 20	30	40	50	60	70	80	90	100	110	120	130	140	150
INCHES	CUBIC FEET													
5:														
TVOL	2	3	4	5										
WVOL	2	2	3	3										
SVOL	1	1	2	2										
7:														
TVOL	5	6	8	9	10	11								
WVOL	3	4	5	6	7	8								
SVOL	2	3	3	4	5	5								
9:														
TVOL	8	11	13	15	17	19	21	22						
WVOL	5	7	9	11	12	14	16	17						
SVOL	4	5	6	7	8	9	10	11						
11:														
TVOL	12	16	19	23	26	28	31	34	36	39	41			
WVOL	8	11	14	16	19	21	24	26	28	30	32			
SVOL	6	8	10	12	14	15	17	18	20	22	23			
13:														
TVOL	17	22	27	32	36	40	44	47	51	54	58			
WVOL	11	16	20	23	27	30	33	37	40	43	46			
SVOL	9	12	15	17	20	23	25	28	30	32	34			
15:														
TVOL		30	36	42	48	53	58	63	68	72	77	81	86	90
WVOL		21	26	31	36	41	45	49	53	58	62	66	69	73
SVOL		17	21	25	28	32	35	39	42	45	48	51	54	57
17:														
TVOL		38	47	54	62	68	75	81	87	93	99	105	110	115
WVOL		27	34	41	47	53	58	64	69	75	80	85	90	95
SVOL		22	28	33	38	43	48	52	57	61	65	69	73	77
19:														
TVOL			58	68	77	86	94	102	109	117	124	131	138	145
WVOL			43	51	59	66	73	80	87	94	101	107	113	120
SVOL			36	43	50	56	62	68	74	79	85	90	96	101
21:														
TVOL			71	83	94	105	115	125	134	143	152	160	169	177
WVOL			53	63	72	81	90	99	107	116	124	132	139	147
SVOL			46	55	63	71	79	86	94	101	108	115	121	128
23:														
TVOL			86	100	113	126	138	150	161	172	183	193	203	213
WVOL			64	76	87	98	109	120	130	140	149	159	168	178
SVOL			57	68	78	88	98	107	116	125	134	142	151	159
25:														
TVOL			102	119	134	149	164	177	191	204	216	228	240	252
WVOL			76	90	104	117	130	142	154	166	178	189	200	211
SVOL			70	83	96	108	119	131	142	153	163	174	184	194
27:														
TVOL				138	157	174	191	207	223	238	253	267	281	294
WVOL				106	122	137	152	167	181	195	208	222	235	248
SVOL				100	115	129	143	157	170	183	196	208	221	233
29:														
TVOL				160	181	202	221	240	257	275	292	308	324	340
WVOL				123	141	159	176	193	210	226	241	257	272	287
SVOL				118	136	153	170	186	202	217	232	247	262	276
31:														
TVOL				183	208	231	253	274	295	315	334	353	371	389
WVOL				141	162	183	203	222	241	259	277	295	312	330
SVOL				139	160	180	199	218	237	255	272	290	307	324

NOTE: BLOCK INDICATES RANGE OF DATA.

1/ TVOL = TOTAL ABOVEGROUND VOLUME OF WOOD AND BARK; EXCLUDES FOLIAGE.

WVOL = VOLUME OF WOOD FROM A 1-FOOT STUMP TO A 4-INCH TOP OUTSIDE BARK; EXCLUDES BARK AND FOLIAGE.

SVOL = SAW-LOG VOLUME IN STRAIGHT MERCHANTABLE SECTIONS AT LEAST 8 FEET LONG TO A 9-INCH TOP OUTSIDE BARK ABOVE A 1-FOOT STUMP.

Table 8--Total tree, wood, and saw-log volume for California-laurel

DIAMETER AT BREAST HEIGHT OUTSIDE BARK 1/	TOTAL HEIGHT (FEET) 20	30	40	50	60	70	80	90	100	110	120	130	140
INCHES	CUBIC FEET												
5:													
TVOL	2	3	3	4	5	6	6						
WVOL	1	2	2	3	3	4	5						
SVOL	1	1	1	2	2	2	3						
7:													
TVOL	4	5	7	8	10	11	12	14	15				
WVOL	2	3	4	6	7	8	9	10	11				
SVOL	1	2	3	3	4	5	6	6	7				
9:													
TVOL	6	8	11	13	15	18	20	22	24				
WVOL	4	5	7	9	11	13	15	17	19				
SVOL	2	4	5	6	7	9	10	11	12				
11:													
TVOL	9	12	16	19	23	26	30	33	36	39	42	45	48
WVOL	5	8	11	14	17	20	23	26	29	32	35	38	42
SVOL	4	6	7	9	11	13	15	17	19	21	23	25	27
13:													
TVOL	12	17	22	27	32	36	41	45	50	54	58	63	67
WVOL	8	12	16	20	24	28	32	37	41	45	50	54	59
SVOL	5	8	11	14	16	19	22	25	28	31	34	37	40
15:													
TVOL		23	29	36	42	48	54	60	66	72	77	83	89
WVOL		16	21	27	32	38	44	49	55	61	67	73	79
SVOL		11	15	19	23	27	31	35	39	43	47	51	55
TVOL		29	37	45	53	61	69	76	84	91	99	106	113
WVOL		20	27	34	42	49	56	64	71	79	87	94	102
SVOL		15	20	25	30	35	40	46	51	56	62	67	72
19:													
TVOL		36	46	56	66	76	86	95	104	113	122	131	140
WVOL		25	34	43	52	62	71	80	90	99	109	118	128
SVOL		19	25	32	38	45	52	58	65	72	79	86	92
21:													
TVOL		44	56	69	81	92	104	115	127	138	149	160	170
WVOL		31	42	53	64	76	87	99	110	122	134	145	157
SVOL		23	32	40	48	56	65	73	82	90	99	107	116
23:													
TVOL		52	67	82	96	110	124	138	151	164	177	190	203
WVOL		37	51	64	78	91	105	119	133	147	161	175	190
SVOL		29	39	49	59	69	79	90	100	110	121	131	142
25:													
TVOL		61	79	96	113	130	146	162	178	193	209	224	239
WVOL		44	60	76	92	109	125	141	158	175	191	208	225
SVOL		35	47	59	71	83	95	108	120	133	145	158	171
27:													
TVOL			92	112	131	151	169	188	206	224	242	260	278
WVOL			71	89	108	127	146	166	185	205	224	244	264
SVOL			55	70	84	99	113	128	143	158	173	188	203
29:													
TVOL			106	129	151	173	195	216	237	258	279	299	319
WVOL			82	103	125	147	170	192	214	237	260	283	306
SVOL			65	82	99	116	133	150	168	185	202	220	237
31:													
TVOL				146	172	197	222	246	270	294	317	340	364
WVOL				119	144	169	195	220	246	272	298	324	351
SVOL				95	114	134	154	174	194	215	235	255	276
33:													
TVOL				165	194	222	250	278	305	332	358	384	411
WVOL				135	163	192	221	250	280	309	339	369	399
SVOL				109	132	154	177	200	223	247	270	293	317
35:													
TVOL				185	218	249	281	311	342	372	402	431	460
WVOL				152	184	217	250	283	316	349	383	416	450
SVOL				124	150	176	202	228	255	281	308	334	361
37:													
TVOL				206	243	278	313	347	381	414	448	480	513
WVOL				171	207	243	280	317	354	392	429	467	505
SVOL				141	170	199	229	259	288	318	348	379	409
39:													
TVOL				229	269	308	346	384	422	459	496	532	568
WVOL				190	231	271	312	353	395	436	478	520	563
SVOL				158	191	224	257	291	324	358	392	426	460
41:													
TVOL				252	296	339	382	424	465	506	546	587	626
WVOL				211	256	301	346	392	438	484	530	577	624
SVOL				177	214	251	288	325	363	400	438	476	514

NOTE: BLOCK INDICATES RANGE OF DATA.

1/TVOL = TOTAL ABOVEGROUND VOLUME OF WOOD AND BARK; EXCLUDES FOLIAGE.

WVOL = VOLUME OF WOOD FROM A 1-FOOT STUMP TO A 4-INCH TOP OUTSIDE BARK; EXCLUDES BARK AND FOLIAGE.

SVOL = SAW-LOG VOLUME IN STRAIGHT MERCHANTABLE SECTIONS AT LEAST 8 FEET LONG TO A 9-INCH TOP OUTSIDE BARK ABOVE A 1-FOOT STUMP.

Table 9--Total tree, wood, and saw-log volume for tanoak

DIAMETER AT BREAST HEIGHT OUTSIDE BARK 1/	TOTAL HEIGHT (FEET) 20	30	40	50	60	70	80	90	100	110	120	130	140
INCHES	CUBIC FEET												
5:													
TVOL	2	3	3	4	5	5	6						
WVOL	1	1	1	2	2	3	3						
SVOL	0	1	1	1	1	2	2						
7:													
TVOL	3	5	6	8	9	10	11	13	14	15			
WVOL	1	2	3	4	4	5	6	7	8	9			
SVOL	1	1	2	3	3	4	5	5	6	7			
9:													
TVOL	6	8	10	12	15	17	19	21	23	25	26		
WVOL	2	3	5	6	8	9	11	12	14	15	17		
SVOL	2	2	4	5	6	7	8	9	11	12	13		
11:													
TVOL	8	12	15	18	21	24	27	30	33	36	39	42	
WVOL	3	5	8	10	12	14	17	19	21	24	26	29	
SVOL	2	4	6	7	9	11	13	15	17	19	21	23	
13:													
TVOL	11	16	21	25	30	34	38	42	46	50	54	58	
WVOL	5	8	11	14	17	21	24	27	31	34	38	42	
SVOL	4	6	8	11	13	16	19	22	25	28	31	34	
15:													
TVOL		21	28	33	39	45	50	56	61	66	71	76	
WVOL		11	15	19	24	28	33	37	42	47	52	57	
SVOL		8	11	15	19	23	26	31	35	39	43	48	
17:													
TVOL		27	35	43	50	57	64	71	78	84	91	97	104
WVOL		14	20	25	31	37	43	49	56	62	68	75	82
SVOL		11	15	20	25	30	35	41	46	52	58	64	70
19:													
TVOL		34	44	53	62	71	79	88	96	105	113	121	129
WVOL		18	25	32	40	47	55	63	71	79	87	96	104
SVOL		14	20	26	32	39	46	53	60	67	75	82	90
21:													
TVOL		41	53	64	75	86	97	107	117	127	137	147	157
WVOL		22	31	40	49	59	69	78	88	99	109	119	130
SVOL		18	25	33	41	49	58	66	75	85	94	104	113
23:													
TVOL			63	77	90	103	115	128	140	152	164	175	187
WVOL			38	49	60	72	84	96	108	120	133	146	158
SVOL			31	40	50	60	71	82	93	104	116	128	140
25:													
TVOL			74	90	106	121	135	150	164	178	192	206	220
WVOL			46	59	72	86	100	115	130	145	160	175	190
SVOL			37	49	61	73	86	99	113	127	141	155	170

DIAMETER AT BREAST HEIGHT OUTSIDE BARK 1/	TOTAL HEIGHT (FEET)												
	20	30	40	50	60	70	80	90	100	110	120	130	140
INCHES	- - - - - - - -						CUBIC FEET	- - - - - - - -					
27:													
TVOL			86	105	123	140	157	174	191	207	223	239	255
WVOL			54	70	86	102	119	136	153	171	189	207	225
SVOL			44	58	73	88	103	119	135	151	168	185	203
29:													
TVOL			99	120	141	161	181	200	219	238	257	275	293
WVOL			63	81	100	120	139	159	180	200	221	242	264
SVOL			52	69	86	103	121	140	159	178	198	218	239
31:													
TVOL				137	160	183	206	228	249	271	292	313	334
WVOL				94	116	138	161	184	208	232	256	280	305
SVOL				80	100	120	142	163	185	208	231	255	279
33:													
TVOL				155	181	207	232	257	282	306	330	353	377
WVOL				108	133	159	185	211	238	266	294	322	350
SVOL				93	115	139	164	189	214	240	267	294	322
35:													
TVOL				173	203	232	260	288	316	343	370	396	422
WVOL				123	152	181	210	241	271	303	334	366	398
SVOL				106	132	159	187	216	245	275	306	337	369
37:													
TVOL				193	226	258	290	321	352	382	412	441	470
WVOL				139	171	204	238	272	307	342	377	414	450
SVOL				121	150	181	213	246	279	313	348	383	419
39:													
TVOL				214	250	286	321	355	389	423	456	489	521
WVOL				156	192	229	267	305	344	384	424	464	505
SVOL				136	170	205	240	277	315	354	393	433	474
41:													
TVOL				236	276	315	354	392	429	466	503	539	574
WVOL				174	214	256	298	341	384	428	473	518	564
SVOL				153	191	230	270	311	354	397	441	486	532
43:													
TVOL				258	302	346	388	430	471	511	551	591	630
WVOL				193	238	284	331	378	426	475	525	575	626
SVOL				171	213	256	301	348	395	443	492	542	593
45:													
TVOL				282	330	378	424	469	514	558	602	645	
WVOL				214	263	314	365	418	471	525	580	636	
SVOL				189	236	285	335	386	438	492	547	602	

NOTE: BLOCK INDICATES RANGE OF DATA.

1/TVOL = TOTAL ABOVEGROUND VOLUME OF WOOD AND BARK; EXCLUDES FOLIAGE.

WVOL = VOLUME OF WOOD FROM A 1-FOOT STUMP TO A 4-INCH TOP OUTSIDE BARK; EXCLUDES BARK AND FOLIAGE.

SVOL = SAW-LOG VOLUME IN STRAIGHT MERCHANTABLE SECTIONS AT LEAST 8 FEET LONG TO A 9-INCH TOP OUTSIDE BARK ABOVE A 1-FOOT STUMP.

Table 10--Total tree, wood, and saw-log volume for California white oak

DIAMETER AT BREAST HEIGHT OUTSIDE BARK 1/		TOTAL HEIGHT (FEET)										
	20	30	40	50	60	70	80	90	100	110	120	130
INCHES	CUBIC FEET											
5:												
TVOL	2	2	3									
WVOL	1	1	2									
SVOL	0	1	2									
7:												
TVOL	4	5	6	8	9	10	11					
WVOL	2	3	4	5	6	7	8					
SVOL	1	2	3	4	6	7	9					
9:												
TVOL	7	9	12	14	16	17	19	21				
WVOL	4	5	7	9	11	12	14	16				
SVOL	1	3	5	7	9	11	14	17				
11:												
TVOL	11	15	18	22	25	28	31	34				
WVOL	6	9	12	14	17	20	23	26				
SVOL	2	4	7	10	13	17	21	25				
13:												
TVOL	16	22	27	32	37	41	46	50	54	58		
WVOL	9	13	17	22	26	30	34	39	43	47		
SVOL	3	6	9	13	18	23	28	34	41	48		
15:												
TVOL		31	38	45	51	58	64	70	75	81	86	92
WVOL		18	24	30	36	42	48	54	60	66	72	78
SVOL		8	12	17	23	30	37	45	53	62	72	82
17:												
TVOL		41	51	60	69	77	85	93	101	108	116	123
WVOL		25	33	41	49	57	65	73	82	90	98	106
SVOL		10	15	22	29	38	47	57	67	79	91	103
19:												
TVOL		53	66	78	89	100	111	121	131	141	150	159
WVOL		32	43	54	64	75	85	96	106	117	127	138
SVOL		12	19	27	36	46	58	70	83	97	112	127
21:												
TVOL		67	83	98	113	127	140	153	165	178	190	201
WVOL		41	55	68	82	95	108	122	135	149	162	175
SVOL		14	23	32	44	56	70	84	100	117	135	153
23:												
TVOL			103	122	140	157	173	189	205	220	235	249
WVOL			68	85	102	118	135	152	168	185	201	218
SVOL			27	38	52	66	83	100	119	138	160	182
25:												
TVOL			125	148	170	190	210	230	249	267	285	303
WVOL			83	104	124	144	165	185	205	226	246	266
SVOL			31	45	60	78	97	117	139	162	186	212

DIAMETER AT BREAST HEIGHT OUTSIDE BARK 1/	TOTAL HEIGHT (FEET) 20	30	40	50	60	70	80	90	100	110	120	130
INCHES						CUBIC FEET						
27:												
TVOL			150	177	203	228	252	275	298	320	341	362
WVOL			100	124	149	174	198	223	247	271	296	320
SVOL			36	52	70	90	111	135	160	187	215	245
29:												
TVOL			177	209	240	269	298	325	352	378	403	428
WVOL			118	148	177	206	235	264	293	322	351	380
SVOL			41	59	80	103	127	154	183	214	246	280
31:												
TVOL			207	245	280	315	348	380	411	441	471	500
WVOL			139	173	208	242	276	310	344	378	412	446
SVOL			47	67	91	116	144	175	208	242	279	318
33:												
TVOL				283	324	364	402	440	476	511	545	579
WVOL				201	241	281	320	360	399	439	478	518
SVOL				76	102	131	162	197	233	272	314	357
35:												
TVOL				325	372	418	462	504	546	586	626	664
WVOL				232	278	323	369	414	460	505	551	596
SVOL				84	114	146	181	220	260	304	350	399
37:												
TVOL				370	424	476	526	574	621	667	712	756
WVOL				265	317	369	421	473	525	577	629	681
SVOL				94	126	162	201	244	289	337	389	443
39:												
TVOL				418	479	538	595	649	703	755	806	855
WVOL				300	360	419	478	537	596	655	714	773
SVOL				103	139	179	222	269	319	372	429	489
41:												
TVOL				470	539	605	668	730	790	848	905	961
WVOL				339	405	472	539	605	672	738	805	871
SVOL				114	153	196	244	295	350	409	471	537
43:												
TVOL				525	602	676	747	816	883	948	1012	1074
WVOL				379	454	529	604	679	753	828	902	976
SVOL				124	167	215	267	323	383	447	515	587
45:												
TVOL				584	670	752	831	907	982	1054	1125	1195
WVOL				423	507	590	673	757	840	923	1006	1088
SVOL				135	182	234	290	352	417	487	561	639

NOTE: BLOCK INDICATES RANGE OF DATA.

1/TVOL = TOTAL ABOVEGROUND VOLUME OF WOOD AND BARK; EXCLUDES FOLIAGE.

WVOL = VOLUME OF WOOD FROM A 1-FOOT STUMP TO A 4-INCH TOP OUTSIDE BARK; EXCLUDES BARK AND FOLIAGE.

SVOL = SAW-LOG VOLUME IN STRAIGHT MERCHANTABLE SECTIONS AT LEAST 8 FEET LONG TO A 9-INCH TOP OUTSIDE BARK ABOVE A 1-FOOT STUMP.

Table 11--Total tree, wood, and saw-log volume for bigleaf maple

Diameter at breast height outside bark 1/	Total height (feet)													
	20	30	40	50	60	70	80	90	100	110	120	130	140	150
Inches	Cubic feet													
5:														
TVOL	2	3	3	3										
WVOL	1	2	2	2										
SVOLI	1	1	2	2										
SVOLX	0	1	1	1										
7:														
TVOL	4	5	6	7	8	9	10							
WVOL	3	4	4	5	6	6	7							
SVOLI	2	3	4	4	5	6	7							
SVOLX	1	1	1	2	2	3	3							
9:														
TVOL	8	10	11	13	14	16	17	18						
WVOL	5	6	8	9	10	12	13	14						
SVOLI	3	4	6	8	9	11	13	14						
SVOLX	1	2	2	3	4	4	5	6						
11:														
TVOL	12	15	18	20	22	24	26	28	30					
WVOL	8	10	13	15	17	19	20	22	24					
SVOLI	4	7	9	12	14	17	19	22	24					
SVOLX	2	3	4	5	6	7	8	9	10					
13:														
TVOL	17	22	26	29	32	35	38	41	43					
WVOL	12	15	19	22	25	28	30	33	35					
SVOLI	6	9	13	16	20	24	27	31	35					
SVOLX	2	4	5	7	8	9	11	12	14					
15:														
TVOL		30	35	40	44	49	52	56	60	63				
WVOL		21	26	31	35	39	42	46	49	53				
SVOLI		13	17	22	27	32	37	42	47	52				
SVOLX		5	7	9	11	13	15	17	19	21				
17:														
TVOL		39	46	53	59	64	69	74	79	83				
WVOL		29	35	41	46	52	57	62	66	71				
SVOLI		17	23	29	35	42	48	55	61	68				
SVOLX		7	9	11	14	17	19	22	24	27				
19:														
TVOL		50	60	68	75	82	89	95	101	107	112			
WVOL		37	46	53	60	67	74	80	86	92	98			
SVOLI		21	29	36	44	52	61	69	77	86	94			
SVOLX		8	11	14	18	21	24	27	31	34	38			
21:														
TVOL		63	74	85	94	103	111	119	126	133	140	147		
WVOL		47	58	67	76	85	93	101	109	117	124	131		
SVOLI		26	35	45	55	65	75	85	95	106	116	127		
SVOLX		10	14	18	22	26	30	34	38	42	46	50		
23:														
TVOL			91	104	115	126	136	145	154	163	171	179	187	
WVOL			71	83	95	105	116	126	135	144	153	162	171	
SVOLI			43	54	66	78	91	103	116	128	141	154	167	
SVOLX			17	22	26	31	36	41	46	51	56	61	66	
25:														
TVOL			110	125	138	151	163	175	186	196	206	216	225	235
WVOL			87	101	115	128	141	153	164	176	187	197	208	218
SVOLI			51	65	79	93	108	123	138	153	168	183	198	214
SVOLX			20	26	31	37	43	49	55	61	67	73	79	85

DIAMETER AT BREAST HEIGHT OUTSIDE BARK 1/	TOTAL HEIGHT (FEET)													
	20	30	40	50	60	70	80	90	100	110	120	130	140	150
INCHES	- - - - - CUBIC FEET - - - - -													
27:														
TVOL			130	148	164	179	194	207	220	233	245	256	267	278
WVOL			104	122	138	154	169	183	197	211	224	237	249	261
SVOLI			60	76	93	110	127	144	162	180	197	215	233	251
SVOLX			24	30	37	44	51	57	64	71	79	86	93	100
29:														
TVOL			152	173	193	210	227	243	258	273	287	300	314	326
WVOL			123	144	163	182	200	217	233	249	265	280	295	309
SVOLI			70	89	108	128	148	168	188	209	229	250	271	292
SVOLX			28	35	43	51	59	67	75	83	91	100	108	116
31:														
TVOL			177	201	223	244	264	282	300	317	333	349	364	378
WVOL			144	168	191	213	234	253	273	291	310	327	345	362
SVOLI			80	102	124	147	170	193	216	240	264	288	312	336
SVOLX			32	41	49	58	68	77	86	96	105	115	124	134
33:														
TVOL			203	231	257	280	303	324	344	364	382	401	418	435
WVOL			167	195	221	247	271	294	316	338	359	379	399	419
SVOLI			91	116	142	168	194	220	247	274	301	328	356	383
SVOLX			36	46	56	67	77	88	98	109	120	131	142	153
35:														
TVOL			232	263	293	320	345	369	393	415	436	457	476	496
WVOL			192	224	254	283	311	337	363	388	412	436	459	481
SVOLI			103	132	160	190	219	249	279	310	341	372	403	434
SVOLX			41	52	64	75	87	99	111	123	136	148	160	173
37:														
TVOL			262	298	331	362	391	418	444	469	493	517	539	561
WVOL			219	255	290	323	354	384	414	442	470	497	523	548
SVOLI			116	148	180	213	246	280	314	348	383	418	453	488
SVOLX			46	59	72	85	98	111	125	139	152	166	180	194
39:														
TVOL			295	335	372	407	439	470	499	528	555	581	606	631
WVOL			247	289	328	365	401	435	468	500	532	562	592	621
SVOLI			130	165	201	238	275	313	351	389	428	466	506	545
SVOLX			52	66	80	95	110	125	140	155	170	186	201	217
41:														
TVOL			329	375	416	455	491	525	558	590	620	649	677	
WVOL			278	325	369	411	451	489	527	563	598	632	666	
SVOLI			144	184	224	265	306	348	390	432	475	518	562	
SVOLX			57	73	89	105	122	138	155	172	189	206	224	
43:														
TVOL			366	416	462	505	546	584	621	656	689	722	753	
WVOL			311	364	413	460	504	548	589	630	669	707	745	
SVOLI			159	203	247	292	338	384	431	478	525	573	621	
SVOLX			63	81	98	116	135	153	171	190	209	228	247	
45:														
TVOL			405	461	512	559	604	646	687	725	763	798	833	
WVOL			347	405	460	512	561	609	656	701	744	787	829	
SVOLI			175	223	272	322	372	423	474	526	578	630	683	
SVOLX			70	89	108	128	148	168	189	209	230	251	272	

NOTE: BLOCK INDICATES RANGE OF DATA.

1/TVOL = TOTAL ABOVEGROUND VOLUME OF WOOD AND BARK; EXCLUDES FOLIAGE.

WVOL = VOLUME OF WOOD FROM A 1-FOOT STUMP TO A 4-INCH TOP OUTSIDE BARK; EXCLUDES BARK AND FOLIAGE.

SVOLI = SAW-LOG VOLUME IN STRAIGHT MERCHANTABLE SECTIONS AT LEAST 8 FEET LONG TO A 9-INCH TOP OUTSIDE BARK IN TREES WITH A MERCHANTABLE FIRST SECTION ABOVE A 1-FOOT STUMP.

SVOLX = SAW-LOG VOLUME IN STRAIGHT MERCHANTABLE SECTIONS AT LEAST 8 FEET LONG TO A 9-INCH TOP OUTSIDE BARK IN TREES WITHOUT A MERCHANTABLE FIRST SECTION ABOVE A 1-FOOT STUMP.

Table 12--Total tree, wood, and saw-log volume for California black oak

DIAMETER AT BREAST HEIGHT OUTSIDE BARK 1/	TOTAL HEIGHT (FEET)													
	20	30	40	50	60	70	80	90	100	110	120	130	140	150
INCHES	CUBIC FEET													
5:														
TVOL	2	3	4	5	6	6								
WVOL	1	2	2	3	3	4								
SVOLI	1	1	1	1	1	1								
SVOLX	0	0	0	0	1	1								
7:														
TVOL	4	6	8	9	11	12	14							
WVOL	3	4	5	6	7	8	9							
SVOLI	2	2	2	2	3	3	3							
SVOLX	1	1	1	1	1	1	1							
9:														
TVOL	7	10	12	15	18	20	22	25	27					
WVOL	5	7	9	10	12	14	15	17	18					
SVOLI	3	4	4	5	5	5	6	6	6					
SVOLX	2	2	2	2	3	3	3	3	3					
11:														
TVOL	10	14	18	22	26	30	33	37	40	44				
WVOL	7	10	13	16	18	21	23	26	28	30				
SVOLI	5	6	7	8	8	9	10	10	10	11				
SVOLX	3	3	4	4	4	5	5	5	5	6				
13:														
TVOL	14	20	26	31	36	41	46	51	56	61	65			
WVOL	10	15	19	22	26	30	33	37	40	43	46			
SVOLI	8	10	11	12	13	14	15	16	16	17	18			
SVOLX	4	5	6	6	7	7	8	8	9	9	9			
15:														
TVOL	19	27	34	41	48	55	61	68	74	81	87			
WVOL	14	20	25	30	35	40	45	50	54	59	63			
SVOLI	12	14	16	18	19	21	22	23	24	25	26			
SVOLX	6	8	8	9	10	11	11	12	13	13	14			
17:														
TVOL	24	34	44	53	62	70	79	87	95	103	111			
WVOL	18	26	33	40	46	52	59	65	71	76	82			
SVOLI	17	20	23	25	27	29	31	32	34	35	36			
SVOLX	9	11	12	13	14	15	16	17	18	18	19			
19:														
TVOL		43	54	66	77	88	98	108	119	129	138			
WVOL		33	42	50	58	66	74	82	89	97	104			
SVOLI		27	31	34	37	39	41	43	45	47	49			
SVOLX		14	16	18	19	20	21	23	24	25	26			
21:														
TVOL		52	66	80	94	107	119	132	144	157	169			
WVOL		41	52	62	72	82	92	101	111	120	129			
SVOLI		36	40	44	48	51	54	57	59	62	64			
SVOLX		19	21	23	25	27	28	30	31	32	33			
23:														
TVOL		62	79	96	112	128	143	158	173	187	202			
WVOL		49	63	75	88	100	112	123	134	145	156			
SVOLI		45	51	56	61	65	69	72	76	79	82			
SVOLX		24	27	29	32	34	36	38	39	41	43			
25:														
TVOL			93	113	132	150	169	186	204	221	238	255	271	288
WVOL			75	90	105	119	133	147	160	174	187	200	212	225
SVOLI			64	71	76	81	86	91	95	99	102	106	109	113
SVOLX			33	37	40	42	45	47	49	51	53	55	57	59

DIAMETER AT BREAST HEIGHT OUTSIDE BARK 1/	TOTAL HEIGHT (FEET) 20	30	40	50	60	70	80	90	100	110	120	130	140	150
INCHES	CUBIC FEET													
27:														
TVOL			109	132	154	175	196	217	237	257	277	297	316	335
WVOL			88	106	123	140	157	173	189	204	220	235	250	265
SVOLI			79	87	94	100	106	111	116	121	126	130	134	138
SVOLX			41	45	49	52	55	58	61	63	65	68	70	72
29:														
TVOL			125	152	177	202	226	250	273	296	319	341	364	386
WVOL			102	123	144	163	183	201	220	238	256	274	291	308
SVOLI			96	105	114	121	128	135	141	147	152	158	163	168
SVOLX			50	55	59	63	67	70	73	76	79	82	85	87
31:														
TVOL				173	202	230	258	285	312	338	364	389	415	440
WVOL				142	166	188	210	232	253	274	295	315	335	355
SVOLI				126	136	145	153	161	169	176	182	189	195	200
SVOLX				65	71	75	80	84	88	91	95	98	101	104
33:														
TVOL				196	228	260	292	322	353	382	412	441	469	498
WVOL				162	189	215	240	265	289	313	337	360	383	406
SVOLI				149	161	171	181	191	200	208	216	223	230	237
SVOLX				77	84	89	94	99	104	108	112	116	120	123
35:														
TVOL				220	256	292	328	362	396	429	462	495	527	559
WVOL				184	214	244	272	300	328	355	382	408	434	460
SVOLI				174	188	201	212	223	234	243	252	261	269	277
SVOLX				91	98	104	111	116	122	127	131	136	140	144
37:														
TVOL				245	286	326	366	404	442	479	516	552	588	624
WVOL				207	241	274	306	338	369	400	430	459	489	517
SVOLI				202	218	233	247	259	271	282	293	303	313	322
SVOLX				105	114	121	128	135	141	147	152	158	163	168
39:														
TVOL				272	318	362	406	448	490	532	573	613	653	692
WVOL				232	270	307	343	378	413	447	481	514	546	579
SVOLI				233	251	268	284	299	312	325	337	349	360	371
SVOLX				121	131	140	148	155	162	169	175	182	187	193
41:														
TVOL				300	351	400	448	495	541	587	632	676	720	764
WVOL				258	300	341	381	421	459	497	534	571	608	644
SVOLI				266	287	307	325	341	357	372	386	399	412	424
SVOLX				138	150	160	169	178	186	193	201	208	214	221
43:														
TVOL						439	492	544	595	645	694	743	791	839
WVOL						377	422	465	508	550	591	632	672	712
SVOLI						349	369	388	406	422	438	453	468	482
SVOLX						181	192	202	211	220	228	236	243	251
45:														
TVOL						480	538	595	650	705	759	813	866	918
WVOL						416	465	513	560	606	651	696	741	785
SVOLI						394	417	438	458	477	495	512	529	544
SVOLX						205	217	228	238	248	258	266	275	283

NOTE: BLOCK INDICATES RANGE OF DATA.

1/TVOL = TOTAL ABOVEGROUND VOLUME OF WOOD AND BARK; EXCLUDES FOLIAGE.

WVOL = VOLUME OF WOOD FROM A 1-FOOT STUMP TO A 4-INCH TOP OUTSIDE BARK; EXCLUDES BARK AND FOLIAGE.

SVOLI = SAW-LOG VOLUME IN STRAIGHT MERCHANTABLE SECTIONS AT LEAST 8 FEET LONG TO A 9-INCH TOP OUTSIDE BARK IN TREES WITH A MERCHANTABLE FIRST SECTION ABOVE A 1-FOOT STUMP.

SVOLX = SAW-LOG VOLUME IN STRAIGHT MERCHANTABLE SECTIONS AT LEAST 8 FEET LONG TO A 9-INCH TOP OUTSIDE BARK IN TREES WITHOUT A MERCHANTABLE FIRST SECTION ABOVE A 1-FOOT STUMP.

Table 13--Total tree and wood volume for Engelmann oak

DIAMETER AT BREAST HEIGHT OUTSIDE BARK 1/	TOTAL HEIGHT (FEET) 20	30	40	50	60	70
INCHES	- - - - - - - - CUBIC FEET - - - - - - - -					
5:						
TVOL	2	2	3			
WVOL	1	1	1			
7:						
TVOL	5	5	6	6	6	
WVOL	2	3	3	3	3	
9:						
TVOL	9	10	11	11	12	
WVOL	4	5	5	6	6	
11:						
TVOL	14	16	17	18	19	20
WVOL	7	8	9	10	10	11
13:						
TVOL	21	24	26	27	29	30
WVOL	11	13	14	15	16	16
15:						
TVOL		33	36	38	40	42
WVOL		18	20	22	23	24
17:						
TVOL		45	49	52	55	57
WVOL		25	28	30	32	33
19:						
TVOL		59	64	68	71	74
WVOL		34	37	40	42	44
21:						
TVOL		75	81	86	91	95
WVOL		44	48	52	55	58
23:						
TVOL		93	101	107	113	118
WVOL		56	61	66	70	73
25:						
TVOL		114	123	131	138	144
WVOL		70	76	82	86	91
27:						
TVOL		137	148	158	166	173
WVOL		85	93	100	106	111
29:						
TVOL		162	176	187	197	206
WVOL		103	112	120	127	134
31:						
TVOL		190	206	220	231	241
WVOL		122	134	143	152	159
33:						
TVOL		221	240	255	269	281
WVOL		144	157	169	179	187
35:						
TVOL		255	276	294	309	323
WVOL		168	184	197	208	218
37:						
TVOL		291	316	336	354	369
WVOL		194	212	227	241	253
39:						
TVOL		330	358	381	401	419
WVOL		223	244	261	276	290
41:						
TVOL			404	430	453	473
WVOL			278	297	315	330
43:						
TVOL			453	482	507	530
WVOL			314	337	357	374

NOTE: 8LOCK INOICATES RANGE OF DATA.

1/TVOL = TOTAL A8OVEGROUNO VOLUME OF WOOO ANO 8ARK; EXCLUOES FOLIAGE.

WVOL = VOLUME OF WOOD FROM A 1-FOOT STUMP TO A 4-INCH TOP OUTSIDE 8ARK; EXCLUOES BARK ANO FOLIAGE.

Table 14--Total tree, wood, and saw-log volume for blue oak

DIAMETER AT BREAST HEIGHT OUTSIDE BARK 1/	TOTAL HEIGHT (FEET) 20	30	40	50	60	70	80	90	100
INCHES					CUBIC FEET				
5:									
TVOL	2								
WVOL	1								
SVOLI	1								
SVOLX	1								
7:									
TVOL	5	6	6	7					
WVOL	3	3	4	4					
SVOLI	2	3	4	5					
SVOLX	2	2	3	3					
9:									
TVOL	8	10	11	13	14	15			
WVOL	5	6	7	8	9	10			
SVOLI	3	5	6	7	9	10			
SVOLX	2	3	4	5	6	7			
11:									
TVOL	13	16	18	20	22	24	25		
WVOL	9	10	12	14	15	16	17		
SVOLI	5	7	9	11	12	14	16		
SVOLX	3	5	6	7	9	10	11		
13:									
TVOL	20	24	27	30	33	35	37	39	
WVOL	13	16	18	21	23	25	26	28	
SVOLI	7	9	12	14	17	19	21	23	
SVOLX	5	6	8	10	12	13	15	16	
15:									
TVOL	27	33	38	42	46	49	52	55	58
WVOL	19	23	27	30	33	35	38	40	42
SVOLI	9	12	15	18	21	24	27	30	33
SVOLX	6	8	11	13	15	17	19	21	23
17:									
TVOL	37	44	51	56	61	65	70	73	77
WVOL	26	32	36	41	45	48	52	55	58
SVOLI	11	15	19	23	27	31	34	38	41
SVOLX	7	10	13	16	19	21	24	26	29
19:									
TVOL	48	57	66	73	79	85	90	95	100
WVOL	34	42	48	54	59	64	69	73	77
SVOLI	13	18	23	28	33	37	42	46	50
SVOLX	9	13	16	20	23	26	29	32	35
21:									
TVOL	60	72	83	92	100	107	114	120	126
WVOL	44	54	62	70	77	83	89	94	99
SVOLI	16	22	28	34	39	45	50	55	60
SVOLX	11	15	19	23	27	31	35	38	42
23:									
TVOL	74	90	102	113	123	132	141	149	156
WVOL	55	68	79	88	97	104	112	119	125
SVOLI	18	26	33	40	46	53	59	65	71
SVOLX	13	18	23	28	32	37	41	45	49
25:									
TVOL	90	109	124	138	150	161	171	181	190
WVOL	68	84	97	109	119	129	138	147	155
SVOLI	21	30	38	46	54	61	68	76	83
SVOLX	15	21	27	32	37	42	47	52	57
27:									
TVOL		130	149	165	179	192	205	216	227
WVOL		102	118	132	145	157	168	178	188
SVOLI		35	44	53	62	70	79	87	95
SVOLX		24	30	37	43	49	54	60	66
29:									
TVOL		154	176	195	212	227	242	255	268
WVOL		123	142	159	174	188	201	214	225
SVOLI		39	50	60	70	80	89	99	108
SVOLX		27	35	42	49	55	62	68	75
31:									
TVOL		180	205	227	247	265	282	298	313
WVOL		145	168	188	206	223	238	253	267
SVOLI		44	56	68	79	90	101	111	122
SVOLX		31	39	47	55	62	70	77	84
33:									
TVOL		208	237	263	286	307	327	345	362
WVOL		170	197	220	242	261	279	297	313
SVOLI		50	63	76	89	101	113	125	136
SVOLX		34	44	53	61	70	78	86	94
35:									
TVOL		238	272	302	328	352	375	396	415
WVOL		198	228	256	280	303	324	344	363
SVOLI		55	70	85	99	112	125	138	151
SVOLX		38	49	59	68	78	87	96	105
37:									
TVOL		271	310	343	374	401	426	450	473
WVOL		227	263	295	323	349	374	397	418
SVOLI		61	77	93	109	124	139	153	167
SVOLX		42	54	65	75	86	96	106	116
39:									
TVOL		307	350	388	422	453	482	509	534
WVOL		260	301	337	369	399	427	453	478
SVOLI		67	85	103	120	136	152	168	184
SVOLX		46	59	71	83	94	105	116	127

NOTE: BLOCK INDICATES RANGE OF DATA.

1/TVOL = TOTAL ABOVEGROUND VOLUME OF WOOD AND BARK; EXCLUDES FOLIAGE.

WVOL = VOLUME OF WOOD FROM A 1-FOOT STUMP TO A 4-INCH TOP OUTSIDE BARK; EXCLUDES BARK AND FOLIAGE.

SVOLI = SAW-LOG VOLUME IN STRAIGHT MERCHANTABLE SECTIONS AT LEAST 8 FEET LONG TO A 9-INCH TOP OUTSIDE BARK IN TREES WITH A MERCHANTABLE FIRST SECTION ABOVE A 1-FOOT STUMP.

SVOLX = SAW-LOG VOLUME IN STRAIGHT MERCHANTABLE SECTIONS AT LEAST 8 FEET LONG TO A 9-INCH TOP OUTSIDE BARK IN TREES WITHOUT A MERCHANTABLE FIRST SECTION ABOVE A 1-FOOT STUMP.

Table 15--Total tree, wood, and saw-log volume for Pacific madrone

DIAMETER AT BREAST HEIGHT OUTSIDE BARK 1/	TOTAL HEIGHT (FEET)										
	20	30	40	50	60	70	80	90	100	110	120
INCHES	CUBIC FEET										
5:											
TVOL	2	3	3	4							
WVOL	1	2	3	3							
SVOLI	1	2	3	3							
SVOLX	0	1	1	1							
7:											
TVOL	4	5	7	8	9						
WVOL	3	4	5	7	8						
SVOLI	2	3	5	6	8						
SVOLX	1	1	2	3	3						
9:											
TVOL	6	9	11	13	15	18	20				
WVOL	4	6	9	11	13	15	17				
SVOLI	3	5	7	9	12	14	17				
SVOLX	1	2	3	4	5	6	7				
11:											
TVOL	9	13	16	20	23	26	29	32	35	38	
WVOL	6	10	13	16	19	23	26	29	33	36	
SVOLI	4	7	10	13	16	20	24	27	31	35	
SVOLX	2	3	4	5	7	8	10	11	13	15	
13:											
TVOL	13	18	23	27	32	36	40	45	49	53	57
WVOL	9	13	18	23	27	32	36	41	46	50	55
SVOLI	5	9	13	17	22	27	32	37	42	47	53
SVOLX	2	4	5	7	9	11	13	15	18	20	22
15:											
TVOL	17	24	30	36	42	48	54	59	65	70	75
WVOL	12	18	24	30	36	42	48	55	61	67	73
SVOLI	7	12	17	22	28	34	40	47	54	60	68
SVOLX	3	5	7	9	12	14	17	20	22	25	28
17:											
TVOL	22	30	38	46	54	61	69	76	83	89	96
WVOL	15	23	31	39	46	54	62	70	78	86	94
SVOLI	9	15	21	28	35	42	50	58	67	75	84
SVOLX	4	6	9	12	15	18	21	24	28	31	35
19:											
TVOL	27	38	48	58	67	76	85	94	103	111	120
WVOL	19	29	38	48	58	68	77	87	97	107	117
SVOLI	11	18	25	34	42	51	61	71	81	91	102
SVOLX	4	7	11	14	18	21	25	30	34	38	42
21:											
TVOL	33	46	58	70	82	93	104	115	125	135	146
WVOL	23	35	47	59	71	83	95	107	119	131	143
SVOLI	13	21	30	40	50	61	72	84	96	108	121
SVOLX	5	9	13	17	21	26	30	35	40	45	50
23:											
TVOL	39	55	70	84	98	111	124	137	150	162	174
WVOL	28	42	56	70	85	99	113	128	142	157	171
SVOLI	15	24	35	47	59	71	85	98	112	127	141
SVOLX	6	10	15	20	25	30	35	41	47	53	59
25:											
TVOL	46	65	82	99	115	131	146	161	176	191	205
WVOL	33	49	66	83	100	117	134	151	168	185	202
SVOLI	17	28	41	54	68	82	98	113	130	146	163
SVOLX	7	12	17	23	28	34	41	47	54	61	68
27:											
TVOL		75	95	115	134	152	170	188	205	222	239
WVOL		58	77	97	117	136	156	176	196	216	236
SVOLI		32	46	62	78	94	112	129	148	167	186
SVOLX		13	19	26	32	39	47	54	62	70	78

DIAMETER AT BREAST HEIGHT OUTSIOE BARK 1/	TOTAL HEIGHT (FEET)										
	20	30	40	50	60	70	80	90	100	110	120
INCHES	- - - - - - - - - - CUBIC FEET- - - - - - - - - -										
29:											
TVOL		86	110	132	154	175	196	216	236	255	275
WVOL		66	89	112	134	157	180	203	226	249	272
SVOLI		37	53	70	88	107	126	146	167	189	211
SVOLX		15	22	29	37	45	53	61	70	79	88
31:											
TVOL		98	125	151	176	200	223	246	269	291	313
WVOL		76	102	128	154	180	206	232	258	284	310
SVOLI		41	59	78	98	120	142	164	188	212	236
SVOLX		17	25	33	41	50	59	69	79	89	99
33:											
TVOL				171	199	226	253	279	304	329	354
WVOL				144	174	203	233	262	292	322	351
SVOLI				87	110	133	158	183	209	236	263
SVOLX				36	46	56	66	77	87	99	110
35:											
TVOL				191	223	254	283	313	342	370	398
WVOL				162	196	229	262	295	328	362	395
SVOLI				96	121	147	175	203	232	261	292
SVOLX				40	51	62	73	85	97	109	122
37:											
TVOL					249	283	316	349	381	412	444
WVOL					218	255	292	330	367	404	441
SVOLI					134	162	192	223	255	287	321
SVOLX					56	68	80	93	107	120	134
39:											
TVOL					276	314	351	387	422	457	492
WVOL					243	284	325	366	407	449	490
SVOLI					146	178	210	244	279	315	351
SVOLX					61	74	88	102	117	132	147
41:											
TVOL					304	346	387	427	466	505	
WVOL					268	313	359	404	450	496	
SVOLI					159	194	229	266	304	343	
SVOLX					67	81	96	111	127	144	
43:											
TVOL					334	380	425	469	512	554	
WVOL					295	345	395	445	495	545	
SVOLI					173	210	249	289	330	373	
SVOLX					72	88	104	121	138	156	
45:											
TVOL					365	416	465	513	560	606	
WVOL					323	377	432	487	542	597	
SVOLI					187	228	269	313	357	403	
SVOLX					78	95	113	131	149	169	

NOTE: BLOCK INOICATES RANGE OF OATA.

1/TVOL = TOTAL ABOVEGROUNO VOLUME OF WOOO ANO BARK; EXCLUOES FOLIAGE.

WVOL = VOLUME OF WOOD FROM A 1-FOOT STUMP TO A 4-INCH TOP OUTSIOE BARK; EXCLUOES BARK ANO FOLIAGE.

SVOLI = SAW-LOG VOLUME IN STRAIGHT MERCHANTABLE SECTIONS AT LEAST 8 FEET LONG TO A 9-INCH TOP OUTSIDE BARK IN TREES WITH A MERCHANTABLE FIRST SECTION ABOVE A 1-FOOT STUMP.

SVOLX = SAW-LOG VOLUME IN STRAIGHT MERCHANTABLE SECTIONS AT LEAST 8 FEET LONG TO A 9-INCH TOP OUTSIOE BARK IN TREES WITHOUT A MERCHANTABLE FIRST SECTION ABOVE A 1-FOOT STUMP.

Table 16--Total tree, wood, and saw-log volume for Oregon white oak

DIAMETER AT BREAST HEIGHT OUTSIDE BARK 1/	TOTAL HEIGHT (FEET)													
	20	30	40	50	60	70	80	90	100	110	120	130	140	150
INCHES	CUBIC FEET													
5:														
TVOL	2	3	4	4	5									
WVOL	1	2	2	3	3									
SVOLI	1	1	2	2	2									
SVOLX	0	1	1	1	1									
7:														
TVOL	4	6	7	9	10	11	12	13						
WVOL	3	4	5	6	7	8	9	10						
SVOLI	2	2	3	4	4	5	6	6						
SVOLX	1	1	1	2	2	2	3	3						
9:														
TVOL	7	10	12	15	17	19	21	23	25	26	28			
WVOL	5	7	9	10	12	14	16	17	19	21	22			
SVOLI	3	4	5	6	8	9	10	11	12	13	14			
SVOLX	1	2	2	3	4	4	5	5	6	6	7			
11:														
TVOL	11	15	19	23	26	29	32	35	38	41	43			
WVOL	7	10	13	16	19	22	25	27	30	33	35			
SVOLI	4	6	8	10	11	13	15	17	18	20	22			
SVOLX	2	3	4	5	5	6	7	8	9	9	10			
13:														
TVOL	16	22	27	32	37	42	46	50	54	58	62			
WVOL	11	15	20	24	28	32	36	40	44	47	51			
SVOLI	6	9	11	14	16	19	21	24	26	28	31			
SVOLX	3	4	5	7	8	9	10	11	12	13	14			
15:														
TVOL	22	30	37	44	50	56	62	68	74	79	84			
WVOL	15	21	27	33	39	44	50	55	60	66	71			
SVOLI	8	12	15	19	22	25	29	32	35	38	42			
SVOLX	4	6	7	9	10	12	14	15	17	18	20			
17:														
TVOL	29	39	49	57	66	74	81	89	96	103	110			
WVOL	20	28	36	44	51	59	66	73	80	87	94			
SVOLI	11	15	20	24	29	33	37	42	46	50	54			
SVOLX	5	7	9	11	14	16	18	20	22	24	26			
19:														
TVOL	37	50	62	73	84	94	103	113	122	131	140			
WVOL	25	36	46	56	66	75	85	94	103	112	120			
SVOLI	13	19	25	31	36	42	47	53	58	63	68			
SVOLX	6	9	12	15	17	20	22	25	27	30	32			
21:														
TVOL	46	62	77	90	104	116	128	140	151	162	173			
WVOL	32	45	58	70	83	94	106	118	129	140	151			
SVOLI	16	24	31	38	45	52	58	65	71	78	84			
SVOLX	8	11	15	18	21	24	27	31	34	37	40			
23:														
TVOL	56	75	93	110	126	141	156	170	184	197	210	223	236	248
WVOL	39	55	71	86	101	116	130	144	158	172	185	199	212	225
SVOLI	20	29	38	46	54	63	71	79	87	94	102	110	118	125
SVOLX	9	14	18	22	26	29	33	37	41	45	48	52	55	59
25:														
TVOL	67	90	111	131	150	169	186	203	220	236	252	267	282	297
WVOL	47	67	86	104	122	140	157	174	191	207	224	240	256	272
SVOLI	24	34	45	55	65	75	84	94	103	113	122	131	140	149
SVOLX	11	16	21	26	31	35	40	44	49	53	57	62	66	70

DIAMETER AT BREAST HEIGHT OUTSIDE BARK 1/	TOTAL HEIGHT (FEET) 20	30	40	50	60	70	80	90	100	110	120	130	140	150
INCHES	CUBIC FEET													
27:														
TVOL		106	131	155	177	199	220	240	259	278	297	315	333	350
WVOL		80	102	124	146	166	187	207	227	247	266	285	304	323
SVOLI		40	53	64	76	88	99	110	121	132	143	154	165	176
SVOLX		19	25	30	36	41	47	52	57	62	68	73	78	83
29:														
TVOL		124	153	181	207	232	256	279	302	324	346	367	388	408
WVOL		93	120	146	171	196	220	243	267	290	313	335	358	380
SVOLI		47	61	75	89	102	115	128	141	154	167	179	192	204
SVOLX		22	29	35	42	48	54	60	67	73	79	85	90	96
31:														
TVOL		143	177	208	239	267	295	322	349	374	399	423	447	471
WVOL		109	140	170	199	227	255	283	310	337	363	390	416	441
SVOLI		54	70	86	102	117	132	147	162	177	192	206	221	235
SVOLX		26	33	41	48	55	62	70	77	84	90	97	104	111
33:														
TVOL		163	202	238	273	306	338	369	398	428	456	484	512	538
WVOL		125	161	195	229	262	294	326	357	388	419	449	479	508
SVOLI		62	80	98	116	134	151	168	185	202	219	235	252	268
SVOLX		29	38	46	55	63	71	79	87	95	103	111	119	126
35:														
TVOL		185	229	270	309	347	383	418	452	485	518	549	580	611
WVOL		143	184	223	261	299	336	372	408	443	478	512	547	580
SVOLI		70	91	111	132	151	171	190	210	229	248	266	285	303
SVOLX		33	43	53	62	71	81	90	99	108	117	126	134	143
37:														
TVOL		208	258	304	349	391	431	471	509	547	583	619	654	688
WVOL		162	208	253	296	339	381	422	462	502	542	581	620	658
SVOLI		79	102	125	148	170	192	214	236	257	278	299	320	341
SVOLX		37	48	59	70	80	91	101	111	121	131	141	151	161
39:														
TVOL		233	289	341	390	437	483	527	570	612	653	693	732	770
WVOL		182	234	285	334	381	429	475	520	566	610	654	698	741
SVOLI		88	114	140	165	190	215	239	263	287	311	335	358	381
SVOLX		41	54	66	78	90	101	113	124	135	147	158	169	180
41:														
TVOL		260	321	379	434	487	538	587	635	681	726	771	815	857
WVOL		204	262	319	373	427	480	532	583	633	683	732	781	829
SVOLI		98	127	155	184	211	239	266	293	319	346	372	398	424
SVOLX		46	60	73	87	100	113	125	138	150	163	175	188	200
43:														
TVOL		288	356	420	481	539	595	650	703	754	805	854	902	949
WVOL		227	292	355	416	475	534	592	649	705	760	815	870	924
SVOLI		108	140	172	203	234	264	294	323	353	382	411	440	468
SVOLX		51	66	81	96	110	124	139	153	166	180	194	207	221
45:														
TVOL		317	392	463	530	594	656	716	775	831	887	941	994	1047
WVOL		252	324	393	461	527	592	656	719	781	842	903	964	1023
SVOLI		119	154	189	223	257	290	323	356	388	420	452	484	515
SVOLX		56	73	89	105	121	137	152	168	183	198	213	228	243

NOTE: BLOCK INDICATES RANGE OF DATA.

1/TVOL = TOTAL ABOVEGROUND VOLUME OF WOOD AND BARK; EXCLUDES FOLIAGE.

WVOL = VOLUME OF WOOD FROM A 1-FOOT STUMP TO A 4-INCH TOP OUTSIDE BARK; EXCLUDES BARK AND FOLIAGE.

SVOLI = SAW-LOG VOLUME IN STRAIGHT MERCHANTABLE SECTIONS AT LEAST 8 FEET LONG TO A 9-INCH TOP OUTSIDE BARK IN TREES WITH A MERCHANTABLE FIRST SECTION ABOVE A 1-FOOT STUMP.

SVOLX = SAW-LOG VOLUME IN STRAIGHT MERCHANTABLE SECTIONS AT LEAST 8 FEET LONG TO A 9-INCH TOP OUTSIDE BARK IN TREES WITHOUT A MERCHANTABLE FIRST SECTION ABOVE A 1-FOOT STUMP.

Table 17--Total tree, wood, and saw-log volume for canyon live oak

DIAMETER AT BREAST HEIGHT OUTSIDE BARK 1/	TOTAL HEIGHT (FEET)												
	20	30	40	50	60	70	80	90	100	110	120	130	140
INCHES	CUBIC FEET												
5:													
TVOL	2	3	3	4	4								
WVOL	1	2	2	2	3								
SVOLI	1	1	1	2	2								
SVOLX	0	0	0	1	1								
7:													
TVOL	4	6	7	8	9	10	10	11					
WVOL	3	4	5	5	6	7	8	8					
SVOLI	2	2	3	3	4	4	5	5					
SVOLX	1	1	1	1	1	2	2	2					
9:													
TVOL	8	10	12	14	15	17	18	19	21				
WVOL	5	7	8	10	11	12	14	15	16				
SVOLI	3	4	5	6	7	8	9	10	10				
SVOLX	1	1	2	2	3	3	3	4	4				
11:													
TVOL	12	15	18	21	24	26	28	30	32				
WVOL	8	10	13	15	18	20	22	24	26				
SVOLI	4	6	8	9	11	12	14	15	16				
SVOLX	2	2	3	3	4	5	5	6	6				
13:													
TVOL	17	22	27	31	34	38	41	44	47	49	52		
WVOL	11	15	19	23	26	29	32	35	38	41	43		
SVOLI	6	9	11	14	16	18	20	22	24	26	28		
SVOLX	2	3	4	5	6	7	7	8	9	9	10		
15:													
TVOL	24	31	37	42	47	51	56	60	64	68	72		
WVOL	16	22	27	32	36	40	45	49	53	57	60		
SVOLI	9	12	16	19	22	25	27	30	33	35	38		
SVOLX	3	5	6	7	8	9	10	11	12	13	14		
17:													
TVOL	31	40	48	55	62	68	74	79	84	89	94		
WVOL	21	29	36	42	48	54	60	65	71	76	81		
SVOLI	12	16	21	25	29	33	36	40	43	47	50		
SVOLX	4	6	8	9	11	12	13	15	16	17	19		
19:													
TVOL	40	52	62	71	79	87	94	101	108	114	120	127	132
WVOL	28	37	46	55	63	70	77	85	91	98	105	111	117
SVOLI	15	21	26	32	37	42	47	51	56	60	65	69	73
SVOLX	6	8	10	12	14	15	17	19	21	22	24	25	27
21:													
TVOL	50	64	77	88	98	108	117	126	134	142	150	158	165
WVOL	35	47	58	69	79	88	98	107	115	124	132	140	148
SVOLI	19	26	33	40	46	52	58	64	70	75	81	86	92
SVOLX	7	10	12	15	17	19	21	24	26	28	30	32	34
23:													
TVOL	61	79	94	107	120	132	143	154	164	174	184	193	202
WVOL	43	58	72	85	97	109	121	132	143	153	163	173	183
SVOLI	23	32	41	49	57	64	71	79	86	93	99	106	113
SVOLX	9	12	15	18	21	24	26	29	32	34	37	39	41
25:													
TVOL	74	94	113	129	144	159	172	185	197	209	221	232	243
WVOL	52	71	88	103	118	133	147	160	173	186	198	210	222
SVOLI	28	39	49	59	68	77	86	95	103	112	120	128	136
SVOLX	10	14	18	22	25	28	32	35	38	41	44	47	50

DIAMETER AT BREAST HEIGHT OUTSIDE BARK 1/	TOTAL HEIGHT (FEET)												
	20	30	40	50	60	70	80	90	100	110	120	130	140
INCHES	- - - - - -						CUBIC FEET					- - - - - -	
27:													
TVOL	87	112	134	153	171	188	204	219	234	248	262	275	287
WVOL	63	85	105	124	142	159	175	191	207	222	237	251	266
SVOLI	33	46	58	70	81	92	102	113	123	133	142	152	161
SVOLX	12	17	21	26	30	34	38	41	45	49	52	56	59
29:													
TVOL	102	131	156	179	200	220	239	257	274	290	306	322	336
WVOL	74	100	124	146	167	187	207	226	244	262	280	297	314
SVOLI	39	54	68	82	95	108	120	132	144	156	167	178	189
SVOLX	14	20	25	30	35	40	44	49	53	57	62	66	70
31:													
TVOL		152	181	208	232	255	277	297	317	336	355	372	390
WVOL		117	144	170	195	219	242	264	285	306	327	347	366
SVOLI		63	79	95	110	125	140	154	167	181	194	207	220
SVOLX		23	29	35	41	46	51	57	62	67	72	76	81
33:													
TVOL		174	208	238	266	293	318	341	364	386	407	428	447
WVOL		135	167	197	226	253	280	305	330	354	378	401	424
SVOLI		72	91	110	127	144	161	177	193	208	223	238	253
SVOLX		27	34	40	47	53	59	65	71	77	82	88	93
35:													
TVOL		198	237	271	303	333	362	389	415	439	464	487	509
WVOL		155	191	226	259	290	320	350	378	406	433	460	486
SVOLI		83	104	125	145	164	183	202	220	238	255	272	289
SVOLX		30	38	46	53	61	68	74	81	87	94	100	106
37:													
TVOL		224	268	307	343	377	409	439	469	497	524	550	576
WVOL		176	218	257	294	330	365	398	431	462	493	523	553
SVOLI		93	118	142	164	186	208	229	249	269	289	308	327
SVOLX		34	44	52	61	69	76	84	92	99	106	114	121
39:													
TVOL		252	300	344	385	423	459	493	526	558	588	618	647
WVOL		199	246	291	333	373	412	450	487	522	557	591	625
SVOLI		105	133	159	185	210	234	257	280	303	325	347	368
SVOLX		39	49	59	68	77	86	95	103	112	120	128	136
41:													
TVOL				385	430	472	513	551	588	623	657	690	722
WVOL				326	374	419	463	505	547	587	626	664	702
SVOLI				178	207	235	261	288	314	339	364	388	412
SVOLX				66	76	86	96	106	115	125	134	143	152
43:													
TVOL				427	478	525	569	612	653	692	730	766	802
WVOL				365	418	468	517	565	611	655	699	742	784
SVOLI				198	230	261	291	320	349	377	405	432	459
SVOLX				73	85	96	107	118	128	139	149	159	169
45:													
TVOL				472	528	580	630	677	722	765	807	847	887
WVOL				405	464	521	575	628	679	728	777	825	872
SVOLI				220	255	289	322	355	386	417	448	478	508
SVOLX				81	94	106	119	131	142	154	165	176	187

NOTE: BLOCK INDICATES RANGE OF DATA.

1/TVOL = TOTAL ABOVEGROUND VOLUME OF WOOD AND BARK; EXCLUDES FOLIAGE.

WVOL = VOLUME OF WOOD FROM A 1-FOOT STUMP TO A 4-INCH TOP OUTSIDE BARK; EXCLUDES BARK AND FOLIAGE.

SVOLI = SAW-LOG VOLUME IN STRAIGHT MERCHANTABLE SECTIONS AT LEAST 8 FEET LONG TO A 9-INCH TOP OUTSIDE BARK IN TREES WITH A MERCHANTABLE FIRST SECTION ABOVE A 1-FOOT STUMP.

SVOLX = SAW-LOG VOLUME IN STRAIGHT MERCHANTABLE SECTIONS AT LEAST 8 FEET LONG TO A 9-INCH TOP OUTSIDE BARK IN TREES WITHOUT A MERCHANTABLE FIRST SECTION ABOVE A 1-FOOT STUMP.

Table 18--Total tree, wood, and saw-log volume for coast live oak

DIAMETER AT BREAST HEIGHT OUTSIDE BARK 1/	TOTAL HEIGHT (FEET)												
	20	30	40	50	60	70	80	90	100	110	120	130	140
INCHES	CUBIC FEET												
5:													
TVOL	2	2	3										
WVOL	1	1	1										
SVOLI	1	1	1										
SVOLX	0	0	0										
7:													
TVOL	4	5	6	7	8	8							
WVOL	2	3	3	4	4	4							
SVOLI	2	2	3	3	4	4							
SVOLX	1	1	1	1	1	2							
9:													
TVOL	7	9	11	12	14	15	17						
WVOL	4	5	6	7	8	8	9						
SVOLI	3	4	5	6	7	8	9						
SVOLX	1	1	2	2	3	3	3						
11:													
TVOL	11	14	17	20	22	24	26						
WVOL	7	8	10	11	13	14	15						
SVOLI	4	6	8	9	11	12	14						
SVOLX	2	2	3	3	4	5	5						
13:													
TVOL	16	21	25	29	32	36	39	42	45	47			
WVOL	10	13	15	18	20	22	23	25	27	28			
SVOLI	6	9	11	14	16	18	20	22	24	26			
SVOLX	2	3	4	5	6	7	7	8	9	9			
15:													
TVOL	23	29	35	40	45	50	54	58	62	66			
WVOL	14	18	22	25	28	31	34	36	38	41			
SVOLI	9	12	16	19	22	25	27	30	33	35			
SVOLX	3	5	6	7	8	9	10	11	12	13			
17:													
TVOL	30	39	47	54	60	66	72	78	83	88	93	98	102
WVOL	20	25	30	35	39	42	46	49	53	56	59	62	65
SVOLI	12	16	21	25	29	33	36	40	43	47	50	54	57
SVOLX	4	6	8	9	11	12	13	15	16	17	19	20	21
19:													
TVOL	39	51	61	70	78	86	93	101	107	114	120	127	133
WVOL	26	34	40	46	51	56	61	66	70	74	78	82	86
SVOLI	15	21	26	32	37	42	47	51	56	60	65	69	73
SVOLX	6	8	10	12	14	15	17	19	21	22	24	25	27
21:													
TVOL	50	64	76	88	99	108	118	127	136	144	152	160	167
WVOL	34	43	52	59	66	73	79	85	90	95	101	106	111
SVOLI	19	26	33	40	46	52	58	64	70	75	81	86	92
SVOLX	7	10	12	15	17	19	21	24	26	28	30	32	34
23:													
TVOL	61	79	94	109	122	134	146	157	167	178	188	197	207
WVOL	43	55	65	74	83	91	99	106	113	120	127	133	139
SVOLI	23	32	41	49	57	64	71	79	86	93	99	106	113
SVOLX	9	12	15	18	21	24	26	29	32	34	37	39	41
25:													
TVOL	74	96	115	132	148	163	177	190	203	216	228	239	251
WVOL	53	67	80	92	103	113	122	131	140	148	157	164	172
SVOLI	28	39	49	59	68	77	86	95	103	112	120	128	136
SVOLX	10	14	18	22	25	28	32	35	38	41	44	47	50

DIAMETER AT BREAST HEIGHT OUTSIDE BARK 1/	TOTAL HEIGHT (FEET)												
	20	30	40	50	60	70	80	90	100	110	120	130	140
INCHES	CUBIC FEET												
27:													
TVOL		114	137	157	176	194	211	227	243	258	272	286	300
WVOL		82	98	112	125	137	149	160	170	180	190	200	209
SVOLI		46	58	70	81	92	102	113	123	133	142	152	161
SVOLX		17	21	26	30	34	38	41	45	49	52	56	59
29:													
TVOL		135	162	186	208	229	249	268	287	304	321	338	354
WVOL		98	117	134	150	164	178	191	204	216	228	239	250
SVOLI		54	68	82	95	108	120	132	144	156	167	178	189
SVOLX		20	25	30	35	40	44	49	53	57	62	66	70
31:													
TVOL		158	189	217	243	268	291	313	335	355	375	394	413
WVOL		116	138	159	177	195	211	227	242	256	270	283	296
SVOLI		63	79	95	110	125	140	154	167	181	194	207	220
SVOLX		23	29	35	41	46	51	57	62	67	72	76	81
33:													
TVOL		182	218	251	281	310	336	362	387	411	434	456	477
WVOL		136	162	186	208	228	247	266	283	300	316	332	347
SVOLI		72	91	110	127	144	161	177	193	208	223	238	253
SVOLX		27	34	40	47	53	59	65	71	77	82	88	93
35:													
TVOL		209	250	287	322	355	386	415	443	471	497	522	547
WVOL		158	188	216	241	265	287	308	329	348	367	385	403
SVOLI		83	104	125	145	164	183	202	220	238	255	272	289
SVOLX		30	38	46	53	61	68	74	81	87	94	100	106
37:													
TVOL		238	284	327	366	404	439	472	504	535	565	594	623
WVOL		182	217	248	277	305	330	355	378	401	423	444	464
SVOLI		93	118	142	164	186	208	229	249	269	289	308	327
SVOLX		34	44	52	61	69	76	84	92	99	106	114	121
39:													
TVOL			321	369	414	456	496	534	570	605	639	672	703
WVOL			248	284	317	348	377	405	432	458	483	507	530
SVOLI			133	159	185	210	234	257	280	303	325	347	368
SVOLX			49	59	68	77	86	95	103	112	120	128	136
41:													
TVOL			361	415	465	512	557	599	640	679	717	754	790
WVOL			281	322	360	395	428	460	491	520	548	575	602
SVOLI			149	178	207	235	261	288	314	339	364	388	412
SVOLX			55	66	76	86	96	106	115	125	134	143	152
43:													
TVOL			403	463	519	572	622	669	715	759	801	842	882
WVOL			317	363	406	446	483	519	553	586	618	649	679
SVOLI			166	198	230	261	291	320	349	377	405	432	459
SVOLX			61	73	85	96	107	118	128	139	149	159	169
45:													
TVOL			448	515	577	635	691	744	794	843	890	936	980
WVOL			356	408	455	500	542	582	621	658	694	728	762
SVOLI			183	220	255	289	322	355	386	417	448	478	508
SVOLX			68	81	94	106	119	131	142	154	165	176	187

NOTE: BLOCK INDICATES RANGE OF DATA.

1/TVOL = TOTAL ABOVEGROUND VOLUME OF WOOD AND BARK; EXCLUDES FOLIAGE.

WVOL = VOLUME OF WOOD FROM A 1-FOOT STUMP TO A 4-INCH TOP OUTSIDE BARK; EXCLUDES BARK AND FOLIAGE.

SVOLI = SAW-LOG VOLUME IN STRAIGHT MERCHANTABLE SECTIONS AT LEAST 8 FEET LONG TO A 9-INCH TOP OUTSIDE BARK IN TREES WITH A MERCHANTABLE FIRST SECTION ABOVE A 1-FOOT STUMP.

SVOLX = SAW-LOG VOLUME IN STRAIGHT MERCHANTABLE SECTIONS AT LEAST 8 FEET LONG TO A 9-INCH TOP OUTSIDE BARK IN TREES WITHOUT A MERCHANTABLE FIRST SECTION ABOVE A 1-FOOT STUMP.

Table 19—Total tree, wood, and saw-log volume for interior live oak

DIAMETER AT BREAST HEIGHT OUTSIDE BARK 1/	TOTAL HEIGHT (FEET) 20	30	40	50	60	70	80	90	100	110	120	130
INCHES	CUBIC FEET											
5:												
TVOL	2	3	4									
WVOL	1	2	2									
SVOLI	1	1	1									
SVOLX	0	0	0									
7:												
TVOL	5	6	7	8	9	10						
WVOL	3	4	5	6	7	7						
SVOLI	2	2	3	3	4	4						
SVOLX	1	1	1	1	1	2						
9:												
TVOL	8	10	12	14	16	17	19	20				
WVOL	5	7	8	10	11	13	14	15				
SVOLI	3	4	5	6	7	8	9	10				
SVOLX	1	1	2	2	3	3	3	4				
11:												
TVOL	12	15	18	21	24	26	28	31				
WVOL	7	10	13	15	17	19	22	24				
SVOLI	4	6	8	9	11	12	14	15				
SVOLX	2	2	3	3	4	5	5	6				
13:												
TVOL	17	21	26	30	33	37	40	43				
WVOL	11	14	18	21	25	28	31	34				
SVOLI	6	9	11	14	16	18	20	22				
SVOLX	2	3	4	5	6	7	7	8				
15:												
TVOL	22	29	34	40	44	49	53	58				
WVOL	14	20	25	29	34	38	42	46				
SVOLI	9	12	16	19	22	25	27	30				
SVOLX	3	5	6	7	8	9	10	11				
17:												
TVOL	29	37	44	51	57	63	69	74	79			
WVOL	19	26	32	38	44	50	55	60	65			
SVOLI	12	16	21	25	29	33	36	40	43			
SVOLX	4	6	8	9	11	12	13	15	16			
19:												
TVOL	36	46	56	64	72	79	86	93	99			
WVOL	24	33	41	48	56	63	70	77	83			
SVOLI	15	21	26	32	37	42	47	51	56			
SVOLX	6	8	10	12	14	15	17	19	21			
21:												
TVOL	44	57	68	78	88	97	106	114	122	129		
WVOL	29	40	51	60	69	78	87	95	103	111		
SVOLI	19	26	33	40	46	52	58	64	70	75		
SVOLX	7	10	12	15	17	19	21	24	26	28		
23:												
TVOL	53	68	82	94	106	117	127	137	146	155		
WVOL	36	49	61	73	84	95	105	116	125	135		
SVOLI	23	32	41	49	57	64	71	79	86	93		
SVOLX	9	12	15	18	21	24	26	29	32	34		
25:												
TVOL	63	81	97	112	125	138	151	162	173	184	195	205
WVOL	43	59	74	87	101	114	126	138	150	162	173	184
SVOLI	28	39	49	59	68	77	86	95	103	112	120	128
SVOLX	10	14	18	22	25	28	32	35	38	41	44	47

DIAMETER AT BREAST HEIGHT OUTSIDE BARK 1/	TOTAL HEIGHT (FEET) 20	30	40	50	60	70	80	90	100	110	120	130
INCHES	- - - - - - - -	- - - -	- - - -	- - - -	- - - -	CUBIC FEET-	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -
27:												
TVOL		95	114	131	147	162	176	190	203	215	227	239
WVOL		69	87	103	119	134	149	163	177	191	204	217
SVOLI		46	58	70	81	92	102	113	123	133	142	152
SVOLX		17	21	26	30	34	38	41	45	49	52	56
29:												
TVOL		109	131	151	170	187	203	219	234	249	263	277
WVOL		81	101	120	139	156	173	190	206	222	238	253
SVOLI		54	68	82	95	108	120	132	144	156	167	178
SVOLX		20	25	30	35	40	44	49	53	57	62	66
31:												
TVOL		125	150	173	194	214	233	251	268	285	301	317
WVOL		93	117	139	160	180	200	219	238	256	274	292
SVOLI		63	79	95	110	125	140	154	167	181	194	207
SVOLX		23	29	35	41	46	51	57	62	67	72	76
33:												
TVOL		142	171	196	220	243	264	285	305	324	342	360
WVOL		107	133	159	183	206	229	251	272	293	314	334
SVOLI		72	91	110	127	144	161	177	193	208	223	238
SVOLX		27	34	40	47	53	59	65	71	77	82	88
35:												
TVOL		160	192	221	248	274	298	321	343	365	385	405
WVOL		121	151	180	208	234	260	285	309	333	356	379
SVOLI		83	104	125	145	164	183	202	220	238	255	272
SVOLX		30	38	46	53	61	68	74	81	87	94	100
37:												
TVOL		179	215	248	278	307	334	359	384	408	431	454
WVOL		136	171	203	234	264	293	321	348	375	401	427
SVOLI		93	118	142	164	186	208	229	249	269	289	308
SVOLX		34	44	52	61	69	76	84	92	99	106	114
39:												
TVOL		200	239	276	309	341	371	400	428	454	480	505
WVOL		153	191	227	262	295	328	359	390	420	450	478
SVOLI		105	133	159	185	210	234	257	280	303	325	347
SVOLX		39	49	59	68	77	86	95	103	112	120	128
41:												
TVOL			265	305	343	378	411	443	473	503	531	559
WVOL			213	253	292	329	365	400	434	468	501	533
SVOLI			149	178	207	235	261	288	314	339	364	388
SVOLX			55	66	76	86	96	106	115	125	134	143
43:												
TVOL			292	336	377	416	453	488	521	554	585	615
WVOL			236	280	323	364	404	443	481	518	554	590
SVOLI			166	198	230	261	291	320	349	377	405	432
SVOLX			61	73	85	96	107	118	128	139	149	159
45:												
TVOL			320	369	414	456	496	535	572	607	642	675
WVOL			260	309	356	402	446	489	530	571	611	651
SVOLI			183	220	255	289	322	355	386	417	448	478
SVOLX			68	81	94	106	119	131	142	154	165	176

NOTE: BLOCK INDICATES RANGE OF DATA.

1/TVOL = TOTAL ABOVEGROUND VOLUME OF WOOD AND BARK; EXCLUDES FOLIAGE.

WVOL = VOLUME OF WOOD FROM A 1-FOOT STUMP TO A 4-INCH TOP OUTSIDE BARK; EXCLUDES BARK AND FOLIAGE.

SVOLI = SAW-LOG VOLUME IN STRAIGHT MERCHANTABLE SECTIONS AT LEAST 8 FEET LONG TO A 9-INCH TOP OUTSIDE BARK IN TREES WITH A MERCHANTABLE FIRST SECTION ABOVE A 1-FOOT STUMP.

SVOLX = SAW-LOG VOLUME IN STRAIGHT MERCHANTABLE SECTIONS AT LEAST 8 FEET LONG TO A 9-INCH TOP OUTSIDE BARK IN TREES WITHOUT A MERCHANTABLE FIRST SECTION ABOVE A 1-FOOT STUMP.

Table 20--Total tree, wood, and saw-log volume for giant chinkapin

OIAMETER AT BREAST HEIGHT OUTSIOE BARK 1/	TOTAL HEIGHT (METERS)													
	3	6	9	12	15	18	21	24	27	30	33	36	39	42
CENTIMETERS	CUBIC METERS													
10:														
TVOL	0.03	0.04	0.06	0.07	0.08	0.09	0.10							
WVOL	.02	.03	.04	.05	.05	.06	.07							
SVOL	.01	.01	.02	.02	.03	.03	.04							
20:														
TVOL	.11	.17	.23	.28	.32	.36	.40	0.44	0.48					
WVOL	.07	.11	.15	.19	.23	.26	.30	.33	.36					
SVOL	.04	.07	.10	.12	.15	.17	.19	.21	.23					
30:														
TVOL	.24	.39	.51	.63	.73	.83	.92	1.01	1.09	1.17	1.25	1.33		
WVOL	.15	.26	.36	.45	.53	.61	.69	.77	.84	.91	.98	1.05		
SVOL	.11	.19	.26	.33	.39	.45	.50	.56	.61	.66	.71	.76		
40:														
TVOL		.70	.92	1.12	1.30	1.48	1.64	1.80	1.95	2.10	2.24	2.38		
WVOL		.48	.65	.81	.97	1.11	1.26	1.39	1.53	1.65	1.78	1.91		
SVOL		.38	.52	.65	.77	.89	1.00	1.11	1.22	1.32	1.42	1.52		
50:														
TVOL			1.44	1.76	2.05	2.32	2.58	2.83	3.06	3.29	3.52	3.73	3.94	4.15
WVOL			1.03	1.29	1.54	1.77	1.99	2.21	2.42	2.63	2.83	3.03	3.22	3.41
SVOL			.89	1.11	1.31	1.51	1.70	1.89	2.07	2.24	2.41	2.58	2.75	2.91
60:														
TVOL			2.08	2.54	2.96	3.35	3.73	4.09	4.43	4.76	5.09	5.40	5.70	6.00
WVOL			1.51	1.89	2.24	2.58	2.91	3.23	3.53	3.83	4.13	4.42	4.70	4.98
SVOL			1.37	1.71	2.03	2.34	2.63	2.92	3.19	3.46	3.73	3.99	4.24	4.49
70:														
TVOL				3.47	4.04	4.58	5.09	5.58	6.05	6.51	6.95	7.37	7.79	8.20
WVOL				2.59	3.08	3.55	4.00	4.44	4.86	5.28	5.68	6.08	6.47	6.85
SVOL				2.47	2.93	3.37	3.80	4.21	4.61	5.00	5.38	5.76	6.12	6.48
80:														
TVOL				4.54	5.30	6.00	6.67	7.31	7.93	8.52	9.10	9.66	10.20	10.74
WVOL				3.42	4.07	4.68	5.28	5.85	6.41	6.96	7.49	8.01	8.53	9.03
SVOL				3.39	4.03	4.64	5.22	5.79	6.34	6.88	7.40	7.91	8.42	8.91

NOTE: BLOCK INDICATES RANGE OF OATA.

1/TVOL = TOTAL ABOVEGROUNO VOLUME OF WOOO ANO BARK; EXCLUDES FOLIAGE.

WVOL = VOLUME OF WOOO FROM A 0.3 METER STUMP TO A 10-CENTIMETER TOP OUTSIOE BARK; EXCLUOES BARK ANO FOLIAGE.

SVOL = SAW-LOG VOLUME IN STRAIGHT MERCHANTABLE SECTIONS AT LEAST 2.5 METERS LONG TO A 23-CENTIMETER TOP OUTSIDE BARK ABOVE A 0.3-METER STUMP.

Table 21--Total tree, wood, and saw-log volume for California-laurel

DIAMETER AT BREAST HEIGHT OUTSIDE BARK 1/	TOTAL HEIGHT (METERS) 3	6	9	12	15	18	21	24	27	30	33	36	39
CENTIMETERS	CUBIC METERS												
10:													
TVOL	0.02	0.03	0.05	0.06	0.07	0.09	0.10	0.11					
WVOL	.01	.02	.03	.04	.05	.06	.07	.08					
SVOL	.00	.01	.02	.02	.03	.03	.04	.04					
20:													
TVOL	.07	.13	.18	.23	.28	.33	.38	.43	0.48	0.52			
WVOL	.04	.07	.11	.16	.20	.24	.28	.32	.36	.41			
SVOL	.02	.05	.07	.10	.12	.15	.18	.20	.23	.25			
30:													
TVOL	.15	.28	.40	.51	.63	.73	.84	.95	1.05	1.15	1.25	1.36	1.45
WVOL	.08	.17	.26	.36	.45	.55	.65	.74	.84	.94	1.04	1.14	1.24
SVOL	.06	.12	.18	.24	.31	.37	.43	.50	.56	.63	.69	.76	.83
40:													
TVOL		.49	.70	.90	1.09	1.29	1.47	1.66	1.84	2.02	2.20	2.37	2.55
WVOL		.31	.48	.65	.82	.99	1.17	1.34	1.52	1.70	1.88	2.06	2.24
SVOL		.23	.34	.46	.58	.70	.83	.95	1.07	1.20	1.32	1.44	1.57
50:													
TVOL		.75	1.08	1.39	1.69	1.98	2.27	2.56	2.84	3.12	3.39	3.66	3.93
WVOL		.49	.76	1.03	1.30	1.57	1.85	2.13	2.41	2.69	2.97	3.26	3.55
SVOL		.37	.56	.76	.96	1.16	1.36	1.56	1.76	1.97	2.17	2.38	2.58
60:													
TVOL		1.07	1.53	1.98	2.41	2.83	3.24	3.65	4.05	4.44	4.83	5.22	5.60
WVOL		.72	1.10	1.49	1.89	2.29	2.69	3.10	3.50	3.92	4.33	4.74	5.16
SVOL		.56	.85	1.14	1.44	1.74	2.04	2.34	2.65	2.95	3.26	3.57	3.88
70:													
TVOL		1.45	2.07	2.67	3.25	3.82	4.38	4.92	5.46	6.00	6.52	7.05	7.56
WVOL		.99	1.51	2.05	2.59	3.14	3.69	4.25	4.81	5.38	5.95	6.52	7.09
SVOL		.78	1.20	1.61	2.03	2.45	2.88	3.30	3.73	4.17	4.60	5.03	5.47
80:													
TVOL				3.46	4.21	4.95	5.67	6.38	7.08	7.78	8.46	9.14	9.80
WVOL				2.70	3.41	4.13	4.86	5.60	6.34	7.08	7.83	8.58	9.33
SVOL				2.17	2.73	3.30	3.88	4.45	5.03	5.61	6.19	6.78	7.36
90:													
TVOL					5.30	6.23	7.13	8.03	8.91	9.78	10.64	11.49	12.33
WVOL					4.35	5.27	6.20	7.13	8.08	9.02	9.98	10.93	11.89
SVOL					3.56	4.30	5.04	5.79	6.54	7.30	8.05	8.81	9.58
100:													
TVOL					6.50	7.64	8.76	9.85	10.94	12.00	13.06	14.10	15.14
WVOL					5.40	6.55	7.70	8.86	10.03	11.21	12.39	13.58	14.78
SVOL					4.50	5.43	6.37	7.32	8.27	9.23	10.19	11.15	12.11
110:													
TVOL					7.83	9.20	10.54	11.86	13.16	14.45	15.72	16.97	18.22
WVOL					6.57	7.97	9.37	10.78	12.21	13.64	15.08	16.53	17.98
SVOL					5.56	6.72	7.88	9.06	10.23	11.41	12.60	13.79	14.98

NOTE: BLOCK INOICATES RANGE OF OATA.

1/TVOL = TOTAL ABOVEGROUND VOLUME OF WOOO AND BARK; EXCLUDES FOLIAGE.

WVOL = VOLUME OF WOOD FROM A 0.3 METER STUMP TO A 10-CENTIMETER TOP OUTSIDE BARK; EXCLUDES BARK AND FOLIAGE.

SVOL = SAW-LOG VOLUME IN STRAIGHT MERCHANTABLE SECTIONS AT LEAST 2.5 METERS LONG TO A 23-CENTIMETER TOP OUTSIDE BARK ABOVE A 0.3-METER STUMP.

Table 22--Total tree, wood, and saw-log volume for tanoak

DIAMETER AT BREAST HEIGHT OUTSIDE BARK 1/	TOTAL HEIGHT (METERS) 3	6	9	12	15	18	21	24	27	30	33	36	39
CENTIMETERS	CUBIC METERS												
10:													
TVOL	0.02	0.03	0.04	0.06	0.07	0.08	0.09	0.10					
WVOL	.00	.01	.02	.02	.03	.03	.04	.05					
SVOL	.00	.01	.01	.01	.02	.02	.03	.03					
20:													
TVOL	.07	.12	.17	.22	.27	.31	.36	.40	0.44	0.49			
WVOL	.02	.05	.07	.10	.13	.16	.19	.22	.25	.29			
SVOL	.01	.03	.05	.07	.09	.12	.14	.17	.19	.22			
30:													
TVOL	.15	.27	.38	.48	.59	.69	.79	.88	.98	1.07	1.16		
WVOL	.05	.11	.18	.24	.32	.39	.46	.54	.62	.69	.77		
SVOL	.03	.08	.13	.18	.24	.30	.36	.42	.49	.55	.62		
40:													
TVOL		.46	.66	.85	1.03	1.20	1.37	1.54	1.71	1.87	2.03	2.19	2.35
WVOL		.21	.33	.46	.59	.73	.87	1.01	1.16	1.31	1.46	1.61	1.76
SVOL		.15	.25	.36	.47	.58	.70	.82	.95	1.08	1.21	1.34	1.48
50:													
TVOL		.72	1.02	1.30	1.58	1.85	2.12	2.38	2.63	2.88	3.13	3.38	3.62
WVOL		.34	.54	.75	.97	1.19	1.42	1.65	1.89	2.13	2.38	2.63	2.88
SVOL		.26	.42	.60	.78	.97	1.17	1.38	1.59	1.80	2.03	2.25	2.48
60:													
TVOL			1.45	1.86	2.25	2.64	3.02	3.39	3.75	4.11	4.46	4.81	5.16
WVOL			.81	1.12	1.44	1.78	2.12	2.47	2.82	3.18	3.55	3.92	4.29
SVOL			.64	.91	1.19	1.48	1.79	2.10	2.42	2.75	3.09	3.43	3.78
70:													
TVOL			1.95	2.51	3.04	3.56	4.07	4.57	5.06	5.54	6.02	6.49	6.96
WVOL			1.13	1.57	2.02	2.49	2.97	3.46	3.96	4.46	4.98	5.50	6.02
SVOL			.91	1.29	1.70	2.11	2.55	3.00	3.46	3.93	4.41	4.89	5.39
80:													
TVOL					3.94	4.62	5.28	5.92	6.56	7.18	7.80	8.41	9.01
WVOL					2.71	3.34	3.98	4.64	5.31	5.99	6.67	7.37	8.07
SVOL					2.31	2.88	3.47	4.08	4.70	5.34	6.00	6.66	7.34
90:													
TVOL					4.96	5.80	6.63	7.44	8.24	9.03	9.81	10.57	11.33
WVOL					3.52	4.33	5.16	6.01	6.87	7.75	8.64	9.54	10.46
SVOL					3.03	3.78	4.55	5.35	6.17	7.01	7.87	8.75	9.64
100:													
TVOL					6.08	7.12	8.14	9.13	10.11	11.08	12.03	12.97	13.90
WVOL					4.43	5.46	6.50	7.57	8.66	9.77	10.89	12.03	13.18
SVOL					3.87	4.82	5.81	6.83	7.87	8.95	10.04	11.16	12.29
110:													
TVOL					7.32	8.57	9.79	10.99	12.17	13.33	14.48	15.61	16.73
WVOL					5.46	6.73	8.02	9.34	10.68	12.04	13.43	14.83	16.25
SVOL					4.82	6.01	7.24	8.51	9.81	11.15	12.51	13.90	15.32
120:													
TVOL					8.66	10.14	11.59	13.01	14.41	15.78	17.14	18.48	
WVOL					6.61	8.14	9.71	11.30	12.93	14.58	16.25	17.95	
SVOL					5.89	7.34	8.85	10.40	12.00	13.63	15.30	17.00	

NOTE: BLOCK INDICATES RANGE OF DATA.

1/TVOL = TOTAL ABOVEGROUND VOLUME OF WOOD AND BARK; EXCLUDES FOLIAGE.

WVOL = VOLUME OF WOOD FROM A 0.3 METER STUMP TO A 10-CENTIMETER TOP OUTSIDE BARK; EXCLUDES BARK AND FOLIAGE.

SVOL = SAW-LOG VOLUME IN STRAIGHT MERCHANTABLE SECTIONS AT LEAST 2.5 METERS LONG TO A 23-CENTIMETER TOP OUTSIDE BARK ABOVE A 0.3-METER STUMP.

Table 23--Total tree, wood, and saw-log volume for California white oak

DIAMETER AT BREAST HEIGHT OUTSIDE BARK 1/	TOTAL HEIGHT (METERS) 3	6	9	12	15	18	21	24	27	30	33	36	39
CENTIMETERS	CUBIC METERS												
10:													
TVOL	0.02	0.03	0.04	0.05									
WVOL	.01	.01	.02	.03									
SVOL	.00	.01	.02	.03									
20:													
TVOL	.08	.14	.19	.24	0.28	0.32	0.36	0.40					
WVOL	.04	.07	.11	.15	.18	.22	.25	.29					
SVOL	.01	.03	.06	.10	.14	.19	.25	.31					
30:													
TVOL	.22	.36	.49	.61	.72	.82	.92	1.02	1.12				
WVOL	.10	.19	.29	.38	.48	.57	.67	.76	.86				
SVOL	.02	.07	.13	.21	.30	.41	.53	.65	.79				
40:													
TVOL		[illegible]	.96	1.19	1.41	1.61	1.81	2.00	2.18	2.36	2.54		
WVOL		.39	.58	.76	.95	1.14	1.33	1.52	1.71	1.89	2.08		
SVOL		.12	.23	.36	.52	.70	.90	1.12	1.36	1.61	1.88		
50:													
TVOL		1.19	1.62	2.00	2.37	2.72	3.05	3.37	3.68	3.98	4.28		
WVOL		.66	.98	1.31	1.63	1.95	2.27	2.59	2.91	3.23	3.55		
SVOL		.18	.35	.55	.79	1.07	1.37	1.70	2.06	2.45	2.86		
60:													
TVOL		1.83	2.47	3.07	3.63	4.16	4.67	5.16	5.63	6.10	6.55	6.99	7.42
WVOL		1.02	1.52	2.02	2.52	3.02	3.51	4.01	4.50	5.00	5.49	5.99	6.48
SVOL		.25	.49	.78	1.12	1.50	1.93	2.40	2.90	3.44	4.02	4.63	5.27
70:													
TVOL			3.55	4.40	5.20	5.96	6.69	7.39	8.07	8.74	9.38	10.02	10.63
WVOL			2.20	2.92	3.64	4.36	5.08	5.80	6.52	7.23	7.95	8.66	9.37
SVOL			.65	1.04	1.49	2.00	2.57	3.20	3.87	4.59	5.36	6.18	7.03
80:													
TVOL			4.85	6.01	7.10	8.14	9.14	10.10	11.03	11.94	12.82	13.68	14.53
WVOL			3.03	4.02	5.02	6.01	7.00	7.99	8.97	9.96	10.94	11.93	12.91
SVOL			.83	1.33	1.91	2.57	3.31	4.11	4.97	5.90	6.89	7.93	9.03
90:													
TVOL					9.35	10.72	12.03	13.30	14.53	15.72	16.88	18.02	19.13
WVOL					6.65	7.97	9.28	10.59	11.90	13.20	14.51	15.81	17.11
SVOL					2.39	3.21	4.12	5.12	6.20	7.36	8.59	9.89	11.26
100:													
TVOL					11.96	13.71	15.39	17.01	18.58	20.10	21.59	23.04	24.47
WVOL					8.56	10.26	11.94	13.63	15.31	17.00	18.67	20.35	22.03
SVOL					2.91	3.91	5.02	6.24	7.55	8.96	10.46	12.05	13.72
110:													
TVOL					14.95	17.14	19.23	21.25	23.21	25.12	26.98	28.79	30.57
WVOL					10.76	12.89	15.01	17.13	19.24	21.35	23.46	25.57	27.68
SVOL					3.47	4.67	6.00	7.46	9.03	10.71	12.51	14.41	16.41
120:													
TVOL					18.32	21.00	23.57	26.04	28.45	30.78	33.06	35.28	37.46
WVOL					13.25	15.87	18.49	21.10	23.70	26.30	28.90	31.50	34.09
SVOL					4.09	5.50	7.06	8.78	10.63	12.61	14.72	16.96	19.31
130:													
TVOL					22.09	25.32	28.41	31.40	34.30	37.11	39.86	42.54	45.17
WVOL					16.06	19.23	22.39	25.55	28.71	31.86	35.01	38.16	41.30
SVOL					4.75	6.39	8.21	10.20	12.35	14.65	17.10	19.70	22.43

NOTE: BLOCK INDICATES RANGE OF DATA.

1/TVOL = TOTAL ABOVEGROUND VOLUME OF WOOD AND BARK; EXCLUDES FOLIAGE.

WVOL = VOLUME OF WOOD FROM A 0.3 METER STUMP TO A 10-CENTIMETER TOP OUTSIDE BARK; EXCLUDES BARK AND FOLIAGE.

SVOL = SAW-LOG VOLUME IN STRAIGHT MERCHANTABLE SECTIONS AT LEAST 2.5 METERS LONG TO A 23-CENTIMETER TOP OUTSIDE BARK ABOVE A 0.3-METER STUMP.

Table 24--Total tree, wood, and saw-log volume for bigleaf maple

DIAMETER AT BREAST HEIGHT OUTSIDE BARK 1/	TOTAL HEIGHT (METERS) 3	6	9	12	15	18	21	24	27	30	33	36	39	42
CENTIMETERS	- - - - - -	- - - -	- - - -	- - - -	- - - -	- - - -	- - - CUBIC	METERS - - -	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -
10:														
TVOL	0.02	0.03	0.04	0.05	0.06									
WVOL	.01	.02	.03	.03	.04									
SVOLI	.01	.01	.02	.03	.04									
SVOLX	.00	.01	.01	.01	.01									
20:														
TVOL	.11	.16	.20	.24	.27	0.30	0.32	0.35						
WVOL	.06	.10	.13	.16	.19	.21	.24	.26						
SVOLI	.03	.06	.09	.12	.16	.19	.23	.26						
SVOLX	.01	.02	.04	.05	.06	.08	.09	.11						
30:														
TVOL	.26	.39	.49	.58	.66	.73	.80	.86	0.92					
WVOL	.16	.26	.34	.42	.49	.55	.62	.68	.73					
SVOLI	.06	.14	.21	.29	.37	.45	.54	.62	.71					
SVOLX	.03	.05	.09	.12	.15	.18	.21	.25	.28					
40:														
TVOL		.74	.93	1.10	1.25	1.39	1.52	1.64	1.75	1.86	1.97			
WVOL		.51	.67	.82	.96	1.09	1.21	1.33	1.44	1.55	1.66			
SVOLI		.25	.39	.54	.68	.83	.98	1.14	1.29	1.45	1.61			
SVOLX		.10	.16	.21	.27	.33	.39	.45	.51	.58	.64			
50:														
TVOL		1.21	1.53	1.81	2.05	2.28	2.49	2.69	2.88	3.06	3.23	3.40		
WVOL		.86	1.14	1.39	1.62	1.84	2.05	2.25	2.44	2.62	2.80	2.98		
SVOLI		.40	.63	.86	1.09	1.33	1.57	1.82	2.07	2.32	2.57	2.83		
SVOLX		.16	.25	.34	.43	.53	.63	.72	.82	.92	1.02	1.12		
60:														
TVOL			2.30	2.71	3.08	3.42	3.74	4.04	4.32	4.59	4.85	5.10	5.34	5.57
WVOL			1.74	2.13	2.49	2.82	3.14	3.45	3.74	4.03	4.31	4.57	4.84	5.09
SVOLI			.92	1.26	1.60	1.95	2.31	2.67	3.03	3.40	3.77	4.15	4.52	4.90
SVOLX			.37	.50	.64	.78	.92	1.06	1.21	1.35	1.50	1.65	1.80	1.95
70:														
TVOL					4.34	4.82	5.27	5.69	6.09	6.47	6.84	7.19	7.53	7.86
WVOL					3.58	4.06	4.52	4.96	5.38	5.79	6.19	6.58	6.95	7.32
SVOLI					2.22	2.70	3.19	3.69	4.20	4.70	5.22	5.73	6.26	6.78
SVOLX					.88	1.08	1.27	1.47	1.67	1.87	2.08	2.28	2.49	2.70
80:														
TVOL					5.84	6.49	7.09	7.66	8.20	8.71	9.20	9.67	10.13	10.57
WVOL					4.90	5.56	6.19	6.79	7.37	7.93	8.47	9.00	9.52	10.02
SVOLI					2.94	3.58	4.23	4.89	5.56	6.23	6.91	7.59	8.28	8.98
SVOLX					1.17	1.42	1.68	1.95	2.21	2.48	2.75	3.02	3.30	3.57
90:														
TVOL					7.60	8.44	9.22	9.96	10.65	11.32	11.96	12.57	13.17	13.74
WVOL					6.46	7.33	8.16	8.96	9.72	10.46	11.18	11.88	12.56	13.22
SVOLI					3.76	4.58	5.42	6.26	7.12	7.98	8.85	9.73	10.61	11.50
SVOLX					1.50	1.82	2.16	2.49	2.83	3.18	3.52	3.87	4.22	4.58
100:														
TVOL					9.60	10.66	11.65	12.59	13.47	14.31	15.12	15.89	16.64	17.37
WVOL					8.28	9.40	10.46	11.48	12.46	13.41	14.33	15.22	16.09	16.95
SVOLI					4.69	5.72	6.76	7.82	8.88	9.96	11.05	12.14	13.24	14.35
SVOLX					1.87	2.28	2.69	3.11	3.54	3.96	4.40	4.83	5.27	5.71
110:														
TVOL					11.87	13.18	14.41	15.56	16.65	17.69	18.69	19.65	20.57	21.47
WVOL					10.36	11.76	13.09	14.37	15.59	16.78	17.93	19.05	20.14	21.21
SVOLI					5.73	6.99	8.26	9.55	10.86	12.17	13.50	14.84	16.18	17.54
SVOLX					2.28	2.78	3.29	3.80	4.32	4.84	5.37	5.90	6.44	6.98
120:														
TVOL					14.40	16.00	17.48	18.88	20.20	21.47	22.68	23.84	24.97	
WVOL					12.71	14.43	16.07	17.63	19.14	20.59	22.00	23.38	24.72	
SVOLI					6.89	8.39	9.92	11.47	13.04	14.62	16.21	17.82	19.43	
SVOLX					2.74	3.34	3.95	4.56	5.19	5.82	6.45	7.09	7.73	
130:														
TVOL					17.21	19.12	20.89	22.56	24.14	25.65	27.10	28.49	29.83	
WVOL					15.35	17.42	19.40	21.29	23.10	24.86	26.57	28.22	29.84	
SVOLI					8.15	9.93	11.74	13.57	15.43	17.30	19.18	21.08	23.00	
SVOLX					3.24	3.95	4.67	5.40	6.14	6.88	7.63	8.39	9.15	

NOTE: BLOCK INDICATES RANGE OF DATA.

1/TVOL = TOTAL ABOVEGROUND VOLUME OF WOOD AND BARK; EXCLUDES FOLIAGE.

WVOL = VOLUME OF WOOD FROM A 0.3 METER STUMP TO A 10-CENTIMETER TOP OUTSIDE BARK; EXCLUDES BARK AND FOLIAGE.

SVOLI = SAW-LOG VOLUME IN STRAIGHT MERCHANTABLE SECTIONS AT LEAST 2.5 METERS LONG TO A 23-CENTIMETER TOP OUTSIDE BARK IN TREES WITH A MERCHANTABLE FIRST SECTION ABOVE A 0.3-METER STUMP.

SVOLX = SAW-LOG VOLUME IN STRAIGHT MERCHANTABLE SECTIONS AT LEAST 2.5 METERS LONG TO A 23-CENTIMETER TOP OUTSIDE BARK IN TREES WITHOUT A MERCHANTABLE FIRST SECTION ABOVE A 0.3-METER STUMP.

Table 25--Total tree, wood, and saw-log volume for California black oak

DIAMETER AT BREAST HEIGHT OUTSIDE BARK 1/	TOTAL HEIGHT (METERS) 3	6	9	12	15	18	21	24	27	30	33	36	39	42
CENTIMETERS	CUBIC METERS													
10:														
TVOL	0.02	0.04	0.05	0.07	0.08	0.10	0.11							
WVOL	.01	.02	.03	.04	.05	.06	.07							
SVOLI	.01	.01	.01	.01	.01	.02	.02							
SVOLX	.00	.00	.01	.01	.01	.01	.01							
20:														
TVOL	.08	.15	.21	.27	.32	.38	.43	0.48						
WVOL	.06	.10	.14	.18	.22	.25	.29	.32						
SVOLI	.05	.06	.07	.08	.09	.10	.10	.11						
SVOLX	.02	.03	.04	.04	.05	.05	.05	.06						
30:														
TVOL	.18	.33	.47	.59	.72	.84	.96	1.07	1.18	1.30				
WVOL	.13	.24	.33	.42	.51	.59	.68	.76	.83	.91				
SVOLI	.13	.18	.21	.24	.27	.29	.31	.32	.34	.36				
SVOLX	.07	.09	.11	.13	.14	.15	.16	.17	.18	.19				
40:														
TVOL		.58	.82	1.05	1.27	1.48	1.69	1.89	2.09	2.29				
WVOL		.44	.61	.78	.94	1.10	1.25	1.39	1.54	1.68				
SVOLI		.39	.46	.52	.58	.62	.66	.70	.74	.77				
SVOLX		.20	.24	.27	.30	.32	.35	.37	.38	.40				
50:														
TVOL			1.28	1.63	1.97	2.30	2.62	2.94	3.25	3.55	3.85	4.15		
WVOL			.99	1.26	1.51	1.76	2.00	2.24	2.47	2.70	2.92	3.14		
SVOLI			.84	.95	1.05	1.13	1.21	1.28	1.34	1.40	1.46	1.52		
SVOLX			.44	.50	.54	.59	.63	.66	.70	.73	.76	.79		
60:														
TVOL			1.83	2.34	2.82	3.30	3.76	4.21	4.65	5.09	5.52	5.94		
WVOL			1.46	1.85	2.23	2.60	2.95	3.30	3.64	3.97	4.30	4.62		
SVOLI			1.37	1.55	1.71	1.84	1.97	2.08	2.19	2.29	2.38	2.47		
SVOLX			.71	.81	.89	.96	1.02	1.08	1.14	1.19	1.24	1.29		
70:														
TVOL				3.17	3.83	4.47	5.10	5.71	6.31	6.90	7.48	8.06	8.63	9.19
WVOL				2.57	3.09	3.60	4.10	4.58	5.05	5.51	5.97	6.42	6.86	7.30
SVOLI				2.35	2.58	2.79	2.98	3.15	3.31	3.46	3.60	3.74	3.87	3.99
SVOLX				1.22	1.34	1.45	1.55	1.64	1.72	1.80	1.88	1.95	2.01	2.08
80:														
TVOL				4.12	4.98	5.82	6.63	7.43	8.21	8.98	9.74	10.49	11.23	11.96
WVOL				3.41	4.11	4.78	5.44	6.08	6.71	7.32	7.93	8.52	9.11	9.69
SVOLI				3.36	3.69	3.99	4.26	4.50	4.74	4.95	5.16	5.35	5.54	5.71
SVOLX				1.75	1.92	2.07	2.21	2.34	2.46	2.58	2.68	2.78	2.88	2.97
90:														
TVOL					6.29	7.34	8.37	9.38	10.36	11.33	12.29	13.23	14.17	15.09
WVOL					5.28	6.15	6.99	7.81	8.62	9.41	10.18	10.95	11.71	12.45
SVOLI					5.06	5.47	5.84	6.18	6.49	6.79	7.07	7.34	7.59	7.83
SVOLX					2.63	2.84	3.04	3.21	3.38	3.53	3.68	3.82	3.95	4.07
100:														
TVOL						9.04	10.30	11.54	12.76	13.96	15.13	16.30	17.44	18.58
WVOL						7.69	8.74	9.77	10.78	11.77	12.74	13.70	14.65	15.58
SVOLI						7.25	7.74	8.19	8.61	9.01	9.38	9.73	10.07	10.39
SVOLX						3.77	4.03	4.26	4.48	4.69	4.88	5.06	5.24	5.40
110:														
TVOL						10.91	12.44	13.93	15.40	16.84	18.27	19.67	21.05	22.42
WVOL						9.42	10.71	11.97	13.20	14.41	15.61	16.78	17.94	19.08
SVOLI						9.36	10.00	10.58	11.12	11.63	12.11	12.56	13.00	13.41
SVOLX						4.87	5.20	5.50	5.78	6.05	6.30	6.54	6.76	6.98
120:														
TVOL							14.77	16.54	18.29	20.00	21.69	23.36	25.00	26.63
WVOL							12.88	14.40	15.89	17.34	18.78	20.19	21.58	22.96
SVOLI							12.62	13.36	14.04	14.68	15.29	15.87	16.41	16.94
SVOLX							6.57	6.95	7.30	7.64	7.95	8.25	8.54	8.81
130:														
TVOL								19.38	21.42	23.43	25.40	27.35	29.28	31.19
WVOL								17.07	18.83	20.56	22.26	23.93	25.59	27.22
SVOLI								16.56	17.40	18.20	18.95	19.66	20.34	20.99
SVOLX								8.61	9.05	9.47	9.86	10.23	10.58	10.92

NOTE: BLOCK INOICATES RANGE OF OATA.

1/TVOL = TOTAL ABOVEGROUNO VOLUME OF WOOO ANO BARK; EXCLUOES FOLIAGE.

WVOL = VOLUME OF WOOO FROM A 0.3 METER STUMP TO A 10-CENTIMETER TOP OUTSIOE BARK; EXCLUOES BARK AND FOLIAGE.

SVOLI = SAW-LOG VOLUME IN STRAIGHT MERCHANTABLE SECTIONS AT LEAST 2.5 METERS LONG TO A 23-CENTIMETER TOP OUTSIOE BARK IN TREES WITH A MERCHANTABLE FIRST SECTION ABOVE A 0.3-METER STUMP.

SVOLX = SAW-LOG VOLUME IN STRAIGHT MERCHANTABLE SECTIONS AT LEAST 2.5 METERS LONG TO A 23-CENTIMETER TOP OUTSIDE BARK IN TREES WITHOUT A MERCHANTABLE FIRST SECTION ABOVE A 0.3-METER STUMP.

Table 26--Total tree and wood volume for Engelmann oak

DIAMETER AT BREAST HEIGHT OUTSIDE BARK 1/	TOTAL HEIGHT (METERS)						
	3	6	9	12	15	18	21
CENTIMETERS	- - - - - - - - - - - CUBIC METERS - - - - - - - - - - -						
10:							
TVOL	0.03	0.03	0.04	0.04			
WVOL	.01	.01	.02	.02			
20:							
TVOL	.15	.18	.20	.22	.23		
WVOL	.07	.08	.10	.10	.11		
30:							
TVOL	.39	.47	.53	.57	.61	.64	.67
WVOL	.20	.24	.28	.30	.32	.34	.36
40:							
TVOL		.94	1.05	1.14	1.22	1.28	1.34
WVOL		.52	.59	.64	.69	.73	.76
50:							
TVOL		1.61	1.80	1.95	2.08	2.19	2.29
WVOL		.93	1.05	1.15	1.23	1.30	1.37
60:							
TVOL		2.49	2.79	3.03	3.22	3.39	3.54
WVOL		1.49	1.69	1.85	1.98	2.10	2.20
70:							
TVOL		3.61	4.04	4.38	4.67	4.91	5.13
WVOL		2.23	2.53	2.77	2.97	3.14	3.30
80:							
TVOL		4.97	5.57	6.04	6.43	6.77	7.07
WVOL		3.16	3.59	3.93	4.21	4.45	4.67
90:							
TVOL		6.60	7.40	8.02	8.54	8.99	9.38
WVOL		4.31	4.88	5.34	5.72	6.06	6.36
100:							
TVOL			9.53	10.33	11.00	11.57	12.09
WVOL			6.43	7.03	7.54	7.98	8.37
110:							
TVOL			11.98	12.99	13.83	14.55	15.20
WVOL			8.25	9.02	9.67	10.24	10.74

NOTE: BLOCK INDICATES RANGE OF DATA.

1/TVOL = TOTAL ABOVEGROUND VOLUME OF WOOD AND BARK; EXCLUDES FOLIAGE.

WVOL = VOLUME OF WOOD FROM A 0.3 METER STUMP TO A 10-CENTIMETER TOP OUTSIDE BARK; EXCLUDES BARK AND FOLIAGE.

Table 27--Total tree, wood, and saw-log volume for blue oak

DIAMETER AT BREAST HEIGHT OUTSIDE BARK 1/	TOTAL HEIGHT (METERS) 3	6	9	12	15	18	21	24	27	30	33
CENTIMETERS	CUBIC METERS										
10:											
TVOL	0.02	0.03									
WVOL	.01	.02									
SVOLI	.01	.02									
SVOLX	.01	.01									
20:											
TVOL	.12	.17	0.21	0.24	0.26						
WVOL	.07	.10	.13	.15	.16						
SVOLI	.04	.08	.11	.13	.16						
SVOLX	.03	.05	.07	.09	.11						
30:											
TVOL	.32	.44	.53	.61	.67	0.73	0.79	0.84			
WVOL	.20	.29	.35	.41	.46	.50	.54	.58			
SVOLI	.09	.16	.22	.28	.34	.39	.44	.50			
SVOLX	.06	.11	.15	.19	.23	.27	.31	.34			
40:											
TVOL		.86	1.04	1.19	1.32	1.43	1.54	1.64	1.73	1.81	
WVOL		.59	.73	.84	.95	1.04	1.12	1.20	1.27	1.34	
SVOLI		.26	.37	.47	.56	.66	.75	.83	.92	1.01	
SVOLX		.18	.25	.32	.39	.45	.52	.58	.64	.70	
50:											
TVOL		1.45	1.75	2.00	2.22	2.41	2.59	2.75	2.91	3.05	3.19
WVOL		1.05	1.29	1.49	1.67	1.83	1.97	2.11	2.24	2.37	2.48
SVOLI		.39	.55	.70	.84	.98	1.11	1.25	1.37	1.50	1.63
SVOLX		.27	.38	.48	.58	.68	.77	.86	.95	1.04	1.13
60:											
TVOL		2.22	2.68	3.06	3.39	3.69	3.96	4.21	4.45	4.67	4.88
WVOL		1.66	2.04	2.36	2.65	2.90	3.14	3.36	3.56	3.76	3.94
SVOLI		.54	.76	.97	1.17	1.36	1.55	1.73	1.91	2.08	2.26
SVOLX		.37	.53	.67	.81	.94	1.07	1.20	1.32	1.44	1.56
70:											
TVOL			3.84	4.38	4.86	5.28	5.67	6.03	6.37	6.69	6.99
WVOL			3.02	3.50	3.92	4.29	4.64	4.97	5.27	5.56	5.83
SVOLI			1.00	1.28	1.54	1.79	2.04	2.28	2.52	2.75	2.98
SVOLX			.69	.88	1.06	1.24	1.41	1.58	1.74	1.90	2.06
80:											
TVOL			5.24	5.98	6.63	7.21	7.74	8.24	8.70	9.13	9.54
WVOL			4.24	4.91	5.50	6.03	6.52	6.97	7.40	7.80	8.19
SVOLI			1.27	1.62	1.95	2.28	2.59	2.90	3.20	3.50	3.79
SVOLX			.88	1.12	1.35	1.58	1.79	2.01	2.22	2.42	2.62
90:											
TVOL			6.90	7.87	8.73	9.49	10.19	10.84	11.44	12.01	12.55
WVOL			5.72	6.62	7.41	8.13	8.79	9.40	9.98	10.53	11.05
SVOLI			1.57	2.00	2.42	2.81	3.20	3.58	3.95	4.32	4.68
SVOLX			1.09	1.39	1.67	1.95	2.22	2.48	2.74	2.99	3.24
100:											
TVOL			8.82	10.07	11.16	12.13	13.03	13.86	14.63	15.36	16.05
WVOL			7.48	8.65	9.69	10.62	11.48	12.29	13.04	13.76	14.44
SVOLI			1.90	2.42	2.92	3.40	3.87	4.33	4.78	5.22	5.66
SVOLX			1.32	1.68	2.02	2.36	2.68	3.00	3.31	3.62	3.92

NOTE: BLOCK INDICATES RANGE OF DATA.

1/TVOL = TOTAL ABOVEGROUND VOLUME OF WOOD AND BARK; EXCLUDES FOLIAGE.

WVOL = VOLUME OF WOOD FROM A 0.3 METER STUMP TO A 10-CENTIMETER TOP OUTSIDE BARK; EXCLUDES BARK AND FOLIAGE.

SVOLI = SAW-LOG VOLUME IN STRAIGHT MERCHANTABLE SECTIONS AT LEAST 2.5 METERS LONG TO A 23-CENTIMETER TOP OUTSIDE BARK IN TREES WITH A MERCHANTABLE FIRST SECTION ABOVE A 0.3-METER STUMP.

SVOLX = SAW-LOG VOLUME IN STRAIGHT MERCHANTABLE SECTIONS AT LEAST 2.5 METERS LONG TO A 23-CENTIMETER TOP OUTSIDE BARK IN TREES WITHOUT A MERCHANTABLE FIRST SECTION ABOVE A 0.3-METER STUMP.

Table 28--Total tree, wood, and saw-log volume for Pacific madrone

DIAMETER AT BREAST HEIGHT OUTSIDE BARK 1/	TOTAL HEIGHT (METERS)											
	3	6	9	12	15	18	21	24	27	30	33	36
CENTIMETERS	CUBIC METERS											
10:												
TVOL	0.02	0.03	0.05	0.06	0.07							
WVOL	.01	.02	.03	.05	.06							
SVOLI	.01	.02	.03	.05	.06							
SVOLX	.00	.01	.01	.02	.03							
20:												
TVOL	.07	.13	.19	.24	.28	0.33	0.38					
WVOL	.05	.09	.14	.18	.23	.28	.33					
SVOLI	.03	.06	.11	.15	.20	.26	.31					
SVOLX	.01	.03	.04	.06	.09	.11	.13					
30:												
TVOL	.16	.29	.41	.52	.63	.74	.84	0.94	1.03	1.13	1.22	
WVOL	.10	.20	.31	.41	.52	.63	.73	.84	.94	1.05	1.16	
SVOLI	.05	.13	.21	.31	.41	.52	.63	.74	.86	.99	1.11	
SVOLX	.02	.05	.09	.13	.17	.22	.26	.31	.36	.41	.46	
40:												
TVOL		.52	.73	.92	1.11	1.30	1.47	1.65	1.82	1.98	2.15	
WVOL		.36	.55	.73	.92	1.11	1.30	1.49	1.67	1.86	2.05	
SVOLI		.21	.35	.51	.67	.85	1.03	1.22	1.42	1.62	1.83	
SVOLX		.09	.15	.21	.28	.35	.43	.51	.59	.68	.76	
50:												
TVOL		.80	1.13	1.43	1.73	2.01	2.29	2.55	2.82	3.08	3.33	3.58
WVOL		.57	.86	1.15	1.44	1.73	2.02	2.32	2.61	2.91	3.20	3.50
SVOLI		.31	.52	.75	.99	1.25	1.52	1.79	2.08	2.38	2.68	3.00
SVOLX		.13	.22	.31	.41	.52	.63	.75	.87	.99	1.12	1.25
60:												
TVOL		1.15	1.61	2.05	2.47	2.88	3.27	3.66	4.03	4.41	4.77	5.13
WVOL		.82	1.23	1.65	2.07	2.49	2.91	3.33	3.76	4.18	4.60	5.03
SVOLI		.43	.71	1.02	1.36	1.71	2.08	2.46	2.85	3.26	3.68	4.10
SVOLX		.18	.30	.43	.57	.71	.87	1.03	1.19	1.36	1.54	1.72
70:												
TVOL			2.18	2.78	3.34	3.89	4.43	4.95	5.46	5.96	6.46	6.94
WVOL			1.67	2.24	2.81	3.38	3.96	4.53	5.11	5.68	6.26	6.84
SVOLI			.93	1.34	1.77	2.23	2.71	3.21	3.72	4.25	4.80	5.36
SVOLX			.39	.56	.74	.93	1.13	1.34	1.56	1.78	2.01	2.24
80:												
TVOL			2.84	3.61	4.35	5.06	5.76	6.44	7.10	7.76	8.40	
WVOL			2.18	2.92	3.67	4.41	5.16	5.91	6.66	7.42	8.17	
SVOLI			1.17	1.68	2.23	2.81	3.41	4.04	4.69	5.36	6.04	
SVOLX			.49	.70	.93	1.17	1.43	1.69	1.96	2.24	2.53	
90:												
TVOL				4.55	5.48	6.38	7.26	8.12	8.95	9.78	10.59	
WVOL				3.70	4.64	5.58	6.53	7.48	8.43	9.38	10.33	
SVOLI				2.06	2.73	3.44	4.18	4.95	5.74	6.56	7.40	
SVOLX				.86	1.14	1.44	1.75	2.07	2.40	2.74	3.10	
100:												
TVOL				5.60	6.74	7.85	8.93	9.98	11.01	12.03	13.02	
WVOL				4.56	5.72	6.89	8.05	9.22	10.40	11.57	12.74	
SVOLI				2.47	3.28	4.13	5.01	5.94	6.89	7.87	8.88	
SVOLX				1.03	1.37	1.73	2.10	2.48	2.88	3.29	3.71	
110:												
TVOL					8.13	9.47	10.77	12.04	13.29	14.51		
WVOL					6.92	8.33	9.74	11.15	12.57	13.99		
SVOLI					3.86	4.86	5.91	7.00	8.12	9.28		
SVOLX					1.62	2.03	2.47	2.93	3.40	3.88		
120:												
TVOL					9.65	11.24	12.78	14.29	15.76	17.21		
WVOL					8.23	9.90	11.58	13.26	14.95	16.64		
SVOLI					4.49	5.65	6.87	8.13	9.44	10.79		
SVOLX					1.88	2.36	2.87	3.40	3.95	4.51		
130:												
TVOL					11.30	13.15	14.96	16.72	18.45	20.15		
WVOL					9.65	11.62	13.59	15.56	17.54	19.52		
SVOLI					5.15	6.49	7.89	9.34	10.84	12.38		
SVOLX					2.16	2.71	3.30	3.91	4.53	5.18		

NOTE: BLOCK INDICATES RANGE OF DATA.

1/TVOL = TOTAL ABOVEGROUND VOLUME OF WOOD AND BARK; EXCLUDES FOLIAGE.

WVOL = VOLUME OF WOOD FROM A 0.3 METER STUMP TO A 10-CENTIMETER TOP OUTSIDE BARK; EXCLUDES BARK AND FOLIAGE.

SVOLI = SAW-LOG VOLUME IN STRAIGHT MERCHANTABLE SECTIONS AT LEAST 2.5 METERS LONG TO A 23-CENTIMETER TOP OUTSIDE BARK IN TREES WITH A MERCHANTABLE FIRST SECTION ABOVE A 0.3-METER STUMP.

SVOLX = SAW-LOG VOLUME IN STRAIGHT MERCHANTABLE SECTIONS AT LEAST 2.5 METERS LONG TO A 23-CENTIMETER TOP OUTSIDE BARK IN TREES WITHOUT A MERCHANTABLE FIRST SECTION ABOVE A 0.3-METER STUMP.

Table 29--Total tree, wood, and saw-log volume for Oregon white oak

DIAMETER AT BREAST HEIGHT OUTSIDE BARK 1/	TOTAL HEIGHT (METERS) 3	6	9	12	15	18	21	24	27	30	33	36	39	42
CENTIMETERS	CUBIC METERS													
10:														
TVOL	0.02	0.04	0.05	0.06	0.07	0.08								
WVOL	.01	.02	.03	.04	.05	.05								
SVOLI	.01	.01	.02	.03	.03	.04								
SVOLX	.00	.01	.01	.01	.01	.02								
20:														
TVOL	.09	.16	.21	.26	.31	.35	0.40	0.44	0.48					
WVOL	.05	.10	.14	.18	.22	.25	.29	.32	.36					
SVOLI	.03	.06	.08	.11	.13	.16	.18	.21	.23					
SVOLX	.01	.03	.04	.05	.06	.07	.09	.10	.11					
30:														
TVOL	.22	.37	.50	.62	.74	.84	.95	1.04	1.14	1.23	1.32	1.41		
WVOL	.13	.24	.34	.44	.54	.63	.72	.81	.90	.98	1.07	1.15		
SVOLI	.07	.14	.20	.26	.32	.37	.43	.48	.54	.59	.65	.70		
SVOLX	.03	.06	.09	.12	.15	.18	.20	.23	.25	.28	.31	.33		
40:														
TVOL		.69	.93	1.16	1.37	1.56	1.75	1.94	2.11	2.28	2.45	2.62		
WVOL		.46	.66	.85	1.03	1.20	1.38	1.55	1.71	1.88	2.04	2.20		
SVOLI		.25	.36	.47	.58	.68	.79	.89	.99	1.09	1.19	1.28		
SVOLX		.12	.17	.22	.27	.32	.37	.42	.47	.51	.56	.61		
50:														
TVOL		1.12	1.51	1.87	2.20	2.52	2.83	3.12	3.41	3.69	3.96	4.22		
WVOL		.77	1.09	1.40	1.70	1.99	2.28	2.56	2.84	3.11	3.38	3.64		
SVOLI		.40	.58	.75	.93	1.09	1.26	1.42	1.58	1.74	1.90	2.06		
SVOLX		.19	.27	.36	.44	.52	.59	.67	.75	.82	.90	.97		
60:														
TVOL		1.65	2.23	2.76	3.26	3.73	4.18	4.62	5.04	5.45	5.85	6.24	6.62	6.99
WVOL		1.15	1.64	2.11	2.56	3.01	3.44	3.86	4.28	4.69	5.10	5.50	5.90	6.29
SVOLI		.59	.85	1.11	1.36	1.60	1.85	2.09	2.32	2.56	2.79	3.02	3.25	3.47
SVOLX		.28	.40	.52	.64	.76	.87	.98	1.09	1.21	1.31	1.42	1.53	1.64
70:														
TVOL			3.10	3.84	4.53	5.19	5.82	6.42	7.01	7.58	8.13	8.68	9.21	9.73
WVOL			2.33	2.99	3.63	4.26	4.87	5.47	6.06	6.64	7.22	7.78	8.35	8.90
SVOLI			1.18	1.53	1.88	2.22	2.55	2.89	3.21	3.54	3.86	4.18	4.49	4.81
SVOLX			.56	.72	.89	1.05	1.20	1.36	1.51	1.67	1.82	1.97	2.12	2.27
80:														
TVOL			4.13	5.11	6.03	6.91	7.74	8.55	9.33	10.09	10.83	11.55	12.26	12.95
WVOL			3.15	4.04	4.91	5.75	6.58	7.39	8.19	8.98	9.75	10.52	11.28	12.03
SVOLI			1.56	2.03	2.49	2.94	3.38	3.82	4.26	4.69	5.11	5.53	5.95	6.37
SVOLX			.74	.96	1.17	1.39	1.60	1.80	2.01	2.21	2.41	2.61	2.81	3.00
90:														
TVOL			5.31	6.58	7.76	8.89	9.97	11.01	12.01	12.99	13.94	14.87	15.78	16.67
WVOL			4.10	5.27	6.40	7.50	8.58	9.64	10.68	11.71	12.72	13.72	14.71	15.70
SVOLI			2.00	2.60	3.19	3.77	4.34	4.90	5.46	6.01	6.55	7.09	7.63	8.16
SVOLX			.94	1.23	1.50	1.78	2.05	2.31	2.57	2.83	3.09	3.34	3.60	3.85
100:														
TVOL			6.66	8.25	9.73	11.14	12.49	13.79	15.05	16.28	17.47	18.64	19.78	20.90
WVOL			5.20	6.68	8.12	9.52	10.88	12.23	13.55	14.85	16.13	17.40	18.66	19.91
SVOLI			2.50	3.25	3.98	4.71	5.42	6.12	6.81	7.50	8.18	8.85	9.53	10.19
SVOLX			1.18	1.53	1.88	2.22	2.55	2.88	3.21	3.54	3.86	4.17	4.49	4.81
110:														
TVOL			8.17	10.12	11.94	13.67	15.32	16.92	18.47	19.97	21.43	22.86	24.26	25.63
WVOL			6.45	8.29	10.07	11.80	13.49	15.16	16.80	18.41	20.00	21.58	23.14	24.68
SVOLI			3.06	3.97	4.87	5.75	6.62	7.48	8.33	9.16	10.00	10.82	11.64	12.46
SVOLX			1.44	1.87	2.30	2.71	3.12	3.53	3.93	4.32	4.71	5.10	5.49	5.87
120:														
TVOL			9.85	12.19	14.38	16.47	18.47	20.39	22.25	24.06	25.83	27.55	29.23	30.89
WVOL			7.85	10.09	12.25	14.36	16.42	18.45	20.44	22.40	24.34	26.26	28.16	30.03
SVOLI			3.67	4.77	5.85	6.91	7.95	8.98	10.00	11.01	12.01	13.00	13.99	14.96
SVOLX			1.73	2.25	2.76	3.26	3.75	4.23	4.71	5.19	5.66	6.13	6.59	7.06
130:														
TVOL			11.69	14.47	17.08	19.55	21.92	24.20	26.42	28.56	30.66	32.70	34.71	36.67
WVOL			9.40	12.08	14.67	17.20	19.67	22.10	24.48	26.84	29.16	31.46	33.73	35.98
SVOLI			4.35	5.65	6.92	8.18	9.41	10.63	11.84	13.03	14.21	15.39	16.55	17.71
SVOLX			2.05	2.66	3.26	3.86	4.44	5.01	5.58	6.14	6.70	7.26	7.81	8.35

NOTE: BLOCK INDICATES RANGE OF DATA.

1/TVOL = TOTAL ABOVEGROUND VOLUME OF WOOD AND BARK; EXCLUDES FOLIAGE.

WVOL = VOLUME OF WOOD FROM A 0.3 METER STUMP TO A 10-CENTIMETER TOP OUTSIDE BARK; EXCLUDES BARK AND FOLIAGE.

SVOLI = SAW-LOG VOLUME IN STRAIGHT MERCHANTABLE SECTIONS AT LEAST 2.5 METERS LONG TO A 23-CENTIMETER TOP OUTSIDE BARK IN TREES WITH A MERCHANTABLE FIRST SECTION ABOVE A 0.3-METER STUMP.

SVOLX = SAW-LOG VOLUME IN STRAIGHT MERCHANTABLE SECTIONS AT LEAST 2.5 METERS LONG TO A 23-CENTIMETER TOP OUTSIDE BARK IN TREES WITHOUT A MERCHANTABLE FIRST SECTION ABOVE A 0.3-METER STUMP.

Table 30--Total tree, wood, and saw-log volume for canyon live oak

DIAMETER AT BREAST HEIGHT OUTSIDE BARK 1/	TOTAL HEIGHT (METERS)												
	3	6	9	12	15	18	21	24	27	30	33	36	39
CENTIMETERS	- - - - - - - -						CUBIC METERS						- - - - - - - -
10:													
TVOL	0.02	0.04	0.04	0.05	0.06	0.07							
WVOL	.01	.02	.03	.03	.04	.05							
SVOLI	.01	.01	.02	.02	.03	.03							
SVOLX	.00	.00	.01	.01	.01	.01							
20:													
TVOL	.11	.16	.21	.25	.28	.32	.35	.38	0.41				
WVOL	.06	.10	.13	.17	.20	.23	.25	.28	.31				
SVOLI	.03	.06	.08	.10	.12	.14	.16	.18	.20				
SVOLX	.01	.02	.03	.04	.05	.05	.06	.07	.07				
30:													
TVOL	.26	.40	.51	.60	.69	.78	.85	.92	.99	1.06			
WVOL	.15	.26	.35	.43	.51	.58	.65	.72	.78	.85			
SVOLI	.08	.14	.20	.25	.31	.35	.40	.45	.49	.54			
SVOLX	.03	.05	.07	.09	.11	.13	.15	.16	.18	.20			
40:													
TVOL		.75	.96	1.14	1.31	1.46	1.61	1.74	1.87	2.00	2.12	2.23	
WVOL		.50	.68	.84	.99	1.13	1.27	1.40	1.53	1.65	1.77	1.89	
SVOLI		.28	.38	.49	.58	.68	.77	.85	.94	1.02	1.11	1.19	
SVOLX		.10	.14	.18	.21	.25	.28	.31	.35	.38	.41	.44	
50:													
TVOL		1.22	1.56	1.87	2.14	2.39	2.63	2.85	3.06	3.27	3.46	3.65	
WVOL		.84	1.13	1.41	1.66	1.90	2.13	2.35	2.57	2.78	2.98	3.18	
SVOLI		.46	.63	.80	.96	1.11	1.26	1.41	1.55	1.69	1.82	1.96	
SVOLX		.17	.23	.30	.35	.41	.47	.52	.57	.62	.67	.72	
60:													
TVOL		1.82	2.34	2.79	3.20	3.57	3.93	4.26	4.58	4.89	5.18	5.46	5.74
WVOL		1.28	1.73	2.15	2.53	2.90	3.26	3.60	3.92	4.24	4.56	4.86	5.16
SVOLI		.69	.95	1.21	1.45	1.68	1.90	2.12	2.33	2.54	2.75	2.95	3.15
SVOLX		.25	.35	.44	.53	.62	.70	.78	.86	.94	1.01	1.09	1.16
70:													
TVOL		2.56	3.29	3.92	4.49	5.02	5.52	5.99	6.43	6.86	7.28	7.67	8.06
WVOL		1.84	2.48	3.07	3.63	4.15	4.66	5.14	5.62	6.07	6.52	6.96	7.38
SVOLI		.97	1.35	1.71	2.04	2.37	2.69	3.00	3.30	3.59	3.88	4.17	4.45
SVOLX		.36	.50	.63	.75	.87	.99	1.10	1.21	1.32	1.43	1.53	1.64
80:													
TVOL			4.41	5.26	6.03	6.74	7.41	8.04	8.64	9.21	9.77	10.30	10.82
WVOL			3.38	4.19	4.95	5.67	6.35	7.02	7.66	8.28	8.89	9.49	10.07
SVOLI			1.82	2.30	2.76	3.20	3.63	4.04	4.45	4.85	5.24	5.62	6.00
SVOLX			.67	.85	1.02	1.18	1.34	1.49	1.64	1.79	1.93	2.07	2.21
90:													
TVOL			5.72	6.82	7.82	8.74	9.60	10.42	11.20	11.95	12.66	13.36	14.03
WVOL			4.45	5.51	6.51	7.45	8.36	9.23	10.07	10.89	11.69	12.48	13.24
SVOLI			2.37	3.00	3.59	4.17	4.73	5.27	5.80	6.32	6.83	7.33	7.82
SVOLX			.87	1.10	1.32	1.54	1.74	1.94	2.14	2.33	2.51	2.70	2.88
100:													
TVOL			7.21	8.60	9.86	11.03	12.12	13.15	14.13	15.07	15.98	16.85	17.70
WVOL			5.69	7.04	8.31	9.52	10.68	11.79	12.87	13.92	14.94	15.94	16.92
SVOLI			3.00	3.80	4.55	5.28	5.99	6.67	7.34	8.00	8.65	9.28	9.90
SVOLX			1.11	1.40	1.68	1.94	2.20	2.46	2.70	2.95	3.18	3.42	3.65
110:													
TVOL					12.17	13.60	14.95	16.22	17.44	18.60	19.71	20.79	21.83
WVOL					10.38	11.88	13.33	14.72	16.06	17.37	18.65	19.89	21.11
SVOLI					5.64	6.54	7.41	8.26	9.10	9.91	10.71	11.49	12.27
SVOLX					2.08	2.41	2.73	3.04	3.35	3.65	3.94	4.23	4.52
120:													
TVOL					14.74	16.48	18.11	19.65	21.12	22.53	23.88	25.19	26.45
WVOL					12.70	14.55	16.31	18.02	19.67	21.27	22.83	24.36	25.85
SVOLI					6.85	7.95	9.01	10.05	11.06	12.05	13.02	13.97	14.91
SVOLX					2.52	2.93	3.32	3.70	4.07	4.44	4.79	5.15	5.49
130:													
TVOL					17.59	19.66	21.61	23.45	25.20	26.88	28.49	30.05	31.56
WVOL					15.30	17.52	19.65	21.70	23.69	25.62	27.50	29.34	31.14
SVOLI					8.20	9.51	10.79	12.02	13.23	14.42	15.58	16.72	17.85
SVOLX					3.02	3.50	3.97	4.43	4.87	5.31	5.74	6.16	6.57

NOTE: BLOCK INDICATES RANGE OF DATA.

1/TVOL = TOTAL ABOVEGROUND VOLUME OF WOOD AND BARK; EXCLUDES FOLIAGE.

WVOL = VOLUME OF WOOD FROM A 0.3 METER STUMP TO A 10-CENTIMETER TOP OUTSIDE BARK; EXCLUDES BARK AND FOLIAGE.

SVOLI = SAW-LOG VOLUME IN STRAIGHT MERCHANTABLE SECTIONS AT LEAST 2.5 METERS LONG TO A 23-CENTIMETER TOP OUTSIDE BARK IN TREES WITH A MERCHANTABLE FIRST SECTION ABOVE A 0.3-METER STUMP.

SVOLX = SAW-LOG VOLUME IN STRAIGHT MERCHANTABLE SECTIONS AT LEAST 2.5 METERS LONG TO A 23-CENTIMETER TOP OUTSIDE BARK IN TREES WITHOUT A MERCHANTABLE FIRST SECTION ABOVE A 0.3-METER STUMP.

Table 31--Total tree, wood, and saw-log volume for coast live oak

DIAMETER AT BREAST HEIGHT OUTSIDE BARK 1/	TOTAL HEIGHT (METERS)													
	3	6	9	12	15	18	21	24	27	30	33	36	39	42
CENTIMETERS	CUBIC METERS													
10:														
TVOL	0.02	0.03	0.04	0.04										
WVOL	.01	.01	.02	.02										
SVOLI	.01	.01	.02	.02										
SVOLX	.00	.00	.01	.01										
20:														
TVOL	.09	.14	.18	.22	0.25	0.28	0.31							
WVOL	.05	.08	.10	.12	.14	.15	.17							
SVOLI	.03	.06	.08	.10	.12	.14	.16							
SVOLX	.01	.02	.03	.04	.05	.05	.06							
30:														
TVOL	.24	.37	.47	.56	.65	.73	.80	0.87	0.94					
WVOL	.15	.22	.28	.34	.39	.43	.47	.51	.55					
SVOLI	.08	.14	.20	.25	.31	.35	.40	.45	.49					
SVOLX	.03	.05	.07	.09	.11	.13	.15	.16	.18					
40:														
TVOL		.71	.92	1.10	1.26	1.42	1.56	1.70	1.83	1.95	2.07			
WVOL		.46	.59	.70	.80	.89	.98	1.06	1.14	1.22	1.29			
SVOLI		.28	.38	.49	.58	.68	.77	.85	.94	1.02	1.11			
SVOLX		.10	.14	.18	.21	.25	.28	.31	.35	.38	.41			
50:														
TVOL		1.20	1.54	1.84	2.12	2.38	2.62	2.85	3.06	3.27	3.47	3.67	3.86	
WVOL		.81	1.03	1.23	1.41	1.57	1.73	1.87	2.01	2.15	2.27	2.40	2.52	
SVOLI		.46	.63	.80	.96	1.11	1.26	1.41	1.55	1.69	1.82	1.96	2.09	
SVOLX		.17	.23	.30	.35	.41	.47	.52	.57	.62	.67	.72	.77	
60:														
TVOL		1.83	2.35	2.82	3.24	3.63	4.00	4.34	4.68	4.99	5.30	5.60	5.88	6.16
WVOL		1.28	1.64	1.95	2.23	2.50	2.74	2.97	3.19	3.40	3.61	3.80	3.99	4.18
SVOLI		.69	.95	1.21	1.45	1.68	1.90	2.12	2.33	2.54	2.75	2.95	3.15	3.34
SVOLX		.25	.35	.44	.53	.62	.70	.78	.86	.94	1.01	1.09	1.16	1.23
70:														
TVOL		2.61	3.36	4.03	4.63	5.19	5.71	6.21	6.69	7.14	7.58	8.00	8.41	8.81
WVOL		1.89	2.42	2.88	3.30	3.69	4.05	4.39	4.72	5.03	5.33	5.62	5.90	6.17
SVOLI		.97	1.35	1.71	2.04	2.37	2.69	3.00	3.30	3.59	3.88	4.17	4.45	4.72
SVOLX		.36	.50	.63	.75	.87	.99	1.10	1.21	1.32	1.43	1.53	1.64	1.74
80:														
TVOL			4.58	5.49	6.31	7.07	7.79	8.47	9.11	9.73	10.33	10.91	11.47	12.01
WVOL			3.39	4.04	4.63	5.17	5.68	6.16	6.62	7.05	7.48	7.88	8.27	8.66
SVOLI			1.82	2.30	2.76	3.20	3.63	4.04	4.45	4.85	5.24	5.62	6.00	6.38
SVOLX			.67	.85	1.02	1.18	1.34	1.49	1.64	1.79	1.93	2.07	2.21	2.35
90:														
TVOL			6.03	7.21	8.29	9.29	10.23	11.13	11.98	12.79	13.58	14.34	15.07	15.79
WVOL			4.57	5.45	6.24	6.97	7.65	8.30	8.92	9.51	10.07	10.62	11:15	11.66
SVOLI			2.37	3.00	3.59	4.17	4.73	5.27	5.80	6.32	6.83	7.33	7.82	8.30
SVOLX			.87	1.10	1.32	1.54	1.74	1.94	2.14	2.33	2.51	2.70	2.88	3.06
100:														
TVOL				9.21	10.59	11.87	13.07	14.21	15.29	16.33	17.34	18.31	19.25	20.16
WVOL				7.11	8.15	9.10	10.00	10.84	11.64	12.41	13.15	13.87	14.56	15.23
SVOLI				3.80	4.55	5.28	5.99	6.67	7.34	8.00	8.65	9.28	9.90	10.52
SVOLX				1.40	1.68	1.94	2.20	2.46	2.70	2.95	3.18	3.42	3.65	3.87
110:														
TVOL				11.49	13.21	14.80	16.30	17.72	19.08	20.37	21.63	22.83	24.01	25.15
WVOL				9.06	10.37	11.59	12.72	13.80	14.82	15.80	16.75	17.66	18.54	19.39
SVOLI				4.70	5.64	6.54	7.41	8.26	9.10	9.91	10.71	11.49	12.27	13.03
SVOLX				1.73	2.08	2.41	2.73	3.04	3.35	3.65	3.94	4.23	4.52	4.80
120:														
TVOL				14.06	16.16	18.11	19.95	21.68	23.34	24.93	26.46	27.94	29.38	30.77
WVOL				11.29	12.93	14.44	15.86	17.20	18.48	19.70	20.88	22.01	23.11	24.17
SVOLI				5.72	6.85	7.95	9.01	10.05	11.06	12.05	13.02	13.97	14.91	15.84
SVOLX				2.11	2.52	2.93	3.32	3.70	4.07	4.44	4.79	5.15	5.49	5.83
130:														
TVOL				16.93	19.46	21.81	24.02	26.11	28.10	30.02	31.86	33.64	35.37	37.05
WVOL				13.83	15.84	17.69	19.43	21.07	22.63	24.13	25.57	26.96	28.30	29.60
SVOLI				6.84	8.20	9.51	10.79	12.02	13.23	14.42	15.58	16.72	17.85	18.96
SVOLX				2.52	3.02	3.50	3.97	4.43	4.87	5.31	5.74	6.16	6.57	6.98

NOTE: BLOCK INDICATES RANGE OF DATA.

1/TVOL = TOTAL ABOVEGROUND VOLUME OF WOOD AND BARK; EXCLUDES FOLIAGE.

WVOL = VOLUME OF WOOD FROM A 0.3 METER STUMP TO A 10-CENTIMETER TOP OUTSIDE BARK; EXCLUDES BARK AND FOLIAGE.

SVOLI = SAW-LOG VOLUME IN STRAIGHT MERCHANTABLE SECTIONS AT LEAST 2.5 METERS LONG TO A 23-CENTIMETER TOP OUTSIDE BARK IN TREES WITH A MERCHANTABLE FIRST SECTION ABOVE A 0.3-METER STUMP.

SVOLX = SAW-LOG VOLUME IN STRAIGHT MERCHANTABLE SECTIONS AT LEAST 2.5 METERS LONG TO A 23-CENTIMETER TOP OUTSIDE BARK IN TREES WITHOUT A MERCHANTABLE FIRST SECTION ABOVE A 0.3-METER STUMP.

Table 32--Total tree, wood, and saw-log volume for interior live oak

DIAMETER AT BREAST HEIGHT OUTSIDE BARK 1/	TOTAL HEIGHT (METERS)												
	3	6	9	12	15	18	21	24	27	30	33	36	39
CENTIMETERS	CUBIC METERS												
10:													
TVOL	0.03	0.04	0.05	0.06									
WVOL	.01	.02	.03	.04									
SVOLI	.01	.01	.02	.02									
SVOLX	.00	.00	.01	.01									
20:													
TVOL	.11	.17	.22	.26	0.30	0.34	0.37						
WVOL	.06	.10	.14	.17	.20	.24	.27						
SVOLI	.03	.06	.08	.10	.12	.14	.16						
SVOLX	.01	.02	.03	.04	.05	.05	.06						
30:													
TVOL	.25	.38	.50	.59	.68	.77	.85	0.92	0.99				
WVOL	.14	.24	.33	.41	.49	.56	.63	.70	.77				
SVOLI	.08	.14	.20	.25	.31	.35	.40	.45	.49				
SVOLX	.03	.05	.07	.09	.11	.13	.15	.16	.18				
40:													
TVOL		.69	.89	1.07	1.23	1.38	1.52	1.65	1.78				
WVOL		.44	.61	.76	.91	1.04	1.18	1.31	1.43				
SVOLI		.28	.38	.49	.58	.68	.77	.85	.94				
SVOLX		.10	.14	.18	.21	.25	.28	.31	.35				
50:													
TVOL		1.08	1.40	1.68	1.93	2.17	2.39	2.60	2.80	2.99			
WVOL		.72	.98	1.23	1.46	1.69	1.90	2.11	2.31	2.51			
SVOLI		.46	.63	.80	.96	1.11	1.26	1.41	1.55	1.69			
SVOLX		.17	.23	.30	.35	.41	.47	.52	.57	.62			
60:													
TVOL		1.57	2.02	2.43	2.79	3.14	3.46	3.76	4.05	4.33	4.60		
WVOL		1.06	1.45	1.82	2.17	2.50	2.81	3.12	3.42	3.71	4.00		
SVOLI		.69	.95	1.21	1.45	1.68	1.90	2.12	2.33	2.54	2.75		
SVOLX		.25	.35	.44	.53	.62	.70	.78	.86	.94	1.01		
70:													
TVOL			2.77	3.32	3.82	4.29	4.73	5.14	5.54	5.92	6.29	6.65	6.99
WVOL			2.03	2.53	3.02	3.48	3.92	4.35	4.77	5.17	5.57	5.96	6.34
SVOLI			1.35	1.71	2.04	2.37	2.69	3.00	3.30	3.59	3.88	4.17	4.45
SVOLX			.50	.63	.75	.87	.99	1.10	1.21	1.32	1.43	1.53	1.64
80:													
TVOL			3.63	4.35	5.01	5.62	6.20	6.74	7.27	7.77	8.25	8.72	9.17
WVOL			2.70	3.38	4.02	4.63	5.22	5.79	6.35	6.89	7.42	7.94	8.45
SVOLI			1.82	2.30	2.76	3.20	3.63	4.04	4.45	4.85	5.24	5.62	6.00
SVOLX			.67	.85	1.02	1.18	1.34	1.49	1.64	1.79	1.93	2.07	2.21
90:													
TVOL			4.61	5.53	6.36	7.14	7.87	8.57	9.23	9.87	10.48	11.07	11.65
WVOL			3.48	4.35	5.18	5.96	6.73	7.46	8.18	8,88	9.56	10.23	10.89
SVOLI			2.37	3.00	3.59	4.17	4.73	5.27	5.80	6.32	6.83	7.33	7.82
SVOLX			.87	1.10	1.32	1.54	1.74	1.94	2.14	2.33	2.51	2.70	2.88
100:													
TVOL			5.70	6.84	7.88	8.84	9.75	10.61	11.43	12.22	12.98	13.71	14.42
WVOL			4.36	5.46	6.49	7.48	8.43	9.36	10.26	11.13	11.99	12.83	13.66
SVOLI			3.00	3.80	4.55	5.28	5.99	6.67	7.34	8.00	8.65	9.28	9.90
SVOLX			1.11	1.40	1.68	1.94	2.20	2.46	2.70	2.95	3.18	3.42	3.65
110:													
TVOL				8.30	9.56	10.73	11.83	12.87	13.87	14.83	15.75	16.64	17.50
WVOL				6.70	7.97	9.18	10.35	11.49	12.59	13.66	14.72	15.75	16.76
SVOLI				4.70	5.64	6.54	7.41	8.26	9.10	9.91	10.71	11.49	12.27
SVOLX				1.73	2.08	2.41	2.73	3.04	3.35	3.65	3.94	4.23	4.52
120:													
TVOL				9.91	11.41	12.81	14.12	15.36	16.55	17.69	18.79	19.85	20.88
WVOL				8.07	9.60	11.07	12.48	13.85	15.18	16.47	17.74	18.99	20.21
SVOLI				5.72	6.85	7.95	9.01	10.05	11.06	12.05	13.02	13.97	14.91
SVOLX				2.11	2.52	2.93	3.32	3.70	4.07	4.44	4.79	5.15	5.49
130:													
TVOL				11.66	13.42	15.06	16.61	18.07	19.47	20.81	22.10	23.35	24.57
WVOL				9.59	11.41	13.15	14.82	16.45	18.03	19.57	21.07	22.55	24.00
SVOLI				6.84	8.20	9.51	10.79	12.02	13.23	14.42	15.58	16.72	17.85
SVOLX				2.52	3.02	3.50	3.97	4.43	4.87	5.31	5.74	6.16	6.57

NOTE: BLOCK INDICATES RANGE OF OATA.

1/TVOL = TOTAL ABOVEGROUND VOLUME OF WOOD AND BARK; EXCLUOES FOLIAGE.

WVOL = VOLUME OF WOOO FROM A 0.3 METER STUMP TO A 10-CENTIMETER TOP OUTSIDE BARK; EXCLUDES BARK AND FOLIAGE.

SVOLI = SAW-LOG VOLUME IN STRAIGHT MERCHANTABLE SECTIONS AT LEAST 2.5 METERS LONG TO A 23-CENTIMETER TOP OUTSIOE BARK IN TREES WITH A MERCHANTABLE FIRST SECTION ABOVE A 0.3-METER STUMP.

SVOLX = SAW-LOG VOLUME IN STRAIGHT MERCHANTABLE SECTIONS AT LEAST 2.5 METERS LONG TO A 23-CENTIMETER TOP OUTSIDE BARK IN TREES WITHOUT A MERCHANTABLE FIRST SECTION ABOVE A 0.3-METER STUMP.

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Biomass Estimators For Thinned Second-Growth Ponderosa Pine Trees

P. H. Cochran, J. W. Jennings, and C. T. Youngberg

Abstract

Usable estimates of the mass of live foliage and limbs of sapling and pole-sized ponderosa pine in managed stands in central Oregon can be obtained with equations using the logarithm of diameter as the only independent variable. These equations produce only slightly higher root mean square deviations than equations that include additional independent variables. A better estimate of live foliage mass is produced when distance from breast height to live crown is added. A better estimate of live limb mass is produced with the addition of height. For other components investigated (bole wood volume, bole wood mass, bark volume and mass, and total aboveground mass) equations that include height, as well as diameter, greatly reduce the root mean square deviations, compared with equations based on diameter alone.

Keywords: Biomass, estimates, second-growth stands, ponderosa pine.

Introduction

Intensive logging of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) stands in south central Oregon since the early 1900's has resulted in large acreages of second growth. Most of these stands are being managed on an even-aged basis with precommercial and commercial thinnings to control stocking levels. No equations for estimating biomass components of young ponderosa pine trees have previously been developed from data collected in central Oregon. We report some equations based on biomass data obtained by destructively sampling 23 ponderosa pine trees growing in precommercially thinned stands in central Oregon.

These equations allow managers to estimate biomass components for trees in similar stands that have been precommercially thinned. Researchers need these estimators to study nutrient cycling and productivity.

P. H. COCHRAN, soil scientist, Silviculture Laboratory, Pacific Northwest Forest and Range Experiment Station, Bend, Oregon. J. W. JENNINGS, soil scientist, U.S. Department of Agriculture, Forest Service, Olympic National Forest, Olympia, Washington. C. T. YOUNGBERG, professor emeritus, Department of Soil Science, Oregon State University, Corvallis, Oregon.

Methods

Two study sites were chosen to represent the range of tree sizes in most of the precommercially thinned, second-growth stands in central Oregon. The six largest trees in the 23-tree sample were selected from a stand 18 kilometers (km) south of Bend, Oregon. The stand originated from seed after clearcutting and had been precommercially thinned 14 years previously. Seventeen other trees were sampled in a second natural stand 40 km southwest of Bend. This stand had been thinned precommercially following overstory removal 18 years before sampling. Site index (Barrett 1978) was 33.5 meters (m) at both locations. Both stands are on soils developing from Mazama pumice and ash and are ashy over loamy, mixed Typic Cryorthents. Tree sizes were smaller at the second location because an overstory was present before thinning. Diameters of the 23 trees ranged from 5.3 to 38.7 centimeters (cm) and heights ranged from 3.11 to 20.63 m.

Healthy appearing trees with intermediate to dominant crowns were selected subjectively to represent the range of diameters, heights, and crown ratios in the two stands. Diameters (D) of selected trees were measured at breast height (bh) to the nearest 0.1 cm, and total heights (H), and crown lengths (C) were determined to the nearest 0.01 m after felling. Crown lengths were divided into thirds and referred to as upper, middle, and lower crown. All live needles including fascicles were separated from branches by crown position. Boles of 17 trees, which ranged from 5.3 to 29.5 cm dbh, were sectioned at 46-cm intervals. For six trees 32.3 to 38.7 cm dbh, disks were removed from the bole at 0.3, 1.37, and 3 m and then 3-m intervals up the stem. Inside and outside bark measurements were taken at each position of sectioning to determine total bole volume inside and outside bark. All needles, limbs, and either entire boles or disks from boles of the larger trees were taken to the laboratory.

For trees greater than 32-cm dbh, foliage and limbs were weighed fresh and then subsampled to determine dry weights. For trees less than 32-cm dbh, bark was stripped from the bole, and all needles, limbs, bole wood, and bole bark were dried and weighed. Bark was stripped from the disks of the six larger trees, dried, and weighed after thickness of the disk was determined at four points. Samples were taken from each disk to determine wood density. Volume of these green wood samples was determined by water displacement, and density was calculated by dividing the dry weight by the green volume. Density of the bole bark was calculated for the larger trees by dividing dry weight of the bark removed from each disk by the volume calculated from the disk thickness and the diameters inside and outside bark for that disk. Bark and wood densities were then applied to volume of bole wood and bark from corresponding segments of the trees greater than 32-cm dbh to estimate weight of bole wood and bark.

Needles were dried at 75 °C for at least 48 hours. Bark and wood were dried at 90 °C for at least 96 hours. Volume of the bole, both inside and outside bark, above the stump to the tip segment was determined using Smalian's formula. The stumps were considered cylinders with diameters at the 0.3-m height, and all tip segments were considered cone shaped.

Snell (1979) described total tree weights of tanoak, black oak, and Pacific madrone using equations of the form

ln (total tree weight) $= a + b$ (ln D); where ln refers to the natural logarithm.

The estimate of live limb mass, L, with the lowest RMSD is

$$\ln L = -3.6363 + 1.2426\,(\ln D) + 0.7659\,(\ln H) + 0.5127\,(\ln C). \quad (5)$$

Two other estimates are

$$\ln L = -4.1068 + 1.5177\,(\ln D) + 1.0424\,(\ln H), \quad (6)$$

and

$$\ln L = -4.5745 + 2.4645\,(\ln D). \quad (7)$$

The R^2, residual mean squares, and RMSD's are:

Equation	R^2	Residual mean square	RMSD Corrected	RMSD Not corrected
			kilograms	kilograms
(5)	0.9525	0.1297	14.06	14.88
(6)	.9510	.1273	14.84	15.42
(7)	.9411	.1454	16.10	17.27

The model using a form factor to determine bole volume had a lower RMSD, 0.021 m^3, than any of the logarithmic equations. Further, multiplication of the estimated bole volume, as determined with the form factor equation, by the overall average density of bole wood, 380 kg/m^3, produced estimates of bole mass with a lower RMSD, 6.67 kg, than produced with the logarithmic equations.

Estimators with the lowest RMSD for bole bark volume, *BV,* and bole bark mass, *BW*, are

$$\ln BV = -10.3786 + 2.0879\,(\ln D) + 0.3799\,(\ln H) \quad (8)$$

and

$$\ln BW = -3.6263 + 1.34077\,(\ln D) + 0.8567\,(\ln H) \quad (9)$$

Residual mean squares are 0.0215 for the bole bark volume equation and 0.0256 for the bole bark mass equation. R^2 is 0.99 for both equations. RMSD, with and without Baskerville's correction, is 0.01 m^3 and 0.01 m^3 for the bole bark volume equation and 2.7 and 2.6 kg for the bole bark mass equation.

The estimator for total aboveground mass, excluding dead limbs and needles, *TW*, with the lowest RMSD is:

$$\ln TW = -2.3371 + 1.5812\,(\ln D) + 0.9036\,(\ln H) \quad (10)$$

R^2 is 0.9949, the residual mean square is 0.0119, and the RMSD, with and without Baskerville's correction, is 25.3 and 25.7 kg. Addition of the other independent variables does not reduce the residual mean square or the RMSD.

Multiple linear regression methods were used to determine the coefficients of each model for each volume and biomass component measured. Corrections for logarithmic bias (Baskerville 1972) were made by dividing residual mean squares by two and adding the result to the constant term of the equation. The root mean square deviation (RMSD), RMSD = $(\Sigma\,(\text{actual value} - \text{estimated value})^2/\,\text{number of estimates})^{0.5}$, was determined for each equation, with and without the correction for bias. The equation with the lowest RMSD for each volume or biomass component was judged the best estimator for that volume or biomass component.

Results and Discussion

Live foliage mass for the sample trees ranged from 0.56 to 48.3 kg. For these trees, 22 percent of the total needle mass is in the upper third of the crown, 45 percent in the mid third, and 33 percent in the lower third. Mass of live limbs ranged from 0.8 to 146 kg. Eleven percent of the live limb mass is in the upper third of the crown, 41 percent in the mid third, and 48 percent in the lower third. Live crown ratios (live crown length divided by total tree height) ranged from 0.44 to 0.82 and averaged 0.7. Wood and bark densities for the 23 trees averaged 0.38 grams per cubic centimeter (g/cm^3) for wood and 0.29 g/cm^3 for bark, with standard deviations of 0.03 and 0.05 g/cm^3, respectively.

The estimate with the lowest RMSD for live foliage mass, *N*, is

$$ln\,N = -3.6362 + 1.93\,(ln\,D) + 0.2234\,(ln\,C) - 0.07329\,K. \quad (1)$$

Dropping live crown length, *C*, produces

$$ln\,N = -3.8984 + 2.1607\,(ln\,D) - 0.07394\,K. \quad (2)$$

Omitting distance between breast height and crown, *K*, and adding total height, *H*, results in

$$ln\,N = -3.0669 + 2.0218\,(ln\,D) + 0.73665\,(ln\,C) - 0.8652\,(ln\,H). \quad (3)$$

Regression with diameter alone yields

$$ln\,N = -3.5328 + 1.992\,(ln\,D). \quad (4)$$

The R^2, residual mean squares, and RMSD's, with and without Baskerville's (1972) correction, are:

Equation	R^2	Residual mean square	RMSD Corrected	RMSD Not corrected
			kilograms	
(1)	0.9799	0.03475	3.01	3.09
(2)	.9792	.03412	3.27	3.35
(3)	.9803	.03403	3.33	4.00
(4)	.9721	.04362	4.11	4.07

Equation (4) demonstrates a close relationship between diameter at breast height and foliage mass, while the next most important variable is the distance between breast height and crown. This is a reflection of the high correlation between sapwood area at the base of the live crown and needle mass (Waring and others 1982). The equation fitted using only *ln D* and *ln H* as independent variables had nearly the same residual mean square and RMSD as equation (4).

Gholz and others (1979) used an equation of this form to describe biomass components for several plants, including ponderosa pine. For nine ponderosa pine trees sampled in Arizona, ranging in size from 15.5 to 79.5 cm in diameter, they present the following estimates for mass in kilograms (kg):

ln (live foliage mass) = -4.2612 + 2.0967 (*ln D*);
ln (live limb mass) = -5.3855 + 2.7185 (*ln D*).

Taras and Clark (1977) related several biomass components, M, of longleaf pine, including limb and foliage mass, to diameter squared times total height (D^2H). Their equations were of the form $\log_{10} M = a + b \log_{10} (D^2H)$.

Various models were tested to determine the estimators with the minimum root mean square deviations. Logarithmic equations were used to reduce heterogeneity of variances and eliminate the need for weighted regressions, because estimates of proper weights for some of the biomass components are unknown. Models tested related some biomass components (*M*) and bole volumes (*V*) to diameter (*D*), height (*H*), live crown length (*C*), and distance to the start of the live crown above breast height (*K*). Because only 23 observations were available, no more than three independent variables were used in fitting equations to the data. Further, interactions of the independent variables were restricted to D^2H and D^2C in the equation-fitting process. *D* is in centimeters while *H, C,* and *K* are in meters. *K* is negative when the crown length extends below 1.37 m. Biomass components are in kilograms, volumes are in cubic meters (m^3), and natural logarithms are symbolized by *ln*.

In addition to these models, the bole wood volume (*V*) was also estimated using a model incorporating form factor (*F*);

$V = a F (D-T)^2 H$, where *T* is double bark thickness and *a* is a constant. Equations developed by DeMars[1] were used for *T* and *F*.

Mass of bole wood was also estimated by multiplying the volume in cubic meters, as determined with DeMars' equation, by the average wood density for all the trees.

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[1] Personal communication with Donald DeMars, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

$\log_{10} T = -0.883813 + 1.39767 \log_{10} D - 0.291682 (\log_{10} D)^2.$

For trees over 20 feet in height,

$$F = 0.712868 + 6.64002/H - 0.760078/D - 1.61467\, D/H + 1.69747\, D^2/H^2.$$

For trees under 20 feet in height,

$$F/W^2 = -1.00602 + 0.566024 (D)(W) + 0.00177039 (H/D) W - 0.0597387 D^2W + 31.5012/H - 117.132/H^2 - 12.0570 (D/H)W + 41.6193 (D/H^2) W + 1.17642 (D^2/H)W - 2.66157 (D^2/H^2) W;$$

where *W* = (height in feet − 2.25)/(height in feet − 4.5).

D and *T* are in inches, *H* is in feet, *a* is equal to 0.005454154, and *V* is cubic feet (ft^3). *V* can be converted to cubic meters by multiplying by 0.028316846592 m^3/ft^3.

Conclusions

Usable estimates of the mass of live foliage and limbs can be obtained with equations using diameter alone. Including distance from breast height to the live crown, along with diameter, as an independent variable produces a better estimate. The addition of height as an independent variable, along with diameter, produces a better estimate for mass of live limbs. The best estimate is considered here as the estimate with the lowest root mean square deviation. Equations using a form factor provided the best estimate of volume and mass of bole wood. The best estimates of volume and mass of bark, as well as total mass aboveground, were obtained by equations using diameter and height. For all estimates except foliage and limb mass, equations using height as well as diameter reduced the RMSD by a factor of at least two, compared with equations using diameter alone. Correction for logarithmic bias only slightly changes root mean square deviations and does not seem to be of practical importance.

The equations presented here are regarded as first approximations for sapling and pole-sized trees in managed stands in central Oregon. These equations should not be extended to larger trees or to other areas without validation.

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Conversion Factors

1 kilometer = 0.6214 miles
1 meter = 3.2808 feet
1 centimeter = 2.54 inches
1 kilogram = 2.2046 pounds
1 cubic meter = 35.3145 cubic feet
1 kilogram per cubic meter = 0.06243 pounds per cubic foot
1 gram per cubic centimeter = 62.428 pounds per cubic foot

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Fourwing Saltbush Establishment in the Keating Uniform Shrub Garden--First Year Results

J. Michael Geist and Paul J. Edgerton

Abstract

Site preparation techniques to aid establishment of fourwing saltbush (Atriplex canescens) were compared at a test location in eastern Oregon. Survival and growth of transplanted seedlings were improved after one season of growth by either spot spraying with herbicides or scalping to reduce competing vegetation. Average growth of seedlings was greater with the spray treatment than with scalp treatment. Control of plant competition should improve transplanting success of fourwing saltbush in many related rangeland areas.

Keywords: Forage production, range production, seedling establishment, site preparation.

Introduction

Land managers commonly seek information on plant materials and techniques for improving forage and cover on livestock and mule deer (Odocoileus hemionus)[1/] foothill ranges adversely affected by wildfire, improper grazing, and other disturbance. In eastern Oregon, these ranges are typically dominated by less desirable forage plants such as cheatgrass brome (Bromus tectorum L.), medusahead wildrye (Elymus caput-medusae L.), Japanese brome (Bromus japonicus Thunb.), big sagebrush (Artemisia tridentata Nutt.), rabbitbrush (Chrysothamnus spp. Nutt.) and a variety of forbs. Some ranges have been successfully seeded to domestic grasses, usually crested wheatgrass (Agropyron desertorum Schult.), to increase available livestock forage and lessen grazing pressure on desirable perennial native plants. Such

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[1/] Scientific and common names are from Garrison and others (1976) and Ingles (1965).

J. MICHAEL GEIST is a principal research soil scientist, Pacific Northwest Forest and Range Experiment Station, Range and Wildlife Habitat Laboratory, C. Street & Gekeler Lane, La Grande, OR. 97850. PAUL J. EDGERTON is a research wildlife biologist, Pacific Northwest Forest and Range Experiment Station, Forestry Sciences Laboratory, 1133 N. Western Avenue, Wenatchee, WA. 98801.

seedings commonly lack a suitable variety of forage or wildlife cover, so land managers often wish to interseed shrubs and herbaceous species. Benefits to both wild and domestic animals result from diversification of the vegetation species and structure (Margalef 1969).

The Keating range in Baker County, Oregon, is typical of foothill areas where vegetative improvement has been a longstanding concern. The range includes 45,000 acres of crucial deer winter range with a mosaic of depleted sites and extensive grass seedings. Mule deer winter on the range from December through March. Livestock, mostly cattle, graze in a variety of management systems, generally from mid-April to late July, and may return in the fall, depending on forage availability.

Fourwing saltbush (Atriplex canescens (Pursh) Nutt.)) has been widely recognized as a valuable shrub for rangeland plantings on a wide variety of ecological sites (Plummer and others 1966). In shrub adaptability studies conducted on the Keating range, this plant has shown high potential for contributing green forage, wildlife cover, and plant diversity on eastern Oregon rangelands.[2]

Competition from herbaceous plants, particularly annual grasses, has been an important factor limiting the establishment and growth of more desirable perennials, including shrubs, on harsh rangeland sites (Holmgren 1956, Hubbard 1957). Effective, yet relatively inexpensive, site preparation techniques are needed to help make range rehabilitation a more attractive investment for range managers. This paper reports the results of a study to determine whether survival and growth of fourwing saltbush transplants would be improved by eliminating herbaceous vegetation through scalping or spraying herbicide.

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[2] Unpublished data on file with the junior author at the Forestry Sciences Laboratory, Wenatchee, WA.

Study Area

The trial was conducted in a deer-proof exclosure called the Keating Uniform Garden located about 30 miles east of Baker, Oregon, within the Keating deer winter range. The exclosure is on a terrace with a soil derived principally from weathered granitic outwash from upper slopes. The soil was formerly mapped as the Brownlee series, but we believe it would now be considered of the Brownscombe series, a fine montmorillonitic, mesic Calcic Argixeroll. The lower subsoil is very weakly to moderately calcareous. The solum is about 64 to 76 centimeters (25 to 30 in) thick. It has a loam to silt loam surface layer 20 to 25 centimeters (8 to 10 in) thick over a clay loam subsurface layer that grades into weathered granitic outwash below the solum. The slope ranges from 2 to 7 percent on a dominantly southern aspect at an elevation of 976 meters (3,200 ft). Precipitation averages 30 centimeters (12 in) and occurs mostly in winter and spring. Fall rains may provide adequate moisture for germination of late season annuals and greenup of cool season grasses.

Existing vegetation at the time of exclosure construction was an established crested wheatgrass seeding. Vegetation on nearby unseeded range suggests that the previous plant community was dominated by big sagebrush, cheatgrass brome, and several forbs, with scattered rabbitbrush and remnant native bunchgrasses. Most of the seeded grass in the portion of the exclosure used for this trial had been removed by discing in 1976, and the vegetation had reverted to a dense cover of cheatgrass brome and less desirable forbs (fig. 1).

Figure 1.--The generally abundant grass and forb competition are shown in the untreated (control) plot in the foreground. Planted shrubs are visible in the scalped and chemically treated plots in the background. Photograph was taken near the end of the growing season.

Readers should recognize that there are limitations in application of the study results, because a single location was utilized. It is unlikely that all locations will respond in exactly the same fashion. Our test location is, however, typical of local problem conditions and we are confident the results in general are broadly applicable to the Keating range. This study has provided guidance for subsequent tests whose results will provide better quantification of treatment responses.

On April 23, 1981, when this study was initiated with field layout and spraying, annual grasses and forbs had germinated and developed to an average height of 3 centimeters (1 in). Pre-treatment estimates of layered canopy coverage (Daubenmire 1959) on 90 plots 1-meter square (9-ft^2) showed that total cover averaged 67 percent; annual grasses averaged 42 percent, perennial grasses 3 percent, and forbs 22 percent. Abundant individual species were cheatgrass brome 42 percent, alfilaria (Erodium cicutarium (L.) L'her.)) 10 percent, and tumblemustard (Sisymbrium altissimum L.) 9 percent. Later observation of untreated plots, when grasses and particularly forbs matured, indicated that layered canopy cover exceeded 100 percent.

Methods

Three replications of three treatments were assigned in a completely random design to nine 5.5- by 20.1-meter (18- by 66-ft) plots. The three treatments were: spot scalp, spot spray, and control (no treatment). Spots were about 1 meter square spaced on 1.8-meter (6-ft) centers to give 30 planting spots per replicated plot or 90 planting locations for each treatment over the three replications for a total of 270 planting locations.

Roundup[3/] herbicide was applied on competing vegetation in the spray spots to the foliar wetting point with a backpack sprayer. Herbicide concentration was about 3 percent v/v (4 fluid ounces of herbicide concentrate per gallon of solution, with 2 fluid ounces of No Foam B sticker per gallon). The concentrate contained 41 percent active ingredient. (Our objectives did not include rate testing so we have no idea whether lower rates would have similarly affected the treated vegetation.) Container-grown fourwing saltbush seedlings were hand planted with tree planting bars in the center of spot treatments and in the same spacing in control plots.

[3/] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others which may be suitable.

Scalping and planting of container stock were performed 2 days after spraying. Scalps were made to about 3-centimeters (1-in) depth with a large hoe. Samples taken at planting indicated an average soil moisture of 24 percent (by weight) in the 2 to 15 centimeters (1 to 6 in) zone and 23 percent in the 15 to 30 centimeters (12 to 18 in) zone. There was a 1 centimeter (1/2 in) thick surface crust of air-dry soil.

The seedlings used in this study were grown from seed provided by the USDA Forest Service, Intermountain Forest and Range Experiment Station and the Utah Department of Fish and Game. The seed was harvested from a seed orchard in central Utah. The original source of the material was Rincon Blanco in Rio Arriba Co., New Mexico, USA (ref. U-92).

Seeds were germinated and seedlings grown in 175-cubic centimeter (10.7-cubic inch) containers for approximately 3 months in a controlled greenhouse environment. A commercial peat and vermiculite potting mix was the growth medium. Water and supplemental fertilizer was applied as necessary. On March 16 lights and heat in the greenhouse were turned off and the seedlings "hardened off" by exposing them to cool, fluctuating temperatures. No temperature records were made. Just prior to planting on April 23 the stems averaged 11.6 centimeters (4.7 in) tall.

First season survival and growth were evaluated in early September 1981. Live plants in each treatment were counted and maximum height of the tallest twigs measured. Missing plants were considered dead but causes of mortality were not determined.

Results were tested by a one-way analysis of variance and by Scheffe's test of treatment means (Freese 1967). Tests of significance were made at a probability less than or equal to 5 percent.

Results

Number of live shrubs, percent survival, and height growth are summarized in table 1. There were significantly more live plants in both scalp and spray treatments than in the control, but there was no difference in survival between the scalp and spray treatments. Height growth on the control was less than half that on other treatments, and height growth was less on scalp than on spray treatments.

Weed invasion at the end of the first growing season was nil and was not quantitatively evaluated. Competition control was excellent by both methods.

Table 1--Mean response by fourwing saltbush transplants to three treatments, measured at the end of the first growing season[1]

Parameter	Control	Scalp	Spray
Number live	13 a	30 b	26 b
Percent live	43 a	99 b	87 b
Mean maximum height of live plants (cm)	15 a	31 b	43 c

[1] Entries on the same line followed by different letters are statistically different, according to Scheffe's test of means. Means were rounded to the nearest whole unit.

Discussion and Conclusions

Preliminary tests of establishment by fourwing saltbush transplants indicate that vegetative competition must be treated to achieve high levels of survival and growth, even when soil moisture conditions are good at planting time.

Fourwing saltbush plants on the control plots, although small, appeared healthy, indicating they had a reasonable chance of surviving winter and possibly growing well the following year.

We suspect that the maintenance of litter and surface soil associated with the spray treatment are advantages over scalping. The litter cover reduces evaporation of surface soil moisture and also provides better protection from erosion. This opinion is based on general conservation principles and was not verified by site-specific data.

Plant spacing was relatively close because of the short duration of this study, and we assumed no rooting interactions among plants. Thus, even if spacing were increased, percentages of survival and growth would likely be unchanged. In an operational project, wider spacing would maximize the area that could be covered with available manpower, plant materials, and time. With wider spacing, however, the value of each shrub increases and initial control of herbaceous competition becomes more critical to the long-term success of the project.

Since funding, labor, and available planting time are usually critically short, we recommend chemical control of competing vegetation under the conditions studied. Although time required for application of treatments was not recorded, spraying was three to four times faster than scalping and was much less tiring.

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Estimating Cubic Volume of Small Diameter Tree-Length Logs From Ponderosa and Lodgepole Pine

Marlin E. Plank and James M. Cahill

Abstract

A sample of 351 ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) and 509 lodgepole pine (*Pinus contorta* Dougl. ex Loud.) logs were used to evaluate the performance of three commonly used formulas for estimating cubic volume. Smalian's formula, Bruce's formula, and Huber's formula were tested to determine which would provide the best estimate of cubic volume when it was applied to tree-length logs. Smalian's formula overestimated the volume by 19 percent, Bruce's formula underestimated by 16 percent, and Huber's formula underestimated by 2 percent. Huber's formula provided the closest estimate and is recommended. Accuracy and bias tests are shown.

Keywords: Cubic volume, log volume, Smalian's formula, Huber's formula, Bruce's formula, scaling.

Introduction

Coniferous trees have a central woody stem comprised of many geometric shapes (fig. 1). The geometric form of logs cut from these trees can vary depending on their position in the tree. Butt logs, for instance, approximate the shape of a concave paraboloid and logs cut from the middle of the tree, usually a convex paraboloid; logs cut from the top are either cones or paraboloids.

The geometric shape of a log dictates the formula to be used to estimate cubic volumes. Smalian's and Huber's formulas are often used to estimate the volume of midstem and upper-stem logs; both formulas assume a parabolic shape. Smalian's formula can also be used on butt logs after the large-end diameter has been reduced to account for basal flare. An equation developed by Bruce (1982) considers the neiloid shape of butt logs and estimates volume with no adjustment to the

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MARLIN E. PLANK is a research forest products technologist and JAMES M. CAHILL is a research forester at Forestry Sciences Laboratory, P.O. Box 3890, Portland, Oregon 97208.

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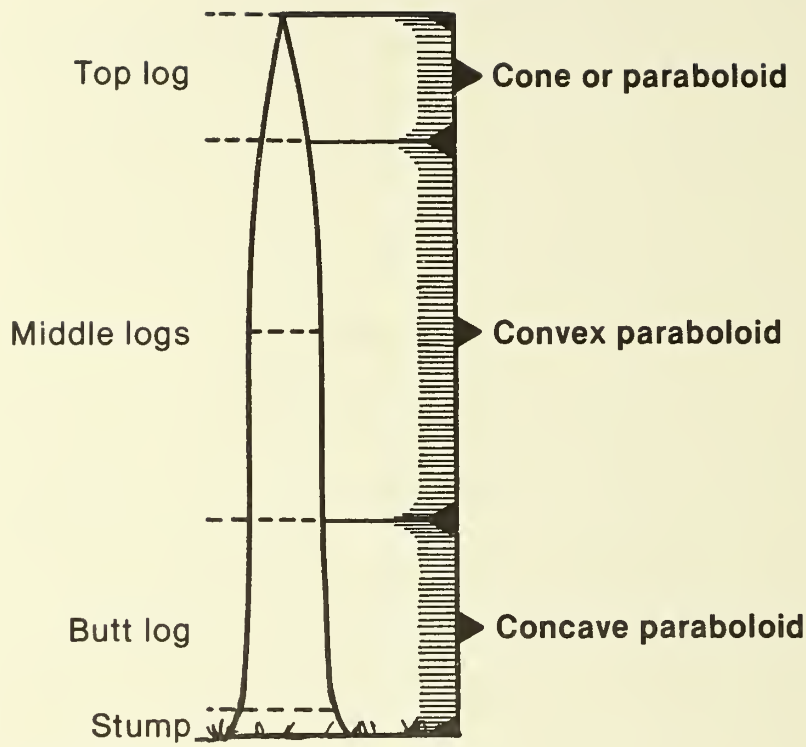

Figure 1--Geometric shapes in a coniferous tree stem.

measurement of the large end. Bruce's equation has proved accurate and unbiased[1] for coast Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) logs, and it is being evaluated by the forest products industry and the USDA Forest Service in the Western United States.

Selecting an accurate and unbiased formula to estimate the cubic volume of small diameter "tree-length" logs is difficult. Tree-length logs usually extend from the stump into the live crown and can have the concave shape of the butt, the convex shape of the midstem, and the conic shape of the top within a single long log. The purpose of this paper is to compare the accuracy and bias of volume estimates made by Bruce's, Smalian's, and Huber's formulas on small diameter, tree-length ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) and lodgepole pine (*P. contorta* Dougl. ex Loud.) logs. None of these equations were designed specifically for tree-length logs, but because they are all in common use, knowledge of their accuracy will be helpful for scalers and mensurationists.

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[1] Max, T. A.; Cahill, J. M.; and Snellgrove, T. A. Validation of butt log estimator for Douglas-fir. Submitted to Forest Science in May 1984.

Methods

Data Base

The data used in this analysis were Scribner log scale measurements recorded on 860 tree-length logs. The sample included 351 ponderosa pine logs from Colorado, Arizona, and South Dakota, and 509 lodgepole pine logs from Wyoming and Oregon. The logs were from several product recovery studies. Generally, trees selected for product recovery studies include the range of stem quality that exists within a geographic area. We think these samples represent a good range of stem forms for small diameter ponderosa and lodgepole pine trees. The following tabulation shows the range of diameters and lengths for the tree-length logs in the sample:

	Number of logs	Range in diameter		Range in length
		Large	Small	
		(Inches)		(Feet)
Ponderosa pine	351	7–20	5– 9	20–50
Lodgepole pine	509	6–18	4–10	20–50

Log Measurements

Lengths and diameters of the tree-length logs were measured and recorded by USDA Forest Service scalers in the mill yard. After the logs were bucked for milling, the dimensions of the short logs were also recorded. Length of the short logs varied from 4 to 20 feet, depending on whether the log was processed into veneer (4 feet), studs (8 feet), or random-length dimension lumber (8 to 20 feet). All measurements were taken according to the USDA Forest Service Log Scaling Handbook (1973) rules.

Midpoint diameters were not directly measured on the logs in the data base. Estimates of the midpoint were made from the short log scale measurements as in the following example. For a 42-foot tree-length log bucked into three short logs, the dimensions of the short logs are as follows:

Butt log: 16 x 12 inches x 16 feet
Middle log: 12 x 9 inches x 16 feet
Top log: 9 x 6 inches x 10 feet

The midpoint of the tree-length log (21 feet) occurred in the second short log. Diameters at each end of that log were 12 and 9 inches and the log length was 16 feet; the average taper was (12 - 9)/16 = 0.187 inch per foot. Because the midpoint of the tree-length log was 5 feet from the large end of the second short log, the midpoint was estimated to be 12-(5 x 0.187) = 11.1 inches. Midpoint diameters were rounded to the nearest inch.

Computation of Actual Log Volume

For our purposes, actual volume of a tree-length log is the sum of the cubic volumes of short logs bucked from the log. The majority of tree-length logs were cut into two or more segments and were processed into lumber. The volume of the butt segment was computed by Bruce's (1982) formula, and the volume of all other segments was computed by Smalian's formula. For the example shown above, the dimensions and volumes of the short logs are:

Butt log: (16 x 12 inches x 16 feet) volume = 15.0 cubic feet
Middle log: (12 x 9 inches x 16 feet) volume = 9.8 cubic feet
Top log: (9 x 6 inches x 10 feet) volume = 3.2 cubic feet

Actual volume of the tree-length log (V_a) is computed by summing the volumes of the short logs: $V_a = 15.0 + 9.8 + 3.2 = 28.0$ cubic feet.

Validation of Actual Volume

To test whether a reasonable estimate of actual volume can be made by adding the volumes of short logs, we used 84 lodgepole pine logs from our data base; measurements had been taken at 4-foot intervals. If the sum of the volume for the 4-foot segments approximated the volume estimated for the entire short log, then our method of calculating short-log volume, and thus the tree-length volume, was accurate. We did not have similar measurements on the ponderosa pine and had to assume that the results of the lodgepole pine validation would apply to the ponderosa pine. The following procedure was used to make this test:

Each of the 84 tree-length logs was divided into a 16-foot butt log and an upper log of variable length. The actual volume for the shorter logs was computed by summing the volume of the 4-foot segments. The volume of each segment was computed by assuming that the segment was a frustum of a cone; that is, with the formula:

$$V = \frac{0.005454}{3} (D_s^2 + D_L^2 + D_s D_L)L;$$

where:

V = volume of the 4-foot segment (cubic feet);
L = length;
D_s = small end diameter inside bark of the segments (inches);
D_L = large end diameter inside bark of the segments (inches);
0.005454 = conversion constant.

The volumes summed from the 4-foot segments were validated by comparing them with the estimates of the short-log volume computed by applying Bruce's (1982) formula on the butt 16-foot short-log segment and Smalian's formula on the top segment. For the 84 test logs, we found that Bruce's equation underestimated the volume of the butt segments by an average of 5.3 percent, and Smalian's formula overestimated the volume of the top segments by an average of 0.4 percent. For the entire tree-length log, the estimated volume, obtained by summing the volumes of the short logs, underestimated the actual volume by 3 percent. We considered this an acceptable level of accuracy.

Computation of Estimated Volume

Estimated cubic-foot volumes of the tree-length logs were computed by Bruce's (1982), Huber's, and Smalian's formulas. The formulas are shown below:

Bruces's: $\text{Volume (cubic feet)} = 0.005454(0.25\ D_L^2 + 0.75\ D_s^2)L;$

Huber's: $\text{Volume (cubic feet)} = 0.005454(D_m^2)L;$

Smalian's: $\text{Volume (cubic feet)} = 0.0027274(D_s^2 + D_L^2)L;$

where:

L is log length;
D_s is small end diameter;
D_m is midpoint diameter;
D_L is large end diameter;
and 0.005454 and 0.0027274 are conversion constants.

By use of the dimensions of the same tree-length log, the cubic-foot volumes estimated by the three formulas are:

Bruce's estimate: $V_b = 0.005454(0.75(6^2) + 0.25(16^2))42.0$

$= 20.8\ ft^3.$

Huber's estimate: $V_h = 0.005454(11^2)42.0 = 27.7\ ft^3.$

Smalian's estimate: $V_s = 0.0027274(6^2 + 16^2)42.0 = 33.4\ ft^3.$

Computation of Bias and Accuracy

The deviations between actual volume (V_a) and the three estimates of actual volume--V_b, V_h, and V_s--were computed for each log. The mean deviation was used to estimate the average bias for the ponderosa and lodgepole pine samples. The square root of the mean squared deviation was used as an estimate of accuracy. The computational formulas for bias and accuracy are shown below:

$$\text{Bias} = \sum(V_a - V_e)/N;$$

$$\text{Accuracy} = \left(\sum(V_a - V_e)^2/N)\right)^{\frac{1}{2}};$$

where:

V_a is the actual volume of a tree-length log;
V_e is the volume estimated by either Bruce's, Smalian's, or Huber's formula; and
N is the number of logs in the sample.

Results

Volume estimates made by Huber's formula had the least amount of bias and were the most accurate (table 1). This was consistent for the ponderosa and lodgepole pine data. On a percentage basis, Huber's formula underestimated the actual volume for both species combined by 2 percent, whereas Bruce's (1982) underestimated it by 16 percent and Smalian's overestimated it by 19 percent.

Table 1--Bias and accuracy of Huber's, Bruce's, and Smalian's formulas for predicting the cubic volume of ponderosa and lodgepole pine tree-length logs

Species	Bias			Accuracy		
	Huber	Bruce (1982)	Smalian	Huber	Bruce (1982)	Smalian
	Cubic feet					
Ponderosa pine	0.39	3.20	-5.31	1.88	5.44	7.21
Lodgepole pine	.38	3.17	-2.96	1.72	4.39	4.32

Discussion

We recommend using Huber's formula for estimating cubic-foot volume for ponderosa and lodgepole pine tree-length logs. For our data, volume estimates made by Huber's formula were less biased and more accurate than estimates made by either Bruce's (1982) or Smalian's formula. Caution is necessary when these results are extrapolated beyond the range of diameters and lengths included in our samples.

Measuring only the midpoint diameter, as required by Huber's formula, has advantages and disadvantages. The obvious advantage is that only one diameter measurement is required on each log. This may represent a reduction in scaling costs. The disadvantages are: Scalers must have access to the middle of the log for caliper measurements, and estimates of bark thickness at the midpoint must be made. These are serious limitations if logs are scaled on trucks but would not be a problem when logs are rolled out in a yard. Finally, computing volumes by Huber's formula is easy and can be done directly in the field. Scalers need only log length and the midpoint diameter to obtain volume estimates by use of tables (USDA Forest Service 1978) of half cylinder cubic volumes.

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Pacific Northwest Forest and Range
Experiment Station
319 S.W. Pine St.
P.O. Box 3890
Portland, Oregon 97208

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Effects of Ash Leachates on Growth and Development of *Armillaria mellea* in Culture

Jimmy L. Reaves, Charles G. Shaw III, Robert E. Martin, and John E. Mayfield

Abstract

Ash leachates from recently burned litter in a ponderosa pine forest in central Oregon were tested for their effects on growth and development of Armillaria mellea in culture. Two isolates were used: one from an infected western hemlock and the other from an infected ponderosa pine tree. Colonies developing from agar discs containing mycelia of the hemlock isolate and grown on a solid agar-base medium supplemented with leachates extracted from 1, 5, 10, or 20 grams of ash per liter of media had significantly lower dry weights than colonies grown on nonsupplemented medium. There were no significant differences among leachate concentrations in dry weight of colonies developing from aerial rhizomorph tips of the hemlock isolate, although these colonies had significantly greater dry weights at each concentration than did those developing from mycelia. Some colonies started with aerial rhizormoph tips of the hemlock isolate developed mycelial fans similar to those found in trees infected with A. mellea. Colonies started with mycelia of the pine isolate and grown on

JIMMY L. REAVES is a graduate research assistant, Department of Biology, Atlanta University, Atlanta, GA 30314. CHARLES G. SHAW III, is a research plant pathologist, Pacific Northwest Forest and Range Experiment Station, Forestry Sciences Laboratory, P.O. Box 909, Juneau, AK 99802. At the time of this study, ROBERT E. MARTIN was supervisory research forester, Pacific Northwest Forest and Range Experiment Station, Silviculture Laboratory, Bend, OR 99701; at present he is professor of wildlands fire management, Department of Forestry and Resource Management, University of California, Berkeley, CA 94720. JOHN E. MAYFIELD is an associate professor of biology, Atlanta University, Atlanta, GA 30314.

media supplemented with 5 grams of ash leachate had significantly less growth than controls or cultures grown on media with 10 grams of ash leachate. Colonies started with aerial rhizomorph tips of the pine isolate showed no significant differences in growth among the leachate treatments. At 1 and 5 grams of ash leachate, colonies started with mycelia of the pine isolate had significantly less growth than colonies started with aerial rhizomorph tips.

Keywords: Root rot, Armillaria mellea, rhizomorphs, mycelial fans, fire (forest), cations.

Introduction

Various species of Armillaria attack woody and herbaceous plants throughout the world (Raabe 1962, Shaw and Roth 1978). The fungus usually spreads disease from plant to plant by rhizomorphs or by contacts between healthy and infected roots (Garrett 1960, Shaw 1974). In forests of the Pacific Northwest, the fungus is widely distributed and causes substantial root rot of ponderosa pine (Pinus ponderosa Laws.) (Adams 1974, Johnson 1976, Shaw and others 1976). In many of these forests, fire has been a major determinant of stand structure and composition (Martin 1976, Weaver 1968). Even though fire control policies over the last 50 years may have altered stand composition to favor tree species less susceptible to Armillaria root rot than ponderosa pine (Shaw and others 1976), the interaction between fire in these forests and the activity of Armillaria has received little attention.

Heat from fire does not penetrate deeply and dissipates relatively quickly (Heyward 1937, Debano and others 1976); thus, a strong direct effect of fire on the fungus in soil is unlikely. Fire, however, can change certain site and soil characteristics that subsequently affect the fungus. For example, burning generally increases soil pH (Ahlgren and Ahlgren 1965, Tarrant 1956) and quantities of water soluble cations (Burns 1952). These changes are usually attributed to the leaching of ash minerals into the soil (Wallace 1976). Grier and Cole (1971) reported that the A and B horizons absorbed 70 to 90 percent of the ions entering soil from an ash layer. Reports by Grier and Cole also show that ion concentration of leachates in the soil solution of burned plots remain higher than the ion concentration of forest floor leachates from unburned, control plots.

Rhizomorphs of Armillaria grow well and branch profusely within litter and humus layers of soil (Redfern 1973)--those constituting the A horizons. Because most leachates from ash are absorbed into these soil layers, these leachates could affect development of A. mellea rhizomorphs, and thus the spread of root rot.

In this study, we evaluated leachates obtained from recently burned litter collected in a ponderosa pine forest for effects on growth and development in culture of two isolates of A. mellea (Vahl. ex Fr.) Kummer.

Materials and Methods

One isolate of A. mellea was obtained from a western hemlock (Tsuga heterophylla (Raf.) Sarg.) tree in western Oregon and another from a ponderosa pine in central Oregon. Both isolates were maintained on a solid medium containing 30 g malt extract, 20 g dextrose, 5 g bacto-peptone, 19 g agar, and 1 ppm benomyl per liter of distilled water. Benomyl was used to reduce colonization by fast-growing contaminate fungi such as Trichoderma spp., Penicillin spp., and Rhizopus spp. (Maloy 1974). Medium pH was adjusted to 5.8-6.0 with 1.0 N HCl prior to sterilization in an autoclave.

All ash was collected from the forest floor after burning a ponderosa pine stand near Bend, Oregon. Ash leachates (AL) were obtained by mixing either 1, 5, 10 or 20 g of ash with 100 ml of distilled water and heating the solution in an autoclave for 3 minutes (hot water extracts). Each suspension was cooled for 2 hours and filtered twice under vacuum through Whatman's No. 1 filter paper. Filtrates were added to the basal medium prepared in 900 ml of distilled water and sterilized in an autoclave for 15 minutes.

Test cultures were established from stock cultures by two different methods: (1) removing a 2-mm agar disc that contained mycelia and submerged rhizomorph sections from 15-day-old pure cultures; or (2) clipping aerial rhizomorph tips measuring approximately 1 mm in length from 21-day-old pure cultures. These mycelial discs and aerial rhizomorph tips were placed on nonsupplemented medium (control) and medium supplemented with leachates obtained from extracting 1, 5, 10, or 20 g of ash. Cultures were grown in 100 x 15 mm plastic petri dishes in the dark for 21 days at 25 °C; there were 10 dishes for each concentration of ash leachate.

After incubation, all cultures were heated in an autoclave for 3 minutes to liquify agar. Colonies were then removed from the melted agar, rinsed in hot tap water, blotted on filter paper, dried in an oven for 48 hours at 90 °C, and weighed. Similar procedures have been used before to measure dry weights of A. mellea colonies grown on solid medium (Adams 1972, Cheo 1982, Shaw 1974).

For each isolate, a two-way analysis of variance using Friedman's test for unblocked data was used to evaluate the effects of ash leachate concentration and inoculum type on colony dry weight. Differences among leachate concentrations were examined within each inoculum type and differences between inoculum types were examined at each leachate concentration. Differences were judged to be significant at $P \leq 0.05$.

Results

Isolate from Hemlock

Colonies started with mycelial discs of the hemlock isolate and incubated on media supplemented with 1, 5, 10, or 20 g of AL had significantly less growth than controls; colonies incubated on 5 g of AL had significantly more growth than those on 1, 10, or 20 g of AL (table 1). There were no significant differences among leachate treatments for colonies started with aerial rhizomorph tips (table 1). At each leachate concentration, except controls, colonies started with aerial rhizomorph tips had significantly higher dry weights than those originating from mycelial discs (table 1).

In the presence of AL, regardless of concentration, formation of rhizomorphs was suppressed in all colonies originating from mycelial discs, and rhizomorph tips were located primarily within the confines of the surface mycelia (fig. 1). In contrast, colonies originating from aerial rhizomorph tips had profuse rhizomorph growth at all AL concentrations (fig. 2).

Table 1--Growth of the western hemlock isolate of *Armillaria mellea* on media supplemented with ash leachates

Leachate concentration	Colonies started with mycelial discs	Colonies started with aerial rhizomorph tips
Grams/liter	Dry weights (milligrams)[1/]	
Control (0)	330 a A	286 a A
1	70 b A	221 a B
5	132 c A	251 a B
10	56 b A	214 a B
20	73 b A	240 a B

[1/]Means of 10 replicates. Within each column, means followed by different lower case letters differ significantly; within each row, means followed by different upper case letters differ significantly.

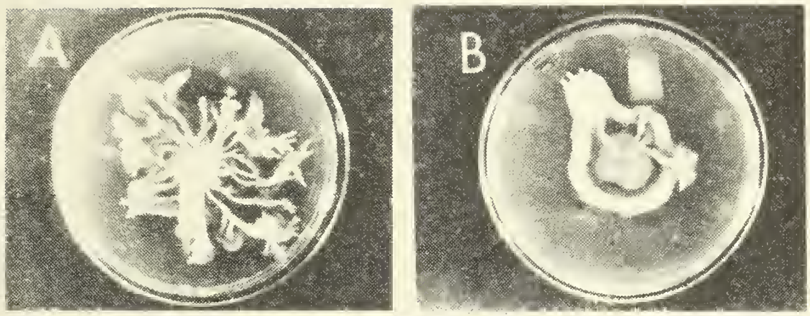

Figure 1.--Cultures of the hemlock isolate of *Armillaria mellea* started from mycelial discs and incubated for 21 days (view from bottom). Compared to controls (A), colonies developing on media containing 1, 5, 10, or 20 g of ash leachate exhibited a marked suppression of rhizomorph formation and growth (B).

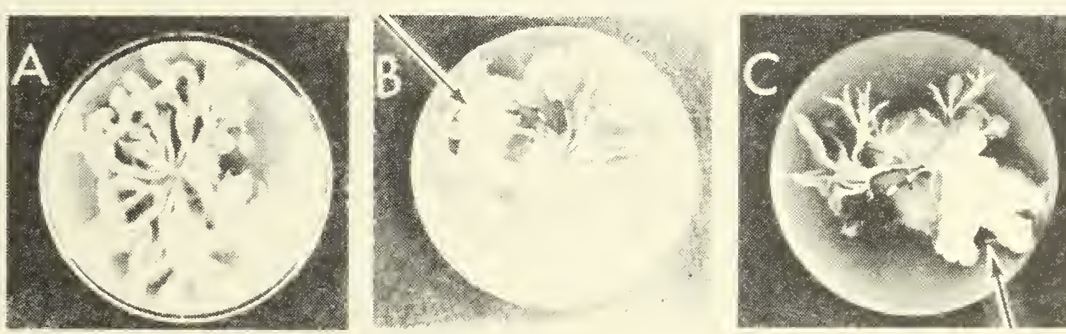

Figure 2.--Cultures of the hemlock isolate of *Armillaria mellea* started from aerial rhizomorph tips and incubated for 21 days (view from bottom). Compared to controls (A) and culture started from mycelial discs (fig. 1), colonies developing on media supplemented with any concentration of ash leachate did not express a marked suppression of rhizomorph formation or growth. Several colonies developing on media amended with 1, 10, or 20, g of ash leachate developed mycelial fans similar to those found in infected trees (arrows, B, C).

Mycelial fans similar to those found beneath the bark of infected pine trees developed at the interface of the agar medium and the petri dish bottom in 80, 50, and 50 percent of the colonies started with aerial rhizomorph tips and grown on media with 1, 10, or 20 g of AL, respectively (fig. 2B, 2C). No such fans developed on control medium or that containing 5 g of AL (fig. 2A). Patterns of rhizomorph branching in colonies originating from aerial rhizomorph tips were similar at all concentrations of AL, but were different from branching patterns of colonies orginating from mycelial discs (figs. 1 and 2).

Isolate from Pine

Colonies started with mycelial discs of the pine isolate and incubated on media supplemented with 5 g of AL had significantly less growth than controls or colonies incubated on media supplemented with 10 g of AL. For colonies started with aerial rhizomorph tips, there were no significant differences in dry weight among leachate treatments (table 2). Colonies started with mycelial discs had significantly less growth than colonies started with aerial rhizomorph tips at 1 and 5 g of AL (table 2).

Colonies orginating from mycelial discs or aerial rhizomorph tips grew vigorously over the media at all concentrations of AL (fig. 3). No mycelial fans developed, nor were variations in rhizomorph morphology observed between the two types of inoculum (fig. 3).

Table 2--Growth of the ponderosa pine isolate of *Armillaria mellea* on media supplemented with ash leachates

Leachate concentration	Colonies started with mycelial discs	Colonies started with aerial rhizomorph tips
Grams/liter	Dry weights (milligrams)[1]	
Control (0)	208 a A	305 a A
1	132 ab A	342 a B
5	105 b A	214 a B
10	267 a A	285 a A
20	181 ab A	258 a A

[1]Means of 10 replicates. Within each column, means followed by different lower case letters differ significantly; within each row, means followed by different upper case letters differ significantly.

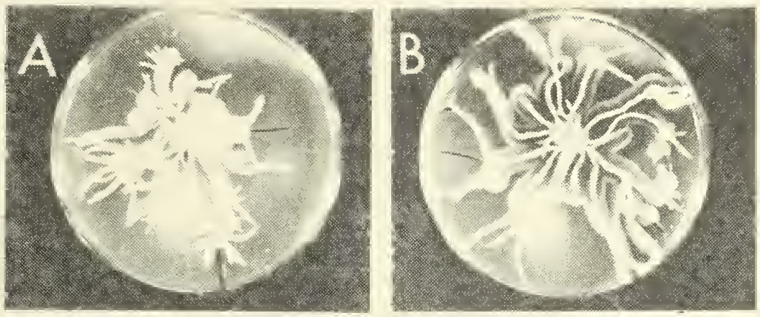

Figure 3.--Cultures of the pine isolate of Armillaria mellea incubated for 21 days (view from bottom). Cultures started with either mycelial discs (A) or aerial rhizomorph tips (B) exhibited profuse rhizomorph development at all concentrations of ash leachate.

Discussion

Isolates from both hemlock and pine showed a general reduction in growth when exposed to various concentrations of AL, although the reduction was not always statistically significant. Interestingly, extracts from dried foliage of many plant species present in the ponderosa pine forest type have a stimulating effect on growth of A. mellea in culture (Adams 1972); such foliage had contributed litter to the forest floor where we burned and collected ash.

In general, AL appeared to have a less pronounced effect on growth of A. mellea colonies originating from aerial rhizomorph tips than from mycelial discs. We attribute this difference to the presence of meristematic tissue within rhizomorph tips (Motta 1969) that allow the fungus to respond rather quickly to the different growing conditions created by AL.

For colonies of the hemlock isolate started with mycelia, ash leachates appear to inhibit growth at a concentration of less than 1 g per liter. A threshold level for the pine isolate is not clear because cultures grown at 5 g AL showed significantly less growth than controls, but those at 10 g had significantly more growth than those at 5 g. Additional concentrations between the 5 g intervals we tested must be evaluated to determine the concentration at which ash begins to inhibit growth in culture.

For both the hemlock and pine isolates, any negative effect of AL on growth of colonies started with aerial rhizomorph tips must occur at a concentration greater than the 20 g AL that we tested.

AL reduced, but did not totally inhibit, formation of rhizomorphs in colonies originating from mycelial discs of the hemlock isolate. Formation of rhizomorphs in such colonies of the pine isolate, however, appeared unaffected by leachates. This difference is probably related to differences between isolates of A. mellea, as they are known to vary in several cultural characteristics (Benton and Ehrlich 1941, Gibson 1961, Lisi 1940, MacLean 1950, Raabe 1966, 1969). These variations make it difficult to infer what effects ash resulting from forest fire may have on the fungus when it leaches through the soil and contacts rhizomorphs.

Mycelial fans similar in appearance to those found in trees infected by A. mellea formed in some cultures originating from aerial rhizomorph tips of the hemlock isolate that were growing on media amended with AL. Their presence may be attributed to morphology of the rhizomorph tip and to the influence of AL on it. Rhizomorphs produce mycelia and invade host cambium as a result of contact between a rhizomorph tip and a host (Redfern 1978). The development of mycelial fans in the aforementioned cultures suggests that their formation may be induced by a chemical factor(s) in addition to the "rhizomorph-host contact phenomenon." Ash has been reported to contain high concentrations of various cations (Grier and Cole 1971). In preliminary studies,[1/] A. mellea grown on medium amended with magnesuim carbonate or any combination of magnesuim carbonate and either potassium or calcium carbonate produced small fan-like rhizomorphs. These cations may stimulate production of mycelial fans in certain isolates of A. mellea.

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Metric Equivalents

1 gram (g) = 0.03527 ounce
1 liter (l) = 1.0567 quarts
1 milliliter (ml) = 0.001056 quart
1 millimeter (mm) = 0.03937 inch
°C = 5/9 (°F - 32)

[1/] J. Reaves, unpublished data.

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Should Ponderosa Pine Be Planted on Lodgepole Pine Sites?

P. H. Cochran

Abstract

Repeated radiation frosts caused no apparent harm to the majority of lodgepole pine (Pinus contorta Dougl.) seedlings planted on a pumice flat in south-central Oregon. For most but not all of the ponderosa pine (Pinus ponderosa Dougl.) seedlings planted with the lodgepole pine, however, damage from radiation frost resulted in reduced height growth.

Keywords: Radiation frost, pumice soil, lodgepole pine, Pinus contorta, ponderosa pine, Pinus ponderosa.

Introduction

In the pumice soil region of south-central Oregon, lodgepole pine (Pinus contorta Dougl.) usually occurs in pure stands on flats and basins, where cold air accumulates at night, whereas ponderosa pine (Pinus ponderosa Laws.) dominates the adjacent higher ground. Stand boundaries are often abrupt, coinciding with slight changes in topography. Reasons for this distribution pattern include superior frost tolerance of developing lodgepole pine cones (Sorenson and Miles 1974) and germinants (Cochran and Berntsen 1973) over ponderosa pine cones and germinants.

Occasionally lodgepole pine stands on level topography have an understory of younger ponderosa pine. Modification of the low temperature extremes at the soil surface by the lodgepole canopy probably allowed the ponderosa pine to become established. A few scattered mature ponderosa pines do exist in some lodgepole pine flats. These ponderosa pine trees are much older and taller than the lodgepole pine and may have started as understory trees beneath an earlier lodgepole pine stand.

P. H. COCHRAN is a soil scientist, Silviculture Laboratory, Pacific Northwest Forest and Range Experiment Station, 1027 N. W. Trenton Ave., Bend, Oregon 97701.

Table 1--Differences in height of lodgepole and ponderosa pines in four "frost pocket" locations in south-central Oregon, fall 1974[1]

Site	Location	Elevation	Year ponderosa pine planted	Range in height: Planted ponderosa pine	Range in height: Natural lodgepole pine
		Feet		Feet	Feet
Snow Creek	S1/2 sec. 10, T. 20 S., R. 8 E.	4,545	1934	8.0-15.0	26.0-33.0
Pipeline flat	S1/2 sec. 2, T. 25 S., R. 8 E.	4,460	1963	1.5- 5.0	8.0-15.0
Shevlin well	NW1/4 sec. 20, T. 28 S., R. 9 E.	5,025	1955	6.5-10.0	20.0-33.0
Shevlin yard	NW1/4 sec. 20, T. 28 S., R. 9 E.	5,150	1955	2.5- 6.5	11.5-13.0

[1]Planting dates for ponderosa pine were obtained from USDA Forest Service records or estimated from ring counts of tree sections taken at ground line. Lodgepole pine at each site was 2 or 3 years younger than the ponderosa pine, indicating that 2-0 or 3-0 ponderosa pine stock was planted.

Planted seedlings do not germinate on the site or need to produce cones. Further, the frost resistance of 2-0 or larger seedlings of either species is thought to be high, provided the dormancy cycle has been correctly managed in the nursery (Cleary and others 1978). Therefore, practicing foresters periodically inquire about the possibility of planting ponderosa pine seedlings in clearcuts on flats and basins previously occupied by lodgepole pine. Such plantings have been attempted in several locations, but lodgepole pine has seeded in, overtopping the ponderosa pine (table 1). Where ponderosa pine seedlings survive, they are deformed or severely suppressed; frost damage to the needles is apparent during some growing seasons.

This paper presents further exploratory comparisons of the early development of ponderosa and lodgepole pine seedlings planted together on soils developing from Mazama pumice. Care should be taken in extrapolating the results to other soils and areas.

Further Comparisons

For the locations shown in table 1, the ponderosa seed source is unknown and may not be adapted to the site. Would the performance of ponderosa pine from appropriate seed sources be satisfactory? To partially answer this question, we planted 100 ponderosa pine and 100 lodgepole pine seedlings interchangeably at a 12- by 12-foot spacing on a "pumice flat" surrounded by lodgepole pine (NW1/4 sec. 31, T. 22 S., R. 11 E., Willamette meridian). Elevation of the area is 4,120 feet. The soil is an ashy over loamy, mixed Typic Cryorthent.

Early juvenile growth of lodgepole pine has been considered superior to that of ponderosa pine on comparable sites. We decided to compare differences in growth rates on the pumice flat with growth rates of the two species planted earlier on sloping topography nearby. Seed collected from the plantation site, 7.3 air miles west of the flat, was germinated in the greenhouse in the spring. The seedlings were kept in the greenhouse until mid-winter when the greenhouse temperature was slowly lowered to match outside temperatures. Next the seedlings were taken outside, then planted interchangeably in April on a 6-percent slope with a west-southwest aspect. The soil at this plantation is very similar to the soil of the pumice flat.

After six growing seasons in the plantation, over 300 undamaged seedlings of each species remained. The lodgepole pine seedlings averaged 2.7 feet in height, and the ponderosa pine seedlings averaged 2 feet. For the seedlings surviving after six growing seasons on the pumice flat at the end of 1983, average heights were:

First planting	Second planting
Lodgepole pine 2.4 feet	Lodgepole pine 2.4 feet
Ponderosa pine 1.2 feet	Ponderosa pine 0.96 feet

At the end of 1983, 8 of the 27 surviving ponderosa pine from the first planting and 8 of the 35 surviving from the second planting in the pumice flat resembled stunted bushes and appeared damaged from repeated radiation frosts. None of the lodgepole pine trees displayed reduced height growth that seemed related to radiation frost damage. Two of the ponderosa pines from the first planting were over 6.6 feet tall, and an additional nine trees appeared to be healthy and have been growing over 8 inches a year. Eight of the 35 ponderosa pines from the second planting also appeared fairly resistant to frost damage and may grow to size suitable for harvest.

Most of the mortality for both plantings on the flat has been caused by pocket gophers (Thomomys spp.). A few trees have also been destroyed by porcupines (Erethizon dorsatum Linn.). There is no indication that pocket gophers or porcupines prefer one species over the other. Crouch (1971) also noted no difference in the susceptibility of ponderosa and lodgepole pines to pocket gophers. Some of the trees, primarily lodgepole pine, have been attacked by the lodgepole pine terminal weevil (Pissodes terminalis Hopping); but in every case, a lateral branch replaced the destroyed terminal, and the height development of the tree appeared to be reduced slightly, if at all.

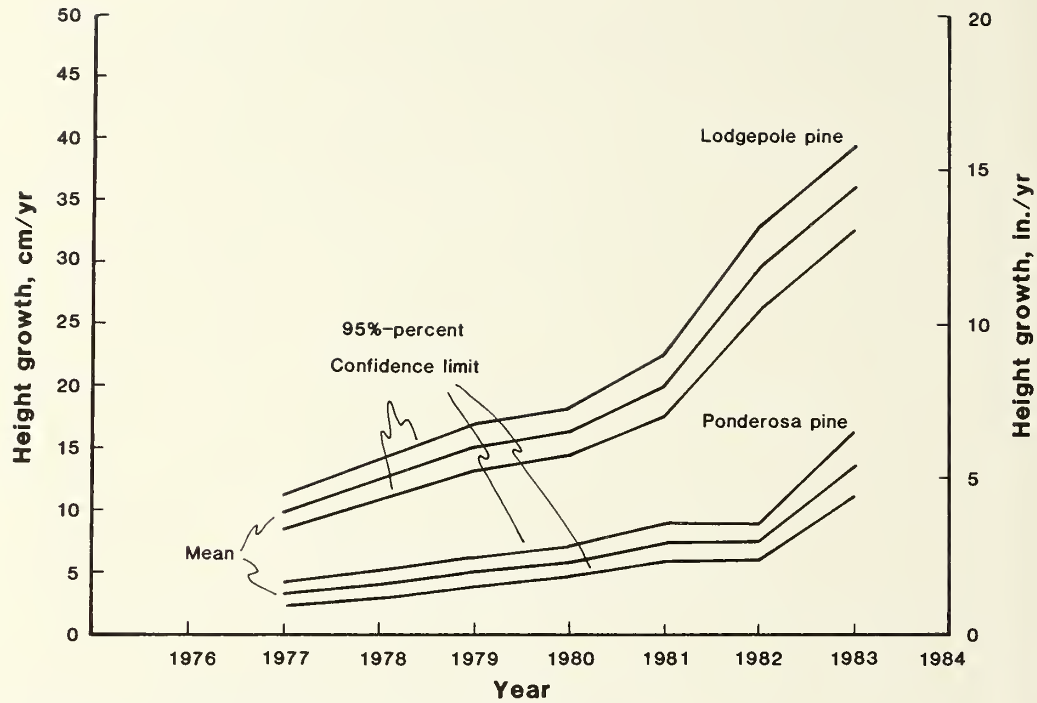

Figure 2.--Height growth per year for lodgepole and ponderosa pine seedlings planted in April 1975.

To obtain another comparison of species performance, we alternately planted 100 2-0 seedlings of each species at a 12- by 12-foot spacing in the spring 1975, on the pumice flat adjacent to the plantation established 4 years earlier. The seed came from zones compatible with this planting site; the seedlings were raised in the Bend Pine Nursery. A severe frost (17 °F minimum temperature in a standard weather shelter at the site) on June 19, 1975, caused no apparent harm to lodgepole pine seedlings, but there was obvious damage to 52 of the ponderosa pine seedlings. Height growth for 1975 was not measured. At the end of 1983, only 35 ponderosa and 40 lodgepole pine seedlings remained. Average heights of the surviving lodgepole and ponderosa pine seedlings were 5.2 feet and 1.9 feet, respectively, in the fall 1983, and height growth rates for this second planting have been significantly different since 1976 (fig. 2).

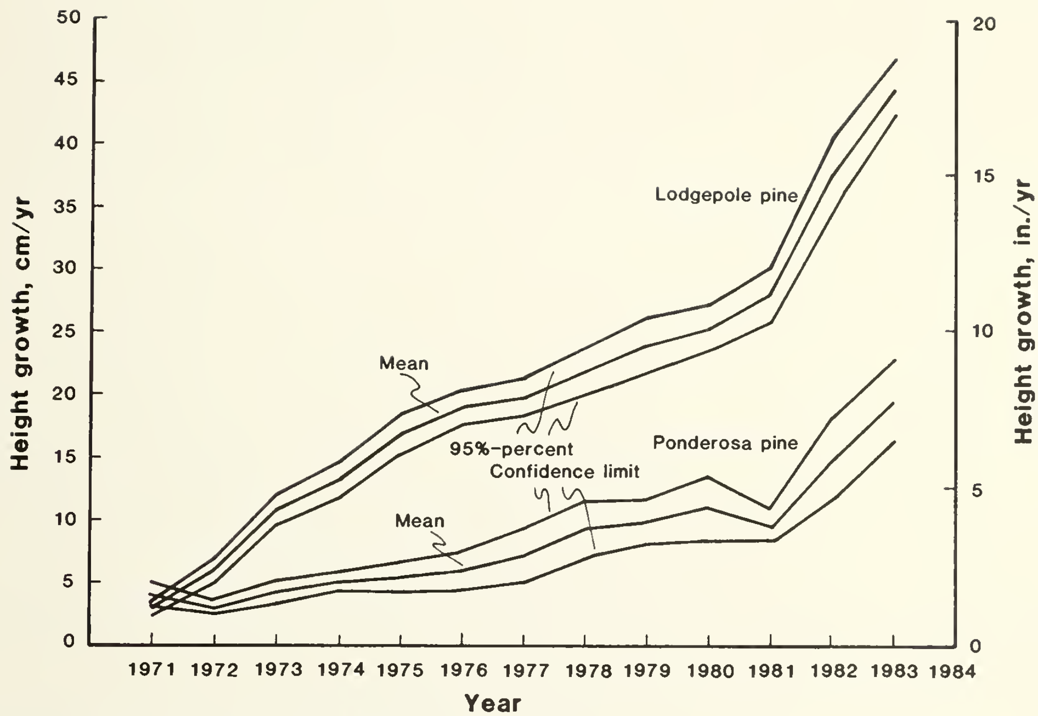

Figure 1.--Height growth per year for lodgepole and ponderosa pine seedlings planted in April 1971.

The 3-0 ponderosa pine stock was raised in the Bend Pine Nursery of the USDA Forest Service, 28 air miles from the planting site; seed had been collected at the 4,000-foot elevation within 18 miles of the planting site. Lodgepole pine seedlings were obtained from roadsides within 10 miles of the planting site because nursery seedlings were not available. The planting was done over a 2-day period in April 1971. Average height growth for the first growing season (fig. 1) was slightly greater for ponderosa pine, possibly because of the nursery fertilization program. From 1972 through 1983, however, height growth of lodgepole pine was superior. At the end of 1983, the 60 surviving lodgepole pines averaged 9 feet in height, significantly[1] taller than the 3.9-foot average for the 27 surviving ponderosa pines. Of the surviving ponderosa pine trees, none was taller than the average height of the lodgepole pine trees. Height growth rates, however, have accelerated with time: 11 of the 27 ponderosa pine trees grew more than 8 inches in 1983, although the best height growth of ponderosa pine was not equal to the average height growth of the lodgepole pine.

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[1]Use of the word "significantly" in this note means that a t test has been applied using a 5-percent level of probability to accept or reject differences as real.

Conclusions

Ponderosa pine planted on flats and basins in the pumice soil region of south-central Oregon will suffer varying degrees of radiation frost damage. Some of the trees will be so severely damaged they will not grow to salable size in a reasonable length of time. Most ponderosa pine trees will exhibit reduced growth rates because of repeated frost damage, but some of the trees may grow normally.

The data and observations presented nere indicate that pumice-mantled flats and basins should be managed for lodgepole pine. Because a small percentage of ponderosa pine seems to be resistant to radiation frost, some seedlings could be planted on flats and basins. The scattered ponderosa pine trees existing in some of the flats might provide a seed source for the planting stock. These plantings could establish a potential future source of seed for geneticists to use in developing ponderosa pine that is more resistant to low temperatures.

Metric Equivalents

1 inch = 2.54 centimeters
1 foot = 0.30 meter
1 mile = 1.61 kilometers
°F = 1.8 (°C) + 32

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Cubic-Foot Tree Volume Equations and Tables for Western Juniper

Judith M. Chittester and Colin D. MacLean

Abstract

This note presents cubic-foot volume equations and tables for western juniper (Juniperus occidentalis Hook.). Total cubic-foot volume (ground to tip, excluding all branches (CVTS)) is expressed as a function of d.b.h. and total height. Utilizable cubic-foot volume (top of 12-inch stump to a 4-inch top, excluding all branches (CV4)) is expressed as a function of CVTS and d.b.h.

Keywords: Cubic-foot volume tables, western juniper, Juniperus occidentalis.

Introduction

Rising costs of energy have stimulated an interest in western juniper as a potential source of energy. In response to this interest, the Forest Inventory and Analysis Work Unit of the Pacific Northwest Forest and Range Experiment Station in Portland, Oregon, is expanding its inventory program[1] to include an assessment for western juniper (Juniperus occidentalis Hook.) wood supply. But no volume equations or tables have been available.

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[1] Regional forest inventories are conducted nationwide by the U.S. Department of Agriculture, Forest Service. The Pacific Northwest Forest and Range Experiment Station conducts surveys in Alaska, California, Hawaii, Oregon, and Washington.

JUDITH M. CHITTESTER is a mathematical statistician and COLIN D. MACLEAN is a principal mensurationist, Pacific Northwest Forest and Range Experiment Station, P. O. Box 3890, Portland, Oregon 97208.

We have developed an equation for estimating the total volume (CVTS) of western juniper trees, expressed as a function of two independent variables: diameter at breast height (d.b.h.) and total height. A second equation is presented to convert total volume to utilizable cubic volume (CV4).

The Basic Data

We needed a volume equation suitable for use on western juniper trees throughout eastern Oregon and northeastern California. Although we would nave preferred using measurements from a large sample of trees representing the complete range of forest conditions found in the region, time and funding restrictions limited us to using available tree measurement data plus a small sample for testing the results from our original data set.

Available data were limited to measurements from 52 trees that were felled and sectioned for a western juniper site index study (Sauerwein 1982). The data were gathered in central, southern, and southeastern Oregon and from one plot in northeastern California. The trees are believed to sample all site indexes throughout the range of western juniper--southwestern Idaho, eastern Oregon, northeastern California, and western Nevada. Juniper trees at higher altitudes in the Sierra Nevada are not represented. Although the trees selected were all dominants, western juniper grows in such open stands that the relative social position of individual trees is not well defined. We are, therefore, assuming that these data are representative of the population and are usable for developing western juniper volume equations.

Second-growth stands were selected representing well-stocked sites free from cutting, excessive grazing, and fire. The three tallest trees per one-fifth acre were cut and measured. Data were recorded on the felled trees at ground line, 1 foot, 4.5 feet, and every 3 feet thereafter to the tip. Inside and outside bark diameters were taken to tenths of inches and heights to tenths of feet. The STX program (Grosenbaugh 1967) was used to calculate CVTS and CV4 for each of the sample trees.

The test set consisted of 24 trees from the area around Madras and Sisters in central Oregon. Trees were selected to bracket the range of diameters and heights common to the species. Only a few trees were found, however, witn diameters over 20 inches. Table 1 shows the distribution of both data sets by 4-inch diameter class.

Table 1--Number of western juniper trees used to develop volume equation, by 4-inch diameter class

Diameter class	Site index study 1/	Test sample 2/	Total
Inches			
5.0-8.9	10	6	16
9.0-12.9	26	9	35
13.0-16.9	9	5	14
17.0-20.9	4	1	5
21.0-24.9	--	1	1
25.0-28.9	--	--	--
29.0-32.9	--	2	2
Total	49	24	73

1/From central, southern, and southeastern Oregon, and from northeastern California.

2/From Madras and Sisters areas, central Oregon.

Developing the Equations

An important assumption of least squares regression is homogeneity of variance. To satisfy this condition, cubic volume was transformed with the method used by Bruce and DeMars (1974). The dependent variable chosen was form factor (F), obtained by dividing total cubic volume including stump by the volume of a cylinder with a basal area and height equal to that of the sample tree (F=CVTS/(BA*H)). This model had been successfully used in developing volume equations for California species (MacLean and Berger 1976).

Least squares regressions were fit using independent variables of total height and d.b.h. outside bark, their powers, and crossproducts. A problem was encountered in fitting short squat trees. Three trees under 18 feet in height were dropped from the data set when the transformation failed. Their omission had negligible effect on our ability to estimate their volumes. After consultation with Bruce,[2] we added a further transformation: the basal area of all trees (BA) was multiplied by $(H/(H - 4.5))^2$, thereby improving the fit for short trees. After the final model was selected using 49 trees, we ran a covariance analysis to see if the 49 trees and the test sample of 24 trees could be combined to obtain a final equation by least squares regression. The covariance analysis showed no significant difference between the slopes, so the sets were combined to obtain the final equation.

To convert CVTS to CV4, we turned to the tarif system developed by the Department of Natural Resources (DNR), State of Washington. We had CV4 computed by the STX program for 51 of the 52 trees from the site index study. When the most recent CV4/CVTS tarif ratios (Chambers and Foltz 1979) were plotted against the study trees, the results were substantially biased, probably because of the heavy taper typically found in western juniper stumps. To correct this bias, we recalibrated the equation, following the model described by Turnbull and Hoyer (1965).

The form factor equation is:

$$F = 0.307 + 0.00086*H - 0.0037*D*H/(H-4.5).$$

The volume equations are:

$$CVTS = BA*F*H*(H/(H-4.5))^2, \text{ and}$$

$$CV4 = (CVTS + 3.48)/(1.18052 + 0.32736*e^{(-0.1*D)}) - 2.948;$$

where:

D = diameter at breast height outside bark (inches),
H = total height including stump and tip (feet),
BA = $0.005454154 * D^2$ (square feet),
F = CVTS/(BA*H),
CVTS = total cubic volume from ground to tip, excluding all branches (cubic feet), and
CV4 = utilizable cubic volume from top of 12-inch stump to a 4-inch top, excluding all branches (cubic feet).

The root mean square error for F was 3.8 percent.

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[2] Personal communication with David Bruce, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, OR, December 1982.

Discussion and Conclusions

Measured volumes were plotted against estimated volumes for CVTS and CV4 (figs. 1, 2). The figures illustrate the lack of bias in the equations as well as the lack of data for large volume trees.

The small samples and the few number of large trees were major difficulties in the development of these equations. Of the 73 trees used to obtain the final equation, only 3 had a d.b.h. greater than 20 inches. Although the volume tables (tables 2, 3) provide reasonable extrapolations, the user should be cautious when applying them to trees above 20 inches d.b.h.

The study is limited to trees in eastern Oregon and northeastern California. Site index curves developed from these data, however, are suitable for the entire range of western juniper (Sauerwein 1982). We think the equations and volume tables presented here will also be valid for the entire range.

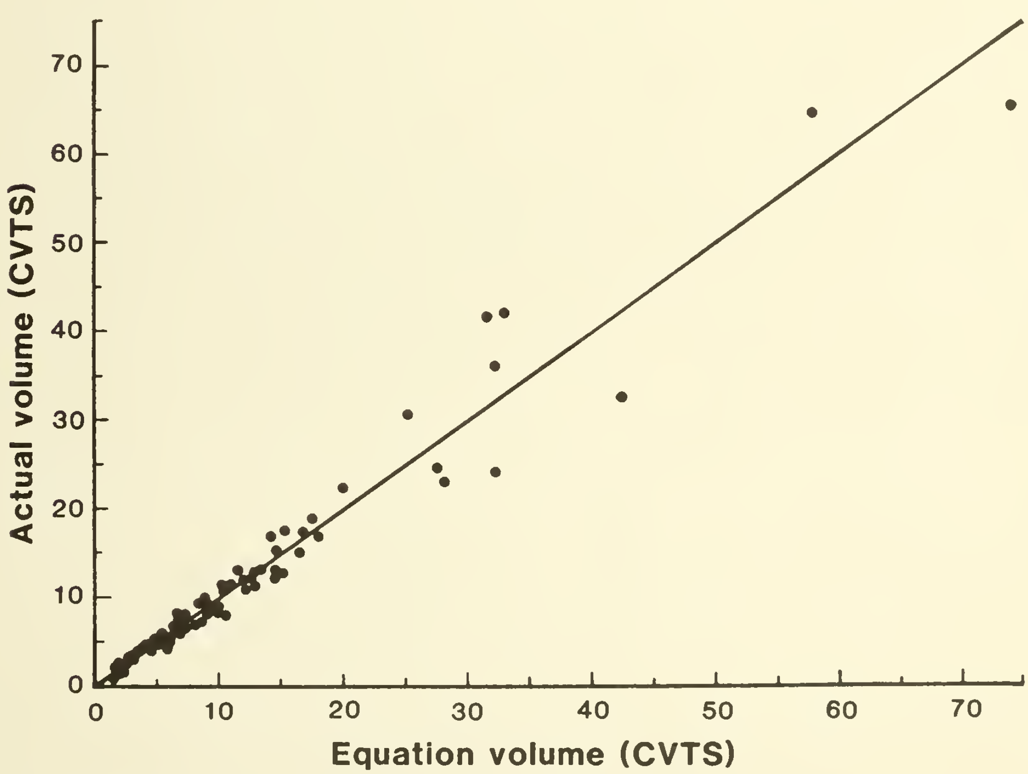

Figure 1.--Relationship between measured cubic-foot volume (CVTS) of 73 western juniper trees and estimates calculated with the equation.

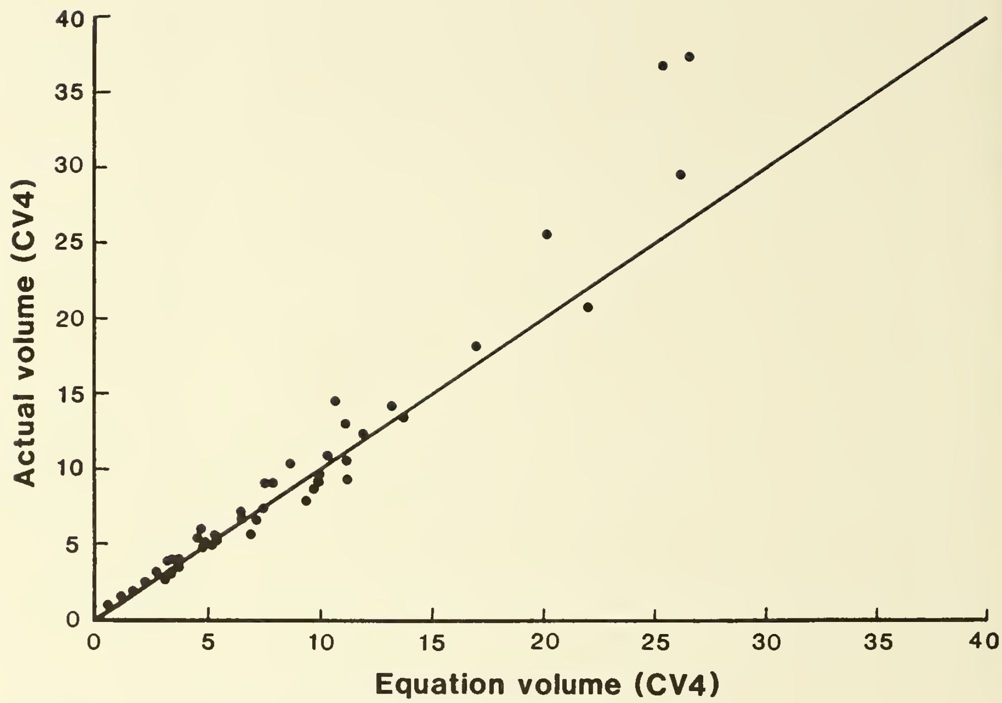

Figure 2.--Relationship between measured utilizable cubic-foot volume (CV4) of 51 western juniper trees and estimates calculated with the equation.

able 2--Cubic-foot volume of western uniper1/ 2/

iameter at reast height utside bark3/	10	20	30	40	50	60	70	80
			Total height (feet)					
nches								
	1	1	2					
	2	2	2	3				
	2	3	3	4	5	6	7	8
	3	3	4	5	7	8	9	11
	4	4	5	7	8	10	12	14
0	4	5	7	8	10	12	14	16
1	5	6	8	10	12	15	17	20
2		7	9	12	14	17	20	23
3		8	11	13	17	20	23	27
4		9	12	15	19	23	27	31
5		10	14	17	21	26	30	35
5		12	15	19	24	29	34	39
7		13	17	22	27	32	38	44
3		14	19	24	29	35	42	48
9		15	20	26	32	39	46	53
0		17	22	29	35	43	50	58
1		18	24	31	38	46	55	63
2		19	26	33	41	50	59	69
3			28	36	45	54	64	74
4			30	38	48	58	68	79
5			32	41	51	62	73	85
5			34	44	54	66	78	91
7			35	46	58	70	83	96
3			37	49	61	74	87	102
9			39	51	64	78	92	108
0			41	54	67	82	97	114
1			43	56	71	86	102	119
2			45	59	74	90	107	125
3			46	61	77	94	112	131
4			48	64	80	98	117	137
5			50	66	83	102	122	143
5			51	68	87	106	127	149
7			53	71	90	110	131	154
3			54	73	93	114	136	160
9			56	75	95	117	141	165
0			57	77	98	121	145	171

/Applies to all western juniper except at higher altitudes n the Sierra Nevada.

/Total tree volume including stump and tip (CVTS). Data set s outlined.

/Diameter classes are midpoint; for example, the 12-inch lass includes 11.5-12.4 inches.

Table 3--Cubic-foot volume of western juniper to a 4-inch top1/ 2/

Diameter at breast height outside bark3/	10	20	30	40	50	60	70	80
			Total height (feet)					
Inches								
5	0	1	1					
6	1	1	1	2				
7	1	2	2	3				
8	2	2	3	4	5	6	7	8
9	3	3	4	5	6	7	9	10
10	3	4	5	6	8	9	11	12
11	4	4	6	7	9	11	13	15
12	5	5	7	9	11	13	15	18
13		6	8	10	13	15	18	21
14		7	9	12	15	18	21	24
15		8	11	14	17	20	24	28
16		9	12	15	19	23	27	31
17		10	13	17	21	26	30	35
18		11	15	19	24	29	34	39
19		12	16	21	26	32	37	43
20		13	18	23	29	35	41	47
21		15	20	25	31	38	45	52
22		16	21	27	34	41	48	56
23			23	30	37	44	52	61
24			24	32	39	48	56	66
25			26	34	42	51	60	70
26			28	36	45	54	65	75
27			29	38	48	58	69	80
28			31	40	51	61	73	85
29			33	43	53	65	77	90
30			34	45	56	68	81	95
31			36	47	59	72	85	100
32			37	49	62	75	90	105
33			39	51	65	79	94	110
34			40	53	67	82	98	115
35			42	55	70	86	102	120
36			43	57	73	89	106	125
37			45	59	75	92	111	130
38			46	61	78	96	115	135
39			47	63	80	99	118	139
40			48	65	83	102	122	144

1/Applies to all western juniper except at higher altitudes in the Sierra Nevada.

2/Stump and top excluded; top diameter = 4 inches; stump height = 12 inches. Data set is outlined.

3/Diameter classes are midpoint; for example, the 12-inch class includes 11.5-12.4 inches.

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A Portable Vacuum for Collecting Arthropods From Drop Cloths

H.G. Paul and R.R. Mason

Abstract

A hand-held vacuum modified for collecting insects and spiders in the field is described. The vacuum with battery is mounted on a lightweight pack-frame and is portable and versatile. It is especially useful for collecting arthropods that are dislodged from foliage samples and drop onto cloths.

Keywords: Field equipment, sampling methods, insect populations.

Forest defoliators are often sampled by beating foliage over a drop cloth and counting the dislodged larvae that fall on the cloth. Foliage beating also affords an opportunity to examine associated arthropods that drop off the branch at the same time. These are usually other insects and spiders, many of which may be predators of small defoliating larvae. Because a variety of species and stages may be involved, these associates are best collected and examined later in the laboratory. Collection has to be quick, however, lest some individuals escape by flying or running off the cloth. A small portable vacuum modified for field use is an excellent tool for rapidly collecting selected specimens from a drop cloth.

The vacuum is a hand-held Black and Decker Car-Vac[1] powered by a 3-ampere, 12-volt electric motor. The suction opening in the front cover is made smaller by plugging the opening with a fitted wooden block and plaster of paris through which a 1/2-inch (12.7-mm) hole is bored (fig. 1A). Suction is through a 3/8-inch

[1]The use of trade names is for the information and convenience of the reader only. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others which may be suitable.

H.G. PAUL is forestry technician and R.R. MASON is research entomologist, Forestry and Range Sciences Laboratory, Route 2, Box 2315, La Grande, Oregon 97850.

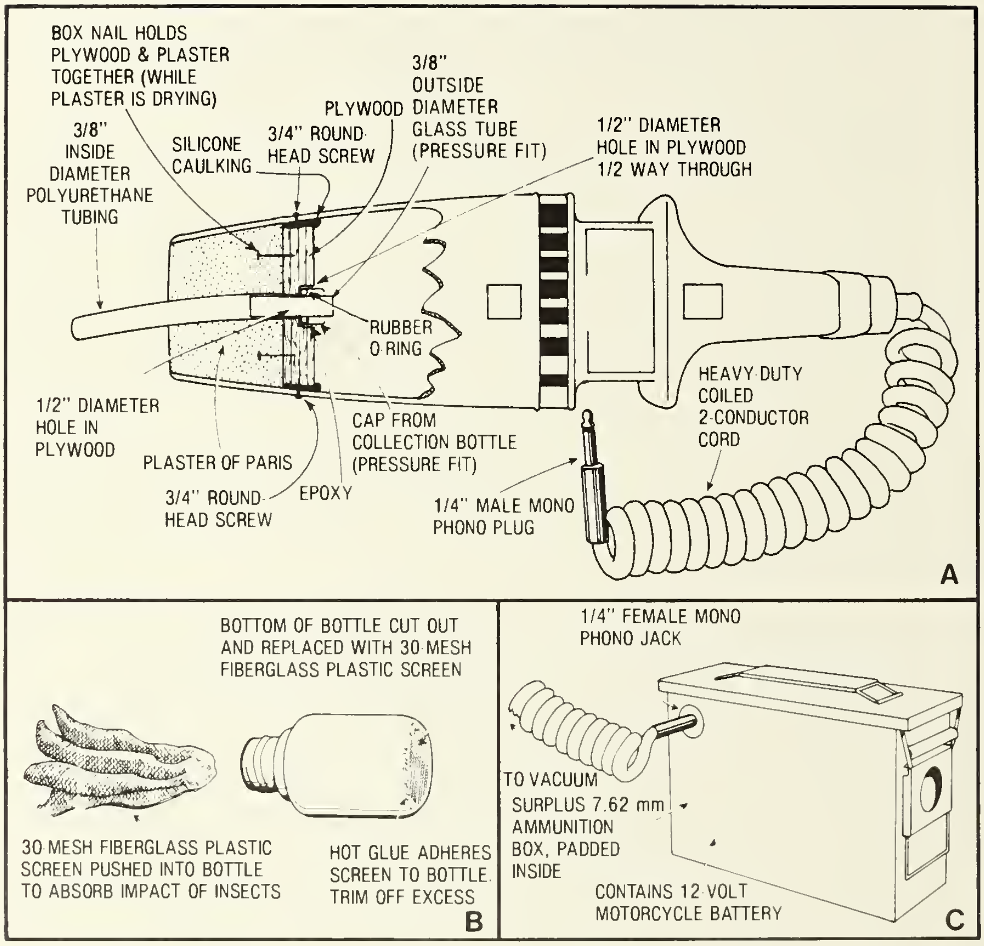

Figure 1.--Schematic diagram of modified Car-Vac: (A) vacuum with modification in the front cover; (B) collection bottle; (C) battery box.

(9.5-mm) flexible plastic tube that passes through the block and feeds into a collection bottle inside the cover. The bottle (fig. 1B) is screened on one end to permit airflow and threaded on the other so that it can be screwed into a cap countersunk on the inside of the block (fig. 1A). The small size of the suction tube permits selective vacuuming of individuals without sucking up large amounts of dry needles and other plant debris from the cloth. Because specimens are pulled through the tube with considerable velocity, a piece of fiber glass screen placed in the vial helps prevent damage to their soft bodies.

Power source for the vacuum is a 12-volt motorcycle battery carried in a padded surplus ammunition box. The box is fitted with a conventional mono plug for connecting the coiled, heavy duty electrical cord from the vacuum (fig. 1C).

Figure 2.--(A) Pack-frame with mounted battery and side holster for vacuum; (B) collecting arthropods from beating cloth.

A lightweight, cargo-type pack-frame is used for carrying both the battery and vacuum in the field. The battery box rests on the frame's bottom support and is held in place by straps. The vacuum is carried in a side holster attached to the frame's web waist belt (fig. 2A). Weight of the entire unit is 20 pounds (9 kg). With this arrangement a person carrying the unit can operate the vacuum with one hand and have the other hand free to hold a beating cloth (fig. 2B). Under normal use, a fully charged batter will operate efficiently for 8 hours before needing recharging.

The equipment described here has been especially successful in collecting insects and spiders from the hand-held beating cloth described by Paul (1979). In our studies, 18- to 20-inch (45- to 50-cm) branches of true firs or Douglas-fir were sampled. With the cloth held underneath, the branches were vigorously rapped with a beating stick. All arthropods that dropped off were vacuumed into the collection bottle within seconds of striking the cloth (fig. 2B). We found that a single 1-ounce (30-ml) bottle usually accommodated the arthropods from 30 such branches. A full bottle is easily removed by unscrewing it from the vacuum and attaching a cap to prevent escape. The collection can then be preserved by dropping the whole bottle in a small jar of 70-percent alcohol. By slightly loosening the screw cap, the alcohol will quickly circulate through the screened end of the bottle.

Despite the narrow suction tube, some needles, bud scales, and other debris are inevitably collected and make separation of specimens in the laboratory more difficult. Arthropods can usually be separated from plant material by emptying the vial contents into a shallow pan of water. Because of their lighter weight, most arthropods float to the top where they can be easily screened off and preserved in alcohol.

We have used this equipment for 3 years to study arboreal arthropod communities in the Pacific Northwest and have had remarkably consistent results. For example, a typical sample of 150 fir branches (3 branches on each of 50 trees) yielded 8 to 10 arthropod orders--usually dominated by spiders (Araneae) (fig. 3). Because the folliage is systematically sampled, total numbers collected can also be translated into density values and the relative abundance of potential predators easily assessed.

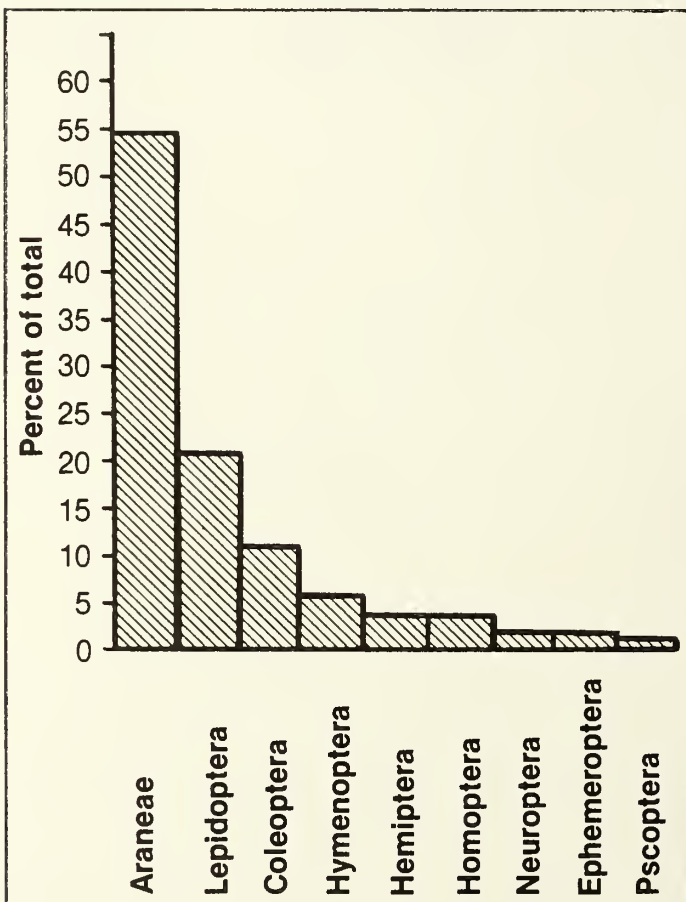

Figure 3.--Numerical composition of arthropods, by order, (sample size = 203) collected by beating and vacuuming the contents from 150 18- to 20-inch (45- to 50-cm) fir branches on a plot near Fort Klamath, Oregon.

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Cruise Design for a 5-Year Period of the 50-Year Timber Sales in Alaska

John W. Hazard

Abstract

Sampling rules and estimation procedures are described for a new cruise design that was developed for 50-year timber sales in Alaska. An example is given of the rate redetermination cruise and analysis for the 1984-1989 period of the Ketchikan Pulp Company sale. In addition, methodology is presented for an alternative sampling technique of sampling with probability proportional to size, sample size calculations, and volume equation development.

Keywords: Timber cruising, sampling design, timber sales, Alaska.

Contents

JOHN W. HAZARD is Station statistician, Forestry Sciences Laboratory, Pacific Northwest Forest and Range Experiment Station, P.O. Box 3890, Portland, Oregon 97208.

Introduction

In the 1950's, the USDA Forest Service awarded 50-year timber sale contracts to Ketchikan Pulp Co. (KPC) and Alaska Lumber and Pulp Co. (ALP) for 1.5 billion cubic feet and 4.97 billion board feet, respectively. These sales, awarded by the Tongass National Forest (Alaska Region), contain a provision for rate redeterminations every 5 years that creates a need to conduct timber cruises for determination of volume and values of included timber. The KPC sale requires that the rate redetermination appraise 960 million board feet (MMBF), and the ALP sale requires an appraisal of 633 MMBF every 5 years for the 50-year period of the sales. These large volumes make it important to use efficient cruise procedures.

The long-term sales have characteristics that complicate the cruise design:

1. The volume for each 5-year period is contained within a large group of cutting units that range in size from a few acres to over 150 acres. The KPC rate redetermination for 1984-89 began with a base of 576 cutting units encompassing 38,640 acres. The ALP 1981-86 rate redetermination contained 477 units encompassing 21,645 acres.

2. The cutting units to be harvested are determined through a negotiation process that allows input from the purchaser before and after the cruise takes place; this causes uncertainty over the selection of the final cutting units.

3. An environmental impact statement (EIS) is prepared for all cutting units in the initial selection for each 5-year period. The final environmental decision may require that some otherwise available cutting units be omitted after they are cruised; this also causes uncertainty over the final cutting units to be selected.

4. The Tongass Land Management Plan requires a specified harvest level to be taken proportionally, by acreage, from four volume classes. Shifts in acreage caused by the selection process may necessitate changes in final cutting units selected in order to meet harvest levels by volume class.

5. New blowdown areas may be substituted as cutting units as they occur. In the 1979-84 KPC rate redetermination, approximately 200 MMBF of timber blew down between cruise completion and the rate redetermination. A major volume substitution had to be made without supporting cruise data.

6. Cutting units not harvested in a preceding period may be carried over to the subsequent period. Market and other factors determine harvest levels in the last year of a period and make the number and location of carryover units uncertain.

7. Cutting unit selection is tentatively completed prior to the cruise. Upon cruise completion, the volume may be more or less than required for the period and may require the deferral or addition of units.

8. Previous cruises failed to adequately sample low-volume, high-value Alaska-cedar (*Chamaecyparis nootkatensis* [D. Don] Spach).

As a result of these problems, the Alaska Region, USDA Forest Service, in conjunction with the Pacific Northwest Forest and Range Experiment Station, designed and implemented a cruise design for the KPC and ALP sales that would address the foregoing problems and would specifically:

1. Allow additions or deletions of acreage to the sale after completion of field data collection for the cruise, without appreciably affecting the reliability of the results.

2. Allow field data collected in deleted units for volume-basal area prediction equations to be retained and used in cruise computations and other related studies.

3. Not require a field sample in every unit in the population.

4. Restrict the amount of individual tree field data collection,[1] but ensure precise volume estimation.

5. Sample high-value species with greater precision than for other species.

6. Provide increased individual tree data for describing species volumes.

7. Meet the specified precision requirements of the KPC and ALP sales.

Objectives

This paper presents a new cruise design to satisfy the stated requirements. It has been implemented by the Ketchikan Area Timber Management staff, Tongass National Forest. This design should have greater efficiency than previous designs because:

1. It takes advantage of gains in precision by stratifying cutting units into homogeneous groups.

2. It reduces travel cost by sampling only a subset of the available cutting units. (Travel cost is a major component of total cost.)

3. It uses an intensive basal area sample from units sampled in the field to provide information on individual species. (Collecting additional information on cutting units during a visit is less costly than going to new cutting units.)

4. It is designed to obtain accurate information from individual trees; information such as volumes by log grades, defect, and species. The FBS sample is controlled to obtain a fixed sample of basal area points distributed uniformly over the auxiliary variable of basal area.

5. It uses an estimation scheme designed to take advantage of all information known about the total sale to increase the precision of the total volume estimates.

[1] Fall, buck, and scale (FBS) was the method of volume determination used in the KPC sale. Other volume methods can also be used with this cruise design.

In addition, it yields other products that will be used for future planning and management of the Ketchikan Area timber management program; for example, (1) volume per acre estimates by species and volume strata, (2) stand volume-basal area equations by species, (3) average defect percentages by species, and (4) average log grade percentages by species.

This new design is described as a stratified, random, equal probability sample of cutting units with selected units subsampled by an intensive systematic sample of basal area points to determine the basal area by species. The basal area by species at each point is converted to volume by stand volume-basal area equations generated from an additional subsample of basal area points as measured by FBS procedures.

A detailed description of the design (that is, sampling rules and estimation procedures) follows in the main text. Appendices are added to:

1. Describe a modification of the design to sample clearcut units with probability proportional to cutting unit size (pps).

2. Present the logic and equations for sample size calculations for both equal probability and pps sampling.

3. Present a practical method of constructing stand volume-basal area equations.

The entire package is illustrated with data and results of an actual 5-year-period cruise for the KPC sale.

The objectives of the cruise design are:

1. To estimate the gross and net volumes of the population (the total area of the 5-year-period sale) with a relative index of reliability of ± 10 percent at the 68 percent confidence probability.

2. To estimate the gross and net volume of the cedar strata with an index of reliability of ± 20 percent at the 68 percent confidence probability.

3. To estimate the following parameters by species without specified levels of precision: Volume by log grades, total defect in the standing tree (woods defect), scaling defect, number of logs per thousand board feet (MBF), and average diameter at breast height (d.b.h.).

The parameters in objective (3), in addition to the information in (1) and (2), are necessary for the appraisal process.

The Population

Proposed cutting units for the 5-year period are laid out on aerial photos and transferred to controlled base maps. The collection of all cutting units in the sale make up the population. The population is partitioned into homogeneous volume strata and a high-value species stratum (that is, collections of entire cutting units that are similar in their average volumes per acre or selected species composition are grouped as subpopulations). In addition, the selection of cutting units in the population must result in the total acreage of all cutting units in the sale being distributed proportionally to the acres appearing in the volume classes of the Tongass management plan.

To designate the units to be selected in each stratum, a prior estimate of the volume per acre by stratum is necessary. The acreage of each potential unit is multiplied by an estimate of mean volume per acre for the appropriate stratum and is then summed for all unit volumes within and among strata to produce a preliminary estimate of the total sale volume. If the initial estimate of the sale volume is low, cutting units must be added to each stratum. If the initial estimate is high, some units will have to be omitted. When the number of acres in the population are proportional to the acres by volume class in the management plan and the approximated total volume equals the required volume, the sampling population is fixed (that is, no units are added or subtracted until the sampling is completed). Adjustments may be required later but for the purposes of drawing the sample and making preliminary estimates the strata areas and number of units will not change.

In the KPC sale there were five strata used. The first four were volume strata, defined as follows:

Strata	Range in volume (MBF/acre)
1	8.0 — 16.55
2	16.56 — 25.25
3	25.26 — 37.40
4	37.41+

The fifth strata was an Alaska-cedar species strata. It included all units that were estimated, from aerial photographs, to contain the highest proportion of cedar volume. This was accomplished in the KPC sale by photointerpreting each unit. If cedar volume was obvious on a unit, that unit was included in the cedar stratum. The intent was to isolate a large percentage of the cedar volume into one stratum. Some cedar volume obviously will exist in the other volume strata.

The population may be stratified into the above-defined volume classes by several methods:

1. Each unit in the population of N units may be placed in one of the strata by either photocruising or photointerpretation or both. All units should not require photocruising to form homogeneous groups. Initially, photocruising is valuable to improve the accuracy of the interpretation.

2. Stand examinations may exist for some units or for stands in close proximity to units in the population. With the aid of type maps, average volumes per acre by types can be obtained from the stand exams. The volume of each unit can be approximated and placed in a volume stratum by first multiplying the acres in each type by the average volume per acre of that type and by then summing the volume of all types on the unit.

It is also possible to use a combination of these two systems. The method used on the KPC sale is described later in the example.

To determine which method does the best job of stratification, select a sample of units that have been previously examined on the ground. Apply the methods being contrasted to this sample of units. The stand exam volume should be assumed to be the actual volume. Each method discussed generates a different prediction of volume for each of the units in this sample.

Regress the actual values over the predicted values for both methods. The one with minimum residual mean square error should provide the best method of stratification.

All units in the population have to be placed in one of L strata ($L=5$, for the KPC sale). The number of units in each stratum is symbolized as N_h, where $h=1, \ldots, 5$. Units need to be arrayed by stratum with acres listed for each unit (M_{hi}). The symbol M_{hi} denotes the acres of the i^{th} unit in the h^{th} stratum. Therefore,

$$M_h = \sum_{i=1}^{N_h} M_{hi}$$

represents the total acreage in the h^{th} stratum.

For example, if the cedar stratum, stratum 5, had 54 units totaling 1,020 acres (413 ha), and the first unit on the list was 17 acres (7 ha) in size, the parameters of this stratum would be symbolized as follows:

$$h = 5;$$
$$N_h = N_5 = 54 \text{ units;}$$
$$M_{hi} = M_{5.1} = 17 \text{ acres (7 ha); and}$$
$$M_h = M_5 = \sum_{i=1}^{54} M_{5i} = 1{,}020 \text{ acres (413 ha)} .$$

A tabulation of the population after it is fixed for sampling might appear as follows (the first column for each stratum lists the acres of each unit and the second column is the cumulative sum of the first column):

	Strata									
	1		2		3		4		5	
Unit no.	Area M_{1i}	Cumulative area ΣM_{1i}	Area M_{2i}	Cumulative area ΣM_{2i}	Area M_{3i}	Cumulative area ΣM_{3i}	Area M_{4i}	Cumulative area ΣM_{4i}	Area M_{5i}	Cumulative area ΣM_{5i}
	(Acres)	(Acres)								
1	$M_{1,1}$	$M_{1,1}$	$M_{2,1}$	$M_{2,1}$	$M_{3,1}$	$M_{3,1}$	$M_{4,1}$	$M_{4,1}$	17	17
2	$M_{1,2}$	$M_{1,1}+M_{1,2}$	etc.	etc.	etc.	etc.	etc.	etc.	etc.	etc.
3	$M_{1,3}$	$M_{1,1}+M_{1,2}+M_{1,3}$								
.	etc.	etc.								
.										
.										
54										1020
.										blank
.										.
.										.
Total acres	M_1	—	M_2	—	M_3	—	M_4	—	1020	—

This tabulation represents the defined population. The next step is to draw the samples from each stratum.

The Design

There are two logical alternative schemes for sampling the population of N units: (1) stratified sampling with units drawn within stratum with pps; and (2) stratified random sampling with units drawn with equal probability. If the strata remain fixed (that is, no units are required to be added or deleted), and they vary considerably in size, pps sampling will be a more efficient method for estimating the total volume for the sale. If sample sizes in all strata are large, then the equal probability sampling design, alternative (2), with a "ratio-to-size" estimator, will compare favorably with the pps estimator (Cochran 1977).

When units are added or subtracted by stratum, the equal probability sample becomes more practical to apply. For example, if an equal number of units are added and subtracted from a stratum, the probability of selection of individual units under equal probability sampling remains the same. Under pps sampling the probability of selection depends on the size of each unit; thus, it will most likely change if units are substituted. Also, if units are either added or subtracted, estimation problems are easier to deal with when equal probability sampling is used.

In the cruise of the KPC sale, units were added to and subtracted from strata due to administrative decisions and catastrophic occurrences; thus, units in each stratum were sampled with equal probability. The pps sampling scheme, which should be considered when the population remains fixed, is described in the appendix (see "Probability Proportion to Size Sampling").

Small sample sizes within strata are likely to occur thereby creating problems from potential bias when using a ratio estimator. Cochran (1977) shows that the "combined ratio estimator" in stratified sampling is extremely variable, and that the "individual ratio estimator" by stratum has large bias for small samples. One of the estimation procedures that appears to provide maximum accuracy, aside from using pps sampling, is the "Quenouille ratio-type estimator." This estimation procedure is recommended by Cochran (1977) when strata are finite and sample sizes are small; it was used for the KPC sale and will be described in more detail (see "Estimation Procedures").

For simplicity, the sample size computations are based on the "individual ratio estimator" procedures. Following collection of the sample observations, the estimates are constructed using "Quenouille's estimators." These estimators are commonly referred to as "jackknife estimators." For details refer to the appendix (see "Sample Size Calculations").

Sampling Rules

Denote the sample drawn from the h^{th} stratum as n_h. In the stratified random sampling design, n_h units are drawn from N_h units with random sampling.

The samples can be drawn with replacement or without replacement. Because each unit drawn will be subsampled with an intensive grid of basal area points, the choice of method for drawing the samples may be important. If units are drawn from strata with replacement, the component of variance from variation among subsampling units (basal area points) can be ignored. This is the same situation that arises when n/N is small or N is assumed infinite. Although not necessary, it is convenient to subsample with replacement; the choice should depend on the size of the sampling fraction and the loss of precision from sampling with replacement. In the KPC sale the subsampling error component was assumed negligible.

After the number of units to be drawn is estimated, the individual units in the sample are identified. The sample for the h^{th} stratum arises from numbering the units of stratum h from 1 to N_h and drawing n_h numbers at random from this interval.

The units represented by these n_h random numbers are visited in the field and cruised for basal area by species. An intensive grid of points is constructed for each unit visited in the field. The KPC sale had one point every 3.5 acres (1.4 ha). The number of subsampling units (points) in the grid of the i^{th} unit of the h^{th} strata is denoted as m_{hi}. The number of basal area points can vary proportionally to the size of the unit, be held constant, or be arbitrary. Consideration was given to developing a self-weighting subsample in each unit. This would require the number of subsample points to be proportional to the size of the unit (that is, the subsampling fraction m_{hi}/M_{hi} is constant). This is desirable for both practical and statistical reasons and was done on the KPC sale.

To convert basal area to volume, a subsample of basal area points must be measured for volume. In the KPC sale, basal area points were sampled by fall buck and scale procedures (FBS). Separate stand volume-basal area prediction equations and log grade factors were constructed for each species. Following the completion of the field work, the point numbers and basal areas measured were arrayed by species and by basal area classes. These arrays were not constructed by strata because in a preliminary look at previous FBS data no differences were found in the volume-basal area relationships among strata.

The net and gross volume per acre prediction equations by species for the KPC sale were developed according to the detailed instructions in the appendix (see "Volume Equation Construction").

Twenty basal area points were drawn by species from each array of points in the KPC sale. The sample was uniformly distributed over the range of basal area to provide equal information for all basal area classes. Points were drawn at random within each species basal area class.

After drawing the 20 FBS plots for each species, the plots were field sampled. The following information was measured and recorded for each tree:

species,
d.b.h.,
gross volume,
net volume,
volume by log grade,
woods defect,
scaling defect, and
number of logs.

The gross and net volumes per acre by species were fitted by regression analysis to basal area per acre by species. Both linear and nonlinear models need to be investigated in both arithmetic and logarithmic scales (see "Volume Equation Construction" in the appendix).

Estimation Procedures

The detailed estimators will follow later in this section. These introductory paragraphs will describe the steps required to form estimates of total volume, volume by species, and volume by log grade. Estimates of the variance are provided only for the total volume estimates.

Picture a two-dimensional array with log grade classes as headings across the top and species as headings down the left side. Totals for the sums of all species and log grades are in the far right column and bottom row of the matrix, respectively. The grand total is the sum of the column totals or of the row totals. Refer to tables 1 and 2 in the appendix for illustrations of this matrix. A matrix with this format is constructed for the total volume (and volume per acre) for each unit sampled for basal area.

Arrays with this same format are then constructed for each strata by combining the matrices from all units sampled within the respective strata. This includes combining the species and log grade totals and the grand total. In the KPC sale, five matrices (one for each stratum) were constructed for volume per acre and five for total volume.

Estimates for the entire population are formed by multiplying the average volume per acre for each cell in the matrix by the acres in the respective stratum and summing over all strata.

The final matrix provides independent estimates for each cell that do not necessarily add to the species or log grade totals or the grand total in the array described above. The grand total is the estimate on which the precision of the cruise is controlled; therefore, if it is necessary for the individual estimates to equal the grand total, the matrix must be adjusted. This can be done by developing a matrix of proportions that expresses the total volume of each cell as a percent of the sum of the total volume of all cells. These proportions can then be applied to the independent estimates of the grand total for each variable of interest. This operation was performed on the KPC sale data.

The volumes per acre, by species for each point within the units sampled for basal area, were obtained by indirect estimation using the stand volume-basal area equations developed from the FBS points. The species volumes per point in each log grade were calculated with an average factor because a significant relationship did not exist between volume and basal area by log grade.

The volume per acre by species on each point was summed for all points on that unit and divided by the number of points to get the average volume per acre for each unit.

The volume per acre for a stratum is a ratio estimate. It is a ratio of the sum of the volumes of all units in the stratum divided by the sum of the acreage of the units. The total population volume is the sum of the stratum volumes.

The estimate of the variance of the total volume is formed as the sum of the variances of all strata weighted by the square of the strata sizes. The variance of basal area points within units (subsampling units) can be assumed to be negligible if strata are large or are sampled with replacement. The volume estimates of each basal area point are assumed to be the true volumes per acre (that is, the volume-basal area equations are treated as volume tables, and standard errors of the equations are ignored).

The estimated total volume ($\hat{Y}_R$) is given symbolically by:

$$\hat{Y}_R = \sum_{h=1}^{L} M_h \hat{R}_h = \sum_{h=1}^{L} M_h \frac{\sum_{i=1}^{n_h} \hat{Y}_{hi}}{\sum_{i=1}^{n_h} M_{hi}}; \qquad (1)$$

where:

$M_h = \sum_{i=1}^{N_h} M_{hi}$ is the total acreage in the h^{th} stratum;

$\hat{R}_h = \frac{\sum_{i=1}^{n_h} \hat{Y}_{hi}}{\sum_{i=1}^{n_h} M_{hi}}$ is the ratio of the total volume from the n_h units sampled in the h^{th} stratum, to the total acres in the n_h sample;

$\hat{Y}_{hi} = M_{hi}\bar{y}_{hi} = M_{hi} \frac{\sum_{j=1}^{m_{hi}} y_{hij}}{m_{hi}}$ is the estimated total volume of the i^{th} unit in the h^{th} stratum;

y_{hij} is the volume per acre for the j^{th} point in the i^{th} unit of the h^{th} stratum;

m_{hi} is the number of basal area points in the i^{th} unit of the h^{th} stratum; and

M_{hi} is the number of acres in the i^{th} unit of the h^{th} stratum.

The volume per acre for the i^{th} unit in the h^{th} stratum is calculated by inserting the basal area per acre into the appropriate volume-basal area prediction equation and solving the equation. The acreage of the i^{th} unit in the h^{th} stratum is known from the initial tabulation of the population by strata.

An approximate, sample-based estimate of the $MSE\ (\hat{Y}_R)$ (Cochran 1977, equation 11.30) is given by

$$v(\hat{Y}_R) = \sum_{h=1}^{L} \left\{ \frac{N_h^2}{n_h} (1 - f_{1h}) \frac{\sum_{i=1}^{n_h} M_{hi}^2 (\bar{y}_{hi} - \hat{Y}_{Rh})^2}{n_h - 1} + \frac{N_h}{n_h} \sum_{i=1}^{n_h} M_{hi}^2 \frac{(1 - f_{2hi}) s_{2hi}^2}{m_{hi}} \right\} ; \qquad (2)$$

where:

N_h, n_h, M_{hi}, and m_{hi} are defined previously;

$1 - f_{1h} = \frac{N_h - n_h}{N_h}$ is the finite population correction factor for the sample of n_h units in the h^{th} stratum;

$1 - f_{2hi} = \frac{M_{hi} - m_{hi}}{M_{hi}}$ is an approximation for the finite population correction factor for the sample of basal area points in the i^{th} unit of the h^{th} stratum.

The term $1 - f_{2hi}$ is an approximation, because each basal area point varies in size. If it is assumed that, on the average, each point samples 1 acre, then there are potentially M_{hi} basal area points in the i^{th} unit of the h^{th} stratum.

This term can also be dropped if M_{hi} is assumed to be infinite.

$\bar{y}_{hi}$ is the average volume per acre for the i^{th} unit in the h^{th} stratum;

$\hat{Y}_{Rh}$ is the average volume per acre for the h^{th} stratum;

$$\hat{Y}_{Rh} = \frac{\sum_{i=1}^{n_h} \hat{Y}_{hi}}{\sum_{i=1}^{n_h} M_{hi}} ;$$

$s_{2hi}^2 = \sum_{j=1}^{m_{hi}} \frac{(y_{hij} - \bar{y}_{hi})^2}{m_{hi} - 1}$ is the variance in volume among the m_{hi} basal area points on the i^{th} unit of the h^{th} stratum; and

y_{hij} is the volume per acre for the j^{th} point on the i^{th} unit in the h^{th} stratum (defined previously).

The second term in equation (2) can be dropped when n_h/N_h is small, when the variance between subsample points is assumed negligible, or if sampling with replacement. The second term was dropped in the KPC sale estimation.

Estimator (1), ($\hat{Y}_R$), is a biased estimator. It may have low variance if the correlation between $\hat{Y}_{hi}$ and M_{hi} is high. The problem that arises is when the strata sample sizes are small ($n \leq 4$), the bias in $\hat{Y}_R$ increases. An alternative procedure designed to reduce bias was developed by Quenouille (Cochran 1977). The Quenouille ratio estimator is recommended whenever strata sample sizes are small and separate ratio estimates are performed (Cochran 1977). The Quenouille estimators were used in the KPC sale estimations.

Keep in mind that this new cruise design utilizes stratified sampling with ratio estimates used for each stratum. The Quenouille estimators $\hat{Y}_Q$ and $v(\hat{Y}_Q)$ (Cochran 1977) will be formed as follows and will take the place of $\hat{Y}_R$ and $v(\hat{Y}_R)$ when n_h values are small, that is:

$$\hat{Y}_Q = \sum_{h=1}^{L} M_h \hat{R}_{Qh} \ . \qquad (3)$$

Note the only change between equations (1) and (3) is that $\hat{R}_{Qh}$ in (3) replaces $\hat{R}_h$ in equation (1), where:

$$\hat{R}_{Qh} = n_h \hat{R}_h - (n_h - 1)\hat{\hat{R}}_h \ . \qquad (3a)$$

Both estimate the average volume per acre for the h^{th} stratum.

The expression $\hat{R}_h$ is the same as defined in equation (1);

$$\hat{\hat{R}}_h = \frac{\sum_{j=1}^{n_h} \hat{R}_{hj}}{n_h} \ ; \text{ and}$$

$$\hat{R}_{hj} = \frac{\sum_{i \neq j = 1}^{n_h} \hat{Y}_{hi}}{\sum_{i \neq j = 1}^{n_h} M_{hi}} \ .$$

The $\hat{R}_{hj}$ values are formed by excluding the units one at a time from the sample, n_h, and forming $\hat{R}_{hj}$ for the remaining units, such that there will be n_h estimates of $\hat{R}_{hj}$ for each stratum.

The sample-based estimator of the variance of the Quenouille estimator is given by:

$$v(\hat{Y}_Q) = \sum_{h=1}^{L} M_h^2 \, v(\hat{R}_{Qh}) \ ; \qquad (4)$$

where, $v(\hat{R}_{Qh})$ is a function of the variance among estimates of $\hat{R}_{hj}$, given by:

$$v(\hat{R}_{Qh}) = \frac{(N_h - n_h)(n_h - 1)}{N_h \, n_h} \sum_{j=1}^{n_h} (\hat{R}_{hj} - \hat{\hat{R}}_h)^2 \ . \qquad (4a)$$

All terms have been defined previously.

Equation (4) ignores the source of variation among points within units, as discussed previously.

Reanalysis

After completion of the cruise, the cutting units that define the population may require changes for the following reasons:

1. Estimated volume from the cruise is too small or too large.

2. Changes in the EIS may result in deletion or addition of units.

3. Additional input in the negotiation process may result in deletion or addition of units.

When cutting units are deleted, they should be removed at random from each stratum. If units are removed and replaced purposively, care should be taken to insure that the average volume per acre and the variance among units within strata do not change appreciably. Units should be removed from the population without the knowledge of which units were field sampled. Information collected in the basal area sample will be dropped for specific units removed from the population.

Units added to the population after the cruise is completed should be stratified by the same procedures used in the stratification of the initial population. If the addition is a very small percentage change in the strata areas, no new field sampling should be required. But if a substantial amount of acreage is added, similar to the blowdown in the 1979-1984 KPC rate redetermination, then additional units should be sampled for basal area in the field. New units to be sampled should be drawn at random with the same intensity as in the previous sampling.

After the additions and deletions are completed, the estimation process is reanalyzed to get the new estimates. This process may be repeated several times to satisfy the EIS, the purchaser, and the Forest Service's objectives.

Adding and subtracting units from the population and reanalyzing the sample as a new stratified random sample should not appreciably affect the reliability of the estimates if the above rules are followed.

Example

The cruise design for KPC's 1984-89 redetermination was implemented in the following manner.

1. The tentative harvest unit selections on which the cruise was based consisted of 576 units encompassing 38,640 acres.

2. The harvest units were arrayed according to their respective strata ranges by determining the acreage, by type, from Forest type maps. The average volume per acre for each type, from timber inventory data, was then multiplied by the acreage of the respective types within the unit. The weighted average volume per acre was then determined for each unit. The total unit acreage was placed in the stratum coinciding with the weighted average volume per acre. The strata ranges were defined as follows:

Strata	Strata Range
	(Average MBF/acre)
1	8.00 - 16.55
2	16.56 - 25.25
3	25.26 - 37.40
4	37.41+
5 (Alaska-cedar)	(All ranges)

The Alaska-cedar stratum was formed to provide greater precision in the estimates of Alaska-cedar volume. Units were placed in this stratum by staff who were familiar with on-the-ground conditions. The intent was to isolate units having a high incidence of Alaska-cedar. Units in other strata also contained Alaska-cedar, but supposedly to a lesser degree.

3. The total sample size (n) for strata 1-4 and the allocation to the individual strata were computed by equations (7) and (8) in the appendix. Estimates of the mean volumes per acre and the strata variances were obtained from prior cruises and from timber inventory information.

Sample size for Alaska-cedar, n_5, was computed independently as follows:

$$n_5 = \frac{t^2 M_5^2 s_5^2}{SE_5^2} .$$

where:

M_5 is the total acres in the Alaska-cedar stratum,

s_5 is the standard deviation in mean volume per acre for the Alaska-cedar stratum,

SE_5 is the specified standard error for stratum 5, and

t is the Student's t value for the specified confidence probability and infinite degrees of freedom.

3a. Specifying precision requirements:

The precision requirements are established by reducing the contracted volume by the right-of-way volume and by the volume of units left over from previous periods. The residual volume in strata 1-4 and stratum 5 are multiplied by the standards specified in the objectives.

The total contracted volume was 960.0 MMBF. There were 31.7 MMBF of right-of-way volume (ROW) and residual volume left over from the previous 5-year period; thus, the 31.7 MMBF is subtracted from the 960 MMBF. The estimate of the total volume in the Alaska-cedar stratum is 116.3 MMBF. This was determined by multiplying the number of acres by an approximation of the average volume per acre. The specified standard error for the Alaska-cedar stratum was ± 20 percent at the 68 percent confidence probability.

Therefore,

$$SE_5^2 = (0.20(116.3))^2 = 541.0 \text{ MMBF}^2 .$$

The residual volume estimate for strata 1-4 is computed as follows:

Total contract volume	960.0 MMBF
ROW and previous units	- 31.7
Cedar stratum	- 116.3
Residual	812.0 MMBF.

The standard error for strata 1-4 was ± 10 percent at the 68 percent confidence probability.

Therefore,

$$SE_{1\text{-}4}^2 = (0.10(812.0))^2 = (81.2)^2 \text{ MMBF}^2 .$$

3b. Preliminary estimates:

Strata	Number of cutting units	Strata size	Standard deviations	Variance
		(M acres)	(MBF/acre)	(MBF/acre)^2
1	$N_1 = 61$	$M_1 = 3{,}242$	$s_1 = 12.625$	$s_1^2 = 159.391$
2	$N_2 = 239$	$M_2 = 16{,}338$	$s_2 = 12.423$	$s_2^2 = 154.331$
3	$N_3 = 161$	$M_3 = 11{,}477$	$s_3 = 19.248$	$s_3^2 = 370.486$
4	$N_4 = 38$	$M_4 = 2{,}132$	$s_4 = 13.751$	$s_4^2 = 189.090$
5	$N_5 = 77$	$M_5 = 5{,}451$	$s_5 = 17.040$	$s_5^2 = 290.362$

The values of N_h and M_h are obtained from the array of units by strata. The values of s_h were obtained from previous FBS plots, thus, are standard deviations among average volumes per acre; that is:

$$s_h^2 = \frac{\sum_{i=1}^{n_h} (\bar{y}_{hi} - \bar{\bar{y}}_h)^2}{n_h - 1} .$$

Note that the accepted standard deviations are rather large relative to the range in average volume that defines the strata boundaries. Therefore, these s_h^2 are probably conservative (that is, n_h values may be larger than necessary).

The variances required in equations (7) and (8) (see appendix) are different from those presented in the above tabulation. The variances required are the variances among total unit volumes within strata, rather than the variances among average volumes per acre. The deviations between average volumes per acre for the i^{th} unit and the average volume for the strata $(\bar{y}_{hi} - \bar{\bar{y}}_h)$ need to be weighted by the square of the acres of the i^{th} unit $(M_{hi}^2(\bar{y}_{hi} - \bar{\bar{y}}_h))$, as in equation (2).

To approximate the variances in equations (7) and (8), all values of s_h, from the tabulation, were multiplied by $\overline{M}_h$, the average size of a unit in stratum h. Because $M_h = N_h\overline{M}_h$, values of $\overline{M}_h$ were used as weights rather than those of N_h. Both should produce approximately the same result.

Normally such complexity to estimate s_h would not be required because approximations for the correct s_h would be available. If values of s_h^2 used in planning are poor estimates of the true variances, the estimates from the cruise will not be biased. Precision estimates will be greater or less than the planned levels.

3c. Computations of n_h:

Inserting estimates into the formula for the Alaska-cedar stratum (h=5) produced $n_5 = 16$; for example:

$$n_5 = \frac{29.7 \times 290.4}{541.0} = \frac{8624.9}{541.0} = 15.9 \text{ units} .$$

Inserting estimates into equation (7) produced $n_{1\text{-}4} = 18$; for example:

$$n = \frac{(40.9 + 203.0 + 220.9 + 29.3)^2}{(81.2^2 + 516.7 + 2521.5 + 4252.1 + 403.1)} = \frac{244{,}134.8}{14{,}286.8} = 17.1 \text{ units} .$$

Strata n_1, n_2, n_3, and n_4 are proportioned from equation (8) as follows:

$$n_1 = 17.1 \left(\frac{40.9}{494.1}\right) = 1.4 \text{ units;}$$

$$n_2 = 17.1 \left(\frac{203.0}{494.1}\right) = 7.0 \text{ units;}$$

$$n_3 = 17.1 \left(\frac{220.9}{494.1}\right) = 7.6 \text{ units; and}$$

$$n_4 = 17.1 \left(\frac{29.3}{494.1}\right) = 1.0 \text{ units.}$$

The resulting sample sizes for each stratum were:

Strata	Computed	Selected
	(Number of units)	(Number of units)
1	2	4
2	7	14
3	8	16
4	2	4
5	16	16
Totals	35	54

The strata sample sizes for strata 1-4 were doubled and the minimum sample size was set at 4 by Timber Management, Tongass National Forest, because this was the first trial of this design and the variance approximations were suspect.

4. Random samples were then selected according to the above allocation. The harvest units selected for visits in the field for each stratum were as follows:

Stratum and unit		Acres
Stratum 1:		
1	63-5	9
2	575-24	48
3	597-19	60
4	596-23	30
		147
Stratum 2:		
1	547-8	81
2	58-9	130
3	42-33	22
4	744-11	90
5	734-21	50
6	740-7	57
7	32-2	106
8	37-5	176
9	620-34	95
10	577-10	38
11	44-75	3
12	44-79	32
13	27-8	45
14	13-5	43
		968

Stratum and unit		Acres
Stratum 3:		
1	41-15	58
2	561-1	33
3	5461-4	73
4	534-3	102
5	531-12	86
6	531-14	100
7	531-40	60
8	60-19	44
9	11-9	41
10	54-5	74
11	736-111	138
12	36-15	50
13	619-45	53
14	620-26	85
15	620-101	46
16	44-1	65
		1,108

Stratum and unit		Acres
Stratum 4:		
1	561-20	25
2	65-21	3
3	45-27	24
4	620-11	90
		142
Stratum 5:		
1	45-34	89
2	65-18	116
3	65-5	55
4	548-2	53
5	548-10	46
6	620-51	32
7	620-96	108
8	577-6	53
9	578-1	68
10	575-10	48
11	586-4	81
12	595-15	105
13	595-26	50
14	573-1	69
15	582-1	88
16	29-50	106
		1,167

The 54 sample units encompassed 3,532 acres (1,429 ha). Basal area points were then located in each unit using a grid that resulted in one basal area point for approximately 3.5 acres (1.4 ha). For example, unit 547-8 in stratum 2 had 81 acres (33 ha); thus, on the average, it should have had 23 basal area points. A total of 1,025 basal area points were taken in the subsample of units using a basal area factor of 40. The tree count was taken by species on each point. Approximately 7,200 trees were sampled on the basal area points.

5. The basal area per acre on each point was displayed by species for all points. Twenty fall, buck, and scale plots for each species were selected—a total of 80 plots. The 20 plots per species were distributed uniformly over the basal area classes as shown in the following tabulation:

Number of trees per point	Western hemlock		Sitka spruce		Alaska-cedar		Western redcedar	
	Total points	FBS plots	Total points	FBS plots	Total points	FBS plots	Total points	FBS plots
1	95	2	263	4	100	3	99	3
2	132	2	104	4	69	3	86	3
3	171	2	62	4	46	3	78	3
4	158	2	26	4	47	3	37	3
5	117	2	12	4 (points 5–8 combined)	24	3	38	3
6	119	2	3		9	3	27	3
7	71	2	0		7	2 (points 7–11 combined)	8	2 (points 7–16 combined)
8	57	2	2		2		13	
9	29	2	0		3		9	
10	10	2 (points 10–14 combined)	0		0		1	
11	6		0		1		1	
12	3		0		0		1	
13	1		0		0		0	
14	1		0		0		0	
15	0		0		0		0	
16	0		0		0		1	

The FBS plots in each basal area class for each species were randomly selected from the total number of plots in that class. For the 95 basal area points having one hemlock tree, for example, two random numbers from 1 to 95 were generated. Each random number corresponded to a basal area point number. The points selected became FBS plots.

6. The 80 plots were visited in the field and the data for a fall, buck, and scale cruise was gathered at each plot. The 80 plots occurred in 36 of the 54 field-sampled units.

7. Regression analyses of gross and net volume per acre (board feet and cubic feet) over basal area per acre, were run. The equations, scatter plots, and other regression analysis statistics appear in figures 1-8 in the appendix. Refer to the section, "Volume Equation Construction," for details on model construction and selection.

8. The volume equations developed in step 7 were applied to the basal area per acre by species on each point developed in step 4 to produce volumes per acre by species for each point. Total unit volume by species was then calculated by combining all points in a unit according to the estimators specified previously. These unit volumes were the ingredients that went into the Quenouille estimators for estimating total volume for the population. Volume by log grade was also constructed at the unit level by applying average factors developed from the FBS plots.

9. Quenouille's estimators, equations (3a) and (4a), by individual species and the total of all species, were used to produce the volumes per acre and the variances for each stratum. An example for stratum 4 appears in table 1. Multiplying the volumes per acre and the variance by the stratum area and the square of stratum area, respectively, produces the estimated total volume by species and its variance for each stratum. This total volume by species and log grade is illustrated for stratum 4 in table 2.

10. Equations (3) and (4) were then used to combine the strata. The total volume for the population and its standard error appear in tables 3 and 4. Note that the total net Scribner board foot volume for the 576 units was 1,367 MMBF, and the amount planned for sale was 960 MMBF. The 576 units exceeded the volume of timber to be sold. The mean volume per acre of each species type or volume stratum used to approximate the total volume was less than what actually existed in the population: If representative data from the same parent population were used in the initial estimate, then the preliminary and final estimates should be much closer.

The objective is, nevertheless, to offer approximately 960 MMBF of timber for the sale. To reduce the 1,367 MMBF to 960 MMBF, units were removed from each strata according to procedures described earlier (see "Reanalysis"). Recall that there was a requirement in the Tongass Management Plan to maintain a specified proportion of acres in each of the volume classes. As units were removed, this specified proportion was monitored. It is possible to remove units and maintain the proportion among strata without adversely affecting the estimation procedures because volume strata were sampled independently.

The sample was reprocessed until the number of units left produced the 960 MMBF. All information from the units removed was discarded (except the FBS information). The collection of units left, after all adjustments, was the "final population."

If the remaining units are a subset of the original population, formed by excluding units randomly from each strata, then the final population is representative of the original "superpopulation," and the sample of FBS plots originally measured will be applicable to all basal area points remaining in the sample. If units are added to form the "final population," and FBS plots have not had the opportunity to be drawn, then consideration should be given to doing some additional sampling to represent the added portion of the "final population."

It is clear that the closer the initial estimate of volume is to the 960 MMBF, the less information is discarded or added. This promotes incentives to do a better job of stratification of cutting units and of initial estimation of the volume of the population.

11. Tables 5 and 6 illustrate the reanalysis of the population estimates of the KPC sale after removing 178 units. Note that the volume estimate was 941.4 MMBF after adjustments and that the standard error of estimate was 4.7 percent of the total.

The targeted precision was ±10 percent. By doubling the intensity of the sample and controlling the precision on the cedar stratum, the precision achieved was much greater than required. Much less sampling could have been performed to meet the ± 10 percent precision standard.

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Metric Equivalent

1 acre = 0.4047 hectare

Literature Cited

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Appendix 1

Sampling With Probability Proportional to Size

As explained earlier, probability proportional to size (pps) sampling is very efficient when units within strata have approximately the same average volume per acre but differ substantially in acreage (size). If, however, the strata sizes are subject to change by the addition or deletion of units, due to administrative decisions or natural causes, then the estimation scheme for pps sampling can become very complex. For this reason it was not used in the KPC sale cruise.

When these restrictions do not exist, pps sampling is the preferred procedure. A pps sample is drawn and estimation accomplished as follows:

Given values for n_h from the sample size calculations and the array of units by strata shown previously, draw n_h random numbers from the h^{th} stratum from the interval 1 to the total acres in the stratum. Each random number represents a specific acre in the stratum. The unit to which a specific random number applies is found by accumulating the acres of units from 1 to N_h, and locating the random number in the interval of accumulated acres. The unit the random number exists in will then identify the unit that will enter the sample.

The n_h units can be drawn with or without replacement. If drawn with replacement, the variance estimation is simplified to involve only the variation among unit means. And, as explained in the text, when n_h/N_h is small (approaches zero), the variation among points within units can be dropped even when sampling without replacement. The recommended method, therefore, is to draw n_h with replacement.

Upon completion of field measurements of the n_h units, the estimate of total volume for the h^{th} stratum is given by:

$$(\hat{Y}_{pps})_h = \frac{M_h}{n_h} \sum_{i=1}^{n_h} \left(\frac{\hat{Y}_{hi}}{M_{hi}} \right) = M_h \frac{\sum_{i=1}^{n_h} \bar{y}_{hi}}{n_h} = M_h \bar{\bar{y}}_h \ ;$$

where:

$\bar{\bar{y}}_h$ is the unweighted volume per acre for the h^{th} stratum; all other terms are defined earlier.

The sample-based estimator of the true variance of $(\hat{Y}_{pps})_h$ is given by:

$$v(\hat{Y}_{pps})_h = \frac{M_h^2 \sum_{i=1}^{n_h} \left(\frac{\hat{Y}_{hi}}{M_{hi}} - (\hat{Y}_{pps})_h \right)^2}{n_h(n_h - 1)} = \frac{M_h^2 \sum_{i=1}^{n_h} (\bar{y}_{hi} - \bar{\bar{y}}_h)}{n_h \, (n_h - 1)} \ .$$

The combined estimates for all strata are given by:

$$\hat{Y}_{pps} = \sum_{h=1}^{L} (\hat{Y}_{pps})_h \ , \qquad (5)$$

and by

$$v(\hat{Y}_{pps}) = \sum_{h=1}^{L} v(\hat{Y}_{pps})_h \ . \qquad (6)$$

Sample Size Calculations

To estimate the size of samples needed for meeting the desired level of precision, preliminary estimates of the variances among units for each stratum have to be available.

Equal probability sampling.—In the equal probability sampling procedure, with the ratio to size estimator and optimum allocation, the total sample size for L strata is:

$$n = \sum_{h=1}^{L} n_h, \text{ computed as follows:}$$

$$n = \frac{\left(\sum_{h=1}^{L} N_h s_h \right)^2}{SE^2 + \sum_{h=1}^{L} N_h s_h^2} \ ; \qquad (7)$$

where:

SE is the standard error of the total estimate required for all strata. This is a modification of Cochran's equation (1977, equation 5.25) for a specified SE of the total estimate. Then:

$$n_h = n \left[\frac{N_h s_h}{\sum_{h=1}^{L} N_h s_h} \right] ; \qquad (8)$$

where:

$$s_h^2 = \sum_{i=1}^{n_h} \frac{M_{hi}^2 (\bar{y}_{hi} - \hat{Y}_{Rh})^2}{n_h - 1} ;$$

$$\bar{y}_{hi} = \frac{\hat{Y}_{hi}}{M_{hi}} = \sum_{j=1}^{m_{hi}} \frac{y_{hij}}{m_{hi}} ;$$

$$\hat{Y}_{Rh} = \frac{\sum_{i=1}^{n_h} \hat{Y}_{hi}}{\sum_{i=1}^{n_h} M_{hi}} ;$$ all of which were defined previously.

Sampling with probability proportional to size (pps).—In pps sampling the computation of sample sizes n_h is straightforward. Equation (6) is used and is given by:

$$v(\hat{Y}_{pps}) = \sum_{h=1}^{L} M_h^2 \sum_{i=1}^{n_h} \frac{\left(\frac{\hat{Y}_{hi}}{M_{hi}} - (\hat{Y}_{pps})_h \right)^2}{n_h (n_h - 1)} ,$$

$$= \sum_{h=1}^{L} M_h^2 \sum_{i=1}^{n_h} \frac{(\bar{y}_{hi} - \bar{\bar{y}}_h)^2}{n_h (n_h - 1)} .$$

This can be simplified to:

$$v(\hat{Y}_{pps}) = \sum_{h=1}^{L} M_h^2 \left(\frac{s_h^2}{n_h} \right) ;$$

where s_h^2 is the variance among volumes per acre for the n_h units in each strata. The size of the individual units do not enter into the final calculations. Equations (7) and (8) are modified for computing the sample sizes by replacing the weights N_h with M_h. This is done because the estimates of s_h^2 are computed on the volumes per acre for each unit. For example:

$$n = \frac{\left(\sum_{h=1}^{L} M_h s_h \right)^2}{SE^2 + \sum_{h=1}^{L} M_h s_h^2} ; \qquad (7a)$$

and

$$n_h = n \left[\frac{M_h s_h}{\sum_{h=1}^{L} M_h s_h} \right] ; \qquad (8a)$$

where:

$$s_h^2 = \sum_{i=1}^{n_h} \frac{(\bar{y}_{hi} - \bar{\bar{y}}_h)^2}{n_h - 1} .$$

Controlling precision on two estimates.—The values of SE arise from the specified levels of precision. In the case of the KPC sale the specified precision was ±10 percent on the total volume at the 68 percent confidence probability and ±20 percent on the estimated volume of the Alaska-cedar stratum at the same confidence probability.

To control the precision on two estimates at the same time, start with the Alaska-cedar stratum ($h = 5$). Compute the sample size for the cedar stratum similar to the example provided earlier. In that example, $SE_5 = 0.20\ (116.3) = 23.3$ MMBF, and $n_5 = 16$ units.

The next step is to compute the sample sizes for the remaining L-1 strata. This can be done by several methods. One method would be to compute n by equation (7) and use the allocation formula, (8), for all strata other than stratum 5. This would insure greater precision than specified for the total. Another alternative would be to specify the precision on just the remaining strata (that is, exclude stratum 5) and compute the sample size using equations (7) and (8) for the remaining strata. A third method—perhaps the most complicated yet the most accurate—would be to compute the SE for the remaining strata by removing the absolute standard error for stratum 5 (the Alaska-cedar stratum). This will result in a new specified SE for the remaining strata.

For example:

If SE = $\pm$ 0.10Y at 68 percent confidence probability, and $\hat{Y}$ = 941.4 MMBF is the best preliminary estimate of Y, then 0.10(941.4) = 94.1 MMBF is the specified absolute SE for the total. The specified SE^2 of the estimated total volume for all strata is given by:

$$SE_{1\text{-}5}^2 = (94.1)^2 = 8{,}862.3 \text{ MMBF}^2 .$$

Because n_5 is computed and there are values for N_h^2 and s_h^2, the specified standard error for strata 1-5 can be reduced by the contribution of stratum 5. This leaves the absolute SE desired for the remaining strata:

$$SE_{1\text{-}5}^2 - SE_5^2 = SE_{1\text{-}4}^2 \text{, or}$$

$$8{,}862.3 - 541.0 = 8{,}321.3 \text{ MMBF}^2 .$$

Equations (7) and (8) can then be used to calculate the n_h values for strata 1 through 4 using $SE_{1\text{-}4}^2 = 8{,}321.3$ MMBF^2.

In stratified sampling a complication arises in choosing a value for the degrees of freedom for the Student's t value. The sample size for looking up the degrees of freedom should be approximated for calculating confidence intervals by the following expression (Cochran 1977, equation 5.16):

$$n_e = \frac{\sum_{h=1}^{L} g_h s_h^2}{\sum_{h=1}^{L} \frac{g_h^2 s_h^4}{n_h - 1}} ;$$

where:

$$g_h = \frac{N_h(N_h - n_h)}{n_h} .$$

The value of n_e (estimated sample size) will lie between the minimum n_h and n.

Volume Equation Construction

Species total volume is an essential ingredient in the appraisal process. In addition, the relationship between volume per acre and basal area per acre will usually differ among species. The sampling procedure used on the cruise for the KPC sale to develop volume equations was therefore designed to produce separate equations for each of the major species.

Four different species sets of equations were produced. Approximately 20 FBS plots per species were selected from the lists of basal area points. These lists were constructed for each species based on the major species at the point. If a point is selected for use with a particular species volume equation it may also be used in other species equations, if other species exist on the point, because all trees regardless of species were FBS sampled on each point.

The lists of basal area points for each species were arrayed by basal area. A uniform sample was drawn over the range of basal area to insure equal sample information over the range of basal area. This was most easily accomplished by partitioning the range of basal areas into *r* discrete classes and drawing 20/*r* points at random from each class. If 20/*r* did not produce a whole number the extra points were spaced equally over the range of the basal area classes.

Detailed information was collected from the FBS plots on the trees selected by the specified basal area factor. Trees selected by the basal area factor were measured for d.b.h. and were then felled and scaled for defect and volume. The logs, by tree, were identified so the number of logs per MBF could be computed later. Each log was also graded.

FBS plots were summarized in the office to produce species estimates of:

- gross and net volume per acre,
- basal area per acre,
- volume by log grade,
- volume of woods defect,
- volume of scaling defect,
- number of logs per MBF, and
- average d.b.h.

Volume estimates were made in both board feet and cubic feet.

The process of developing volume-basal area equations is an exploratory one. In general, a linear relationship of volume per acre over basal area per acre works well; however, occasions may exist where nonlinear models are more appropriate. Another consideration in the development of volume-basal area equations is the conditioning of the extremes of the curves. For example, it may be desirable to condition the curve through zero or to be asymptotic to the basal area axis at a positive volume.

The model with the minimum residual sums of squares for the KPC sale was

$$y = ax^b ;$$

where:

y is gross and net cubic and board foot volumes per acre;
a and b are coefficients; and
x is basal area per acre.

The volume-basal area equations developed are shown in figures 1-8.

Developing equations for major species should in general pose no problems. Minor species with highly variable form or defect may not be able to be estimated singly, however, and may have to be combined with another major species of similar geometric configuration.

Volume by log grade can also be investigated for a prediction equation of volume per acre expressed as a function of basal area per acre. If statistically significant equations exist, they can be used in the estimation of volume by log grades. If not, a set of average factors by species should be used to prorate the final estimates of total net and gross volumes by species into volumes by log grade. Average factors by species were used in the KPC sale cruise.

The final volume equations are applied to each basal point sampled in the field and a volume per acre by species is constructed (y_{hij}) for the j^{th} point in the i^{th} unit of the h^{th} stratum, so that all basal area points will possess volume per acre estimates.

The estimates of volume and variance in estimated volume are then formed according to equations (1) through (6).

Appendix 2
Tables and Figures

Table 1—Timber cruise summary of volume per acre by species and by grade for stratum 1, KPC sale[1]

		Grades							
Species	Units	Peeler or Select	1	2	3	4	Utility	Cull	Total
Sitka spruce (code 098)	Gross board feet	1,150.1	880.6	728.7	233.5	0	1,030.6	423.3	4,446.9
	Net board feet	896.7	694.1	642.4	182.6	0	927.3		3,343.1
	Gross cubic feet	195.8	157.1	159.9	92.3	0	106.3	95.7	807.1
	Net cubic feet	184.4	142.8	149.0	86.5	0	70.7		633.4
Western redcedar (code 242)	Gross board feet	0	1,509.6	2,610.4	3,358.9	0	0	2,199.6	9,678.5
	Net board feet	0	1,084.1	1,816.2	2,580.6	0	0		5,480.9
	Gross cubic feet	0	321.6	535.7	994.2	0	0	581.6	2,433.2
	Net cubic feet	0	279.3	472.4	882.1	0	0		1,633.8
Western hemlock (code 263)	Gross board feet	3,641.3	2,762.9	4,837.1	2,730.2	0	3,037.5	2,570.0	19,579.2
	Net board feet	3,004.2	1,974.6	3,895.6	2,282.1	0	2,645.1		13,801.5
	Gross cubic feet	560.8	587.2	1,069.9	876.1	0	650.3	614.1	4,358.5
	Net cubic feet	528.5	520.7	960.4	809.0	0	454.8		3,273.4
Alaska cedar (code 042)	Gross board feet	925.4	4,120.5	2,600.2	1,449.6	0	0	1,035.4	10,131.0
	Net board feet	813.1	2,885.5	1,948.9	1,119.1	0	0		6,766.6
	Gross cubic feet	202.4	667.4	654.7	541.3	0	0	263.8	2,329.6
	Net cubic feet	190.7	624.2	598.3	493.9	0	0		1,907.1
All species	Gross board feet	5,716.8	9,273.7	10,776.5	7,772.2	0	4,068.1	6,228.2	43,835.6
	Net board feet	4,714.0	6,638.3	8,303.2	6,164.4	0	3,572.4		29,392.2
	Gross cubic feet	958.9	1,733.4	2,420.3	2,504.0	0	756.6	1,555.2	9,928.3
	Net cubic feet	903.7	1,566.9	2,180.1	2,271.5	0	525.5		7,447.8

[1] Supporting information: Long-term sale 1984-89, number 01042; Forest number 5; Region 10. Stratum 1: 4 units were measured; numbers 199, 366, 440, and 458 contained 9, 48, 30, and 60 acres, respectively; 57 units were not measured; 61 units contained 3,242 acres.

Table 2—Timber cruise summary of total volume in thousand feet by species and by grade for stratum 1, KPC sale[1]

Species	Units	Total volume by grade							
		Peeler or Select	1	2	3	4	Utility	Cull	Total
Sitka spruce (code 098)	Gross board feet	3,728.7	2,855.0	2,362.6	757.2	0	3,341.2	1,372.2	14,416.9
	Net board feet	2,907.0	2,250.3	2,082.8	592.0	0	3,006.3		10,838.4
	Gross cubic feet	634.7	509.3	518.5	299.3	0	344.5	310.1	2,616.5
	Net cubic feet	597.9	462.8	483.0	280.3	0	229.3		2,053.4
Western redcedar (code 242)	Gross board feet	0	4,894.3	8,462.9	10,889.5	0	0	7,131.0	31,377.6
	Net board feet	0	3,514.5	5,888.3	8,366.2	0	0		17,769.0
	Gross cubic feet	0	1,042.7	1,736.7	3,223.3	0	0	1,885.7	7,888.4
	Net cubic feet	0	905.5	1,531.7	2,859.7	0	0		5,296.8
Western hemlock (code 263)	Gross board feet	11,805.0	8,957.5	15,682.0	8,851.3	0	9,847.7	8,332.0	63,475.7
	Net board feet	9,739.6	6,401.6	12,629.4	7,398.6	0	8,575.3		44,744.6
	Gross cubic feet	1,818.0	1,903.8	3,468.7	2,840.5	0	2,108.3	1,990.9	14,130.1
	Net cubic feet	1,713.5	1,688.1	3,113.6	2,622.7	0	1,474.5		10,612.4
Alaska cedar (code 042)	Gross board feet	3,000.0	13,358.7	8,429.8	4,699.7	0	0	3,356.6	32,844.8
	Net board feet	2,636.0	9,354.9	6,318.4	3,628.1	0	0		21,937.4
	Gross cubic feet	656.1	2,163.8	2,122.6	1,754.8	0	0	855.1	7,552.5
	Net cubic feet	618.4	2,023.6	1,939.6	1,601.4	0	0		6,183.0
All species	Gross board feet	18,533.9	30,065.5	34,937.3	25,197.6	0	13,188.9	20,191.9	142,115.0
	Net board feet	15,282.7	21,521.4	26,918.8	19,984.9	0	11,581.6		95,289.4
	Gross cubic feet	3,108.8	5,619.6	7,846.6	8,117.8	0	2,452.8	5,041.9	32,187.6
	Net cubic feet	2,929.8	5,080.0	7,067.9	7,364.1	0	1,703.8		24,145.7

[1] Supporting information: Long-term sale 1984-89, number 01042; Forest number 5; Region 10. Stratum 1: 4 units were measured; numbers 199, 366, 440, and 458 contained 9, 48, 30, and 60 acres, respectively; 57 units were not measured; 61 units contained 3,242 acres.

Table 3—Timber cruise summary of total volume, woods defect, scaling defect, and other characteristics for 576 units in the 1984-89 recruise of the KPC sale[1]

Item	Estimates
Scribner volume:	
Gross (MMBF)	1,896.7
Net (MMBF)	1,367.4
Net per acre (BF)	35,388.4
Cubic volume:	
Gross (MMCF)	412.6
Net (MMCF)	310.7
Net per acre (CF)	8,043.0
Woods defect (percent):	
Scribner	27.9
Cubic	24.7
Scaling defect (percent):	
Scribner	15.8
Cubic	11.0
Number of logs per thousand board feet	5.3
Number of logs per cunit	2.5
Number of trees per acre	125.9
Average d.b.h. (inches)	19.3

[1] Supporting information: Long-term sale 1984-89, number 01042; Forest number 5; Region 10.

Table 4—Timber cruise summary of estimated total volume and the standard error for 576 units in the 1984-89 recruise of the KPC sale[1]

Item	Scribner volume				Cubic volume			
	Per acre	Total	Standard error		Per acre	Total	Standard error	
	Board feet	- - Million board feet - -		Percent	Cubic feet	- Million cubic feet -		Percent
Gross	49,087.7	1,896.7	--	--	10,680.6	412.7	--	--
Net	35,388.4	1,367.4	59.6	4.4	8,042.6	310.8	10.4	3.4

[1]Supporting information: Long-term sale 1984-89, number 01042; Forest number 5; Region 10.

Table 5—Timber cruise summary of volume, woods defect, scaling defect, and other characteristics for 398 units in the 1984-89 recruise of the KPC sale[1]

Item	Estimates
Scribner volume:	
Gross (MMBF)	1,299.2
Net (MMBF)	941.3
Net per acre (BF)	36,178.0
Cubic volume:	
Gross (MMCF)	292.16
Net (MMCF)	212.3
Net per acre (CF)	8,159.0
Woods defect (percent):	
Scribner	27.5
Cubic	24.8
Scaling defect (percent):	
Scribner	15.2
Cubic	10.9
Number of logs per thousand board feet	5.6
Number of logs per cunit	2.6
Number of trees per acre	131.4
Average d.b.h. (inches)	19.4

[1]Supporting information: Long-term sale 1984-89, number 01042; Forest number 5; Region 10.

Table 6—Summary of estimated total volume and the standard error for 398 units in the 1984-89 recruise of the Ketchikan Sale[1]

	Scribner volume				Cubic volume			
Item	Per acre	Total		Standard error	Per acre	Total	Standard error	
	Board feet	Million - board feet -		Percent	Cubic feet	Million - cubic feet -		Percent
Gross	49,930.1	1,299.3	--	--	10,843.9	108.4	--	--
Net	36,177.9	941.4	44.6	4.7	8,159.2	212.3	7.7	3.6

[1] Supporting information: Long-term sale 1984-89, number 01042; Forest number 5; Region 10.

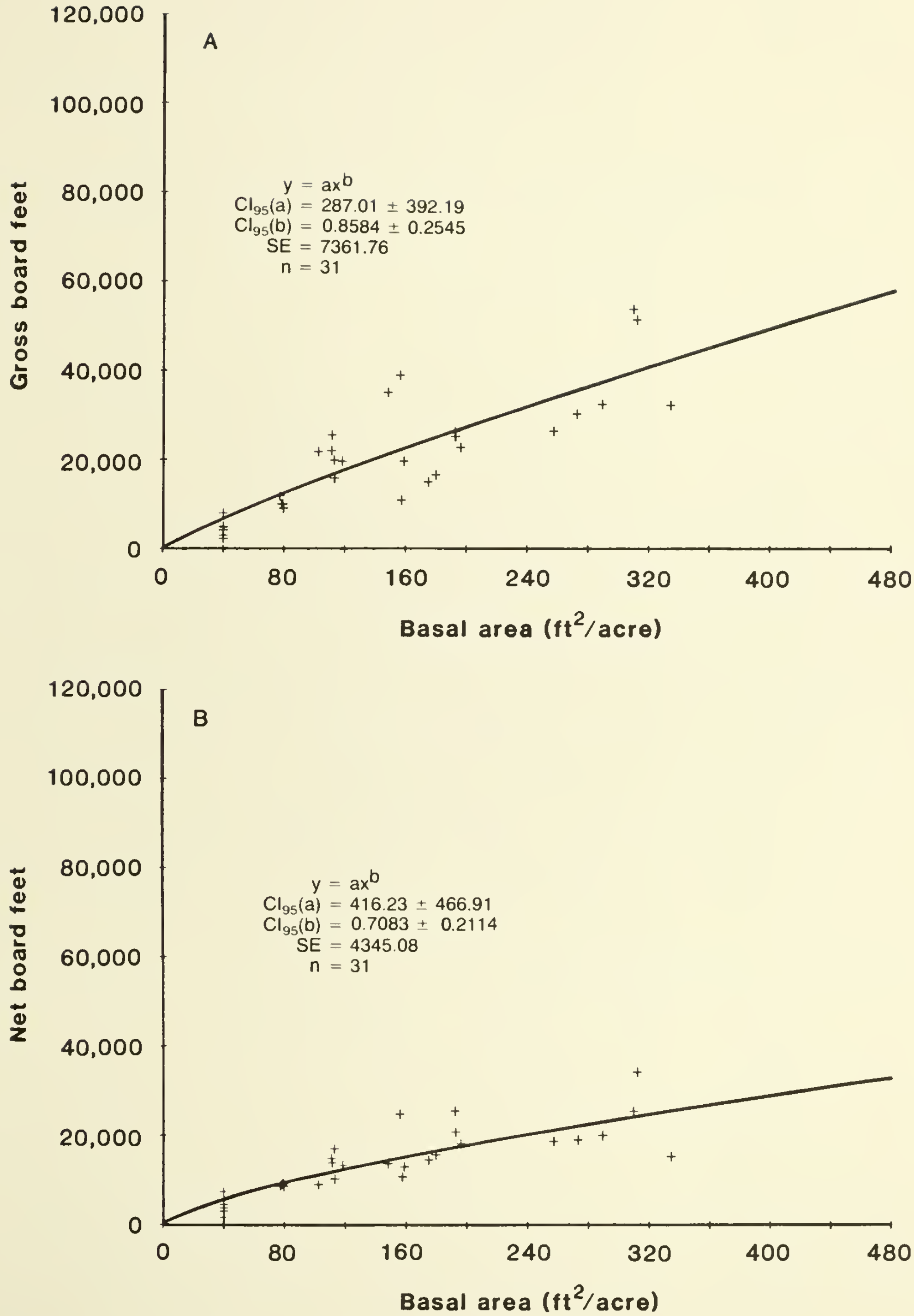

Figure 1.—Regressions of (A) gross board foot volume per acre and (B) net board foot volume per acre of Alaska-cedar (species 042) over basal area per acre for the KPC sale.

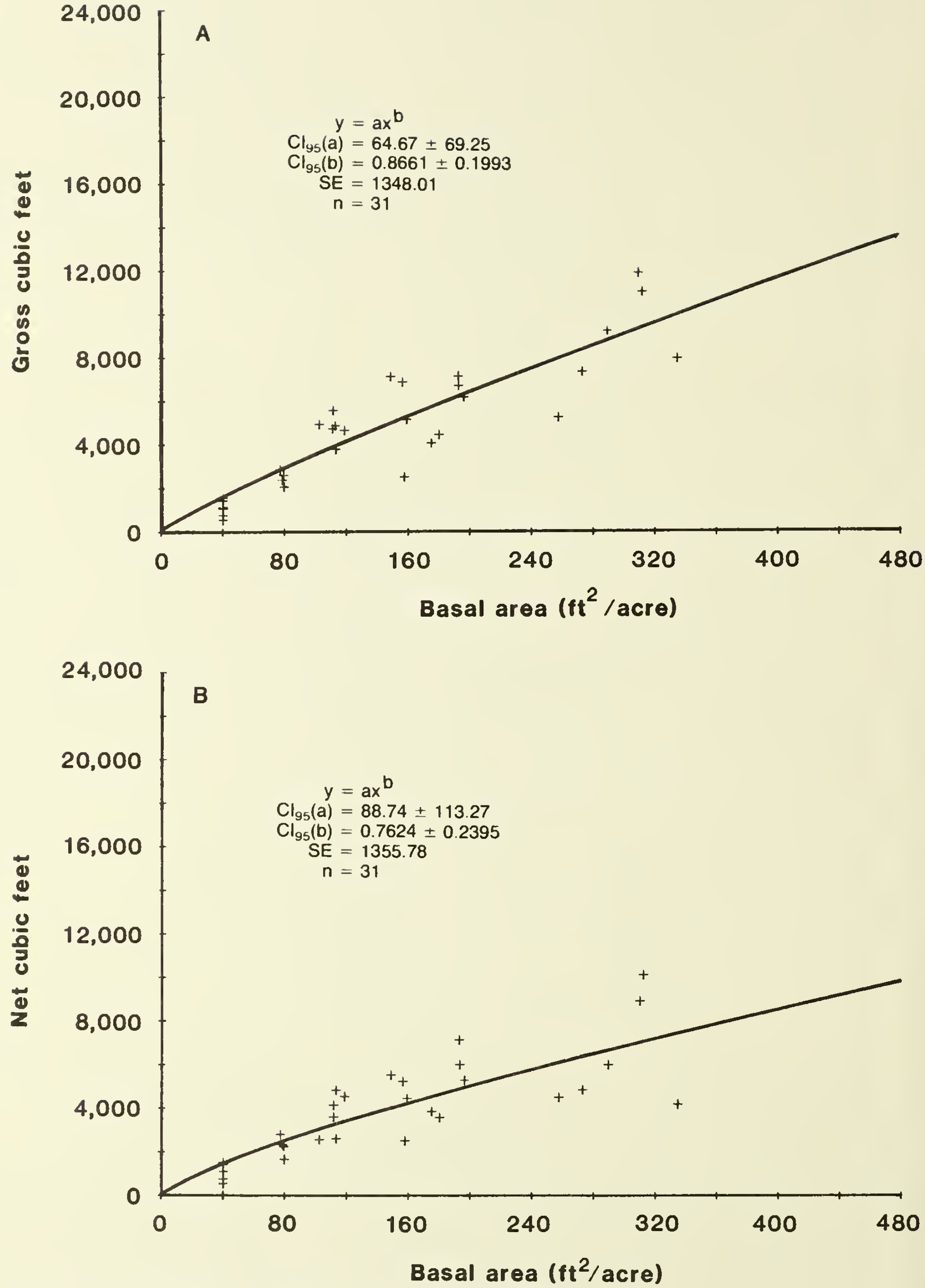

Figure 2.—Regressions of (A) gross cubic foot volume per acre and (B) net cubic foot volume per acre of Alaska-cedar (species 042) over basal area per acre for the KPC sale.

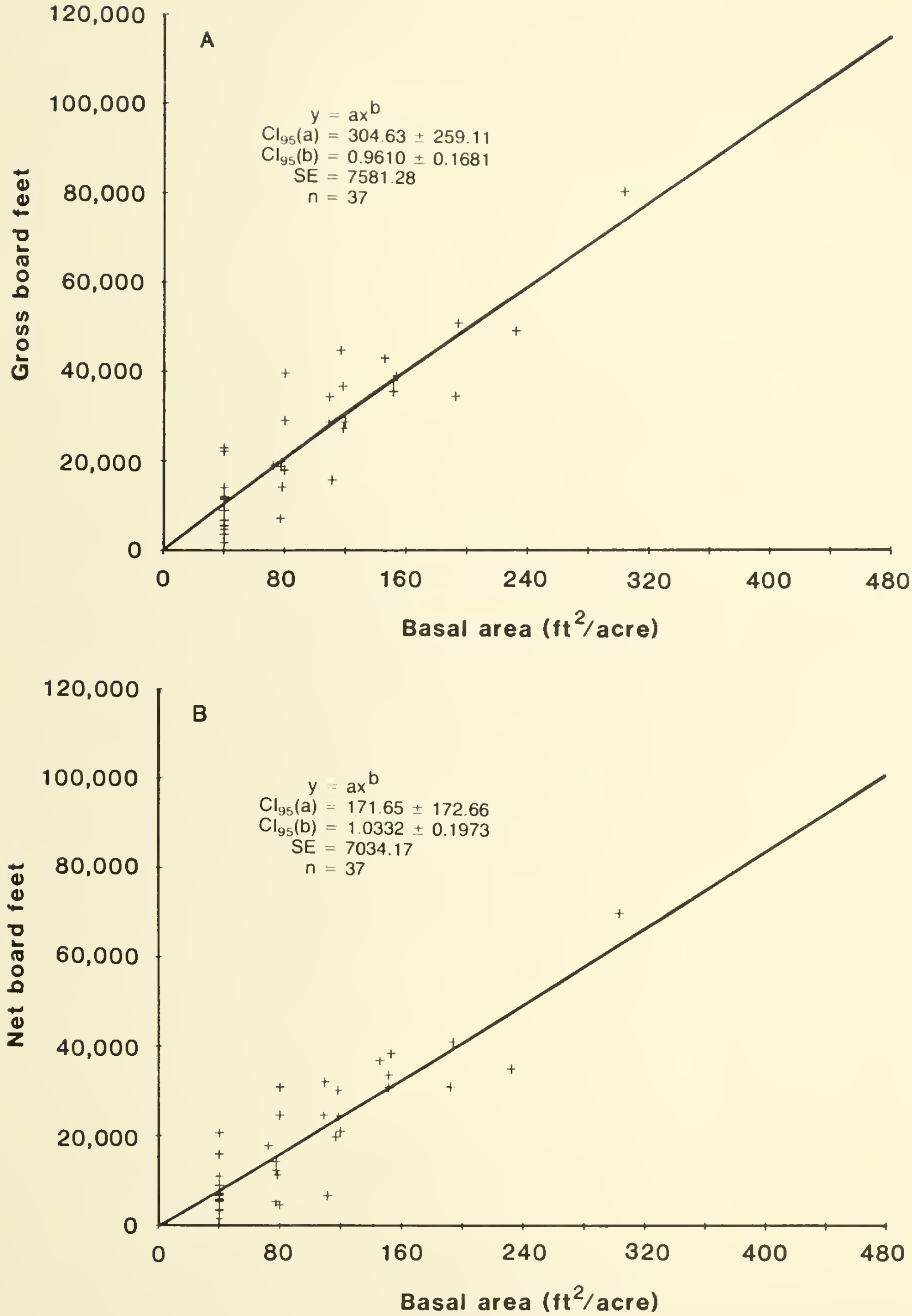

Figure 3.—Regressions of (A) gross board foot volume per acre and (B) net board foot volume per acre of Sitka spruce (species 098) over basal area per acre for the KPC sale.

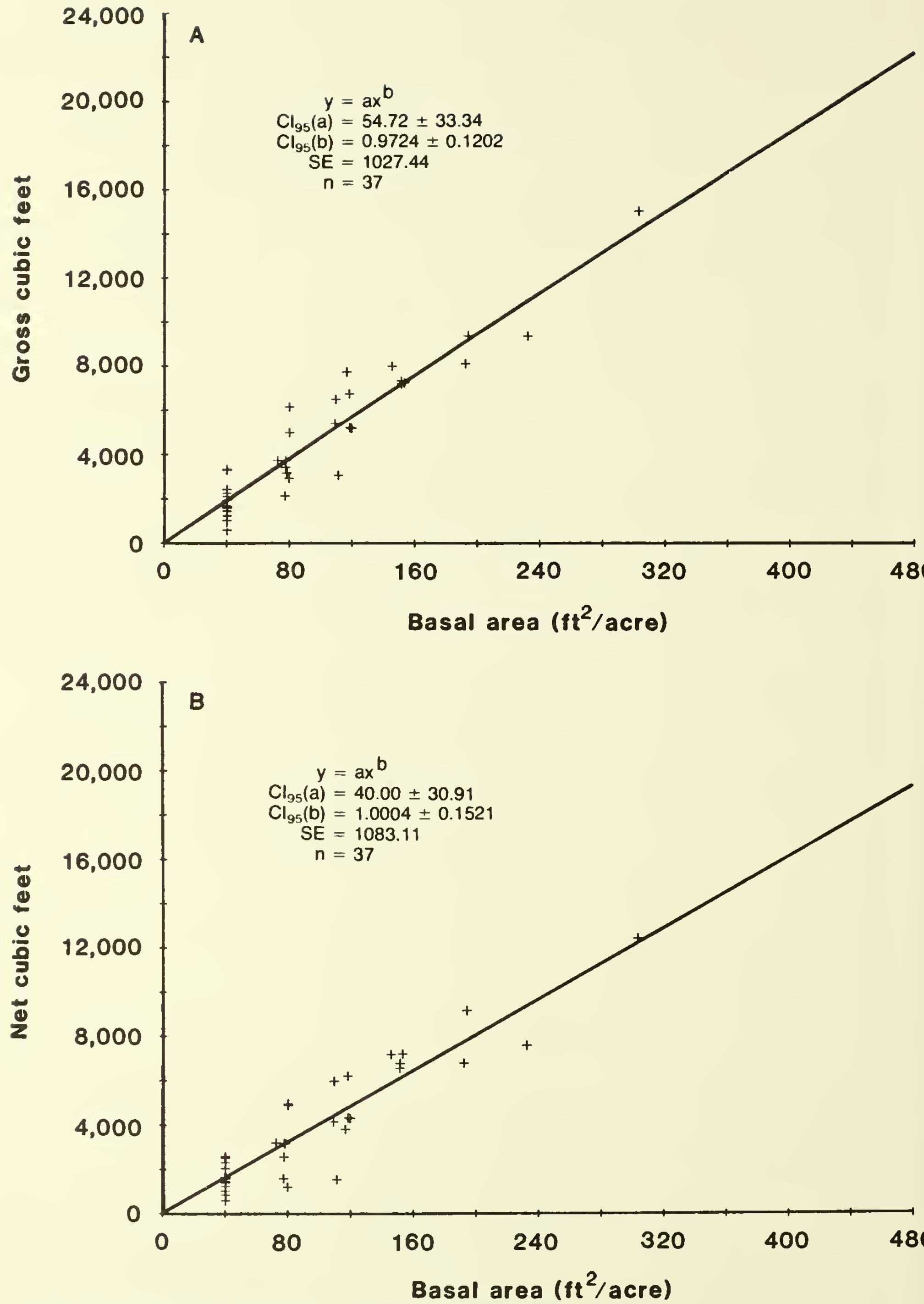

Figure 4.—Regressions of (A) gross cubic foot volume per acre and (B) net cubic foot volume per acre of Sitka spruce (species 098) over basal area per acre for the KPC sale.

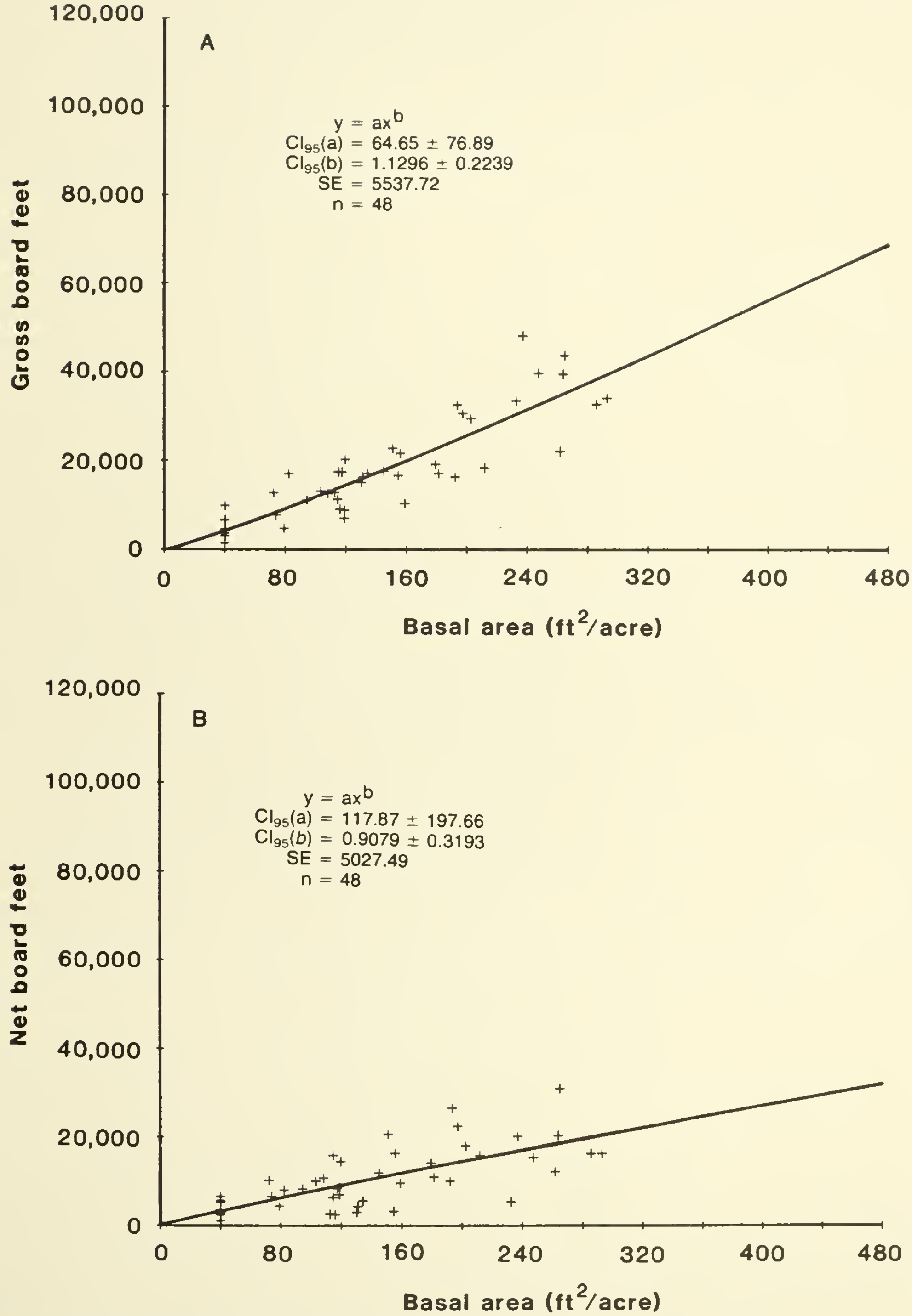

Figure 5.—Regressions of (A) gross board foot volume per acre and (B) net board foot volume per acre of western red-cedar (species 242) over basal area per acre for the KPC sale.

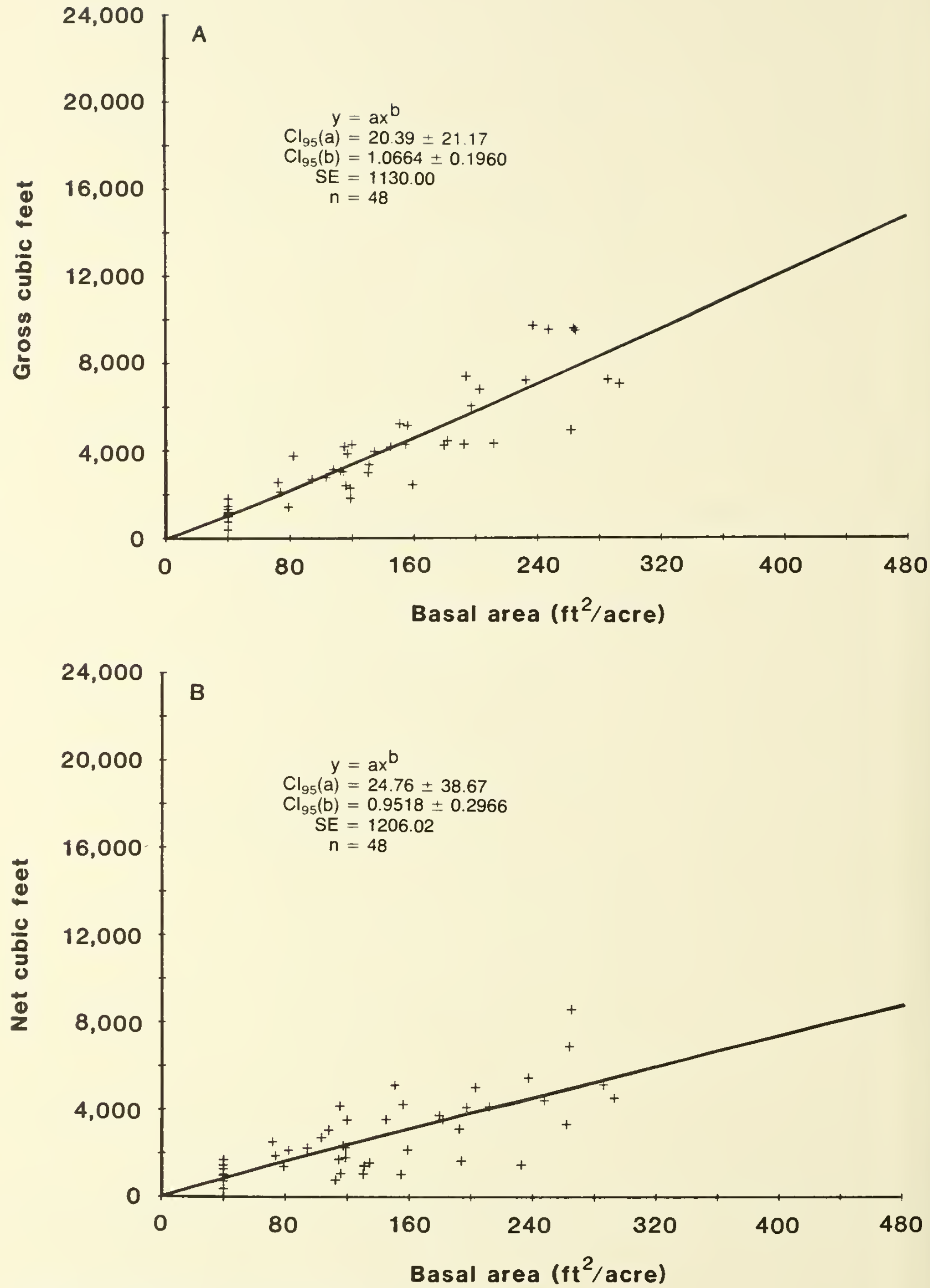

Figure 6.—Regressions of (A) gross cubic foot volume per acre and (B) net cubic foot volume per acre of western red-cedar (species 242) over basal area per acre for the KPC sale.

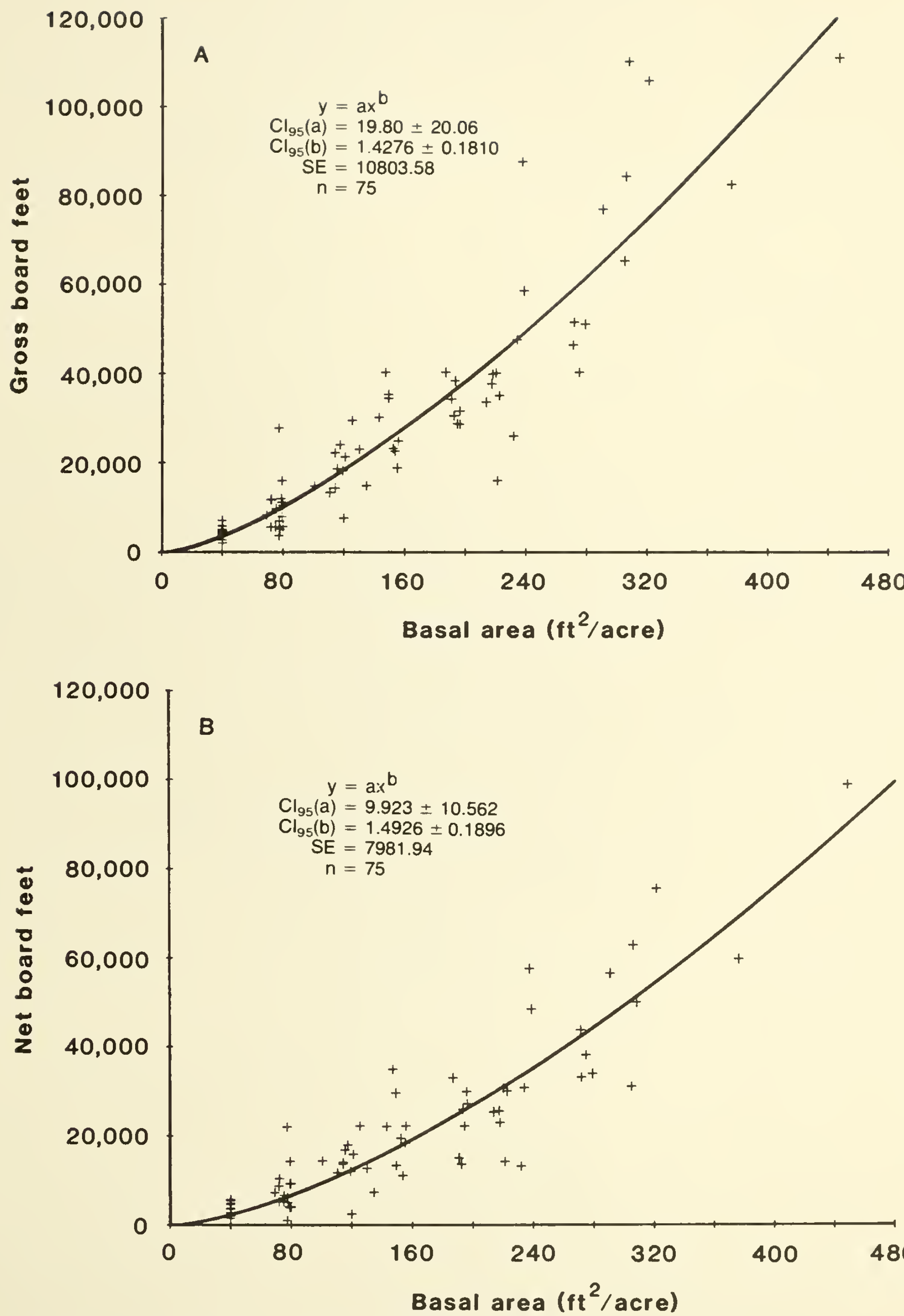

Figure 7.—Regressions of (A) gross board foot volume per acre and (B) net board foot volume per acre of western hemlock (species 263) over basal area per acre for the KPC sale.

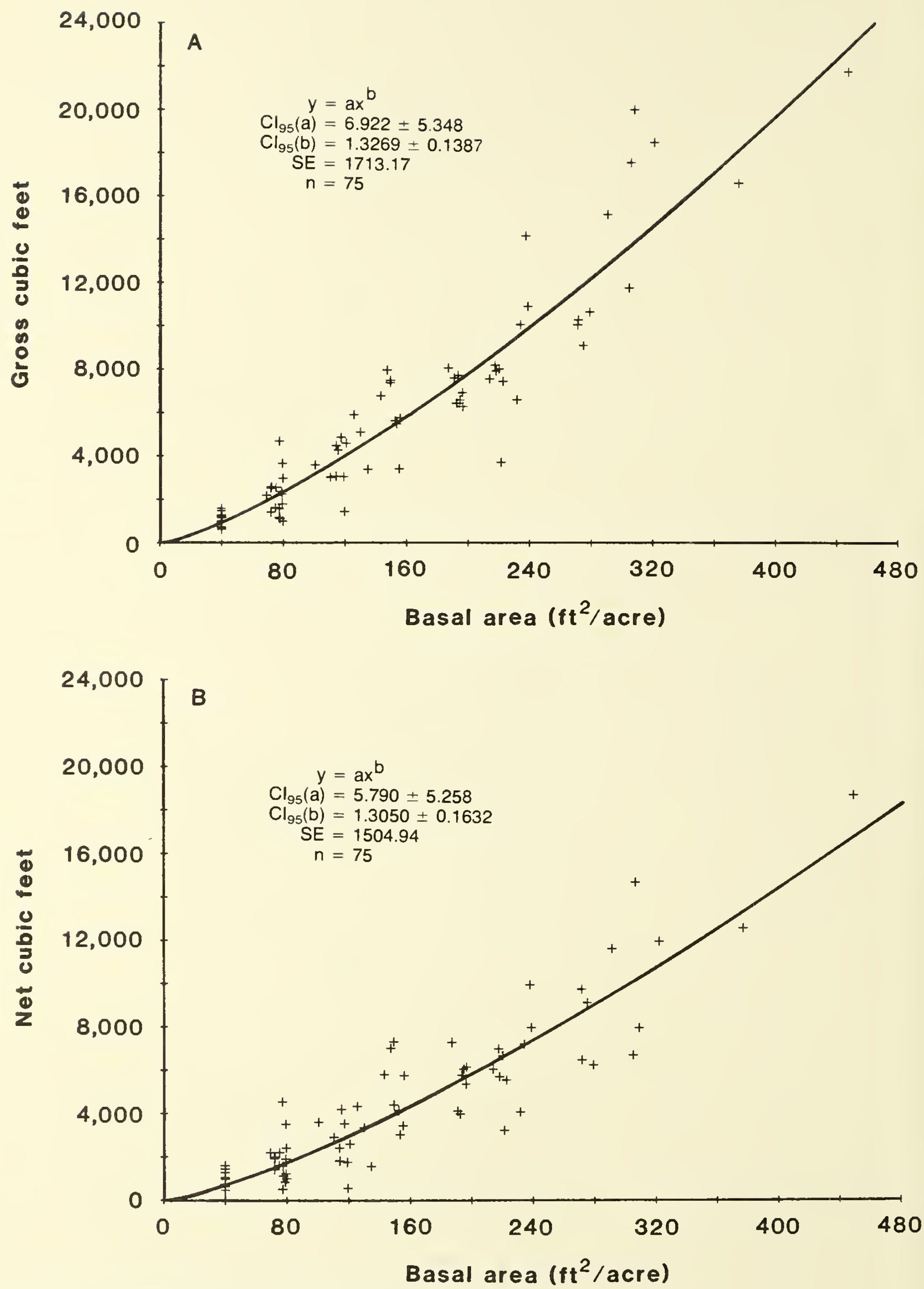

Figure 8.—Regressions of (A) gross cubic foot volume per acre and (B) net cubic foot volume per acre of western hemlock (species 263) over basal area per acre for the KPC sale.

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Pacific Northwest Forest and Range
Experiment Station
319 S.W. Pine St.
P.O. Box 3890
Portland, Oregon 97208

United States Department of Agriculture

Forest Service

Pacific Northwest Forest and Range Experiment Station

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Early Wide Spacing in Red Alder (*Alnus rubra* Bong.): Effects on Stem Form and Stem Growth

Bernard T. Bormann

Abstract

A thinning trial was established in 1962 in a 7-year-old red alder stand in northwestern Washington. Spacings were 8 x 8 ft (dense), 12 x 12 ft (intermediate), and 16 x 16 ft (open). The effect of early thinning on growth and stem form was measured in 1982, 20 years after spacing treatment. There was negligible tree lean and sweep in open and intermediate stands except in areas affected by trees leaning into the plots from outside. Red alder trees generally appear to be displaced horizontally by competing trees toward nearby open areas. Production of straight, nonleaning trees can be achieved by wide and even spacing at an early age. Trees grown in this fashion will yield significantly more high-quality wood per unit volume than can be obtained from trees in unmanaged stands.

Keywords: Thinning effects, plantation spacing (-growth, stem form, precommercial thinning.

Introduction

Initial interest in managing red alder (*Alnus rubra* Bong) in the Pacific Northwest centered around the ability of red alder to fix large amounts of atmospheric nitrogen and improve other soil properties (Tarrant and Miller 1963). These effects have since been observed on a wide variety of sites (Bormann and DeBell 1981, Tarrant and others 1969). Alder-induced changes in soil properties can result in large increases in growth of associated species (DeBell and Radwan 1979, Miller and Murray 1978).

The rapid juvenile growth rate of red alder is well known to foresters who have spent considerable effort attempting to remove it from conifer plantations. Growth rate of red alder in unmanaged stands is high (Smith 1974, Smith 1978, Worthington and others 1960), but stem form is usually poor. Thinning increases growth of individual trees, especially in relatively young stands (Lloyd 1955, Olsen 1967, Smith 1978, Warrack 1964, Williamson 1968). Analysis of a young plantation spacing trial

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BERNARD T. BORMANN is a research plant physiologist, Pacific Northwest Forest and Range Experiment Station, Forestry Sciences Laboratory, P.O. Box 909, Juneau, Alaska 99802.

has shown that stand density is a key factor controlling the partitioning of photosynthate to stem growth (Bormann and Gordon 1984). Precommercial thinning in pure alder stands less than 17 years of age has not previously been evaluated.

The only available projections of growth in managed alder stands (DeBell and others 1978) are based largely on yield tables from unmanaged stands (Worthington and others 1960). Sensitivity analysis has indicated that small changes in projected alder yield will result in large change in profitability of alder grown alone or in crop rotation management systems (Tarrant and others 1983). There is, therefore, a need for better information on alder yield in managed stands.

Tree form must also be considered when evaluating the profitability of alder management. By rough estimate, approximately half of the wood volume in an alder stem is recoverable as lumber relative to wood volume recovery in a Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) stem of equal volume. Leaning trees contain more reaction wood resulting in lower wood quality. If lean and sweep of alder could be reduced through management, the amount of recoverable wood and wood quality would be increased. This would eventually create an increase in stumpage price.

Methods

The study area is in northwest Washington, near Arlington, in a natural stand of red alder that apparently developed in 1955 after a mature conifer stand was removed. An unreplicated thinning trial that consisted of three spacing levels (8 x 8, 12 x 12, and 16 x 16 feet [referred to as dense, intermediate, and open, respectively]) was established in 1962 (at age 7) by Pilchuck Tree Farm, Inc. One-tenth-acre, square quadrats were laid in a line with the dense spacing in the middle. A 16.5-foot strip, thinned to the dense spacing, was left between treatments. No buffer strips were established around the perimeter of these quadrats. The current spacing of the surrounding area appeared similar to the dense spacing treatment. Vegetation in the area consists of pure and mixed stands of Douglas-fir and red alder with occasional western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) and western redcedar (*Thuja plicata* Donn ex D. Don). Common understory species include salmonberry (*Rubus spectabilis* Pursh) and elderberry (*Sambucus racemosa* L.). The soil is a gravelly silt loam developed on glacial till.

For the intermediate and open spacings, we measured diameter at breast height (d.b.h.), total height (linear distance from tree base to tree terminal), and degree and direction of lean on all trees in the quadrats. Lean is defined as the angle between two lines--one an imaginary vertical line originating at the tree base and the other a straight line from the tree base to the terminal bud. Tree volume was calculated using the equation by Curtis and others (1968). Twenty trees in the dense spacing were randomly selected in order to calculate an average height and degree of lean for that plot. A volume-d.b.h. equation was constructed from these trees to predict tree volume on a stand basis. Degree and direction of lean of all border trees adjacent to open and intermediate quadrats were also evaluated. Border trees were judged to be leaning into the plots if their horizontal direction of lean exceeded 10 degrees from the plot border line toward the plot.

Results

Many trees outside the open and intermediate stands leaned directly into the plots and greatly influenced the growth of trees in the plots near the perimeter (table 1). In the open and intermediate quadrats 86 percent and 56 percent of these trees, respectively, leaned into the plots. The ratio of these trees leaning in and out of the plots (12.5 and 5.0) was considerably higher than 1, the value expected if trees leaned in random directions. Thus, for both open and intermediate spacing, only the interior quarter of the 0.1-acre plots was considered to be representative.

Trees in the interior quarter of the open and intermediate quadrats had little or no lean, averaging only 1-2 degrees. Lean was much higher on the outer three-quarters of these plots. This is attributable to the effects of trees outside the plots leaning in. The highest average lean, nearly 4 degrees, was observed in the dense spacing. Examination of tree location and degree and direction of lean makes it clear that trees lean toward previously open areas if displaced by competing trees (fig. 1). This is further demonstrated by a row of alders planted in an open field (fig. 2). Here all adjacent trees lean in opposite directions. In general, curvature or sweep appears to be positively related to the degree of lean.

Wide spacing effectively redistributed growth to fewer trees. Cubic volume to a 4-inch top (CV4) per tree increased from 9.1 cubic feet in dense stands to 15.6 cubic feet and 25.4 cubic feet in intermediate and open quadrats, respectively. Site index (Worthington et al. 1960) based on the tallest 40 per acre (minimum of 4 trees) was 114 to 119.

Table 1--Effect of spacing on growth and tree lean

Variable	Dense spacing with side buffers only	Intermediate spacing: Entire plot no buffer	Intermediate spacing: Interior quarter	Open spacing: Entire plot no buffer	Open spacing: Interior quarter
Average d.b.h.	7.0	9.1	8.9	9.9	11.2
Average height	76.7	81.5	83.2	82.3	84.5
Average height of four tallest trees 1/	84.0	87.8	85.8	87.4	84.5
Site index of four tallest trees 2/	114	119	117	119	115
Number of trees per acre	500	200	280	150	160
Percent mortality 3/	27	34	8	12	6
Average CV4 per tree 4/	9.07	16.53	15.55	19.44	25.38
CV4 per acre	5/ 4531	3306	4355	2916	4060
Percent leaning in 6/	-	58	-	86	-
Number leaning in per number leaning out 6/ 7/	-	5.0	-	12.5	-
Average lean	3.8°	3.4°	2.0°	2.9°	1.0°

- = no data

1/Equals tallest 40 trees per acre on 0.1-acre plots.
2/From Worthington and others (1960).
3/Current density relative to spacing density.
4/Using equations of Curtis and others (1968).
5/Volume in this plot based on d.b.h.-CV4 equations: CV4 = 3.06(d.b.h.) - 12.3; R^2 = 0.970.
6/Trees outside the plot that are leaning into the plot.
7/Disregards trees leaning nearly parallel (+/-10°) to plot line.

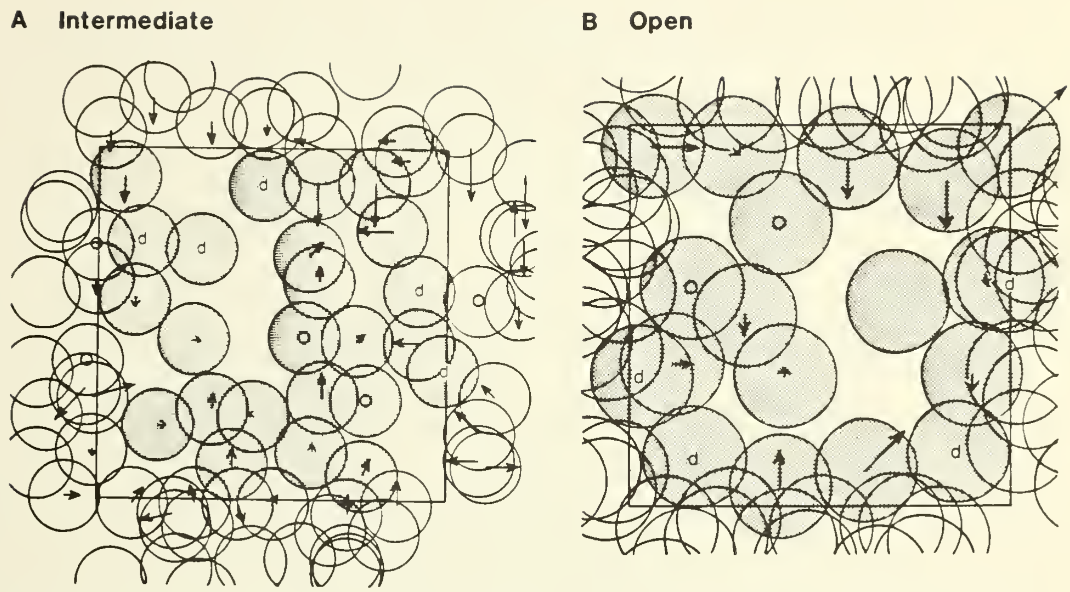

Figure 1.--Stem maps and degree and direction of lean for intermediate (A) and open (B) stands. The area of circles represents the area theoretically available for each tree based on treatment spacing (spacing distance squared). Arrows indicate direction of lean. The length of each arrow is proportional to the maximum degree of lean. A "d" next to trees within plot boundaries indicates a standing dead tree. An open circle at the tree center indicates there was no measurable lean.

Figure 2.--In a row of alder planted in an open field, adjacent trees tend to lean, in opposite directions, toward open areas.

Estimates of CV4 per acre at age 27 ranged from 2,916 to 4,531 cubic feet. A standing CV4 of 4,718 cubic feet per acre can be extrapolated from projections made by DeBell and others (1978) for a 28-year-old alder stand growing on site 115 with initial plantation spacing of 8 X 16 feet and thinned to 16 X 16 at age 9. This projected value is 16 percent higher than the volume observed in the open quadrat (4,060 cubic feet). This discrepancy may be explained in a number of ways. First, the projection includes an additional year's growth and assumes no mortality other than by harvest. If the CV4 of an average tree in the open quadrat is multiplied by the spacing density (170 tree per acre), the CV4 is calculated to be only 9 percent less than the projected value. Second, juvenile growth in a plantation might be expected to be higher than in a thinned natural stand because trees are planted and because they would probably experience less intraspecific competition before age 7. Thus, it appears these data are supportive of the projections by DeBell and others (1978).

Conclusions

This unreplicated case study offers evidence that thinning red alder at an early age is effective in reallocating stem growth to fewer stems. On this site it appears that after thinning to a 16 x 16 feet spacing at age 7, trees with an average d.b.h. of 12 inches can be produced in 28-29 years.

Trees in open stands did not lean and appeared to have little sweep. Lumber recovery from these trees should be much higher than that from trees in unthinned plots. Wood quality may also be improved because less reaction wood is formed. At least two-thirds of the length of stems in the open quadrat were free of branches. Branches in the live crown were not excessively large and a minimal amount of epicormic branching was noted. Measurements and observations suggest that stumpage price for trees in managed stands should be appreciably higher than that for unmanaged natural stands.

Lean in red alder is attributed largely to horizontal displacement of crowns toward openings. Trees with the least competition did not lean, even if openings were present nearby. Wide and even spacing should substantially reduce lean in red alder.

Acknowledgment

Alan Staringer gave permission to conduct this study on spacing trials of the Pilchuck Tree Farm, Inc. D.S. DeBell, R.F. Tarrant, and D.L. Reukema provided many helpful comments during preparation and review of this paper.

Metric Equivalents

1 inch = 2.5 centimeters
1 foot = 30.5 centimeters
1 cubic foot = 0.0283 cubic meter
1 acre = 0.4047 hectare

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Site Index, Height Growth, Normal Yields, and Stocking Levels for Larch in Oregon and Washington

P.H. Cochran

Abstract

Even-aged stands of larch in Oregon and Washington have cubic volume yields similar to yields from larch in Idaho and Montana. Site index values derived from the heights of the single tallest tree on 1/5-acre plots at an age at breast height of 50 years range from 50 to 110 feet. These values have the same index to productivity as the site index values of 30 to 90 feet based on average height of dominant and codominant trees at a total age of 50 years. Maintaining basal area levels between 45 and 75 percent of normal once trees reach commercial size is recommended.

Keywords: Site index, increment (height), yield (forest), stocking level, larch.

Introduction

Western larch (Larix occidentalis Nutt.) is an important commercial species in the mixed conifer forests east of the Cascade Range in portions of Oregon and Washington. Larch occurs along the east slopes of the Cascades in Washington and north-central Oregon, in the Ochoco Mountains in Oregon, in the Wallowa and Blue Mountains of northeastern Oregon and southeastern Washington, and in the Okanogan Highlands in northeastern Washington. Larch is an aggressive pioneer species, existing in nearly pure, seral stands and also as a component with Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco), grand fir (Abies grandis (Dougl. ex D. Don) Lindl.), Engelmann spruce (Picea engelmannii Parry ex Engelm.), lodgepole pine (Pinus contorta Dougl. ex Loud.), and ponderosa pine (Pinus ponderosa Dougl. ex Laws.).

P.H. COCHRAN is a soil scientist at the Silviculture Laboratory, Pacific Northwest Forest and Range Experiment Station, 1027 N.W. Trenton Avenue, Bend, Oregon 97701.

The most serious pest of larch in the Northwest in recent years has been the larch casebearer (*Coleophora laricella* (Hubner)), an introduced insect. Some native and introduced parasites now appear to be bringing the casebearer under control.

Larch is easily established and has rapid early growth. With control of the casebearer likely within the next decade, larch may be even more important in future managed forests in Oregon and Washington.

Most of the research on western larch has been conducted in Montana and Idaho. A summary of much of this research is available in Technical Bulletin 1520 (Schmidt and others 1976).

This research note presents site index and height growth curves for even-aged larch stands constructed from data collected in natural stands in Oregon and Washington. Equations are given for converting these site index values to those of Bulletin 1520. Equations describing normal basal area and volume for stands presented in Bulletin 1520 appear applicable for use in Oregon and Washington. Tests of this applicability are presented. Finally, stocking level curves for use in management of even-aged larch stands are given.

Site Index and Height Growth Curves

Site index curves are used to indicate the potential productivity of forest land. The site index curves presented give the estimated height of the tallest tree when the age at breast height of that tree is 50 years. The height growth curves define the average pattern of height development for the tallest trees in stands of a given site quality. Height growth curves are appropriately used for construction of yield tables but do not provide optimum estimates of site index from measured height and age in an existing stand (Curtis and others 1974).

Construction Method

The method used is outlined by Cochran (1979b) and is similar to that used by Barrett (1978) and Dahms (1975). The basis of the method was suggested by Curtis and others (1974), and an outline is presented in the appendix.

The age of 50 years at breast height (bh equals 4.5 feet) was chosen as the index age. The site index here is defined as the height of the single tallest tree on a 1/5-acre plot at a bh age of 50 years. Stem analysis data from 18 plots in Oregon and 5 plots in Washington were used to construct the curves.

Some of these plots were sampled in an earlier study (Cochran 1979a, 1979b, 1979c), and they contained Douglas-fir or grand fir. These 1/5-acre plots did have at least one dominant larch which was as tall as or taller than the tallest Douglas-fir or grand fir. Stem analysis showed that these larch had maintained this dominance during the life of the stand. Most of the plots used for constructing curves had at least three dominant larch, and some 1/5-acre plots sampled were pure or nearly pure larch. The characteristics of the plots sampled for construction of site index and height growth curves are given by Cochran (1979b). Briefly, these plots were even aged and had not been disturbed during their history. At the time of sampling, the crown canopy was closed or nearly closed but the closure had only recently occurred. Suppressed trees were absent or nearly so, and competition between trees sufficient to reduce height growth on the dominants was not apparent. The dominant trees did not contain a group of narrow annual rings or show any evidence of top damage. Some plots were rejected after sampling because abrupt breaks in height growth determined from stem analysis showed evidence of past damage even though this damage was not visible at the time of sampling.

Up to five of the tallest larch trees on each plot were felled and sectioned at a 1-foot stump, at 4.5 feet (bh), at 10 feet, and then at 10-foot intervals up the stem. Rings were counted at each section and were recorded for the appropriate height. Height was plotted as a function of age at breast height for each sectioned tree on a single sheet of graph paper for each plot. All trees for the same plot were graphed together to determine if the same tree had always been the tallest for its age. Shifts in the tree of maximum height with age occur with Douglas-fir and white or grand fir (Cochran 1979b, 1979c) and also with lodgepole pine (Dahms 1963), but they occurred with larch on only one plot. Freehand curves of height over age at breast height were drawn for each tree. The highest points at each decadal age interval for each plot were used in construction of the site index and height growth curves. The site index for each plot was defined as the tallest height at bh age 50 read from the graph of heights versus age at breast height for that plot. Procedures from this point are given in the appendix. An understanding of curve construction leads to an appreciation of their proper use, so the appendix is recommended reading even for the occasional user.

Results

The distribution of plots by site index was:

Number of plots	Site index (feet)
1	48-59
5	60-69
5	70-79
7	80-89
4	90-99
1	100-110

The average site index was 78.1 feet. Because few stands were sampled beyond a bh age of 100 years, the curves were limited to bh ages of 100 years or less (fig. 1).

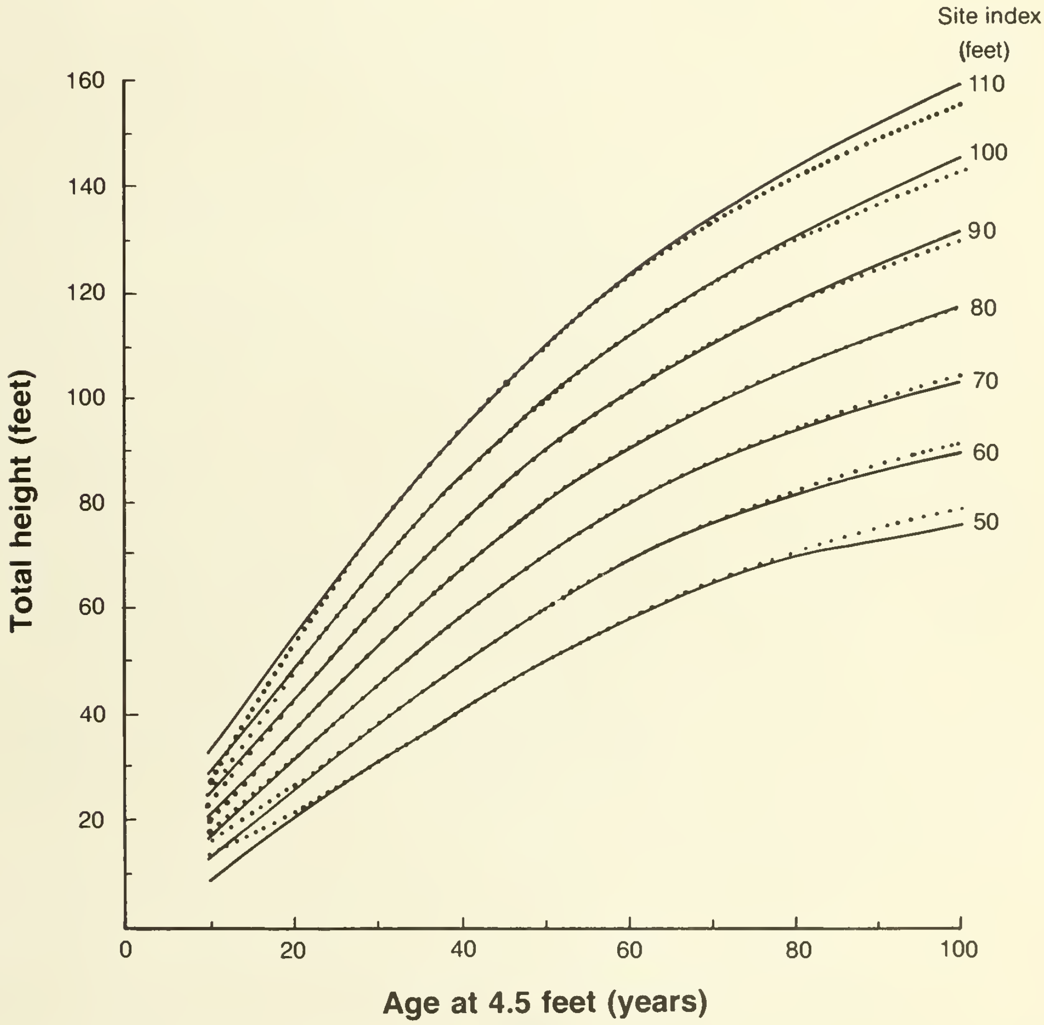

Figure 1.--Site index (solid lines) and height growth (dotted lines) curves for western larch.

Estimating Site Index

The following procedure is advised for determining the site index of a stand:

A. Select suitable plots with the following characteristics:

(1) Even aged at the groundline (practically, there are no remnants from earlier stands and the present stand is one storied).
(2) No visible signs of past growth suppression or top damage.

B. Establish boundaries of a 1/5-acre plot with a prespecified shape.

C. Measure the height of the three tallest trees on the plot.

D. Extract increment cores from these trees to determine their age at breast height.

E. Use the breast high age and total height for each tree to determine a site index value for each tree.

(1) Use figure 1 (the site index curves, not the height growth curves) for rough field estimates.
(2) Obtain a more precise estimate by using the appropriate a and b values in table 1 to solve the equation,

$$\text{Site index} = 4.5 \text{ feet} + a + b\,(\text{height} - 4.5 \text{ feet}). \quad (1)$$

(3) The appropriate equation in the appendix can be used with a calculator.

Table 1--Values for a and b by years between decades for the family of regressions[1] for estimating site index for western larch

Age at breast height	0		1 year		2 years		3 years		4 years		5 years		6 years		7 years		8 years		9 years	
	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
Years																				
10	35.486	2.475	32.952	2.393	30.605	2.314	28.436	2.238	26.432	2.166	24.583	2.097	22.88	2.031	21.311	1.968	19.867	1.907	18.539	1.85
20	17.317	1.795	16.193	1.743	15.158	1.693	14.204	1.646	13.323	1.601	12.508	1.558	11.752	1.517	11.049	1.479	10.392	1.442	9.776	1.408
30	9.194	1.375	8.644	1.344	8.119	1.314	7.616	1.287	7.131	1.261	6.660	1.236	6.201	1.213	5.751	1.191	5.307	1.170	4.868	1.151
40	4.431	1.132	3.996	1.115	3.560	1.099	3.124	1.083	2.687	1.069	2.248	1.056	1.043	1.807	1.365	1.031	.920	1.020	.475	1.010
50	0	1.00	-.417	.990	-.862	.981	-1.305	.973	-1.745	.965	-2.181	.958	-2.612	.951	-3.036	.949	-3.452	.938	-3.859	.931
60	-4.256	.925	-4.641	.920	-5.013	.914	-5.371	.909	-5.713	.904	-6.039	.898	-6.347	.893	-6.637	.888	-6.907	.883	-7.156	.878
70	-7.384	.874	-7.590	.869	-7.775	.864	-7.936	.859	-8.074	.854	-8.109	.849	-8.282	.844	-8.352	.839	-8.399	.834	-8.425	.829
80	-8.429	.823	-8.413	.818	-8.377	.813	-8.323	.807	-8.253	.802	-8.167	.797	-8.067	.791	-7.956	.786	-7.836	.780	-7.708	.775
90	-7.576	.770	-7.441	.764	-7.308	.759	-7.179	.754	-7.057	.749	-6.946	.744	-6.849	.740	-6.772	.735	-6.717	.731	-6.690	.727
100	-6.695	.723																		

[1] To estimate site index select the appropriate a and b values for the breast high age of the sample tree. Substitute these values in the equation, Site index - 4.5 feet = a + b (total height - 4.5 feet). For example, for a sample tree 48 years old at breast height and 60 feet in total height, solve the equation S - 4.5 = 0.920 + 1.020 (60 - 4.5), for a site index of 62.0 feet.

F. Record as the site index value for the plot, the highest of the three values determined.

For plots in even-aged stands with Douglas-fir and grand fir as well as larch, the tallest three to five trees should be sampled regardless of species. The site index for Douglas-fir and grand fir should be determined as described by Cochran (1979b, 1979c). The site index of the plot is the highest site index determined regardless of species. Even though shapes of the curves for the three species are different, there is probably no practical difference in the heights at bh age 50 for the three species on the same site.

Differences in heights of the three species on the same plot at age 50 may be a reflection of slightly uneven ages resulting in slight suppression in height growth of the younger trees or top damage to some species but not to others.

For sites capable of supporting closed crown canopies in Oregon and Washington, site index values for larch as defined here do not range much below 50 feet. When a proper estimating procedure yields a lower site index, past top damage or high stand density has probably reduced height growth. Highest site indexes do not exceed 110 feet for any substantial amount of area.

Relationship to Other Curves for Larch

For the site index curves in Bulletin 1520 (Schmidt and others 1976), an age of 50 years at groundline rather than at breast height is used. Also, the height in the site index system of Bulletin 1520 is not the height of the tallest tree on a 1/5-acre plot but the average height of the dominant and codominant trees. Age at breast height is easier to determine than age at groundline. Height of the single tallest tree on a 1/5-acre plot is easier to determine than the average height of the dominants and codominants partly because of problems in defining a codominant. Further, the number of dominant and codominant trees changes with time. Therefore, site index curves constructed from stem analysis would not do a good job of predicting a site index based on a different number of dominants and codominants at ages younger than the maximum age shown by the curves.

Equations that use age as a variable in Bulletin 1520 use groundline or total age (A1). For 10 plots of even-aged larch in Oregon and Washington with site index values (S) ranging from 54 to 100 feet, the age at groundline was determined by digging around the stumps, cutting the stump at groundline, and counting the rings for at least five dominant and five codominant trees. Age at bh (A) was also determined by ring count. The average number of years necessary to reach 4.5 feet for dominant and codominant trees is:

$$A1 - A = 13.8 - 0.066\ (S), \qquad (2)$$

R^2 is 0.31 and the standard error is 1.7 years.

Bulletin 1520 gives site index values of 30 to 80 feet whereas Region 1 (Northern Region) Forest Service Handbook (FSH 2409.21g R1, November 1970, Management of Western Larch--Northern Region) presents site index values ranging from 30 to 90 feet. If we assume that the site index values for Region 1 (S1) of 30 to 90 feet are equivalent to the same ranges of heights as the site index values (S) of 50 to 110 feet as determined for the Oregon-Washington data, then,

$$S = S1 + 20. \qquad (3)$$

So that this assumption could be tested, some summaries of the original data used to construct the curves presented in Bulletin 1520 were obtained.[1/] These summaries had age at groundline, the site index S1, and numbers of trees with their average height by 1-inch diameter classes for each plot. Eighty-six plots were picked where the height of the tallest larch tree could be obtained. For these plots total age ranged from 15 to 114 years, and S1 ranged from 24 to 84 feet. Next, S was calculated from equation (3) and then an age at 4.5 feet was determined from equation (2) for each plot. With this age as the age of the tallest tree, the site index from the appropriate equation in the appendix was calculated. This site index, $\hat{S}$, was then related to the site index, S1, given for the plot. The result is:

$$\hat{S} = 1.058\ (S1) + 17.93. \qquad (4)$$

R^2 is 0.81 and the standard error is 7.5 feet.

[1/] Data furnished by Ward W. McCaughey, Forester, Forestry Sciences Laboratory, Intermountain Forest and Range Experiment Station, Bozeman, Montana 59717, March 3, 1983.

The sum of squares of the difference between S--determined from equation (3)--and $\hat{S}$ (SS_3) was calculated for the 86 plots. This sum of squares was used with the sum of squares determined in obtaining equation (4), SS_4, to test the joint hypothesis that the slope and intercept are 1 foot and 20 feet, respectively:

$$F = ((SS_3 - SS_4)/2)/(SS_4/84).$$

F with 2 and 84 degrees of freedom was 0.2, and equation (3) was considered valid.

Normal Basal Areas and Volume Yields

Methods

To test the validity of equations in Bulletin 1520 (Schmidt and others 1976) for describing normal basal area and volume yields, I assembled 154 observations of the necessary stand data from prism points or plots (at least 1/5-acre in size) taken in stands across the range of larch in Oregon and Washington. Of these 154 samples, 116 were in 32 even-aged larch stands (2 to 16 observations per stand), and the remaining samples were taken in small, scattered pockets of even-aged larch less than 2 acres in size. On all the points or plots at least 60 percent of the basal area was in larch. The site index of each sample was determined by measuring the height and age at breast height of at least the three tallest trees, by calculating the site index for each of these trees from the appropriate equation given in the appendix, and by assigning the highest value obtained as the site index for the sample. Age at breast height was also determined for at least three codominant trees, and the average breast height age of these dominant and codominant trees was used as the breast height age for each sample.

For the plots, the diameter (D) of each tree was measured and at least 15 trees were measured with an optical dendrometer. Total wood volumes inside bark (V) of the trees measured with dendrometers were determined by processing the measurements with the STX program (Grosenbaugh 1964). An equation relating the natural logarithm of volume to the natural logarithm of diameter of the form $\ln V = a + b \ln D + c (\ln D)^2$ was determined for each plot and was used to determine the volume of the remaining trees.

For the prism points, the diameter and height were measured for each counted tree. Equations relating volume (V) to dbh (D), and height (H) were developed from trees sectioned in a previous study (Cochran 1979a):

Species	Equation	Number of trees	R^2	Standard error
Larch	$\ln V = -6.9499 + 1.6782 \ln D + 1.3287 \ln H$	133	0.994	0.096
Douglas-fir	$\ln V = -5.8785 + 1.8357 \ln D + 1.0279 \ln H$	210	.997	.098
White/grand fir	$\ln V = -6.1860 + 1.7533 \ln D + 1.1684 \ln H$	202	.998	.096
Engelmann spruce	$\ln V = -5.77345 + 1.8507 \ln D + 1.0182 \ln H$	50	.998	.083
Western white pine	$\ln V = -6.1498 + 1.7048 \ln D + 1.1769 \ln H$	22	.995	.087
Ponderosa pine	$\ln V = -6.0336 + 1.8715 \ln D + 1.0166 \ln H$	137	.996	.109
Lodgepole pine	$\ln V = -5.4821 + 1.9249 \ln D + 0.9139 \ln H$	67	.989	.120

In these equations ln indicates natural logarithms, and V is the cubic-foot volume inside bark including stump and tip calculated by Smalian's formula. The 1-foot stump was assumed to be a cylinder with a diameter equivalent to the diameter at 1 foot inside bark. The number of trees per acre, basal area per acre, volume per acre, and the diameter of the tree of average basal area (Dg) were determined for each sample.

After total age (A1) is converted to age at bh (A), and the site index of Bulletin 1520 (S1) to the site index presented here (S), the equations for estimating normal basal area in square feet per acre and total cubic-foot volume in Bulletin 1520 are:

$$\ln BA = 5.2459 - 25.5667/(A - 0.066S + 13.8) + 0.008543\ (S - 20); \quad (5)$$

and

$$\ln V = -7.03317 - 72.1299/(A - 0.066S + 13.8) + 3.07121 \ln (S - 20) + 2.38666 \ln (100\ N) - 0.36349\ (\ln 100\ N)\ (\ln (S - 20)); \quad (6)$$

where:

$$N = \frac{\text{actual basal area}}{\text{normal basal area from equation (5)}}. \quad (7)$$

The above equations were used to calculate the basal area and volume for each of the 154 samples. Calculated basal areas were compared with actual basal areas. Calculated volumes were also compared with the volume determined for each plot with the local volume equations or the volume calculated for each point from the equation with ln D and ln H as independent variables. These volumes determined from local volume equations or from measurements of D and H are referred to here as actual volumes. Site index for these 154 samples ranges from 49.6 to 111 feet. Ages at breast height range from 14 to 146 years and fractions of normal--N, equation (7)--range from 0.38 to 1.81.

Results and Discussion

Use of equation (5) resulted in an average overestimate of basal area of 25.1 percent for the 154 samples. The average absolute difference between actual and estimated basal areas was 33.8 percent. Percent differences were calculated as actual value minus estimated value times 100 divided by the actual value. There was no significant relationship of site index or age with differences between actual and estimated basal areas. A stepwise regression relating percent differences between actual and estimated basal areas to site index and age had an R^2 value of 0.014 and an F value of 1.07 with 2 and 151 degrees of freedom. F equals the regression mean square divided by the residual mean square in the analysis of variance. The average fraction of normal for these 154 samples (equation 7) was 0.87.

"Actual" volumes for the 154 samples averaged 4,741 ft^3/acre, and the average of estimated values (equation 6) was 4,500 ft^3/acre. The estimated values averaged 4.3 percent lower than actual values. The average absolute difference between actual and estimated values was 11.2 percent. These differences were related to site index. Stepwise regression shows that the equation relating percent difference between actual and estimated volumes to site index had an R^2 of 0.087 and an F value of 14.5 with 1 and 152 degrees of freedom. Examination of that data revealed that the percentage of species other than larch increased with increasing site index values for the points.

When volumes were calculated by the volume equation for larch for each tree regardless of species, the volume for the 154 samples averaged 4,504 ft^3/acre, 0.5 percent greater than volumes estimated by equation 6. The average absolute difference was 9.9 percent. There was no meaningful correlation of these percent differences with site index, age, or fraction of normal. A stepwise regression relating these percent differences between actual and estimated volumes to S, A, and fraction of normal produced an equation with an R^2 value of 0.03 and an F value of 1.6 with 3 and 150 degrees of freedom.

The results for estimating basal area indicate that a majority of the samples taken in Oregon and Washington had densities lower than normal by Bulletin 1520 standards. The lack of correlation of the differences between actual and estimated values with site index and age, however, indicates that the equation for normal basal area given in Bulletin 1520 or its modification (equation 5) is acceptable for use in Oregon and Washington. The equation for estimating volume (equation 6) takes density into account, and the average underestimate of volumes with this equation was due to the stem volume equations used in estimating volumes for the points. These equations for the other species produced higher stem volumes for the same diameter at breast height and height than did the larch equation. The small differences between values calculated by the larch stem volume equation and equation (6) indicate that equation (6) is suitable for estimating total cubic volume yield for larch in Oregon and Washington.

Stocking Level Curves

Methods and Assumptions

The Forest Service in Region 1 (FSH 2409.21, R1, November 1970, Amendment No. 2) recommends commercial thinning from below, leaving 45 percent of normal basal area. They further recommend allowing the stand develop to 75 percent of normal basal area before the next entry. Within these limits, it is assumed that suppression and mortality related to suppression will be avoided without sacrificing too much of the potential of the site to produce usable wood. This assumption needs verfication through studies of growing stock levels.

Stepwise regressions relating trees per acre (T/A) to diameter of the tree of average basal area (Dg), site index (S), and age at breast height (A) were run so that a relationship between tree size, trees per acre, and basal area per acre for normal stands could be obtained. For the 154 observations the actual number of trees per acre was divided by the fraction of normal (equation 7) to produce the number of trees per acre used. Stepwise regression techniques were also used to determine age at breast height as a function of site index, quadratic mean diameter, and stocking level (N).

Tentative Results

Both age and site index as well as quadratic mean diameter are significantly related to the number of trees per acre:

$$\ln (T/A) = 10.001 - 1.7301 \ln Dg. \quad (8)$$

$$\ln (T/A) = 9.1273 - 1.74643 \ln Dg + 0.20978 \ln S. \quad (9)$$

$$\ln (T/A) = 6.73066 - 1.98897 \ln Dg + 0.5556 \ln S + 0.34049 \ln A. \quad (10)$$

The residual mean square and R^2 values for equations 8, 9, and 10 are:

Equation	Residual mean square	R^2
8	0.00887	0.983
9	.00702	.986
10	.00101	.998

A is related to Dg and S by:

$$\ln A = 7.0389 - 1.01552 \ln S + 0.71232 \ln Dg. \quad (11)$$

R^2 is 0.69, and the residual mean square is 0.05188.

Adding the natural log of the stocking level reduced the residual mean square only slightly to 0.05166, so the addition of ln N as an independent variable was not accepted.

From equations (10) and (11), tentative stocking level curves (fig. 2) were created. These curves display the influence of site index as well as quadratic mean diameter on basal area and trees per acre for managed stands of larch of commercial size.

Summary

Lack of meaningful correlation between differences in measured and predicted values of basal area and larch volume per acre to site index and age at breast height indicate several things: (1) The equations of Bulletin 1520 (Schmidt and others 1976) for estimating normal basal area and cubic volume yield are applicable for larch in Oregon and Washington; (2) for bh ages up to 100 years the site index values as determined in this paper can be converted to the site index values presented in Bulletin 1520 and vice versa; (3) the equation relating total or groundline age to age at breast height is reasonable; and (4) several other tables, equations, and graphs concerning larch volumes and yields in Bulletin 1520 are applicable to Oregon and Washington. When necessary, conversions from total age to age at breast height and from the site index values of Bulletin 1520 to the site index values presented here can be easily accomplished.

Metric Equivalents

1 acre = 0.405 hectare
1 foot = 0.304 8 meter
1 square foot/acre = 0.229 568 square meter/hectare
1 tree/acre = 2.47 trees/hectare
1 cubic foot/acre = 0.069 972 cubic meter/hectare

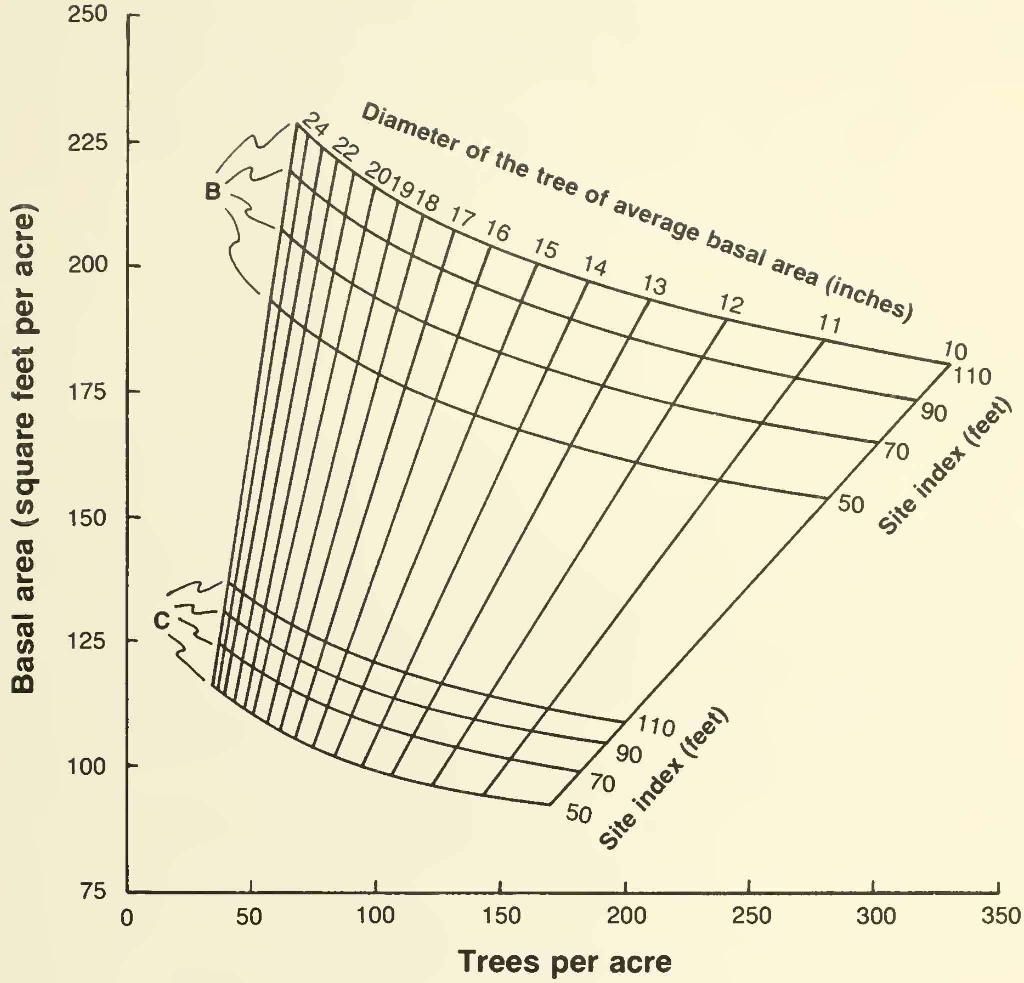

Figure 2.--Stocking level curves for larch. The "B" lines represent 75 percent of normal stocking, and the "C" lines represent 45 percent of normal stocking. Stands should be managed so that they are at the "B" level for a commercial entry. Commercial thinnings should be from below and should reduce stocking to the "C" level.

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Appendix

Both site index and height growth curves are constructed from an average height curve determined from data from all the plots and then adjusted to the desired site index by use of the linear relationship existing between height and site index at any age. Height growth and site index curves are different because the equations

$$S - 4.5 \text{ feet} = a + b\,(H - 4.5 \text{ feet}) \text{ and}$$

$$H - 4.5 \text{ feet} = a_1 + b_1\,(S - 4.5 \text{ feet})$$

have different slope and intercept values for all ages except the index age.

Site Index Curve Construction

1. The tallest heights (H) at each decade were read from the freehand curves and related to the site index S for each plot by the equation $S - 4.5$ feet $= a + b\,(H - 4.5$ feet). The following estimates were obtained:

Age at breast height (Years)	a	b	R^2	Standard error of the estimate	Number of observations
10	34.9375	2.4723	0.66	7.54	23
20	17.1072	1.8104	.81	5.66	23
30	11.0280	1.3345	.93	3.35	23
40	2.7235	1.1636	.98	1.6	23
50	0	1.0	1.0	0	23
60	-2.8567	.9091	.98	1.78	23
70	-8.0847	.8777	.96	2.58	23
80	-8.9310	.8184	.95	2.91	18
90	-12.0663	.7821	.94	3.08	11
100	-9.9663	.7215	.92	3.77	9

The nine sample plots at bh age 100 have site indexes of 48.6, 62, 70, 78, 78, 82, 83, 86.8, and 87.4 feet.

2. The above decadal estimates of b were smoothed over age at breast height (A) (fig. 3) by the equation (forced through the b value of 1 at a breast high age of 50 years),

$$\hat{b} = 3.51412 - 0.125483A + 0.0023559A^2 - 0.00002028A^3 + 0.00000064782A^4.$$

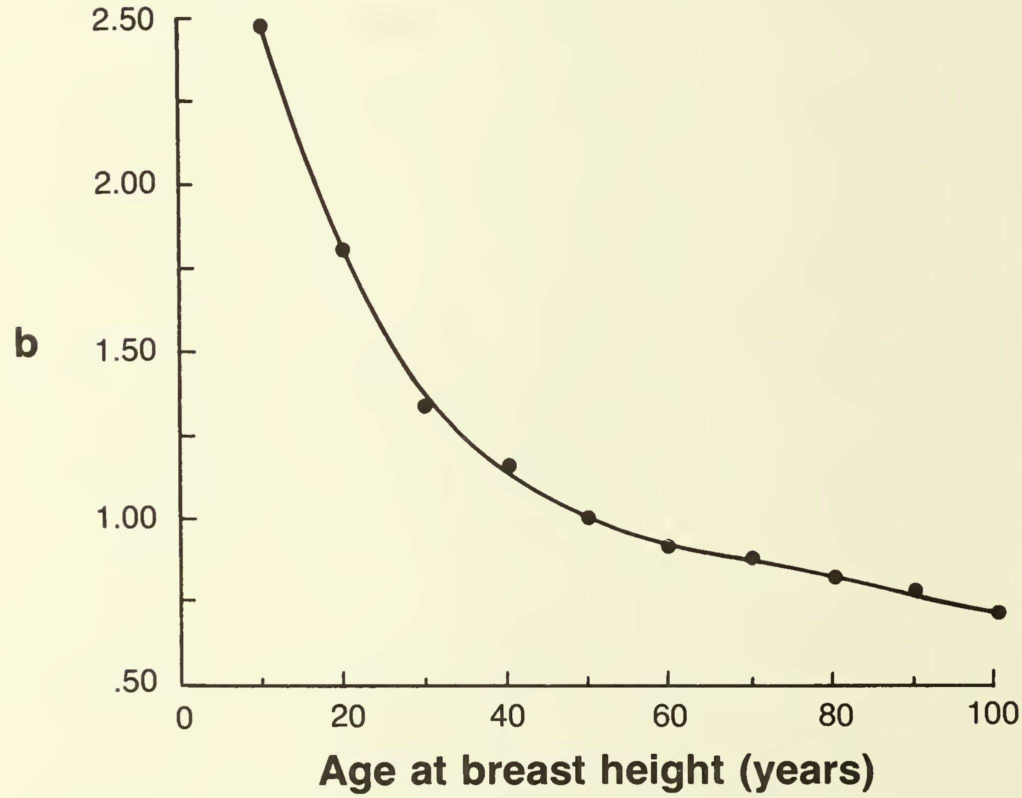

Figure 3.--b values as a function of age in the equation, S - 4.5 feet = a + b (H - 4.5 feet). Points are actual b values. Solid line is the curve expressed by the equation,

$$\hat{b} = 3.51412 - 0.125483A + 0.0023559A^2 - 0.00002028A^3 + 0.000000064782A^4.$$

The standard error and R^2 values for this equation are 0.0183 foot and 0.9989. The resulting $\hat{b}$ values are those appearing in table 1.

3. The following equation (with a standard error of 0.11 foot and an R^2 of 0.999), expressing decadal mean heights ($\bar{H}$) as a function of age, was forced through the mean site index (78.07 feet) at 50 years and a height of 4.5 feet at 0 years (fig. 4):

$$\hat{H} - 4.5 \text{ feet} = 1.46897A + 0.0092466A^2 - 0.00023957A^3 + 0.0000011122A^4.$$

Here $\hat{H}$ is an estimate of $\bar{H}$. At ages beyond 70 years, the sample became progressively smaller an the mean site was slightly different. Average heights were adjusted to the mean overall site index using a_1 and b_1 values of the individual regression of $H - 4.5$ feet $= a_1 + b_1 (S - 4.5)$ with S equaling 78.07 for ages 80, 90, and 100 years before fitting the average height curve.

4. H and the smoothed slope b of regressions for each year were then used to calculate the corresponding intercept a:

$$\hat{a} = \bar{S} - 4.5 - \hat{b}\,(\hat{H} - 4.5).$$

These "a" values appear in table 1.

5. Substituting expressions for a, b, and H in the linear equation of step 1 gives the final equation used to estimate site index as a function of breast high age and height (fig. 1).

$$S = 78.07 + (H - 4.5)\,(3.51412 - 0.125483A + 0.0023559A^2 - 0.00002028A^3 + 0.000000064782A^4) - (3.51412 - 0.125483A + 0.0023559A^2 - 0.00002028A^3 + 0.000000064782A^4)\,(1.46897A + 0.0092466A^2 - 0.00023957A^3 + 0.0000011122A^4).$$

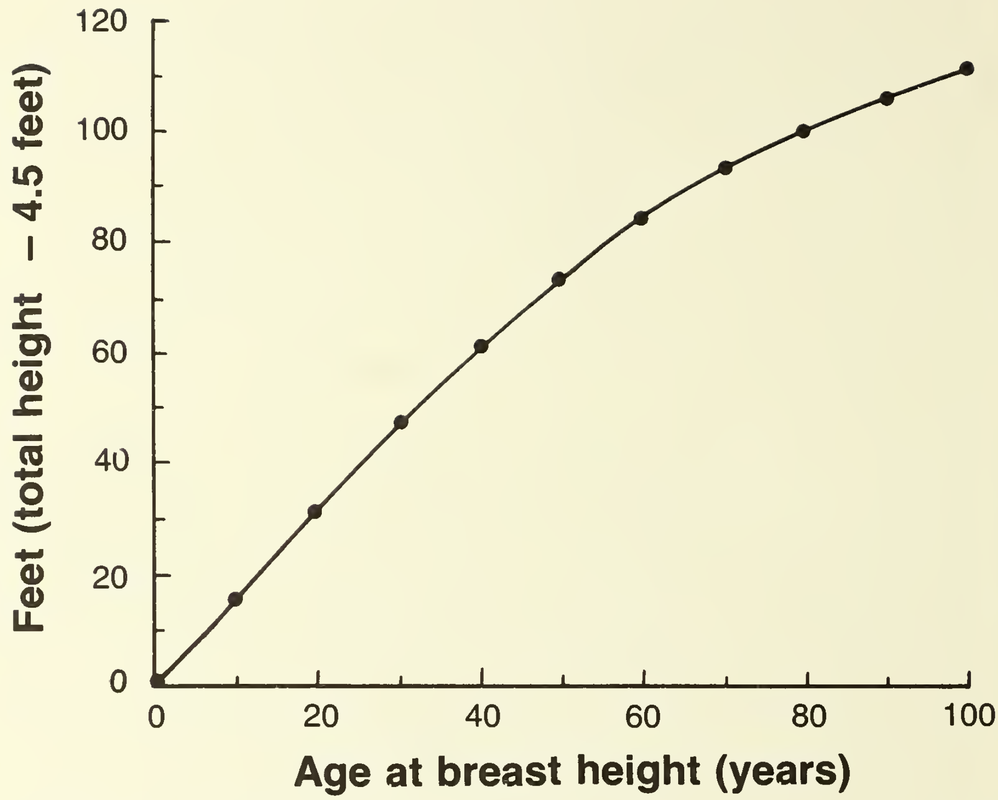

Figure 4.--Average of the tallest heights for each decade minus 4.5 feet for the plots used in construction of the site index and height growth curves. Points are actual values minus 4.5 feet. The solid line is expressed by the equation,

$$\bar{H} - 4.5 \text{ feet} = 1.46897A + 0.0092466A^2 - 0.00023957A^3 + 0.0000011122A^4.$$

Height in this equation is considered to be the average height of the tallest trees for the sampled plots as a function of age at breast height.

Height Growth Curve Construction

1. The site indexes for each plot were related to the tallest heights at each decade by the equation:

$$H - 4.5 = a_1 + b_1 (S - 4.5);$$

and the following estimates were obtained:

Age at breast height	a_1	b_1	R^2	Standard error of the estimate	Number of observations
(Years)					
10	-4.1042	0.2682	0.66	2.48	23
20	-1.7242	.4473	.81	2.81	23
30	-4.5870	.6994	.93	2.43	23
40	1.3808	.8464	.98	1.36	23
50	0	1.0	1.0	0	23
60	4.6559	1.0794	.98	1.94	23
70	12.5292	1.0942	.96	2.89	23
80	15.6530	1.1563	.95	3.46	18
90	20.8149	1.2022	.94	3.82	11
100	21.2321	1.281	.92	5.03	9

2. The above decadal estimates of b_1 were smoothed over age (fig. 5) by the equation:

$$\hat{b}_1 = -0.12528 + 0.039636A - 0.0004278A^2 + 0.0000017039A^3.$$

The standard error and R^2 values are 0.017 foot and 0.9909.

3. Appropriate rearrangement and substitution for a_1, b_1, and H in the linear equation of step 1 gives the final equation used to estimate height as a function of age and site index:

$$H = 4.5 + 1.46897A + 0.0092466A^2 - 0.00023957A^3 + 0.0000011122A^4 + (S - 4.5)(-0.12528 + 0.039636A - 0.0004278A^2 + 0.0000017039A^3) - (73.57)(-0.12528 + 0.039636A - 0.0004278A^2 + 0.0000017039A^3).$$

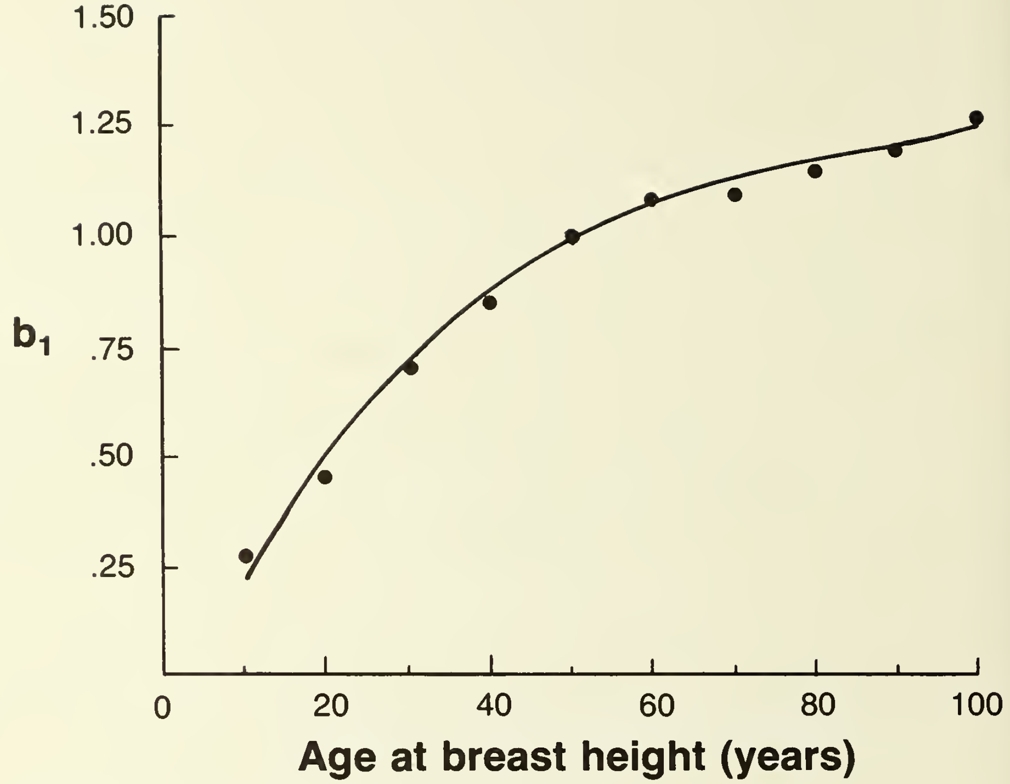

Figure 5.--b_1 values in the equation $H - 4.5$ feet $= a_1 + b_1$ $(S - 4.5$ feet$)$ as a function of age. Points are actual b_1 values. The solid line is expressed by the equation,

$$\hat{b}_1 = -0.12528 + 0.039636A - 0.0004278A^2 + 0.0000017039A^3.$$

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Pacific Northwest
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Experiment Station

Research Note
PNW-425
June 1985

Tree Basal Area as an Index of Thermal Cover for Elk

J. Edward Dealy

Abstract

The relationship of basal area to crown closure was studied in five major forest types of the Blue Mountains of Oregon and Washington. The regressions developed give wildlife and forest managers a tool for estimating the amount of crown closure if data are not available from stand examinations. Information is used in determining quantity and quality of elk thermal cover.

Keywords: Basal area, crown closure, thermal cover, wildlife habitat, Cervidae.

Introduction

Thermal cover for elk is a habitat feature, such as a stand of conifer trees, that provides protection against changes in an animal's body temperature above and below critical tolerances (thermoregulation). Generally, as crown closure increases, the effectiveness of a stand to provide thermal cover improves. Optimum thermal cover is determined by the animal as well as by the habitat. Changes in season, temperature, wind, and radiation create different thermoregulation demands on the animal. Crown closures that provide optimum thermal cover under one set of weather conditions may not be optimum under others. Variability among and within conifer stands often provides a wide range of crown closure and thermal cover characteristics that correspond to animals' changing needs.

For summer ranges in the Blue Mountains region of Oregon and Washington, the optimum level of elk thermal cover for management purposes is defined as a stand of coniferous trees at least 12 m (40 ft) tall and exceeding an average of 70 percent crown closure (Thomas and others 1979). Use varies with the animals' needs and the amount of cover; for example, during summer high temperature periods, elk need clumps of trees that provide dense shade (often 90 to 100 percent crown closure and multitiered crowns) for maximum cooling (Leckenby and Adams 1981), whereas on a winter range the best available thermal cover may be less than optimum for protection.

A better understanding of optimum thermal cover under a variety of weather, site, and seasonal conditions will help managers to appropriately manipulate forest stands to provide this component of elk habitat.

J. EDWARD DEALY is principal research ecologist at the Pacific Northwest Forest and Range Experiment Station, Forestry Sciences Laboratory, P.O. Box 909, Juneau, Alaska 99802.

The objective of this study was to determine if crown closure of conifers in unmanaged natural stands in the Blue Mountains of Oregon and Washington could be predicted from tree basal area measurements. If so, stand basal area, which is usually available, could be used to estimate crown closure and in turn to help managers manipulate stands to achieve optimum thermal cover.

Methods

Plots were located in six geographical areas of the Blue Mountains region of Oregon and Washington: (1) the north portion of the Umatilla National Forest (Walla Walla District); (2) the north portion of the Wallowa-Whitman National Forest (Wallowa Valley District and Hells Canyon National Recreation Area); (3) the southeastern portion of the Umatilla National Forest (Ukiah and Dale Districts plus part of the Baker District of the Wallowa-Whitman National Forest); (4) the southwest portion of the Umatilla National Forest (Heppner District); (5) the Malheur National Forest (Prairie City and John Day Districts); and (6) the Ochoco National Forest (Paulina District).

Plots were established by Oregon State Department of Fish and Wildlife research scientists at specific locations used by elk during all seasons (Leckenby and Adams 1981); 609 plots were stratified into five Society of American Foresters cover types (Eyre 1980) and were identified by symbols (Hall 1976) (referred to as "formation-associations"):

Cover type (SAF)	No.	Symbol (Hall 1976)
Interior Ponderosa Pine	237	CP
Interior Douglas-Fir	210	CD
Grand Fir	213	CW
Lodgepole Pine	218	CL
Engelmann Spruce-Subalpine Fir	206	CE

All plots sampled were in unmanaged stands (there was no evidence of tree removal). A single sample of basal area, using a basal area factor of 10 (Dilworth and Bell 1967) was taken at each plot with a prism. Four readings of crown closure were taken at cardinal directions and 15 feet from the plot center with a type A densiometer (Lemmon 1956) and were averaged.

For each cover type, crown closure and basal area (BA) were related by use of regression analysis. An empirical fit of the data was made by using the models of Y as a function of $\mathrm{Log}_{10}(X + 1)$, and Y as a function of various powers of x (x^1, x^2, and x^3).

From this analysis the equation model percent crown cover = $a + b[\mathrm{LOG}_{10}(BA+1)]$ was found to be the best fit.

Results and Discussion

For 70 percent crown closure in CP, CD, CW, SL, and CE formation-associations, the corresponding basal area values are 190, 80, 64, 145, and 70 square feet per acre, respectively (figs. 1-5). The percentage of variation in crown closure associated with basal area (r^2) ranged from 0.21 for CE to 0.49 for CW (table 1). These regressions are best used in cases where crown closure data are not available. It should be noted that, whatever the basal area, when 70 percent crown closure is approached on most curves (figs. 2-4), reliability is relatively high (confidence limits are narrow). F tests for all the regressions presented for formation-associations were significant ($p < 0.01$).

These regressions apply only to unthinned stands. Use of these regressions to judge the level of thermal cover that will remain after a stand is thinned is not appropriate. Crown characteristics of remnant trees after cutting in a dense stand are different from crown characteristics of an open stand that developed naturally to the same level of closure. Use of the crown closure-basal area relationships described here would overestimate crown closure—sometimes dramatically.

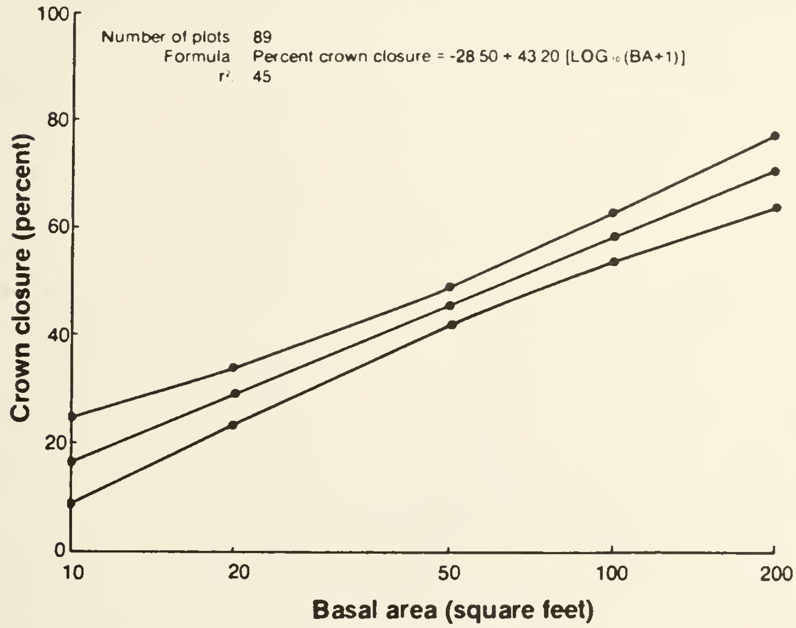

Figure 1.—Regression curve showing crown closure as a function of basal area for the Ponderosa Pine (CP) formation-association.

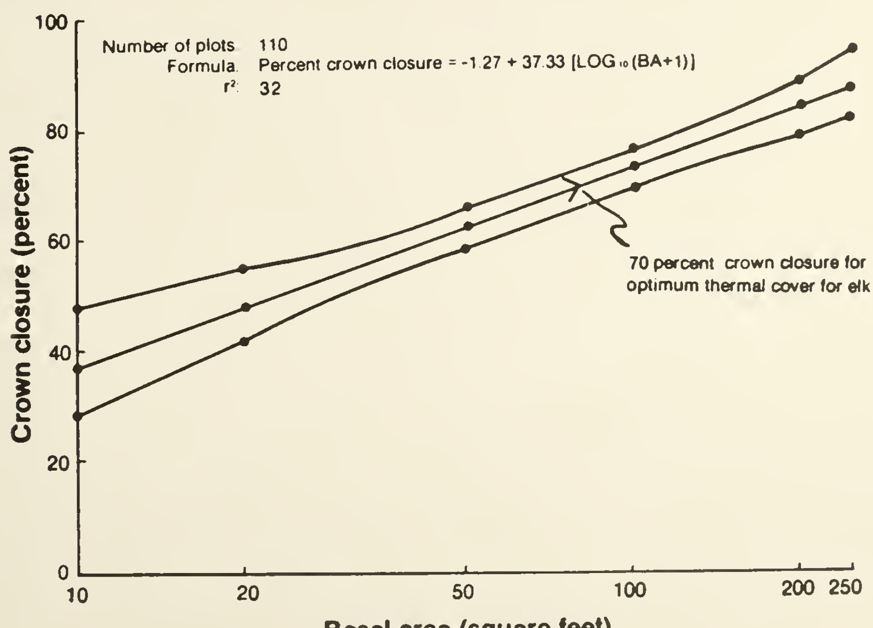

Figure 2.—Regression curve showing crown closure as a function of basal area for the Douglas-Fir (CD) formation-association.

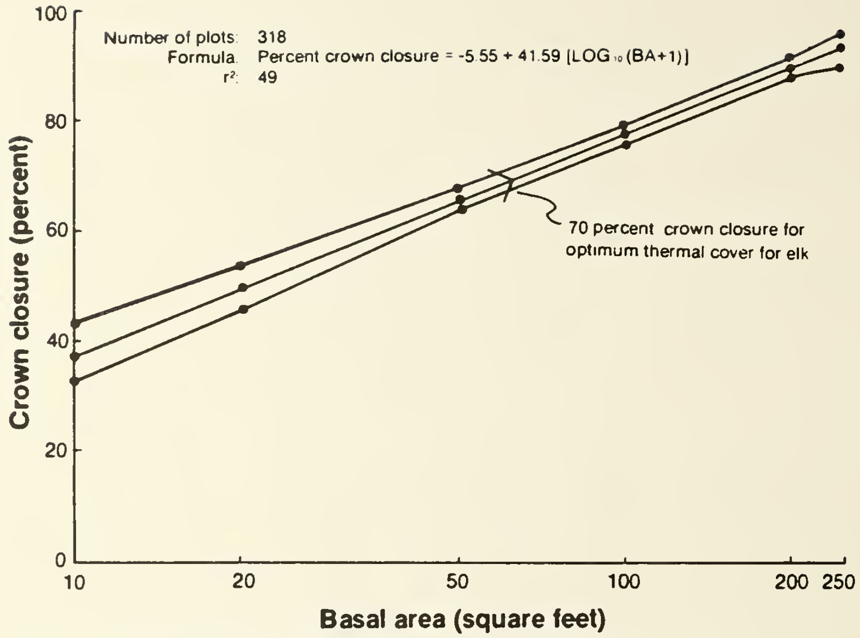

Figure 3.—Regression curve showing crown closure as a function of basal area for the White Fir (CW) formation-association.

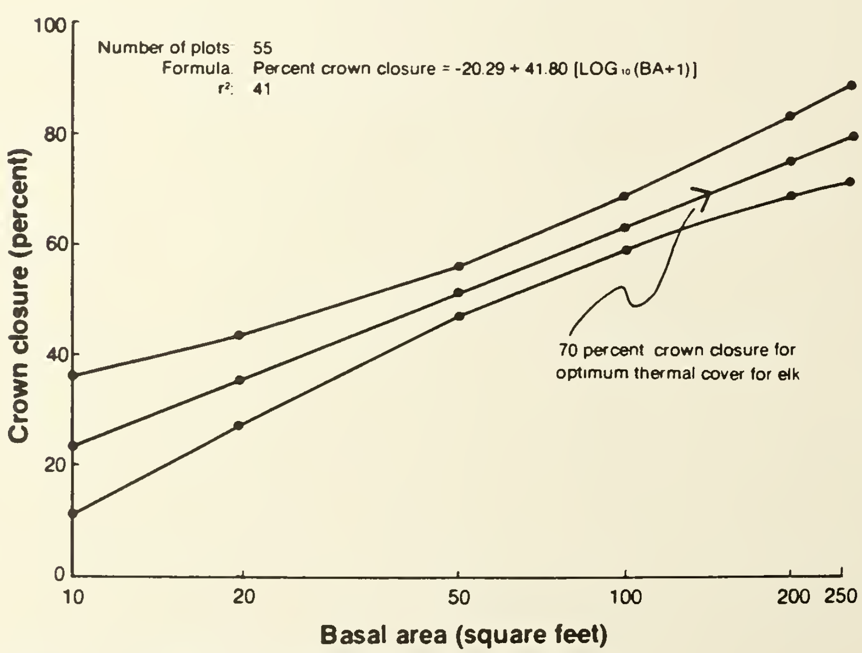

Figure 4.—Regression curve showing crown closure as a function of basal area for the Lodgepole Pine (CL) formation-association.

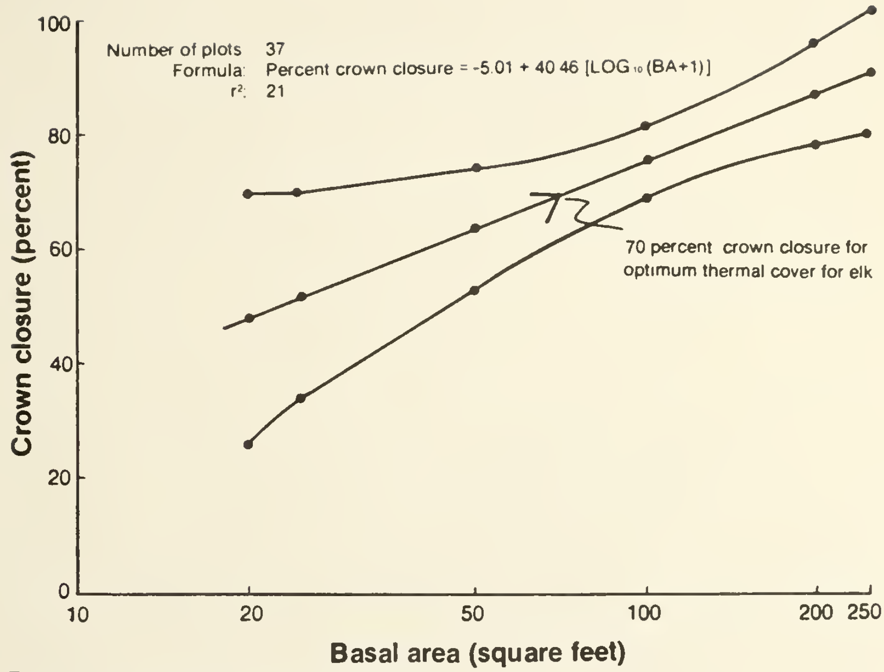

Figure 5.—Regression curve showing crown closure as a function of basal area for the Engelmann Spruce-Subalpine Fir (CE) formation-association.

Table 1—Values by formation-association for regression coefficients a and b in the formula percent crown cover = a + b[LOG_{10}(BA+1)], plus information for evaluating reliability of the crown closure-basal area correlations[1]

Formation-association	Number of plots	Sampled basal area: Maximum	Sampled basal area: Minimum	Significance of: a	Significance of: b	Significance of: F	Significance of: r^2
CP	89	220	10	−28.50	43.20	0.01	0.45
CD	110	280	10	− 1.27	37.33	.01	.32
CW	318	320	10	− 5.55	41.59	.01	.49
CL	55	270	10	−20.29	41.80	.01	.41
CE	37	270	20	− 5.01	40.46	.01	.21

[1] Symbols are from Hall (1976), cover types from Eyre (1980): "C" designates a stand of conifers; P, Ponderosa Pine; D, Douglas-Fir; W, White (or Grand) fir; L, Lodgepole Pine; and E, Engelmann Spruce-Subalpine Fir; r^2, coefficient of determination.

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Pacific Northwest Forest and Range
Experiment Station
319 S.W. Pine St.
P.O. Box 3890
Portland, Oregon 97208

United States Department of Agriculture

Forest Service

Pacific Northwest Forest and Range Experiment Station

Research Note PNW-426

May 1985

How to Identify Brooms in Douglas-fir Caused by Dwarf Mistletoe

Robert O. Tinnin and Donald M. Knutson

Abstract

Dwarf mistletoe causes obvious brooms in Douglas-fir. The brooms are the easiest means of recognizing the presence of dwarf mistletoe; however, dwarf mistletoe is not the only cause of brooming in Douglas-fir. Therefore, accurate identification of dwarf mistletoe brooms is important. If no evidence of aerial shoots can be found in the brooms, and if the brooms occur infrequently, are all relatively small, or are found only in trees where a stand has been opened, then dwarf mistletoe is probably not the cause of brooming. Dwarf mistletoe brooms generally have aerial shoots present and are found in stands where brooms of various sizes are common.

Three different types of dwarf mistletoe brooms can be identified in Douglas-fir. Each may affect host trees in different ways, but all are detrimental.

Keywords: Broom damage, dwarf mistletoe, *Arceuthobium douglasii*, disease symptoms, Douglas-fir, *Pseudotsuga menziesii*.

Introduction

There are several causes of brooming in Douglas-fir; however, only Douglas-fir dwarf mistletoe (*Arceuthobium douglasii* Engelm.) causes brooming that reduces growth significantly and increases mortality (Hawksworth and Wiens 1972). The brooming caused by the dwarf mistletoe is both obvious and distinctive and is the key to timely detection of the parasite. The purpose of this paper is to describe and illustrate proper identification of the brooms of Douglas-fir dwarf mistletoe and to discuss some of the other types of brooms found in Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco).

ROBERT O. TINNIN is Professor of Biology and Assistant Dean of Liberal Arts and Sciences, Portland State University, Portland, Oregon 97207. DONALD M. KNUTSON was Research Plant Pathologist, Forestry Sciences Laboratory, Pacific Northwest Forest and Range Experiment Station, Corvallis, Oregon. He is currently a private consultant of plant pathology and Adjunct Professor of Forestry at the University of Minnesota, St. Paul, Minnesota 55455.

Types of Dwarf Mistletoe Brooms

The brooms caused by Douglas-fir dwarf mistletoe begin as small sprays of twigs radiating from a swollen limb (fig. 1) but in time they become large, more or less spherical in shape, and often with long, droopy twigs. Well-developed brooms cause considerable change in the appearance of host trees (fig. 2). The primary structure of brooms is composed of host tissue. Although the parasite is present throughout each broom, the only visible portions of dwarf mistletoe are the reproductive shoots which are called "aerial shoots." Their height is about equal to the length of the needles of the Douglas-fir (fig. 3) and they are distributed along the twigs among the needles.

Figure 1.--Early infection caused by Douglas-fir dwarf mistletoe. Note the swelling and abundance of adventitious twigs.

Figure 2.--Douglas-fir tree heavily infected by dwarf mistletoe.

Figure 3.--Mature aerial shoots of Douglas-fir dwarf mistletoe. The scars left on the twig by aerial shoots that have died and fallen off the twig are noted at the arrow.

The most likely place to find aerial shoots in older brooms is on the 4- to 6-year-old tissue of the infected twigs. In young brooms, the aerial shoots occur on the swollen limb at the site of the original infection. Aerial shoots of dwarf mistletoe in a broom clearly indicate that dwarf mistletoe caused formation of the broom.

If aerial shoots are not present in a broom, look at some of the other brooms on neighboring trees. Sometimes aerial shoots are scarce on individual brooms but rarely will there be a total absence of aerial shoots. In their absence look for the basal cups (fig. 3, at arrow), which remain long after the aerial shoots fall off the twig. If no evidence of aerial shoots is found after searching for a few minutes in each of several brooms, do not yet assume that mistletoe can be excluded as the cause. Examine the stand. Several broomed trees found together in a stand, with at least some of the trees supporting brooms larger than 6 feet (2 m) in diameter, strongly indicate the presence of dwarf mistletoe. In our experience trees located more than 0.25 mile (0.4 km) from major infection sites are rarely infected by dwarf mistletoe. If no aerial shoots are present in a broom, one may assume that dwarf mistletoe is not the cause of brooming if one or more of the following is true: all brooms are relatively small, brooms occur only on trees left after a stand has been opened, or the brooms are relatively isolated in the stand.

Three distinctly different types of dwarf mistletoe brooms are found on Douglas-fir, and each gives an infected tree a different appearance. The differences are probably due primarily to the original site of establishment of the parasite. Infections that originate near the tip of a limb that has grown to several feet in length stimulate what we call a Type I broom that, because of its weight, causes the branch to droop (fig. 4). Type I brooms are usually of limited size because the weight of the broom causes the whole limb to break off the tree.

Type II brooms (fig. 5) result from an infection originating closer to the main trunk, usually within a few feet. These brooms become quite large. Often the primary supporting limb grows to an erect position, parallel to the trunk. These brooms support a profusion of smaller branches, all infected

Figure 4.--Example of Type I broom.

Figure 5.--Example of limb development at the point of attachment to the bole for a Type II broom.

with mistletoe. Many of the lateral twigs growing on these branches become droopy, reaching 20 feet (6 m) in length and showing very little diameter growth.

Type III brooms (figs. 6 and 7) arise from an infection near, or possibly on, the bole. They are characterized by several branches that radiate from a common location on the bole. Type III brooms cannot be accurately distinguished from Type II brooms at a distance. Both of these broom types may attain large size, have long, droopy twigs and look like the broom in figure 2.

Figure 6.--Example of the base of a Type III broom. Note the abundance of limbs radiating from a common point on the bole (also see fig. 7).

Figure 7.--Type III broom at the point of attachment of the broom to the bole.

Brooms Caused By Other Agents

Brooms caused by other agents can be distinguished from those caused by dwarf mistletoe. The types discussed are provided by way of example; the list is not comprehensive.

1. "Bunch brooms" (Buckland and Kuijt 1957, Goheen and others 1951).

Bunch brooms are dense brooms found occasionally in old-growth Douglas-fir (fig. 8), as well as in other tree species. The brooms are compact, the foliage is dense, and the needles typically are shorter than normal. There seem to be more twigs than usual, none of which elongate properly. The cause of bunch brooms is unknown although both pathogens and genetic mutation have been suggested by Buckland and Kuijt (1957).

Figure 8.--Example of a bunch broom.

Figure 9.--Examples of stimulation brooms.

2. "Stimulation brooms" (Hawksworth 1961)

Stimulation brooms are the brooming of branches along the bole (fig. 9) and often occur after a stand is opened, such as following thinning or road building. The added light and increased growth rate caused by removal of adjacent trees stimulate dormant buds to grow near existing branches.

3. Other types of brooms

The type of broom shown in figure 10 is rare in Douglas-fir. Its cause is unknown. Although these brooms look very much like those caused by dwarf mistletoe, their isolated occurrence and the absence of aerial shoots easily distinguishes them from dwarf mistletoe brooms.

Although other types of brooms are occasionally observed, there are no other types that could be confused with dwarf mistletoe brooms if the distinguishing characteristics of the latter, which we have described, are kept in mind.

Figure 10.--Example of a broom that resembles those caused by dwarf mistletoe.

Significance For Management

The three different types of brooms caused by Douglas-fir dwarf mistletoe have somewhat different effects on the growth of host trees. Type II brooms are significant because, after attaining some size, they are accompanied by a substantial reduction in bole diameter above the point of attachment. Of course, many brooms in a tree, regardless of type, will cause substantial growth loss in the host.

Limb pruning is considered a cost-effective form of management, but Type I brooms are the only ones that, when removed, totally eliminate dwarf mistletoe from the tree including the bole. Nevertheless the removal of any dwarf mistletoe broom, regardless of broom type, will benefit the host tree.

Acknowledgments

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Comparison of a Degree-Day Computer and a Recording Thermograph in a Forest Environment

Boyd E. Wickman

Abstract

A field test showed that degree-days accumulated by a miniature computer and a recording thermograph in early spring and summer were comparable. For phenological studies the biophenometer was as accurate and more efficient than the hygrothermograph.

Keywords: Degree days, phenology, temperature (-plants, field equipment, insect control.

Introduction

There has been increasing use of accumulated "degree-days" for predicting insect development and for timing other biological events. The phenology of most insects and plants is highly dependent on the thermal accumulation commonly described as "degree-days." Degree-days have usually been determined by averaging the daily maximum and minimum temperatures obtained from recording thermographs and by assuming the sine curve as an approximation of the diurnal temperature curve. The program accumulates a degree-day for every degree above a predetermined development threshold (Arnold 1960). The calculation of a degree-day by this method gives only an approximation of the true degree-days to which organisms are exposed. Fluctuating temperatures caused by the maritime influence or passing weather fronts can modify the actual degree-days accrued during any 24-h period. A method to correct for unusual fluctuations involving both lower and upper thresholds has been reported by Baskerville and Emin (1969) and further modified by Allen (1976).

BOYD E. WICKMAN is supervisory research entomologist, Pacific Northwest Forest and Range Experiment Station, Forestry and Range Sciences Laboratory, Route 2, Box 2315, La Grande, Oregon 97850.

The interest in calculating degree-days for predictive models of insect development for management purposes (Harcourt 1981) and the development of miniature computers have resulted in the production of "growing degree-day" computers, or biophenometers, for field use. These compact, battery-powered instruments are now marketed by several companies. They have the advantage of measuring temperatures every 10 min and of instantly computing and updating all data; they thus provide a continuous record of heat-unit accumulation. Five channels of operation can be programmed for different maximum cutoff and minimum base temperatures. There are no charts to change, maximum-minimum readings to decipher on charts, or degree-day calculations to make. This paper reports a field of comparison of the TA51 Biophenometer, made by Omnidata International,[1/] and battery-powered, 31-d recording hygrothermographs for determining degree-day accumulations in a forest environment.

Materials and Methods

A battery-powered, 31-d recording hygrothermograph and a TA51 biophenometer were placed side by side in a standard weather shelter in an open area on two plots being used to study the phenology of Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough). The plots are located near Fort Klamath in southern Oregon and have been used continuously for monitoring degree-days and insect and host tree phenology during late spring and summer months since 1976 (Wickman 1977).[2/] They are located in mixed conifer stands on the east slope of the Cascade Range at elevations of 4500 ft (1372 m) on Plot C and 4200 ft (1280 m) on Plot H. More precise descriptions of the stands and plot configurations are given in Wickman (1977). Instruments were placed in the field on March 17, 1981, and checked approximately every 2-3 weeks in the spring and about once a month during the summer and early autumn.

Based on previous studies (Wickman 1976, 1977), a threshold temperature of 42 °F (5.6 °C) was used for calculating degree-days on the hygrothermograph charts. The daily mean temperature was obtained by summing the maximum and minimum and dividing by two. A base temperature of 42 °F and an upper cutoff temperature of 110 °F (43.3 °C) was programmed into the TA51.[3/] The starting date for accumulating heat units was April 1. Heat units were accumulated by subtracting 42 °F from the mean daily temperature and counting each degree above 42 °F as 1 degree-day.

[1/] Use of a trade name does not imply endorsement or approval of any product by the USDA Forest Service to the exclusion of others that may be suitable.

[2/] Unpublished data on file, B.E. Wickman, Forestry and Range Sciences Laboratory, La Grande, Oregon.

[3/] The instruments used for this test were programmed for calculating °F. The biophenometer is also available for calculating °C.

Results

A threshold for degree-day accumulation was not recorded on the hygrothermograph located at the higher elevation (Plot C) until April 14; on the lower elevation (Plot H), the first thresholds were recorded March 27 and 28 but were not used in the calculations because April 1 was the arbitrary starting date for measurements on both plots. By April 15, Plot C recorded 7 degree-days from hygrothermograph calculations and 16 degree-days on the TA51. Plot H on the same date had accumulated 17 degree-days on the hygrothermograph and 30 on the TA51. In most years, mid-April has been the starting date for accumulating heat units on the study plots at Fort Klamath. The TA51 started accumulating heat units sooner than the thermographs on both plots. It was evidently sensitive to brief periods of warm temperatures during spring days; these periods were masked by averaging maximum and minimum temperatures on the hygrothermographs. The data showed, however, that differences between the two sets of instruments were less than early spring variation found in 5 yr of previous measurements (Wickman 1981).

Degree-day accumulation in late spring can be used to predict development of Douglas-fir tussock moth and host tree bud burst (Wickman 1976). A comparison of the TA51 with hygrothermograph records during this period was the primary purpose for this test. Degree-day accumulations as measured by the hygrothermographs for April, May, and June for both plots were comparable to past measurements on both plots; but the TA51 had accumulated an additional 60 degree-days on both plots by June 23 (fig. 1). The differences, however, were not critical for predicting plant or insect development.

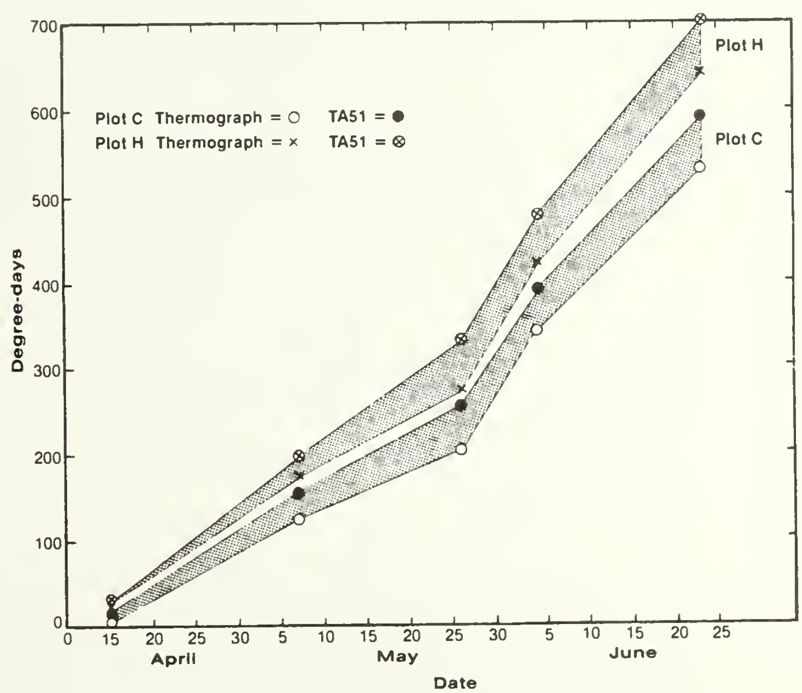

Figure 1.—Accumulated degree-days from the thermograph and TA51, by calendar date.

When accumulated degree-days (April-June) calculated from the thermographs were plotted against TA51 computations for each plot, the linear relation was excellent; but accumulations were slightly greater with the TA51; and most of this divergence of heat unit accumulation occurred before May 25 (fig. 2).

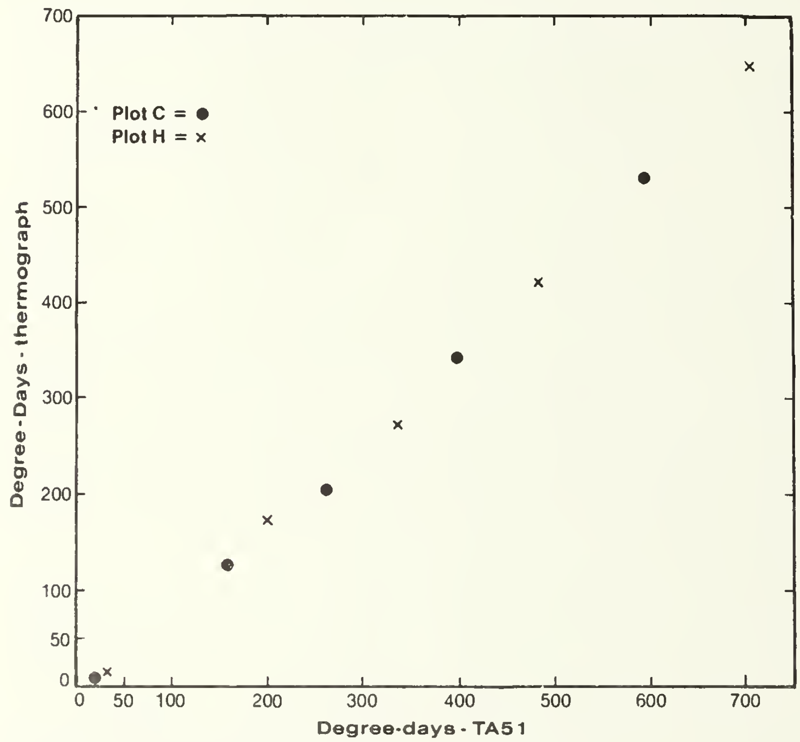

Figure 2.—Accumulated degree-days from the thermograph and TA51, April 1 to June 23, 1981.

A similar comparison of the accumulated degree-days for the total growing season (April 1 to October 8) produced an even better linear relation (fig. 3). This improvement was partially caused by an unknown anomaly late in the season on Plot H where degree-day accumulation calculated by the thermograph exceeded by 49 degree-days that computed by the TA51. The reverse occurred on Plot C: by the end of the season the TA51 accumulated 68 more degree-days than the amount calculated from the thermograph. From a total of nearly 3000 degree-days accumulated to October 8 these discrepancies are minor.

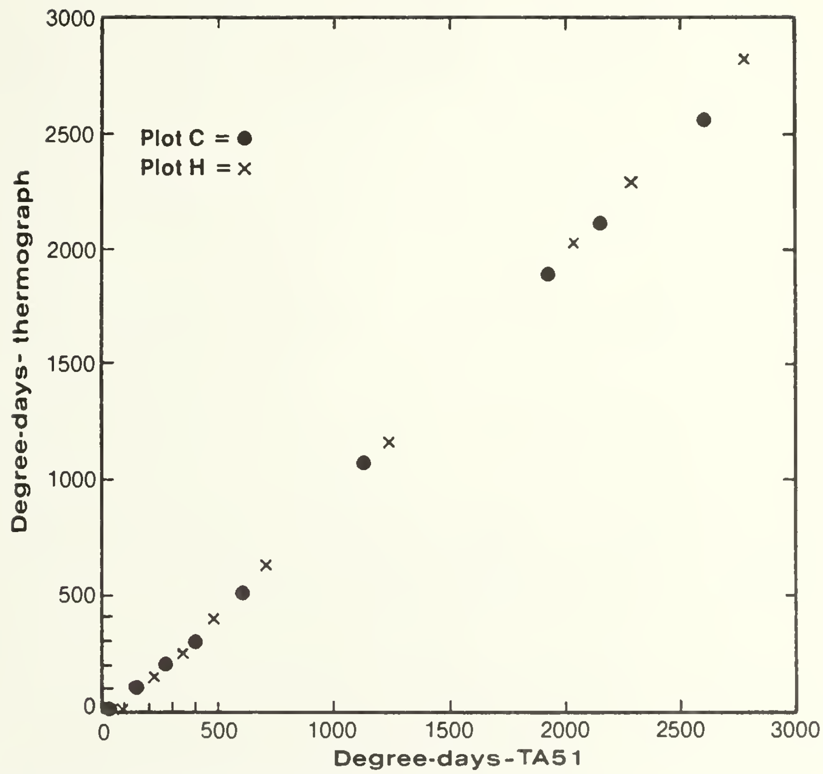

Figure 3.—Accumulated degree-days from the thermograph and TA51, April 1 to October 8, 1981.

Except for slightly higher degree-day accumulations during the first 2 mo of the growing season, the degree-days accumulated by the TA51 were very similar to those calculated from averaging daily maximum and minimum temperatures on hygrothermograph charts. This is not surprising as the spring and summer diurnal temperatures follow a consistent pattern at Fort Klamath except during an occasional spring storm or an afternoon summer thunderstorm. There were about 14 such weather episodes at Fort Klamath during the 6 mo from April to October 1981. Temperature fluctuations caused by some of the spring storms could account for the additional degree-days computed by the TA51 early in the season. The ability of the TA51 to record temperatures and compute degree-days at 10-min intervals gives it an inherent sensitivity advantage over a thermograph.

Hygrothermographs are useful for recording other types of weather measurements; but for accumulating degree-days, the TA51 proved to be a convenient, accurate instrument. For forest environments, it should compute degree-day data more precisely than would recording hygrothermographs and with a savings in time needed to service conventional hygrothermographs and to calculate degree-days.

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Pacific Northwest Forest and Range
Experiment Station
319 S.W. Pine St.
P.O. Box 3890
Portland, Oregon 97208

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Maintaining Cultures of Wood-Rotting Fungi

E.E. Nelson and H.A. Fay

Abstract

Phellinus weirii cultures were stored successfully for 10 years in small alder (*Alnus rubra* Bong.) disks at 2 °C. The six isolates tested appeared morphologically identical and after 10 years varied little in growth rate from those stored on malt agar slants. Long-term storage on alder disks reduces the time required for maintaining cultures and the risk of contamination inherent in frequent transfers necessary in storage on agar slants.

Keywords: Root rot, *Phellinus weirii,* cultures, laboratory methods, storage methods, cold storage.

Mycologists, plant pathologists, and others have often wished that cultures of fungi could be kept indefinitely in the laboratory ready to use, with little or no maintenance, and without altering their physiology or structure. Until recently, our culture collection, mainly isolates of *Phellinus weirii* (Murr.) Gilbertson, was kept at 2-5 °C on malt agar slants and transferred to fresh media annually. Isolates appeared normal 15 or more years, but the procedure was time consuming and risk of contamination of the cultures was greater than seemed necessary.

We propose an alternative that requires infrequent attention. Five isolates of *P. weirii* from roots of mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.) growing at high elevations in the Cascade Range in Oregon, and five isolates from roots of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) growing at low elevations in western Oregon and Washington were compared for their abilities to survive over a range of temperatures (Nelson and Fay 1975). With the same procedures used in that study, we have maintained cultures of *P. weirii* for more than 10 years at 2 °C. Thin sections of red alder (*Alnus rubra* Bong.) stemwood were placed over gravel and water in loose-capped, 60-ml-capacity French Square bottles; they were autoclaved and seeded with a small agar plug of the desired fungal isolate. Once the fungus had colonized the disks, bottles were tightly capped and maintained at a constant temperature. We successfully isolated *P. weirii* from all bottles of 6 of the original 10 isolates maintained at 2 °C for 10 years. We used malt agar containing 1 p/m benomyl as our isolation medium.

E.E. NELSON is a research plant pathologist and H.A. FAY is a biological laboratory technician at the Pacific Northwest Forest and Range Experiment Station, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, Oregon 97331.

After 10 years storage, we compared the growth rate and general appearance of the colonies of the six isolates maintained on alder disks with the growth rate and general appearance of the colonies of the same isolates maintained over the same period on malt agar slants. Subcultures of each isolate from both methods of storage were grown in 1.5 percent malt agar in individual petri plates incubated in the dark at 5, 10, 15, 20, 25, and 30 °C. Four replicates of the six isolates from both storage methods were measured periodically, daily in most cases. Colony diameter was plotted over time for each temperature, and slope of maximum growth was determined. Isolates stored in alder disks generally had slightly slower rates of growth than those stored on malt agar slants (fig. 1). Analysis of variance determined that these differences, though small, were significant (P = 0.05), as were differences in growth among isolates. We noted no differences in morphology of an isolate stored on disks vs. those stored on slants. No pathogenicity tests were made.

We have not used this means of storing cultures of other fungi; however, there is reason to expect the technique to be applicable to cultures of other species of wood-rotting fungi. We suggest that others explore this alternative to frequent periodic maintenance of their culture collections of wood-rotting fungi.

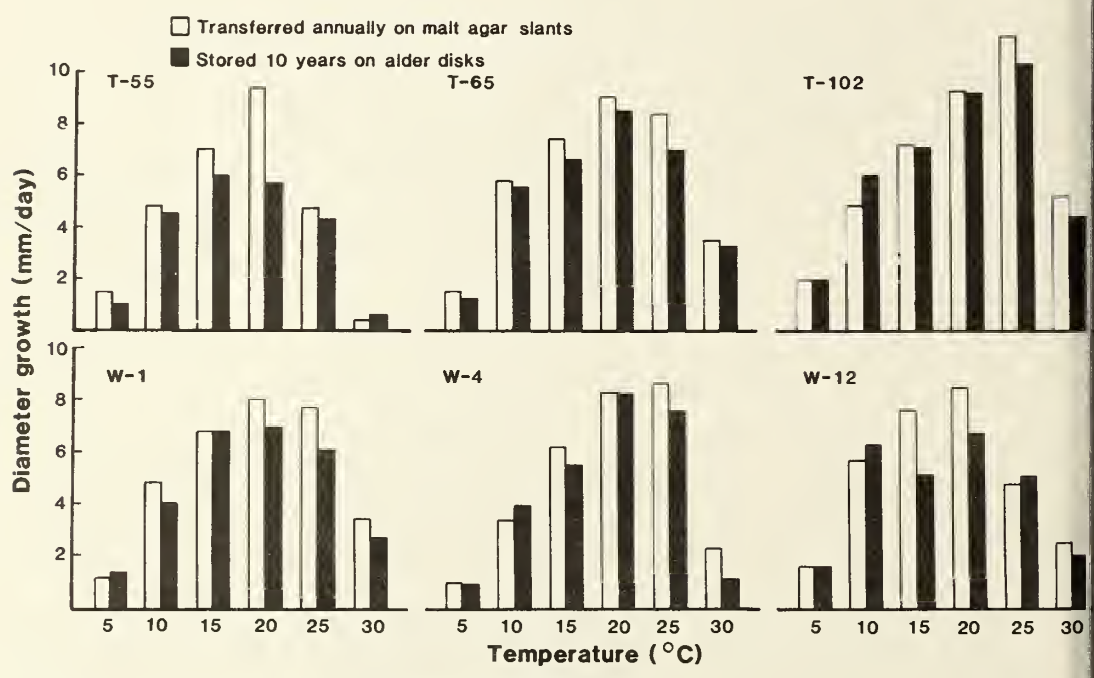

Figure 1.—Maximum rates of growth of *Phellinus weirii* isolates by two storage methods; three isolates are from a high elevation mixed conifer forest (W), and three are from a lower elevation Douglas-fir forest (T).

English Equivalents

1 milliliter (ml) = 0.001056 quart
1 millimeter (mm) = 0.0394 inch
°C = 5/9 (°F - 32)

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A Ponderosa Pine-Grand Fir Spacing Study in Central Oregon: Results After 10 Years

K.W. Seidel

Abstract

The 10-year growth response from an initial spacing study established in a ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) and grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.) plantation was measured in central Oregon. The study was designed to compare the growth rates of pure pine, pure fir, and a 50-percent mixture of each species planted at 6-, 12-, and 18-foot spacings. Height growth of pure pine was about twice as great as that of pure fir because of damage to the fir from frost and animals; growth of the pine-fir mixture was intermediate. Both basal area and total cubic volume increment per acre increased at the narrower spacing but diameter growth per tree was less. The height advantage of the pine is likely to be maintained in the future.

Keywords: Stand density, plantation spacing (-growth, increment, ponderosa pine, grand fir, central Oregon, Oregon (central).

Introduction

Spacing and thinning studies distributed over a range of sites, stand ages, and species provide information on the growth response of managed stands that enables the forest manager to select tree spacing or to design thinning schedules to meet land management objectives. Such information is also useful in developing and verifying long-term growth and yield models of managed stands. Considerable information is available on the growth response of pure, even-aged stands of many species to various density regimes, but little is known about the response of mixed species stands.

In 1974, a spacing study was begun in a plantation established with seedlings of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) and grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.) in central Oregon. The purpose was to obtain information on the productivity of pure and mixed stands of these species at several spacings in terms of diameter, height, basal area, and volume growth. This paper reports results from the first 10 years of the study or two 5-year growth periods (1975-79 and 1980-84). Results are strictly applicable only to the plant community in which the study is located but should be generally useful in similar mixed conifer communities of comparable site quality on the east slopes of the Cascade Range in Oregon from Bend to Klamath Falls.

K. W. Seidel is a research forester at the Pacific Northwest Forest and Range Experiment Station, Silviculture Laboratory, 1027 N.W. Trenton Avenue, Bend, Oregon 97701.

Study Area and Methods

The study is located in the Lookout Mountain unit of the Pringle Falls Experimental Forest in the Deschutes National Forest about 35 miles southwest of Bend, Oregon. The study is on a north-facing, 20-percent slope at an elevation of about 5,100 feet. The soil is a well-drained Typic Cryorthent (Shukash series) developed in dacite pumice originating from the eruption of Mount Mazama about 6,500 years ago. It has an Al, AC, C1, C2 pumice horizon about 3 feet deep over the buried soil.

The study area is a 20-acre clearcut in a mixed conifer/snowbrush-chinkapin plant community (Volland 1982). Typical ground cover in this community consists primarily of snowbrush (*Ceanothus velutinus* Dougl. ex Hook.), greenleaf manzanita (*Arctostaphylos patula* Greene), and golden chinkapin (*Castonopsis chrysophylla* (Dougl.) A. DC.). Site index of mature ponderosa pine in the area is about 90 feet at age 100 (Meyer 1961).

Three initial spacings (6 by 6, 12 by 12, and 18 by 18 feet) and three species combinations (pure pine, pure fir, and 50 percent of each species) were tested in a completely randomized split-split plot design. Whole plot treatments were spacings, split-plot treatments were species combinations, and time periods were the split-split plot factor. Each spacing was replicated three times for a total of nine whole plots, and each whole plot was split into three subplots to result in 27 subplots (fig. 1). The 50-percent pine-fir subplots were planted by alternating pine and fir seedlings within each row. Twenty-four trees were measured in the interior of each plot; plot size, including buffer strips, ranged from 0.1 acre to 0.54 acre, depending on spacing. No thinning is planned for these plots in the future.

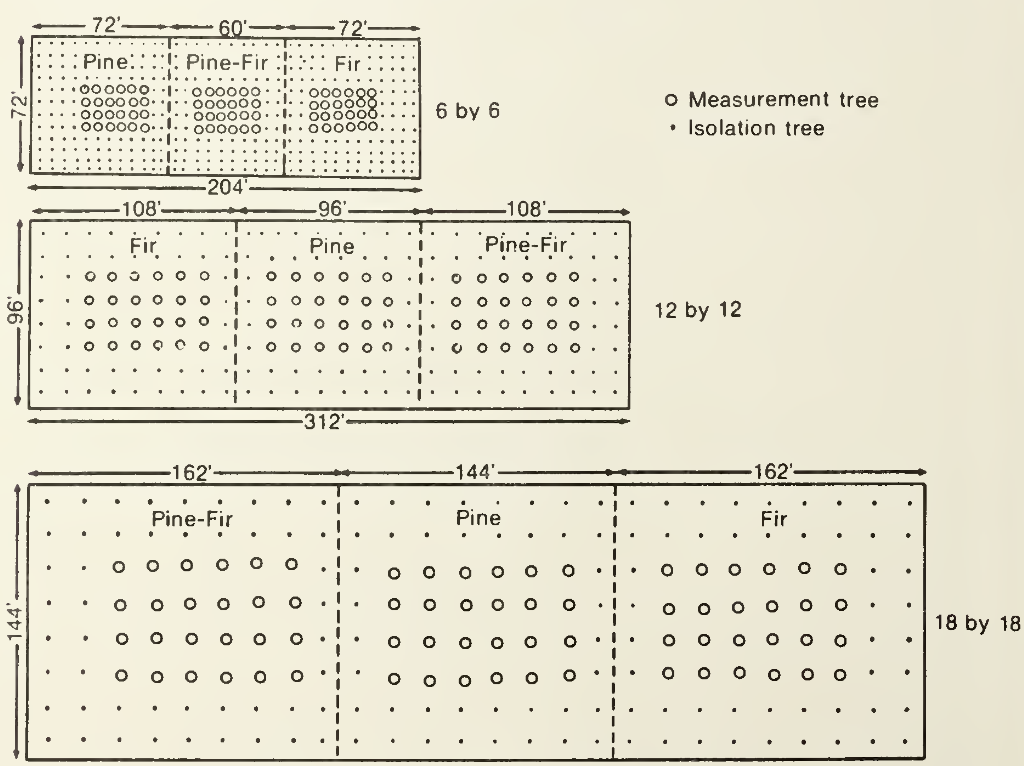

Figure 1.—One replication of spacing plots showing random assignment of the species combination split plots within each whole plot.

Planted seedlings were 2-0 bare root ponderosa pine grown in the USDA Forest Service nursery in Bend and 2-year-old containerized grand fir grown in a greenhouse in 1-quart milk cartons. Seed of both species was collected near the study area in 1971. Seedlings were planted with an auger from May 27 to June 7, 1974. The entire carton was removed from around the fir seedlings just before planting leaving the root ball intact. Fir seedlings were thinned to two per carton before planting and two pine seedlings were planted at each spot. Both fir and pine seedlings were thinned to one per spot at the end of the third growing season. Extra seedlings of both species were planted near the plots and used to replace those in the plots that died during the first 2 years. Snowbrush, manzanita, and chinkapin within the study area were sprayed with herbicide in June 1976 and June 1979 to eliminate competition from these species.

Total height of all plot trees was measured to the nearest 0.1 foot, in spring 1975 and autumn 1979 and 1984. Diameter at breast height (d.b.h.) of trees 0.6 inch or larger was measured to the nearest 0.05 inch in 1979 and 1984. An equation expressing total cubic volume inside bark as a function of diameter^2 x height (D^2H) was constructed for each species and used for volume estimation in 1979 and 1984. Remeasurement of this study is planned at 5-year intervals with publication of the latest results every 10 years.

Split-plot analyses of variance were used to compare spacings, species mix, and growth periods for height, basal area, and volume growth. Tukey's test was used to determine significant differences among treatment means.

Characteristics of the plots after planting and in 1979 (age 7) and 1984 (age 12) are given in table 1. Average height of the planted pine was only slightly greater (0.6 foot) than that of the fir (0.4 foot); after 10 years, average diameter of measurable trees at each spacing was about 2 inches.

Results

Mortality and Damage

Survival of both pine and fir seedlings was excellent. Only 2 percent of the pine and 1 percent of the fir seedlings died during the first 2 years after planting. Of the 324 seedlings (measurement trees) of each species present at the end of the third growing season, one pine seedling died before the 1979 remeasurement and six fir seedlings died during the second 5-year period (1980-84).

Fir seedlings were damaged by birds eating terminal buds during 1976 and by freezing temperatures killing new growth in spring 1979. This resulted in slower height growth of many seedlings. These results are not surprising because previous studies have shown white fir (*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.) to be considerably less frost tolerant than ponderosa pine in clearcut areas (Fowells and Stark 1965, Schubert 1956). A few fir were also damaged by deer rubbing their antlers on terminal shoots. Pine seedlings were undamaged except for some snow breakage on a few seedlings during one winter.

Table 1—Characteristics of ponderosa pine-grand fir plots and subplots in 1975, 1979, and 1984

Year, spacing, and species composition	Trees per acre	Trees per acre 0.6-inch d.b.h. or larger		Quadratic mean diameter 1/	Average height 2/	Basal area 1/	Total volume 1/
			percent	inches	feet	ft^2/acre	ft^3/acre
1975 (age 2):							
6 by 6 feet--							
Pure pine	1,200	--	--	--	0.7	--	--
Pure fir	1,200	--	--	--	.4	--	--
Pine-fir	1,200	--	--	--	.6	--	--
Mean	1,200				.6		
12 by 12 feet--							
Pure pine	304	--	--	--	.6	--	--
Pure fir	304	--	--	--	.5	--	--
Pine-fir	304	--	--	--	.6	--	--
Mean	304				.6		
18 by 18 feet--							
Pure pine	134	--	--	--	.6	--	--
Pure fir	134	--	--	--	.4	--	--
Pine-fir	134	--	--	--	.6	--	--
Mean	134				.5		
1979 (age 7):							
6 by 6 feet--							
Pure pine	1,200	183	15	0.7	3.8	0.50	8.2
Pure fir	1,200	--	--	--	2.1	--	--
Pine-fir	1,200	117	10	.7	2.9	.40	5.7
Mean	1,200	100	8	.7	2.9	.30	4.6
12 by 12 feet--							
Pure pine	300	17	6	.8	3.5	.06	1.0
Pure fir	304	--	--	--	2.3	--	--
Pine-fir	304	13	4	.7	3.0	.04	.6
Mean	303	10	3	.7	2.9	.03	.5
18 by 18 feet--							
Pure pine	134	11	8	.9	3.6	.06	.6
Pure fir	134	--	--	--	2.2	--	--
Pine-fir	134	--	--	--	2.8	--	--
Mean	134	4	3	.9	2.9	.02	.2
1984 (age 12):							
6 by 6 feet--							
Pure pine	1,200	1,150	96	2.3	9.7	32.6	205.7
Pure fir	1,183	283	24	1.0	5.2	2.4	17.5
Pine-fir	1,200	867	72	2.3	8.3	24.6	156.8
Mean	1,194	767	64	1.9	7.7	19.9	126.7
12 by 12 feet--							
Pure pine	300	295	98	2.7	10.3	11.8	71.9
Pure fir	296	207	70	1.2	6.8	1.7	11.7
Pine-fir	295	249	85	2.3	8.8	7.6	46.9
Mean	297	250	84	2.1	8.6	7.0	43.5
18 by 18 feet--							
Pure pine	134	134	100	3.0	10.5	6.6	37.6
Pure fir	134	60	45	1.0	5.7	.3	2.3
Pine-fir	132	99	75	2.7	8.4	3.9	22.6
Mean	133	98	73	2.2	8.2	3.6	20.8

1/ All trees 0.6 inch d.b.h. and larger.
2/ All trees.

Table 2—Periodic annual increment of a ponderosa pine and grand fir plantation during two 5-year measurement periods from 1975 to 1984.

Measurement period and spacing	Diameter growth 1/				Height growth				Gross basal area growth 2/				Gross total volume growth 2/			
	Pine	Fir	Pine-fir	Mean	Pine	Fir	Pine-fir	Mean	Pine	Fir	Pine-fir	Mean	Pine	Fir	Pine-fir	Mean
	inches				feet				ft^2/acre				ft^3/acre			
1975-79 (age 2 to 7):																
6 by 6 feet	--	--	--	--	0.6	0.4	0.6	0.5	0.10	--	0.08	0.06	1.6	--	1.1	0.9
12 by 12 feet	--	--	--	--	.6	.3	.5	.5	.01	--	.01	.01	.2	--	.1	.1
18 by 18 feet	--	--	--	--	.6	.4	.4	.5	.01	--	--	.003	.1	--	--	.03
1980-84 (age 7 to 12):																
6 by 6 feet	0.50	--	0.50	0.50	1.2	.6	1.0	.9	6.5	.5	4.8	3.9	39.5	3.5	30.2	24.4
12 by 12 feet	.61	--	.64	.62	1.4	.9	1.2	1.2	2.4	.3	1.5	1.4	14.2	2.3	9.2	8.6
18 by 18 feet	.68	--	--	.68	1.4	.7	1.1	1.1	1.3	.7	.8	.7	7.4	.5	4.5	4.1

1/ Arithmetic mean diameter growth of trees 0.6 inch d.b.h. or larger at beginning of 5-year period and living through the period. Based on growth of 31 pine seedlings.
2/ Includes ingrowth.

Diameter Growth

Diameter growth data are limited for these first two growth periods because none of the fir seedlings had reached 0.6-inch d.b.h. by 1979, and only about 10 percent of the pine seedlings had attained this size. Growth of these 31 trees was excellent, however, and ranged from an average of 0.5 inch per year at the 6-foot spacing to 0.68 inch annually at the 18-foot spacing during the second 5-year period (table 2). No statistical comparisons were made for diameter growth because too few trees existed per experimental unit.

Height Growth

The most rapid rate of height growth (1.4 feet per year) was found on pure pine at the 12- and 18-foot spacings during the second period; the slowest growth rate (0.3 to 0.4 foot per year) was measured on pure fir during the first period (table 2, fig. 2). Significant differences ($P<0.01$) in height growth were found among spacings, species combinations, and growth periods. Height growth during the second period was twice that of the first period (0.5 vs. 1.1 foot per year) when averaged over all spacings and species combinations (table 2). All three species combinations were significantly different from each other with height growth averaging 1.0 foot per year for the pure pine, 0.8 foot for the pine-fir mixture, and 0.6 foot for the pure fir. Growth of fir was considerably less than that of pine during the second period because of the freezing and animal damage sustained by the fir. Although average height growth differences between pine and fir were not large on an annual basis, after 10 years this difference in growth rates resulted in pine being almost twice as tall as fir (10.2 vs. 5.9 feet) (table 1).

Growth differences among spacings were not as large as those among species combinations. Height growth at the 6-foot spacing was significantly less than at the 12- or 18-foot spacing but no significant differences were found between the 12- and 18-foot spacings.

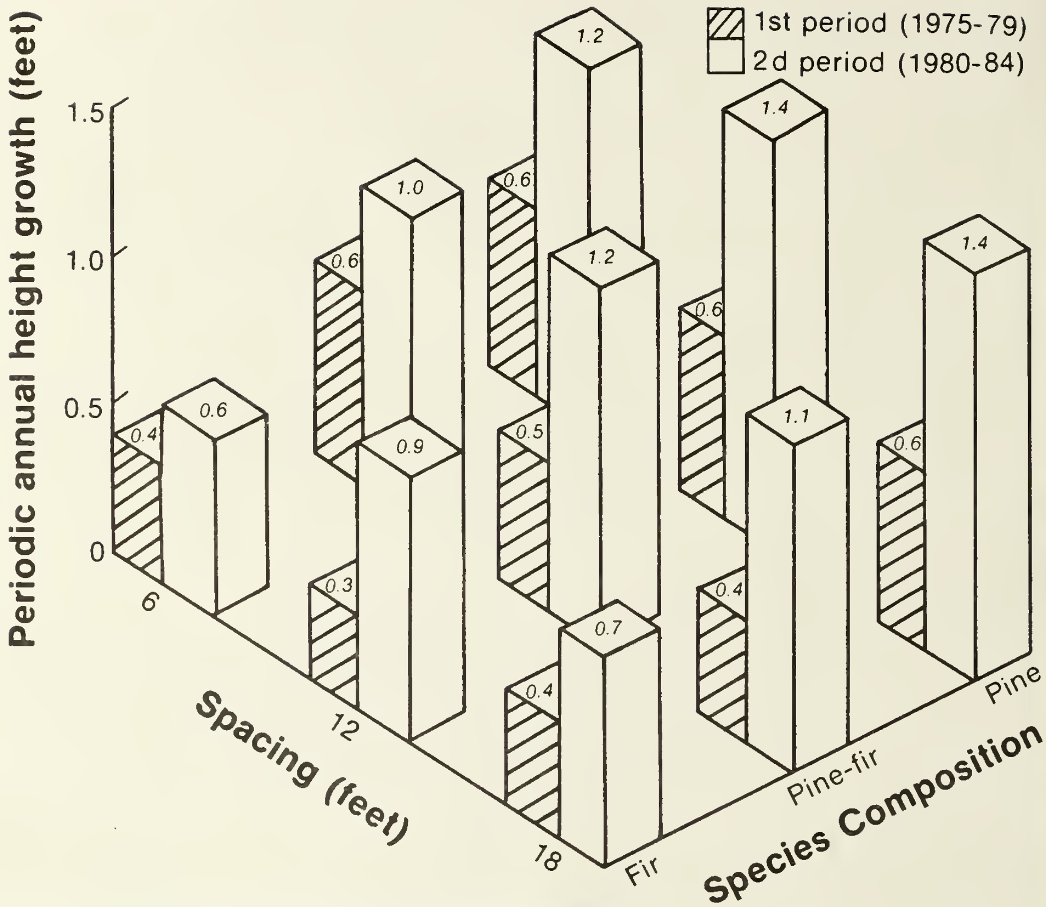

Figure 2.— Periodic annual height increment by species, spacing, and growth period, based on growth of all trees living through each 5-year period.

Basal Area and Volume Growth

During the first period, basal area and total cubic volume growth per acre was very small because most trees were less than 4.5 feet tall (table 2). During the second period, growth increased greatly (especially for pine) as more trees reached measurable size (ingrowth). For pure pine at the 6-foot spacing, for example, annual volume increment increased from 1.6 to 39.5 cubic feet per acre from the first to the second period. About 90 percent of volume increment during the second period was ingrowth.

Spacing and species combinations were significantly different ($P<0.01$) for both basal area and volume growth during the second period. Growth was significantly greater ($P<0.01$) at the 6-foot spacing but no significant differences existed between the 12- and 18-foot spacings. All three species combinations were significantly different ($P<0.01$) from each other: the greatest growth occurred in pure pine, intermediate growth in pine-fir, and least growth in pure fir (table 2). The spacing-species interaction was also significant ($P<0.01$) for both basal area and volume increment because of the much greater growth for pine and pine-fir at the 6-foot spacing as compared to fir (table 2).

Discussion

Ten years after establishment of this spacing study in a ponderosa pine-grand fir plantation, results already are typical of those generally found in initial spacing studies—greater diameter growth per tree at wider spacings and greater volume growth per acre at closer spacings. Because of the more rapid height growth of the pine, a stratified, two-storied stand is developing with pine the dominant species. Although pine is clearly dominant after 10 years, in the absence of freezing or animal damage, growth of grand fir was comparable to that of pine. For example, the most rapidly growing pine grew 9.9 feet in height during the 10-year study period compared to 9.7 feet for an undamaged fir.

It is apparent that grand fir plantations can be established with survival rates as good or better than those of ponderosa pine by using seedlings grown in large containers. The major disadvantage appears to be the greater susceptibility of grand fir to frost and animal damage in clearcuts, which results in reduced height and volume growth. The damage sustained by the fir during the first 5 years after planting resulted in a growth advantage for pine that is likely to be maintained for many years.

Metric Equivalents

1 foot = 0.3048 meter
1 inch = 2.54 centimeters
1 acre = 0.4047 hectare
1 square foot per acre = 0.2296 square meter per hectare
1 cubic foot per acre = 0.0700 cubic meter per hectare
1 tree per acre = 2.47 trees per hectare
1 quart = 0.9463 liter

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Transport of Bedload Sediment and Channel Morphology of a Southeast Alaska Stream

Margaret A. Estep and Robert L. Beschta

Abstract

During 1980-81, transport of bedload sediment and channel morphology were determined at Trap Bay Creek, a third-order stream that drains a 13.5-square kilometer watershed on Chichagof Island in southeast Alaska. Bedload sediment was sampled for 10 storms: peak flows ranged from 0.6 to 19.0 cubic meters per second, and transport rates ranged from 4 to 4400 kilograms per hour. Peak transport rates typically occurred during peak streamflow. Transport of bedload sediment at a riffle over 1600 meters upstream from the mouth of the watershed was greater for most storm events than that measured at another riffle 22 meters downstream. Transport was greatest at the downstream riffle, however, during the most severe storm of the season and during another storm 1 week later. Both magnitude of storm and availability of sediment appeared to determine the transport of bedload sediment in Trap Bay Creek. Regression relationships were developed between streamflow (independent variable), several transport variables, and particle sizes in two diameter classes (D_{50} and D_{90}). Analysis revealed that total bedload discharge was positively correlated with streamflow; transport of either diameter class, however, had no consistent relationship with streamflow from one storm to the next. Relationships between particulate organic matter and streamflow were also highly variable from storm to storm. Observations indicated that large organic debris, especially fallen trees, played a major role in determining channel morphology; tidal action was an important factor affecting channel characteristics in the lower 1300 meters of the channel.

Keywords: Bedload, sediment transport, channels (stream), stormflow, southeast Alaska.

Introduction

The distribution of sediment by particle size and total sediment load of mountain streams is influenced by numerous factors, including geology, geomorphology, and climate. Additional changes in the sediment load can result from land use activities which often affect the spatial and temporal availability of sediment. Such changes can alter the dynamic equilibrium between sediment transport and water discharge, thus initiating changes in channel form and altering the physical and biological characteristics of the system (Hall and Krygier 1967, Heede 1975, Park 1977).

MARGARET A. ESTEP is a graduate research assistant and ROBERT L. BESCHTA is an associate professor, Department of Forest Engineering, Oregon State University, Corvallis, OR 97331.

In steep mountainous topography of the Pacific Northwest, accelerated sedimentation from mass soil movements often follows road building and timber harvesting (Beschta 1978, Lyons and Beschta 1983, Swanson and Fredriksen 1982, Swanston and Swanson 1976). The steep slopes and erodable soils characteristic of watersheds in southeast Alaska are similarly subject to mass movement following timber harvest (Swanston 1974). Because fisheries resources are often adversely affected by increased sedimentation (Chapman 1961, Hall and Krygier 1967, Phillips 1971), these nonpoint sources of sediment represent a concern in southeast Alaska, where timber and fisheries provide substantial economic benefits to the State.

Suspended sediment consists of the relatively small particles in transport by a stream; these particles are usually dispersed throughout the water column by stream turbulence. The biological effects of increased suspended sediment in small streams has been documented (Brusven 1980, Hynes 1970, Nuttal 1972). Bedload sediment consists of relatively coarse particles transported near or on the bottom of the stream; average velocities of these particles are much less than that of the stream. These larger sediment sizes can have an important effect on the quality of spawning gravel and the morphology of mountain streams, but little is known about the relationships between bedload sediment transport, flow conditions, and characteristics of the stream system. To identify these interactions we began a study in an undisturbed watershed in southeast Alaska. Results are presented and compared with those for another mountain stream, Flynn Creek, in western Oregon.

Study Site Description

The study stream, Trap Bay Creek, is located in the northeast corner of Chichagof Island in the Tongass National Forest and drains a watershed about 13.5 km^2 in area (fig. 1). Elevation of the watershed ranges from sea level to 1320 m.

Figure 1.—Location of Trap Bay Creek.

The watershed is a glacial cirque valley bounded by serrate ridges with a horn peak at the southern end. Slope gradient ranges from nearly level adjacent to the valley floor to greater than 100 percent along the sides of the ridges. Vegetation is characteristic of the temperate rain forests of southeast Alaska. Sitka spruce (*Picea sitchensis* (Bong.) Carr.) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) dominate the old-growth forest, with scattered western redcedar (*Thuja plicata* Donn.) and red alder (*Alnus rubra* Bong.). The understory consists of blueberry (*Vaccinium alaskaense* Howell), huckleberry (*Vaccinium parvifolium* Sm.), ferns, mosses, and numerous vascular plants. Dense thickets of salmonberry (*Rubus spectabilis* Pursh.), ferns, skunk cabbage (*Lysichitum americanum* Hult. and St. John), and nettles (*Urtica lyallii* S. Wats.) alternate with alder clones and an occasional hemlock in riparian zones. Devils club (*Oplopanax horridus* (Sm.) Miq.) can also be found along streams and in the forest, especially in clearings and on steep slopes with shallow soils.

Climate

The climate is cool, moist, maritime, and typical of the southeast Alaska panhandle. There is little variation in daily temperature, primarily because of the moderating influence of the sea; air temperatures rarely exceed 18 °C in summer or drop much below freezing in winter. Low pressure frontal systems release large amounts of rainfall in southeast Alaska when they are lifted orographically by coastal mountains as they move inland from the Gulf of Alaska. The watershed receives about 1700 mm of annual precipitation, mostly as light to moderate rainfall. October is typically the wettest month, whereas April, May, and June are often relatively dry (Harris and others 1974). Upper elevations of the watershed may receive appreciable snowfall during the fall and winter.

Geology and Soil

Detailed geologic maps are not available for most of southeast Alaska. Sidle and Swanston (1982) found soils of a northwest facing slope on the east side of the watershed to be underlain by graywacke, a poory sorted sandstone composed of quartz and feldspar surrounded by a clay matrix. Mid- to upper-slope soils were 15 to 50 cm thick and well-drained.

Soils at elevation less than 1500 m have developed primarily from compacted ablation till, which typically overlies the bedrock in southeast Alaska's glacial cirque valleys (Harris and others 1974). Soils that have developed under forests are generally Spodosols and are typically covered by a thick organic layer 15 to 25 cm thick. Organic soils (muskegs) cover much of the lowland area of the watershed and may help regulate streamflow (Harris and others 1974).

Stream System

The streambed of Trap Bay Creek is composed of small to medium cobbles, gravel, and coarse sand, with increased abundance of silt and fine sands in areas of deposition. Gravel bars are numerous and obvious during low flows. Cobbles several centimeters in diameter and larger armor most stream riffles; sand and gravel particles are common between and underneath the armor particles.

The study reach for sampling bedload is located between 1590 and 1612 m from the mouth of the stream and has an average channel gradient of approximately 0.5 percent. It consists of two riffles separated by an 18-m long channel depression or pool. Bankfall widths were 13.7 m and 12.6 m at the upper and lower riffles, respectively. Between these two riffles bankfull width averages 10.7 m. Stream banks average approximately 0.8 m high at bankfull. Bed materials in this reach are similar to those found throughout the stream, with cobbles paving the riffles and finer particles more abundant in the pool.

Channel characteristics of Trap Bay Creek are strongly influenced by the stabilizing roots of streamside vegetation and by large organic debris (trees and root wads). Many pool-riffle sequences have formed where smaller pieces of organic debris (small logs and tree branches) have accumulated against fallen trees. Large organic debris is somewhat less important morphologically in the lower reaches where tides greater than 6 m can cause flotation of otherwise stable debris. Tides influence the lowest 1300 m of the channel where streambanks are subject to frequent sloughing because the protection by tree roots is no longer available.

Methods

Bedload transport was sampled in the study reach of Trap Bay Creek during 10 storms occurring in September and October 1980. Data from a water-level recorder located 1520 m from the mouth of the stream was used with periodic flow measurements to develop storm hydrographs.

Temporary bridges were constructed over the channel at each end of the study reach (1590 m and 1612 m from the mouth) to facilitate collecting samples from each riffle and to prevent disturbing the streambed during sampling. Bedload samples were taken with a handheld Helley-Smith[1/] pressure-differential sampler equipped with a square 7.6-cm aperture (Emmett 1981). A 6000-cm^2 collection bag (0.2-mm mesh) reduced the possibility of clogging (Beschta 1981, Johnson and others 1977).

Subsamples were taken at equally spaced positions across the stream; the 8-10 subsamples were combined to form a single bedload sample for each bridge location. The relative proportion of organic and inorganic sediment was determined by burning the samples at 320 °C for 24 hours. Inorganic residues were then sieved to obtain distribution by particle size.

Sediment rating curves were developed using a power equation:

$$BLD = aQ^b;$$

where:

BLD = bedload discharge, in kg hr^{-1};
Q = streamflow, in $m^3\ s^{-1}$; and
a and b = regression coefficients.

This equation form was selected because it generally provided the best "straight-line" relationship between variables. Power equations were also used to correlate streamflow to transport of particulate organic matter (POM), the median diameter of particles in a bedload sample (D_{90}), and to analyze data on bedload transport from Flynn Creek, Oregon (Edwards 1980, O'Leary and Beschta 1981).

Only transport of POM was studied; no analysis was made of particle size. The Helley-Smith sampler is effective at trapping particles 0.2 mm in diameter and larger traveling within 7.6 cm of the bed; thus the data represent a conservative estimate of total POM transport.

[1/] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.

Measurements of channel morphology were taken within the lowest 1650 m of the channel in summer 1980. Thalweg elevations, bankfull width, and the distance of the thalweg from the east bank were measured at 15-m intervals. The locations of large organic debris, gravel bars, and pools were determined and referenced to stakes marking the 15-m intervals. Cross section profiles were measured approximately every 50 m of stream length. More frequent measurements (every 0.6 m) were made within the study reach where bedload was sampled. In August 1981, a 260-m section of the lower channel (between 1390 and 1650 m) was surveyed again, taking detailed thalweg elevations and cross section profiles between 1590 and 1610 m.

Results and Discussion

Streamflow

Return periods of the storms occurring during the sampling period cannot be definitively rated because historical records on precipitation and streamflow are not available for the Trap Bay Creek area. Estimates of the recurrence intervals, however, were obtained by comparing peakflows with regionally developed equations (USDA Forest Service 1979). All storms during which sampling was conducted were estimated to have recurrence intervals of less than 2 years, except for the more severe storm of October 1, which probably had a recurrence interval from 2 to 5 years.

The lag time between the onset of precipitation and hydrograph peak varied from less than 1 to more than 5 hours, depending on the intensity of rainfall and antecedent precipitation. Stormflows generally lasted over 6 hours. The relatively large storm of October 1 released nearly 70 mm of precipitation over a 10-hour period, with a peak intensity of 13 mm hr^{-1}; 33 mm of precipitation had also fallen the previous day.

Bedload Transport

Bedload discharge ranged from 4 to 4200 kg hr^{-1} and from 15 to 4400 kg hr^{-1} at the downstream and upstream riffles, respectively. The greatest transport rates at both sites occurred during the October 1 storm event, with relatively high bedload transport occurring nearly coincident with the hydrograph peak. At the upstream riffle, however, the maximum rate sampled occurred well into the recession limb of the storm hydrograph (fig. 2).

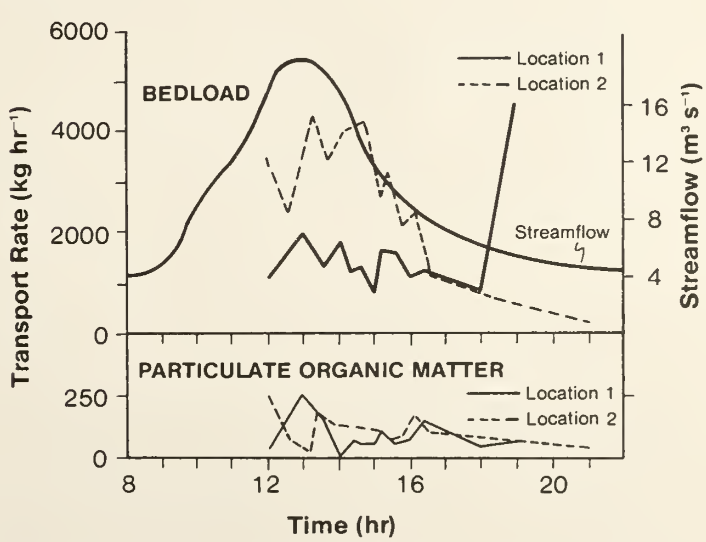

Figure 2.—Storm hydrograph for October 1, 1980, with transport rate of bedload and particulate organic matter at two sampling stations in Trap Bay Creek. Location 1 is 22 m upstream of location 2.

Transport rates at the upstream riffle exceeded those at the downstream riffle during nearly all storms. Apparently sediment was transported past the upstream riffle and deposited in the pool during the relatively small and more frequent hydrologic events. During the large storm of October 1, however, this situation was reversed (fig. 2), with more material being exported past the downstream riffle than was coming in from above. Langbein and Leopold (1968) theorized that a gravel riffle is an expression of a kinematic wave, and that it requires repeated flows of sufficient magnitude to transport material from one zone of concentration to the next. This theory could explain the apparent discrepancies in transport rates sampled in Trap Bay Creek at two locations only 22 m, or approximately two channel widths, apart. Lesser flow events were capable of transporting material to and past the sampling location at the upstream riffle, which represents one zone on concentration. An event of greater magnitude was required to initiate transport of this material past the downstream riffle to the next zone of concentration.

An estimated 10.8 t of material was removed from storage in the study reach from 1980 to 1981, based on changes in cross section of the channel (fig. 3). Estimates of sediment transport for the 10 storms during the fall 1980, based on the Helley-Smith bedload samples, are 11.4 t of material transported past the upstream riffle and 20.7 t of material transported past the downstream riffle. The difference of 9.3 t, most of which can be attributed to effects of the October 1 storm, agrees closely with the estimate based on cross section changes. Much of the sediment exported from this reach appears to have come from near the sides of the channel (both banks and bed) (fig. 3).

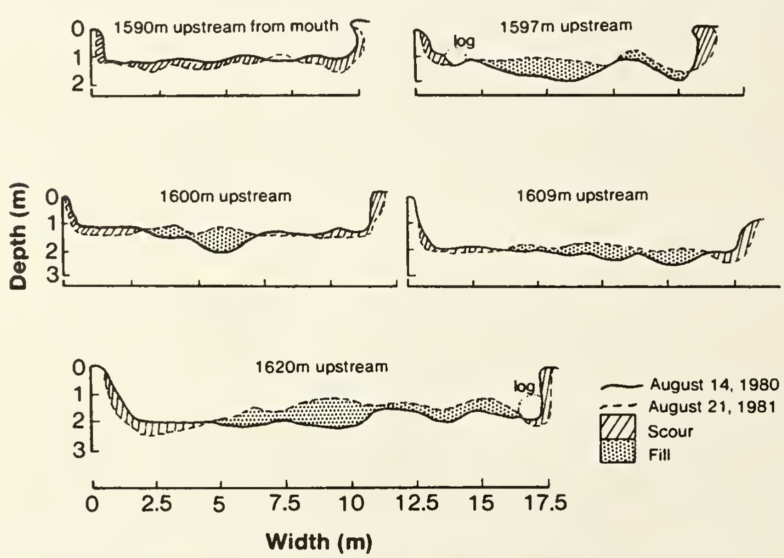

Figure 3.—Net changes in channel cross sections for selected locations upstream from the watershed mouth.

Rating curves between bedload transport and streamflow were developed for individual storms by using data from both upstream and downstream sampling locations (fig. 4). Separate sets of equations developed for bedload transport at each sampling location or for rising and falling hydrograph conditions did not greatly increase the coefficients of determination (r^2). Equations developed from all sample data from Trap Bay Creek, and also from Flynn Creek in Oregon, are shown in table 1.

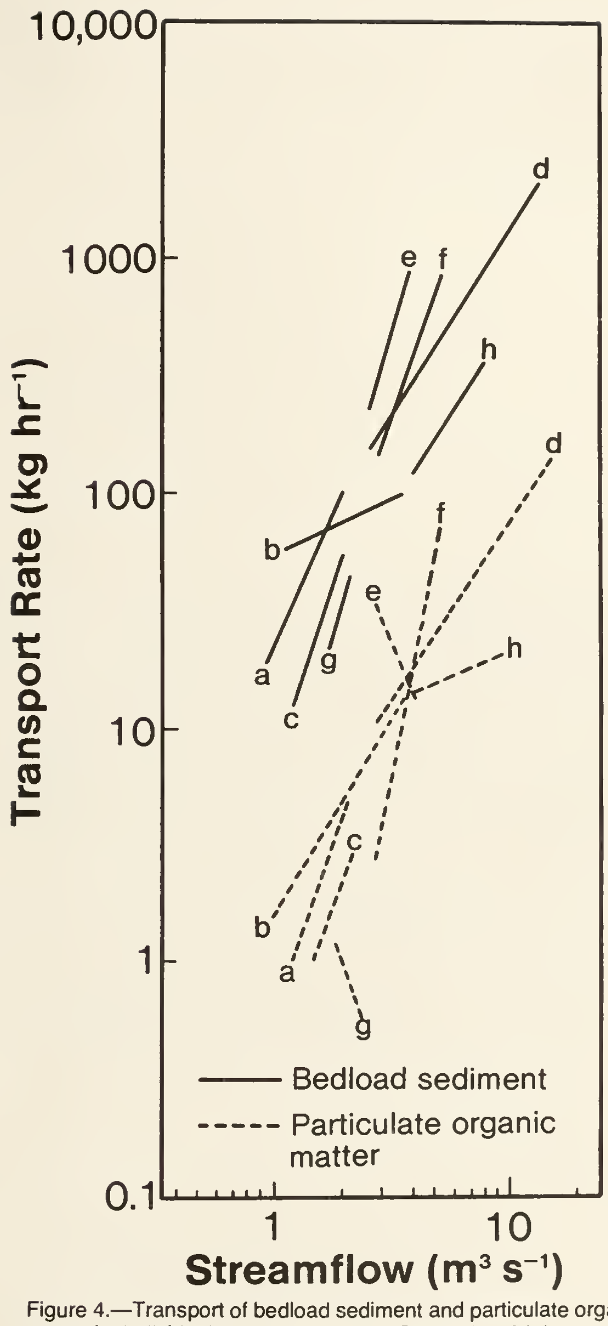

Figure 4.—Transport of bedload sediment and particulate organic matter for individual storm events: a = September 24, b = September 28, c = September 30, d = October 1, e = October 2, f = October 5, g = October 7, and h = October 17.

In general, bedload transport at Trap Bay Creek was positively correlated with streamflow, although considerable variation is evident between the rating curves for individual storms (fig. 4). These results suggest that extrapolation of rating curves to estimate bedload transport during other storms or flow levels will result in large errors and that data on bedload transport need to be collected over a wide range of flow conditions before a representative relationship can emerge from the large amount of background variability. Peak flows greater than 2.0 m^3 s^{-1} were required to produce appreciable movement of bedload sediment.

Coefficients of determination for equations developed from larger bedload particle sizes (> 2.0 mm) during individual storms averaged approximately 0.50 and were essentially the same as those for rating curves developed from particles > 0.25 mm. Supply limitations could influence the relationships between bedload transport and stream discharge. Streamflow was a dominant factor influencing bedload transport during moderate events at the upper riffle because material was readily available for transport. Transport past the lower riffle was limited, however, except during and following the storm October 1, an event of relatively large magnitude. The energy available during small storms was apparently insufficient to transport material through the study reach. Hence, the dynamics of sediment supply (Δ storage) and availability of energy interact in such a manner that sediment transport rates at two locations in a channel may appear to behave independently. Although there appeared to have been a general increase in material transport with increasing discharge at Trap Bay Creek, streamflow was only one factor influencing bedload transport. Furthermore, transport appeared to occur in pulses or "waves," probably because of differences in hydraulic conditions and characteristics of the armor layer of the two riffles.

No significant relationships ($\alpha = 0.10$) were found between streamflow and particle sizes D_{50} and D_{90}. Average diameters of D_{50} and D_{90} were approximately 2 and 11 mm, respectively. Again, the apparent lack of a strong correlation between rates of bedload transport and streamflow during individual storms or between particle size and streamflow should perhaps be expected if sediment is being routed downstream as a wave or series of waves. With transport occurring in such a manner, rates of bedload transport could vary widely at a given flow; such variability is reflected in the data collected at Trap Bay Creek. Furthermore, there was no obvious relationship between particle size and rate of bedload transport.

Considerable variability is apparent in transport of POM (fig. 4). Different factors (density, size, and shape) and processes may control the supply and transport of organic and inorganic material, even though both types are partially correlated with streamflow. A seasonal trend towards reduced POM at a given discharge is suggested by data from latter fall storms, a pattern typically found with suspended sediment loads (Beschta 1978, Beschta 1980, Paustian and Beschta 1979).

Channel Morphology

The resurvey of the study reach in August 1981 indicated fill at the upstream end and scour at the downstream end of the reach (fig. 5). Furthermore, the channel widened downstream from the upper riffle. Downstream from the 1504 m location, the left bank was being undercut and the thalweg elevation shifted towards this bank. A substantial shift in thalweg occurred at the upstream riffle but little change was apparent at the downstream riffle. Fill had occurred in the downstream portion (from 1592 to 1602 m) of the reach, a section of stream that could be characterized as a shallow pool. In contrast, scouring had occurred in another pool 30.5 m downstream from the study reach and the thalweg elevation there decreased by nearly 0.3 m. Cross section profiles within the study reach (fig. 3) tend to confirm indications of scour and fill from the thalweg surveys: where thalweg depths decreased, channel cross sections show net fill; and where depths increased, net scour prevailed.

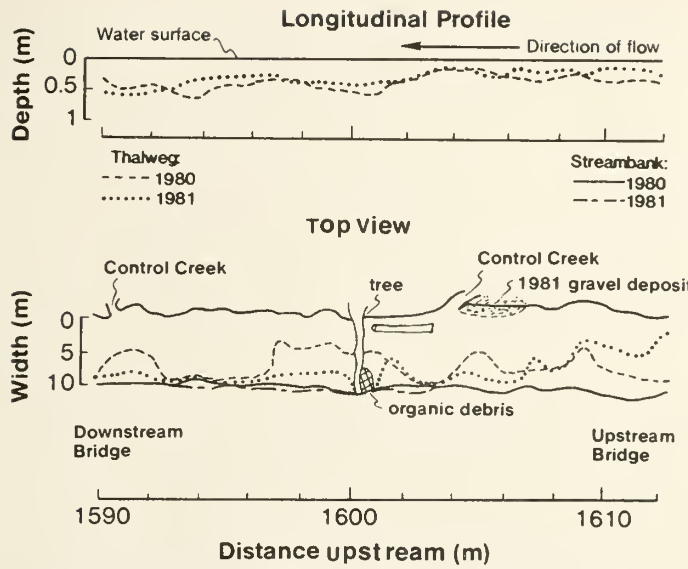

Figure 5.—Thalweg depth, thalweg position, and channel characteristics of Trap Bay Creek between bridges used for sampling bedload sediment.

Large organic debris appeared to have an important influence on channel morphology, especially upstream from the study reach. Here, much of the debris was tree-sized and had remained in place for relatively long periods of time. Smaller debris tended to become trapped and concentrated against fallen trees, resulting in localized channel scouring and thus obscuring the occurrence of pool-riffle sequences formed solely by fluvial processes. Trees in the channel, however, did not appear to block fish passage but, instead, provided cover for spawning adults.

Results of the 1980 survey measurements (fig. 6) indicate a general increase downstream in thalweg depth with respect to the water surface. The 1981 resurvey, from 1350 to 1500 m along the channel, indicated that sediment has been routed out of the upper portions of the channel with depositions immediately downstream. No significant changes in stream width occurred between 1980 and 1981.

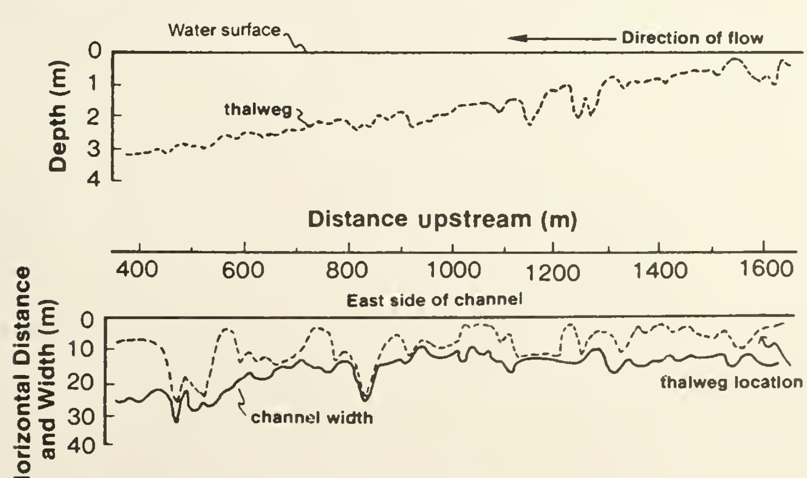

Figure 6.—Thalweg depth, thalweg location (distance from east side of channel), and channel width of a 1200-m section of Trap Bay Creek, 1980.

Morphometric change was observed in the channel, mostly downstream from 1300 m, where the stream was subject to tidal influence and human activity associated with several ongoing research projects. These changes included widespread bank-cutting, tree-tipping, and shifting of gravels within the tidal influence zone. Trampling along the banks, removal of large organic debris, and the construction of two fish weirs undoubtedly contributed to some of the changes that took place. Width-depth ratios were determined for 20 cross sections between the 730- and 1645-m channel locations in 1980 and remeasured in 1981. Data for the cross section at 838 m were excluded because the width-depth ratio was nearly an order of magnitude greater than at other cross sections. A highly significant ($\alpha = 0.01$) increase in the width-depth ratio occurred: from 16.5 in 1980 to 18.5 in 1981.

Trap Bay Creek appears to be a morphologically active stream. Tidal action, high flows, and instream research activities are effecting morphology changes in the lower portions of Trap Bay Creek, whereas stormflows and large organic debris are important factors above the tidal influence zone.

Comparison of Trap Bay Creek and Flynn Creek

Flynn Creek is a third-order stream that drains a 2.2-km^2 watershed in the Alsea River basin of western Oregon; its sediment transport has been studied extensively (Edwards 1980, Jackson and Beschta 1982, O'Leary and Beschta 1981, VanSickle and Beschta 1983). Both Flynn Creek and Trap Bay Creek watersheds receive most of their precipitation in the form of light to moderate rainfall from frontal storms of long duration; total precipitation and average temperatures are similar for the two areas. In contrast to the Trap Bay watershed, soils at Flynn Creek are deeper (most about 1 m) and are derived from sandstone bedrock. Forest vegetation consists predominantly of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and red alder (*Alnus rubra* Bong.). Average elevation of Flynn Creek watershed is 320 m with a relief ratio of 0.13; for the Trap Bay Creek watershed they are 590 m and 0.24. The Flynn Creek watershed is about one-third as long and one-tenth as wide as the Trap Bay watershed.

Power equations of relationships between bedload transport and streamflow have also been developed for Flynn Creek (table 1). In general, "b" coefficients for the Flynn Creek equations were greater than those for Trap Bay Creek, indicating that transport tended to increase more rapidly with increasing discharge at Flynn Creek. The "a" coefficients tended to be somewhat less for Flynn Creek equations, which probably reflects the difference in drainage area and, hence, the size of flow events.

Table 1—Equations for transport of bedload sediment and particulate organic matter for Trap Bay Creek, southeast Alaska, and Flynn Creek, western Oregon

Particle size stream, and location	Drainage area	Water year	Equation[1/]	r^2	n	Source of information[2/]
	km					
For particles ≥ 0.25 mm:						
Trap Bay Creek, AK—						
Riffle study reach	13.50	1981	$BLD = 23.0\,Q^{1.61}$	0.69	132	1
Flynn Creek, OR—						
Fishtrap site	2.18	1978	$BLD = 12.6\,Q^{4.51}$	0.58	187	2
Fishtrap site	2.18	1979	$BLD = 30.6\,Q^{4.13}$	0.93	59	3
Fishtrap site	2.18	1980	$BLD = 2.9\,Q^{-1.22}$	0.62	114	4
Riffle site	2.05	1979	$BLD = 262.7\,Q^{2.46}$	0.79	26	3
Bedrock chute	1.51	1979	$BLD = 60.6\,Q^{1.98}$	0.90	6	3
For particles ≥ 2 mm:						
Trap Bay Creek, AK—						
Riffle study reach	13.50	1981	$BLD = 10.0\,Q^{1.72}$	0.66	132	1
Flynn Creek, OR—						
Fishtrap site	2.18	1979	$BLD = 2.2\,Q^{5.27}$	0.92	59	3
Riffle site	2.05	1979	$BLD = 115.7\,Q^{2.64}$	0.77	26	3
For particles ≥ 0.2 mm:						
Trap Bay Creek, AK—						
Riffle study reach	13.50	1981	$POM = 0.7\,Q^{1.86}$	0.71	132	1
Flynn Creek, OR—						
Fishtrap site	2.18	1979	$POM = 35.5.\,Q^{2.55}$	0.96	59	3
Riffle site	2.05	1979	$POM = 41.5\,Q^{2.70}$	0.81	26	3

[1/] BLD = bedload sediment transport, in kg hr^{-1}; Q = streamflow, in $m^3\ s^{-1}$; and POM = particulate organic matter, in kg hr^{-1}

[2/] 1 = Estep (1983), 2 = O'Leary and Beschta (1981), 3 = Edwards (1980), 4 = Beschta and others (1981).

A difference in the size and shape of bedload particles between the two streams may be reflected in the data collected from sampling bedload sediment during the largest storm at Flynn Creek (February 7, 1979) (Edwards 1980, Jackson and Beschta 1982) and the largest storm at Trap Bay Creek (October 1, 1980) (Estep 1983). The February 7 storm at Flynn Creek had a recurrence interval of approximately 1.8 years and for the 24-hour period produced a measured bedload yield of 13 t at a riffle. Riffles in Flynn Creek are typically characterized by a loosely formed armor layer comprised of 1- to 5-cm gravels overlaying a sand-gravel mixture (Jackson and Beschta 1982). The October 1 storm at Trap Bay Creek had a much longer recurrence interval (2-5 years) and for a 24-hour period produced a measured bedload yield of approximately 8 t. Particles comprising the armor layer at Trap Bay Creek are generally five times larger in diameter than those at Flynn Creek. Hence, greater relative discharge would be necessary to initiate and maintain transport of the larger and more angular particles in Trap Bay Creek than would be required to disrupt the armor and transport particles characterizing the bed of Flynn Creek. Interestingly, the D_{50} class of sediment in transport generally remained below 5 mm during both storms. These results would indicate, based on the work of Parker and Klingeman (1982) that the composition of the underlying bed material is quite similar for both streams.

Summary and Conclusions

The hand-held Helley-Smith sampler (modified with a larger bag) and temporary bridges over the stream provided a means of obtaining bedload sediment transport data in a relatively inaccessible area. Samples obtained enabled determination of bedload and POM transport in mountain streams.

Transport of bedload sediment was highly variable, both in time and space, but, in general, was positively correlated with streamflow. The rating curve relationships developed during this study period appeared to be site and storm specific. Diameter of particle size was not significantly related to discharge or to the total amount of material in transport. Transport of POM was positively correlated with streamflow even though the mechanisms controlling the availability and mobility of organic matter are obviously different than for sediment transport.

Storm events with a recurrence interval less than 1 year appeared to transport sediment past the upstream riffle of the study reach and into a pool where it was temporarily stored. Transport past the lower riffle required an event of greater magnitude. Once the streambed had been disturbed, transport past the lower riffle was accomplished by lesser magnitude events until an armor layer had reformed or the amount of sediment became limited. Unlike transport during storms of lesser magnitude, sediment transport during the storm of greatest magnitude did not increase proportionally at the riffle. Therefore, sediment availability appears to be limited at both upper and lower riffles. Any activity resulting in increased availability of sediment (increased input of sediment from upstream and/or alterations of the hydraulic characteristics of the stream) are likely to increase overall transport rates.

Extreme spatial and temporal variation in bedload transport was characteristic of both Flynn Creek and Trap Bay Creek. Although Trap Bay Creek is larger and steeper than Flynn Creek, total sediment yield appeared to be less and transport appeared to increase less rapidly with increasing streamflow. This may reflect the difference in the size and shape of particles comprising the bed: particles along the surface of the bed are typically larger and more angular at Trap Bay than those at Flynn Creek. An armor layer that resists transport is more likely to form in Trap Bay Creek.

Trap Bay Creek is a morphologically active stream that widened and filled in throughout its lower 1700 m between 1980 and 1981. Changes in channel morphology appear to be influenced by large organic debris in conjunction with streamflow and transport of bedload sediment. In addition, tidal action and research activities may have affected changes in the lower 1300 m of the channel.

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Metric Equivalents

1 millimeter (mm) = 0.039 inch
1 centimeter (cm) = 0.39 inch
1 meter (m) = 3.28 feet
1 kilometer (km) = 0.62 mile
1 tonne (t) = 2,205 pounds
°C = 5/9 (°F-32)

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Pacific Northwest Forest and Range
Experiment Station
319 S.W. Pine St.
P.O. Box 3890
Portland, Oregon 97208