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Predicting Crown Weight of Coast Douglas-fir and Western Hemlock

J.A. Kendall Snell and Brian F. Anholt

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Abstract

Snell, J. A. Kendall, and Brian F. Anholt.
1981. Predicting crown weight of coast Douglas-fir and western hemlock. USDA For. Serv. Res. Pap. PNW-281, 13 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Equations are presented for estimating weights of total crowns and crown components for Douglas-fir and western hemlock.

Keywords: Crown weights, biomass, residue weights, Douglas-fir, *Pseudotsuga menziesii*, western hemlock, *Tsuga heterophylla*.

Summary

Five large coast Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) and three large western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) were sampled to supplement existing data on crown weight and accumulative proportion equations for these species west of the summit of the Cascade Range in Oregon and Washington.

Existing data for the same species were categorized as coming from either east or west of the summit of the Cascade Range. Analysis of covariance was used to determine whether the crown weight slope coefficients developed from the east side data were significantly different from those developed from the west side data. No difference was found, and the sets of data were pooled and refitted to the same regression model used in the covariance analysis.

No difference was found between the slope coefficients for live crown weights when a transformation of d.b.h. was used as the single independent variable; but when a transformation of height was also included, a difference in slope coefficients was found. Also, a significant difference was found between the slope coefficients of dead branchwood weight.

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Introduction

This publication provides regression equations that can be used to estimate weights of total crowns and crown components[1] for coast Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*, up to 87-inch diameter at breast height (d.b.h.) and western hemlock, *Tsuga heterophylla* (Raf.) Sarg., up to 47-inch d.b.h. The equations were developed from data obtained from several sources: (1) *Inland* data--obtained from Brown (1978) who conducted an extensive study of the crown weights of 11 commercial conifers in western Montana and northern Idaho. He included much of Fahnestock's (1960) data that had been collected in the same geographic region and was compatible. (2) *Coastal* data--from Grier[2] and Woodard (1974), collected from forested areas west of the summit of the Cascade Range. (3) *Shelton* data--obtained from eight large trees (five Douglas-fir and three western hemlock) in the Shelton Ranger District of the Olympic National Forest and sampled in conjuction with this study.

For ease of discussion, the above sets of data will be referred to in this paper as *inland*, *coastal*, or *Shelton* data sets.

Description of Data

The *inland* data were collected from two crown-class categories--dominant/codominant[3] and intermediate/suppressed. The *coastal* data were collected in direct proportion to the frequency distribution of d.b.h. and tree height of sample stands. An exception was Woodard's (1974) data; these were collected by a method similar to that described for the *inland* data, except that no data were collected for intermediate/suppressed trees.

Since the *inland* data were collected in an environment notably different from that where the *coastal* and *Shelton* data were collected, it did not seem prudent to pool data sets without first finding out whether their respective slope coefficients were significantly different. This was done by using analysis of covariance; and when no significant difference was found between slope coefficients, the data sets were pooled.

Before an analysis of covariance could be done, however, the *inland* data had to be adjusted to represent the typical frequency distribution of d.b.h. and tree height found in sample stands. This was accomplished by using a mix of 35-percent dominant/codominant and 65-percent intermediate/suppressed crown class (Reukema and Bruce 1977). This mix was used as weighting factors during regression and analysis of covariance.

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[1] Components are defined as needles and branchwood in four diameter categories: 0.0- to 0.24-inch, 0.25- to 0.99-inch, 1.0- to 2.99-inch, and 3-inch and greater.

[2] Chuck Grier, University of Washington, Seattle. These data were a consolidation of data collected and used by Grier and his colleagues--Dice (1970), Emmingham (1974), Fujimori (1971), Fujimori et al. (1976), Grier and Logan (1977), Grier and Waring (1974), Heilman (1961), and Krumlik (1974).

[3] For definitions of the categories, see Ford-Robertson (1971).

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Woodard's (1974) data was excluded from all analyses of covariance since he sampled only dominant/codominant trees. This meant his data could not be weighted to achieve a representative d.b.h./height frequency. Since the d.b.h. range of the *Shelton* data did not overlap that of the *inland* data, it was also excluded from all analyses of covariance.

Discrepancies between sample sizes of the same data set are noted when they are used for different analyses. These discrepancies are caused by some trees being without vital information for one analysis but not for others. Missing data is common in most analyses, but it is more apparent and burdensome when data from many investigators are combined.

Limitations of the Data

The limited number of sample trees and the fact that they were not all randomly selected in the strict statistical sense are limitations of the data the reader and/or user should recognize. Nonrandom sample selection technically negates standard regression analyses, and users must be suspicious of misleading results. Standard regression analyses were used in spite of this limitation. We believe, however, that the sample trees were selected in a manner that makes them representative of Douglas-fir and western hemlock found in Pacific Northwest and Rocky Mountain areas and the nonrandom selection of trees is not a serious limitation. Users making weight estimates for use with high-cost operations, however, are advised to carefully check the validity of their estimates--it may be necessary to develop local estimators.

Field Procedures

Field procedures used to collect the *Shelton* data were essentially identical to those reported by Brown (1978) for the *inland* data. This was done to facilitate statistical combination of the two data sets.

Five Douglas-fir trees ranging from 36.1- to 86.9-inch d.b.h. and three western hemlocks ranging from 45.0- to 46.5-inch d.b.h. were selected from the Shelton Ranger District of the Olympic National Forest. The trees were dominants and codominants and were selected to represent other similar-sized trees in the area.

The live crown of each sample tree was visually divided into three horizontal sections according to branching characteristics. All dead branches within and below the live crown were considered to be a fourth section. Each tree was climbed as high as safely possible and topped. As the climber proceeded up each tree all limbs were cut flush with the bole. The limbs from each of the four crown sections (three live and one dead) were weighed separately in the field with spring scales. The three live crown sections were categorized as lower, middle, and upper. From each live crown section we selected a typical branch which we termed "a sample branch." Each sample branch was separated into component classes (see footnote 1). A moisture sample was taken in the field from each component immediately after each sample branch component was weighed. The moisture samples were later oven-dried at 103°C for 24 hours. The raw data are shown in the appendix.

Data Analysis

The Shelton data were analyzed (see below), and resulting data pooled with other data sets depending on the result of the analysis of covariance between the inland and coastal data sets. The pooled data sets were used to develop the regression equations.

Live crown analysis.--To separate the crowns of the Shelton trees into component weights, the three horizontal live crown sections were analyzed separately and then combined. The sample branches, which represented all branches in their sections, were separated into component classes. Using total green weights of sample branches as the base, accumulative proportions[4] were developed for each sample branch.

Accumulative proportions are the progressively summed component weights divided by their sum of all component weights. These proportions when subtracted one from the other yield the proportion for individual components.

These individual proportions were multiplied by their respective section total green weight, yielding estimates of their total component green weights. The moisture samples from each crown section were used to convert component green weights of crown sections to ovendry weights. The individual ovendry components were totaled for the three crown sections to get an estimate of total weight of tree components. By adding the totals for each tree, an estimate was obtained of total ovendry live crown weight. With this total as the base, accumulative proportions, which applied to the entire tree, were developed for each sample tree.

The data used for this study were classified as being from either the east or west side of the summit of the Cascade Range. Data from the same side--although from different investigators--were considered to represent the same population and were pooled into one data set. As mentioned earlier, analysis of covariance was used as an objective means to test whether tree data from the east side (inland data set) or west side (coastal and Shelton data sets) could be pooled.

The regression models used in the covariance analysis were selected from a computer program (REX) (Grosenbaugh 1967). Three criteria were used to select the models for the analysis of covariance: (1) They had the lowest ratio of mean squared residuals (RMSQR) (Grosenbaugh 1967) of all models examined. (2) When plotted against a scatter of their raw data they visually fit the data best. (3) They were examined to see how logically they predicted beyond the limits of their data, and those models that obviously predicted erroneously were discarded. These three criteria were used to select several models for each data set (inland and coastal), and those models that were common between them were used in the analysis of covariance and are shown in table 1.

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[4] Proportion 1 (P1) = foliage weight divided by total branch weight (t.b.w.); P2 = P1 + (0.0- to 0.24-inch-diameter branchwood weight (d.b.w.) divided by t.b.w.); P3 = P2 + (0.25- to 0.99-inch-d.b.w. divided by t.b.w.); P4 = P3 + (1.0- to 2.99-inch-d.b.w. divided by t.b.w.).

Table 1 --Covariance analysis statistics comparing regression slope coefficients between data sets for inland and coastal Douglas-fir and western hemlock[1]

Species[2]	Model number[3]	Sample size (n)	[4] R^2	MSE[5]	F-statistic for slope[6]
		LIVE CROWN WEIGHT			
Inland DF	1	56	0.91	0.2797	3.03
Coastal DF	1	112	.90	.3986	
Inland DF	2	56	.94	.1841	5.79**
Coastal DF	2	103	.94	.2506	
Inland WH	1	27	.98	.0561	6.83
Coastal WH	1	28	.92	.3079	
Inland WH	3	27	.98	.0581	5.41**
Coastal WH	3	28	.96	.1669	
		DEAD CROWN WEIGHT			
Inland DF	4	33	.91	683.4	621.48**
Coastal DF	4	74	.95	147.3	

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[1] Inland data is from Brown (1978) who conducted studies in western Montana and northern Idaho. Coastal data are from Grier (see footnote 2 of text) and Woodard (1974) for west of the summit of the Cascade Range.

[2] DF = Douglas-fir, WH = western hemlock.

[3] Model 1, $\ln(W)= B1 + B2 \ln(d)$; model 2, $\ln(W)= B1 + B2 \ln(d) + B3 (h/d)$; model 3, $\ln(W)= B1 + B2 \ln(d) + B3 \ln(h)$; model 4, $DW = B1 + B2 (d^3)$; where ln = natural logarithm; W = live crown weight in ovendry pounds; B1, B2, and B3 = regression coefficients; d = d.b.h. in inches; h = total tree height in feet; and DW = dead crown weight in ovendry pounds.

[4] Coefficient of determination.

[5] MSE = mean square error of residuals.

[6] Two asterisks indicate a significant difference at the 0.01 level between regression coefficients of the two data sets.

Table 2 --Regression equations for predicting live crown weight of Douglas-fir and western hemlock

Species[1]	Prediction equations[2]	Sample size (n)	[3] R^2	$\sqrt{MSE}$[4]
DF	W = Exp(0.0623+1.949 ln(d))[5]	173	0.91	227.1
DF	W = Exp(-0.7224+1.888 ln(h)-0.3873 (h/d))[5]	108	.97	237.8
WH	W = Exp(0.3157+1.907 ln(d))[5]	58	.94	196.0
WH	W = Exp(4.577+3.228 ln(d)-1.760 ln(h))	32	.97	131.7

[1] DF = Douglas-fir; WH = western hemlock.

[2] W = live crown weight in ovendry pounds; Exp = 2.7183 to the power enclosed in parentheses; ln = natural logarithm; d = d.b.h. in inches; h = total tree height in feet.

[3] Coefficient of determination.

[4] For logarithmic functions, the mean square error of residuals (MSE) was calculated as $\sum(P-O)^2/df$, where P and O are predicted and observed values, respectively, transformed to arithmetic units and df is the residual degrees of freedom.

[5] The (mean square error of residuals from transformed data)/2 was added to the intercept regression coefficient (Baskerville 1972) to correct for log bias inherent in dependent log transformations.

Models 2 and 3 suggest that a slight but noticeable reduction in mean square error can be gained over model 1 by adding a transformation which includes height. Since height is not always available, however, model 1 with d.b.h. as the only independent variable was also compared with covariance analysis.

As shown in table 1, no significant difference was found between inland and coastal slope coefficients for model 1. Based on this information, the inland, coastal, and Shelton data sets were pooled to develop one live crown weight equation that can be used on either side of the Cascade Range for Douglas-fir with less than 87-inch d.b.h. and western hemlock with less than 47-inch d.b.h. The equations are presented in table 2. Conversely, when the inland and coastal data sets were compared for models 2 and 3 (which contain a transformation with height and apply to Douglas-fir and western hemlock respectively), a significant difference was found between their slope coefficients. Therefore, only the coastal and Shelton data sets were pooled (both are west-side data sets) to develop weight equations for the west side of the Cascade Range.

Dead Crown Analysis.--The only data available for analysis of dead crown weight was for Douglas-fir. When weighted regression was used through the REX (Grosenbaugh 1967) computer program, the following common model fit both the coastal and inland Douglas-fir data sets better than other models examined:

Model 4 $DW = B1 + B2\,(d^3)$,

where

DW = dead branchwood weight in oven-dry pounds

$B1$ and $B2$ = regression coefficients

d = d.b.h. in inches.

When covariance analysis was used, a significant difference was found between the slope coefficients of model 4 when they were fitted to the two data sets.

Since the slope coefficients were different, the coastal and inland data were not combined. Only the coastal and Shelton data were used to develop the dead crown weight equation. Since the inland data was not included, there was a gap in the data between 10- and 30-inch d.b.h. making it difficult to fit a curve to the remaining data points. A visual examination of the probable slopes for the data between 1- to 10- and 30- to 90-inch d.b.h. revealed that they would differ noticeably. Therefore, segmented polynomial regression was used to fit a curve to the data. The slopes of the two segmented curves intersected at 9.8-inch d.b.h. The resulting model is shown below and is further illustrated in figure 1.

$$DW = 22.46 + 0.0010(X) + 0.2425(Z)$$

where

DW = dead crown weight in ovendry pounds

If d.b.h. is equal to or less than 9.8 inches, $X = 9.8^3$.

If d.b.h. is greater than 9.8 inches, $X = d^3$.

If d.b.h. is equal to or less than 9.8 inches, $Z = d^2 - 9.8^2$.

If d.b.h. is greater than 9.8 inches, $Z = 0.0$.

The sample size (n), coefficient of determination (R^2), and the square root of the mean square error of residuals (MSE) are 90, 0.97, and 17.74, respectively. This model consists of two curve segments that join at 9.8-inch d.b.h. It was constrained to be continuous at 9.8-inch d.b.h.; but its first derivative was not constrained to be continuous at the point where they join, causing an irregular curve. Until additional data become available, it seems reasonable from the data presented in figure 1, to assume that dead weight increases only slightly between 10- and 30-inch d.b.h.

Accumulative proportions.--Accumulative proportion equations (see footnote 4) were developed for the live crown weight of Douglas-fir; the equations are presented in table 3 and illustrated in figure 2. Most of the coastal data could not be used in these analyses because the crown weight of sample trees had not been separated into components (see footnote 1) except for Woodard's (1974). Since the Woodard (1974), inland, and Shelton data were all dominant/codominant trees, and they all had the same crown component separations, these data were pooled to develop the Douglas-fir accumulative proportions equations.

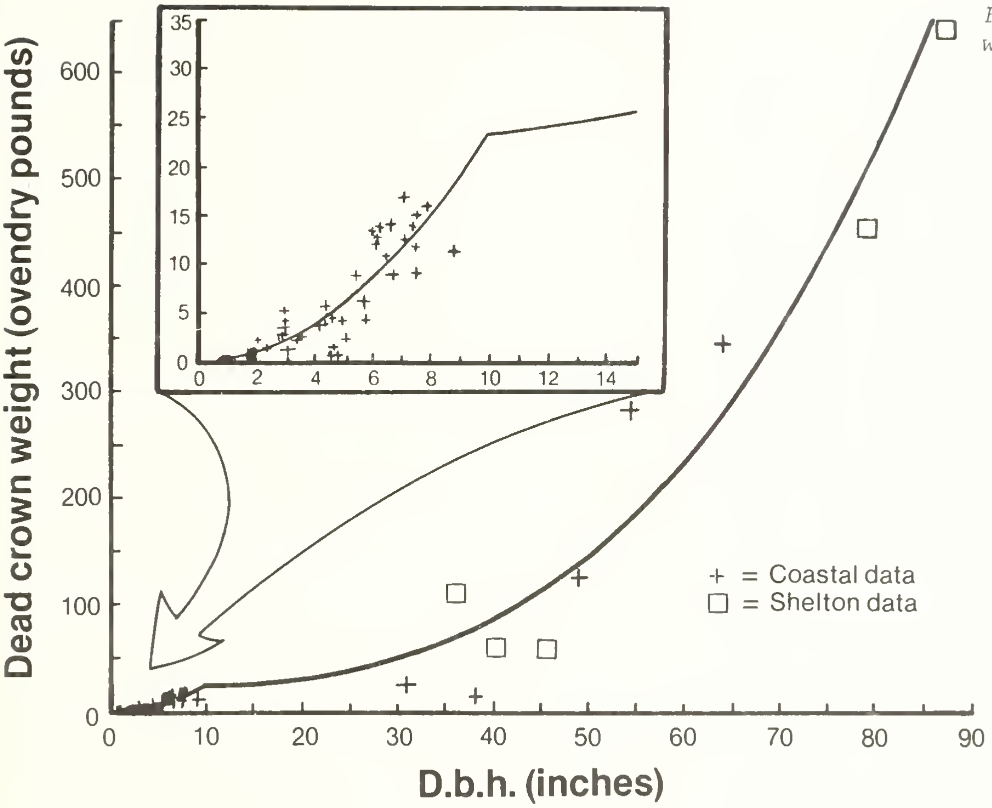

Figure 1.--Dead crown weight of Douglas-fir.

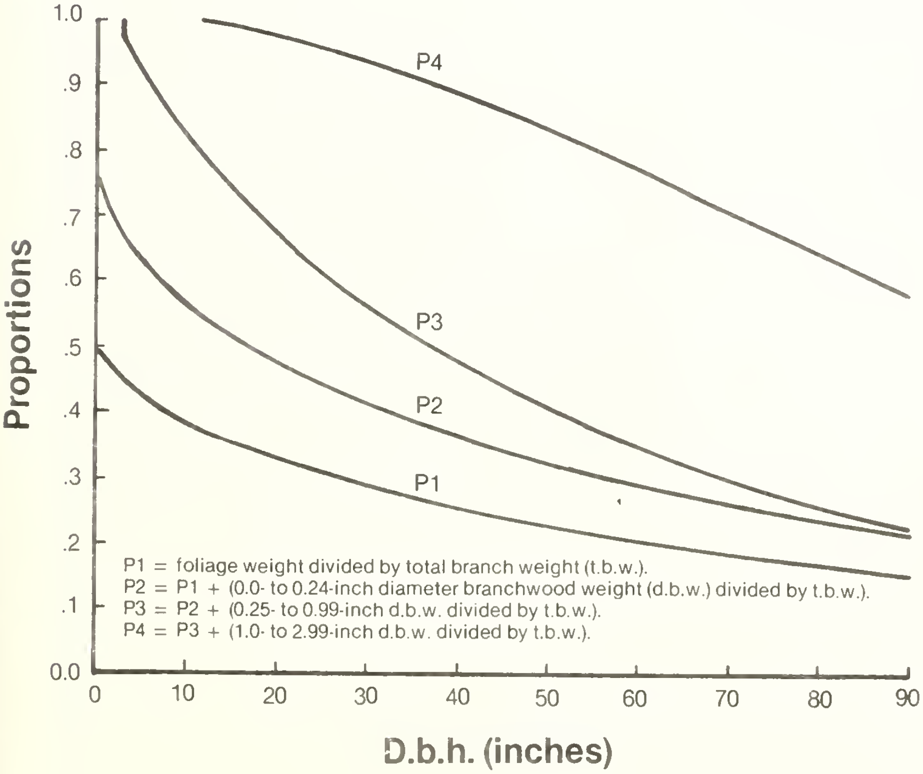

Figure 2.--Accumulative proportions for live crown weight of Douglas-fir.

There were insufficient data for regression analysis of the accumulative proportions for west-side western hemlock.

Table 3 --Accumulative proportion equations for live crown weight of coastal Douglas-fir

$$P = \text{Exp}(B1 + B2\ (d)^{B3})$$ [1]

P	Regression coefficients			Number of observations	MSE[2]	Conditions
	B1	B2	B3			
1	-0.6916	-0.0546	0.6842	33	0.0021	
2	- .2676	- .0683	.6482	33	.0037	
3	.0693	- .0415	.8050	33	.0071	If d is less than 2 inches, P3 = 1.00.
4	.0122	- .0002	1.7623	18	.0015	If d is less than 11 inches, P4 = 1.00.

[1] P = accumulative proportion; Exp = 2.7183 to the power enclosed in parentheses; B1, B2, and B3 = regression coefficients; and d = d.b.h. in inches.

[2] MSE = mean square error of residuals.

Results and Discussion

For model 1, no difference was found between slope coefficients for either Douglas-fir or western hemlock. Therefore, the data were pooled for each species and refitted to model 1. The equations developed from these pooled data (see table 2) provide land managers in the Pacific Northwest with equations for predicting live crown weight using d.b.h. as the only independent variable. These can be used for Douglas-fir and western hemlock up to 87- and 47-inch d.b.h., respectively.

A significant difference was found between slope coefficients for models 2 and 3 of the *inland* and *coastal* data sets. Therefore, the *inland* and *coastal* data sets were not combined for either species. The *Shelton* and *coastal* data sets were combined and fitted to a regression model, however, since they were both west-side data sets (see table 2). By including the *Shelton* trees and excluding the *inland* trees when the data were refitted for Douglas-fir, the MSE changed from being smaller to being larger than the MSE of model 1. This anomaly was unfortunate but further illustrates the need for more work to identify the correct model(s) for predicting crown weight.

Accumulative proportion data were insufficient to develop regression equations for the *coastal* trees; therefore, statistical comparisons between *inland* and *coastal* regression coefficients were not possible. The *Shelton* and Woodard (1974) trees were, however, separated into components (see footnote 1); and although their d.b.h. ranges did not overlap with the *inland* trees, it was possible to plot these data for visual comparisons. It was our opinion the data sets fitted together logically and could be pooled. Accumlative proportion functions were fitted to these pooled data for Douglas-fir (see table 3 and footnote 4); but since the data were too scant for western hemlock, regression equations were not developed. For small western hemlock (less than 30-inch d.b.h.), Brown (1978) provides proportion equations; but for larger western hemlock, the averages of proportions developed from the three *Shelton* trees (average d.b.h. of 45.6 inches), may be helpful--P1, P2, P3, and P4 are 0.23, 0.35, 0.47, and 0.85, respectively (see footnote 4).

Until more data are available, these accumulative proportions should yield reasonable estimates of crown component proportions for large coastal western hemlock.

Note that the proportion equations were developed from dominant/codominant trees; if applied to intermediate/suppressed trees, additional error could result.

Comparisons were also made between slope coefficients for dead branchwood of *inland* and *coastal* Douglas-fir; a significant difference was found in the regression slopes of the two data sets. Therefore, only the *Shelton* and *coastal* data were combined and fitted to a segmented polynomial model. Data were not available to develop equations for weights of dead branchwood of west-side western hemlock.

Although more data on Douglas-fir dead branchwood are needed, an interesting phenomenon appeared in comparisons of weights of inland and coastal Douglas-fir dead branchwood. For a given d.b.h. (especially above 10-inch d.b.h.), the dead branchwood weight of the inland tree is notably greater than that of the coastal tree. Evidently, dead branches do not persist as long in a moist climate as they do in a drier inland climate. Although the weight of live branchwood of coastal and inland trees is similar, the weight of dead branchwood appears greatly different.

Although crown weight and proportion equations were developed for coast Douglas-fir and western hemlock, more data are needed to strengthen them. To estimate the crown weights of other west coast conifers see Snell and Brown (1980).

Metric Conversions

When you know	multiply by	to find
inches	2.540	centimeters
feet	0.305	meters
pounds	0.454	kilograms
pounds per square foot	4.883	kilograms per square meter
tons per acre	2.242	metric tonnes per hectare
cubic feet per acre	0.070	cubic meters per hectare
degrees Fahrenheit	(5/9)(°F-32)	degrees Celsius

Literature Cited

Baskerville, G. L.
1972. Use of logarithmic regression in the estimation of plant biomass. Can. J. For. Res. 2:49-53.

Brown, James K.
1978. Weight and density of crowns of Rocky Mountain conifers. USDA For. Serv. Res. Pap. INT-197, 56 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Dice, S. F.
1970. The biomass and nutrient flux in a second-growth Douglas-fir ecosystem (a study in quantitative ecology). Ph.D. thesis. Univ. Wash., Seattle. 165 p.

Emmingham, William H.
1974. Physiological responses of four Douglas-fir populations in three contrasting field environments. Ph.D. thesis. Oreg. State Univ., Corvallis. 162 p.

Fahnestock, G. R.
1960. Logging slash flammability. USDA For. Serv. Res. Pap. INT-58, 67p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Ford-Robertson, F. C., ed.
1971. Terminology of forest science, technology practice and products. 349 p. Soc. Am. For., Washington, D.C.

Fujimori, Takao.
1971. Primary productivity of a young Tsuga heterophylla stand and some speculations about biomass of forest communities on the Oregon coast. USDA For. Serv. Res. Pap. PNW-123, 11 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Fujimori, Takao, Saburo Kawanabe, Hedeki Saito, Charles C. Grier, and Tsunahide Shidei.
1976. Biomass and primary production in forests of three major vegetation zones of the northwestern United States. J. Jap. For. Soc. 58(10):360-373.

Grier, Charles C., and Robert S. Logan.
1977. Old-growth Pseudotsuga menziesii communities of a western Oregon watershed: Biomass distribution and production budgets. Ecol. Monogr. 47(4):373-400.

Grier, Charles C., and Richard H. Waring.
1974. Conifer foliage mass related to sapwood area. For. Sci. 20:205-206.

Grosenbaugh, L. R.
1967. REX-FORTRAN-4 SYSTEM for combinatorial screening or conventional analysis of multivariate regressions. USDA For. Serv. Res. Pap. PSW-44, 47 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Heilman, P. E.
1961. Effects of nitrogen fertilization on the growth and nitrogen nutrition of low-site Douglas-fir stands. Ph.D. thesis. Univ. Wash., Seattle. 214 p.

Krumlik, G. J.
1974. Biomass and nutrient distribution in two old-growth forest ecosystems in south coastal British Columbia. M.S. thesis. Univ. B.C., Victoria. 180 p.

Reukema, Donald L., and David Bruce.
1977. Effects of thinning on yield of Douglas-fir: Concepts and some estimates obtained by simulation. USDA For. Serv. Gen. Tech. Rep. PNW-58, 36 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Snell, J. A. K., and J. K. Brown.
1980. Handbook for predicting residue weights of Pacific Northwest conifers. USDA For. Serv. Gen. Tech. Rep. PNW-103. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Woodard, Paul M.
1974. Predicting crown slash weights in Douglas-fir. M.S. thesis. Univ. Wash., Seattle. 94 p.

Appendix

Table 4 --Crown weight data by foliage and branchwood component for five dominant Douglas-fir and three dominant western hemlock trees sampled on the Shelton Ranger District of the Olympic National Forest

D.b.h.	Total tree height	Live crown length	Ovendry weight of live crown components						Ovendry weight of dead crown components		
			Needles	0-0.24 inch	0.25-0.99 inch	1.00-2.99 inches	3.00+ inches	Total	1.00-2.99 inches	3.00+ inches	Total
Inches	Feet	Feet	Pounds						Pounds		
					DOUGLAS-FIR						
36.1	180	82	245.2	96.2	205.8	614.9	172.4	1334.5	112.7	0	112.7
40.6	176	110	301.0	122.7	261.3	437.9	307.3	1430.2	63.4	0	63.4
45.3	185	82	491.2	188.3	400.7	606.9	195.4	1882.5	59.8	0	59.8
78.9	218	116	659.8	265.5	326.1	1004.5	1352.6	3608.5	459.9	0	459.9
86.9	255	140	1009.6	383.9	707.8	1848.1	2244.4	6193.8	74.5	568.7	643.2
					WESTERN HEMLOCK						
45.0	204	127	518.9	276.6	233.2	742.3	178.0	1949.0	39.2	0	39.2
45.3	165	90	661.4	354.1	366.9	1183.3	488.8	3054.5	0	83.8	83.8
46.5	187	123	491.2	201.3	291.9	832.5	431.3	2247.2	147.2	0	147.2

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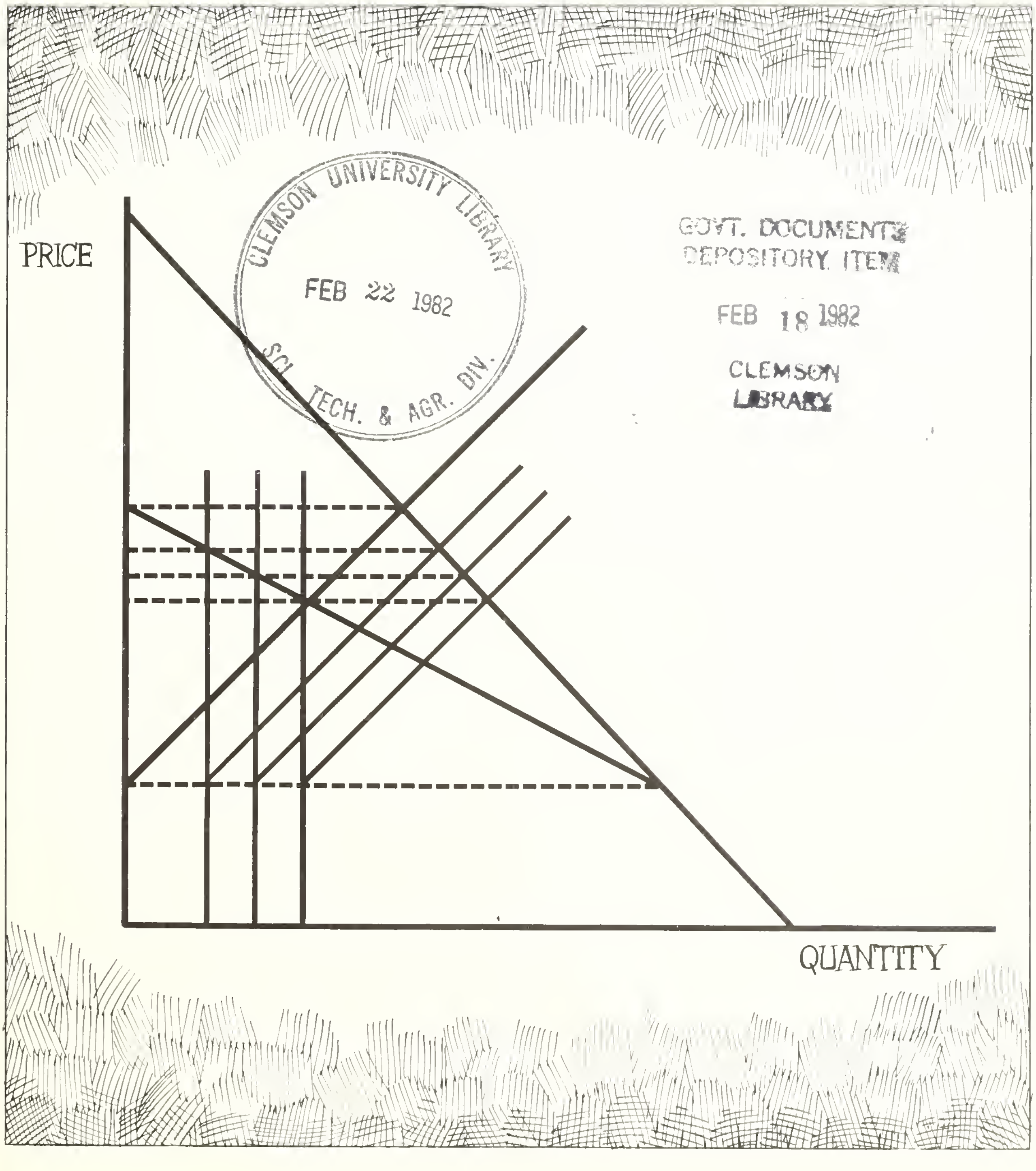
Projections of the Demand for National Forest Stumpage by Region; 1980-2030

Richard W. Haynes, Kent P. Connaughton, and Darius M. Adams



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Abstract

Haynes, Richard W., Kent P. Connaughton, and Darius M. Adams. 1981. Projections of the demand for National Forest stumpage, by Region, 1980-2030. USDA For. Serv. Res. Pap. PNW-282, 13 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

The concept of regional demand is described and applied to the demand for National Forest stumpage. Specifically, demand functions for stumpage (price-quantity relationships) are developed by decade for the major National Forest Regions. The demand functions are consistent with the 1980 timber program prepared under requirements of the Renewable Resources Planning Act of 1974 (RPA) and provide forest planners with a mechanism to relate National Forest Regional harvest levels to prices.

Keywords: Projections (demand), supply/demand (forest products), stumpage prices, National Forests.

Summary

The National Forest Management Act of 1976 has stimulated interest in assessing demands for timber on National Forests as a price-quantity relationship. Assessments must be coinsistent with both economic theory and the projections of forest products markets made to support USDA Forest Service timber programs required by the Renewable Resources Planning Act of 1974 (RPA).

A model of Regional demand for National Forest stumpage is based on concepts from economic theory and uses data from the RPA efforts. The resulting demand relationships can be used to investigate policy questions such as the effects on price of changing National Forest harvest flows. The magnitude of the impact of National Forest timber supply on prices and quantities in the product and factor markets depends on the product-demand relationship, derived demand, and the supply of stumpage from other ownerships. The principles of demand that apply to a geographic region have implications for individual National Forests in that region.

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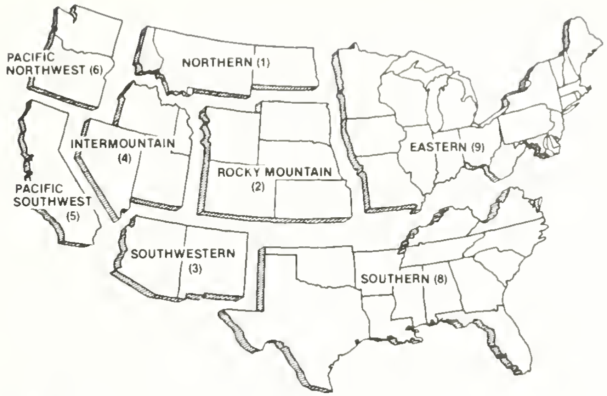
Introduction

The National Forest Management Act (NFMA) (U.S. Laws, Statutes, etc. 1976) has lead to significant changes in National Forest planning. Some of the most important changes deal with economic concepts in planning. The regulations issued pursuant to the act specifically state that "projections of demand . . ., in conjunction with the supply cost information will be used to evaluate the level of goods and services that maximizes net public benefits; to the extent possible demand will be assessed as a price-quantity relationship (USDA Forest Service 1979)." This last statement has led to speculation about the nature of demand functions at both the National Forest and regional level—particularly how demand functions might be defined in ways that are consistent with both economic theory and the projections of forest products markets made to meet requirements of both the Renewable Resources Planning Act (RPA) (U.S. Laws, Statutes, etc. 1974) and the NFMA.

The purpose of this paper is to provide demand relationships for National Forest timber for each Forest Service Region (fig. 1A). These relationships can be used in planning at Forest Service regional and national levels. They are based on projections of softwood stumpage price and quantity that were made for each geographical region (fig. 1B) for the 1980 RPA effort (USDA Forest Service 1980a). Forest Service Administrative Regions are hereafter capitalized. The geographic regions used in RPA planning are not.

This paper deals only with regional demand for National Forest timber. It is written for National Forest planners and others interested in the planning process. Resource analysts and others interested in the effect on price of harvest levels on the National Forests may also find this information useful. Since regional harvest levels are likely to affect local prices, our results have implications for planning on individual National Forests. These implications, however, are not yet significantly developed and are only briefly discussed in this report.

A



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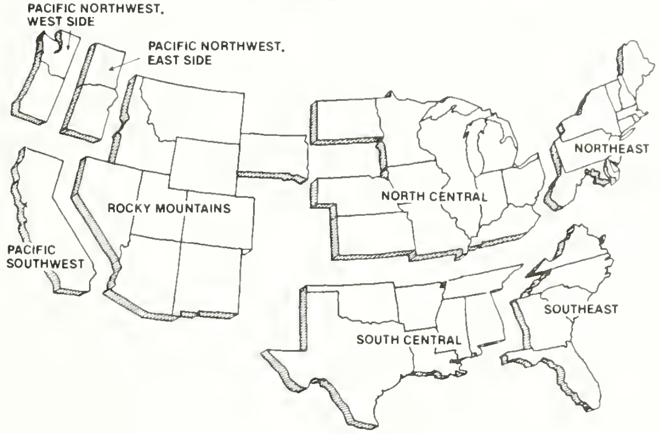

Figure 1A.—USDA Forest Service Administrative Regions excluding Alaska.

Figure 1B.—The 1980 Renewable Resources Planning Act (RPA) regions. Alaska is excluded in the analysis and Hawaii is added to the Pacific Southwest.

We view demand as the relationship between price and the maximum quantity of a good or service that buyers are willing to purchase. The demand for stumpage is derived from the demand for wood products. We further derive the demand of a region for stumpage on the National Forests from the demand for stumpage on all ownerships. Our approach is the same as that used in the Roadless Area — Intensive Management Tradeoff Study (Fight et al. 1978) to simulate the impacts of withdrawals of roadless areas on prices in a region. The demand curves and projections are fully consistent with the 1980 RPA assessment (USDA Forest Service 1980b) of the Nation's timber resource, and with the high bound recommended RPA program for the 1980's.

The paper is organized into three parts: (1) a discussion of the concept of regional demand and how it applies to stumpage on the National Forests, (2) projections of the demand curves, and (3) an interpretation of the results. The first section is prefaced by a review of the concepts of demand, supply, market price, and price elasticity. Examples are presented to illustrate the demand curves developed in the second part. The implications for planning on individual National Forests are discussed in the third part.

Regional Demand and Its Application to National Forest Stumpage

Stumpage prices are established on individual sales where prices capture differences in species, quality, transportation costs, technology, contract length, and bidder competition. Though stumpage markets are localized, unrestricted trade between local areas is possible, so prices for a particular species in one area must be in line with prices at other locations adjusted for differences in transportation costs. If not, purchasers from neighboring areas will buy in the lower priced area, driving prices up until they are the same (net of transportation costs) as other areas. This process is called arbitrage, and its implications are that we can treat average stumpage prices as if they were determined in regional rather than local markets. To further simplify our analysis, we assume that there is a single "composite" species. The price of our single species is the volume-weighted average price of all species within the region.

Demand, Supply, and Market Price

In this section, we review the basic concepts which are essential for an understanding of the demand for stumpage. Throughout, we make the assumption that regional stumpage markets correspond to the conventional notion of competitive markets.[1] In a competitive market, resources (stumpage) are efficiently allocated through the market forces of supply and demand.

Demand.—Demand curves express the relationship between alternative prices of a commodity and the quantities consumers are willing to purchase at each price. The demand relationship is determined by the preferences of consumers, the income of consumers, and the prices of substitutes and complements. Curve D_p in figure 2 is an example of a demand curve. It slopes downward to the right, indicating that consumers would purchase greater and greater quantities as price falls lower and lower. All demand relationships correspond to a given interval of time, so a complete description of demand is given in terms of the quantity demanded per unit of time. The curves reported elsewhere in this paper are for the annual quantity demanded.

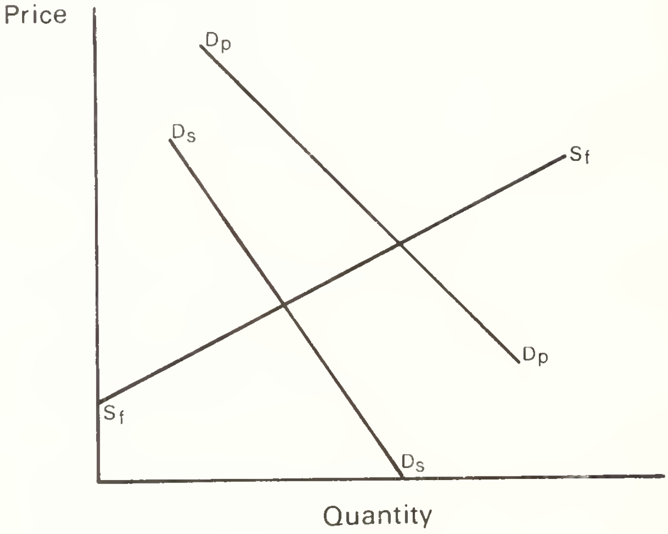

Figure 2.—The derived demand for stumpage.

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[1] The traditional assumptions which underlie a competitive market are: 1) many producers and buyers, each too small to affect price, 2) homogeneous product, 3) producers and buyers have perfect information, and 4) producers are free to enter and leave the market.

The demand for stumpage is derived from the demand for wood products (Gregory 1972, Haynes 1977). Therefore, the shape and position of the regional demand curve for stumpage is dependent not only on the supply of stumpage from other sources and the supply of other manufacturing inputs for the wood products sector, but also on the shape of the demand curve for wood products. Figure 2 shows a graphical derivation of the demand for stumpage assuming a fixed coefficient production function.[2] The demand for wood products is shown as D_p and the supply curve for all factors of production **other** than stumpage is shown as S_f. The derived demand is the vertical difference between D_p and S_f and represents the maximum amount that could be paid for each quantity of stumpage while still compensating all other factors of production.

When we speak of a shift in demand, we are referring to a change in the position of the demand curve. Such a shift is shown as the change from D_1 to D_2 in figure 3. An example of such a shift would be the change in demand which we project through time (e.g. D_1 might correspond to 1980 and D_2 to 1990). A change in quantity demanded, however, corresponds to a movement along a demand curve.

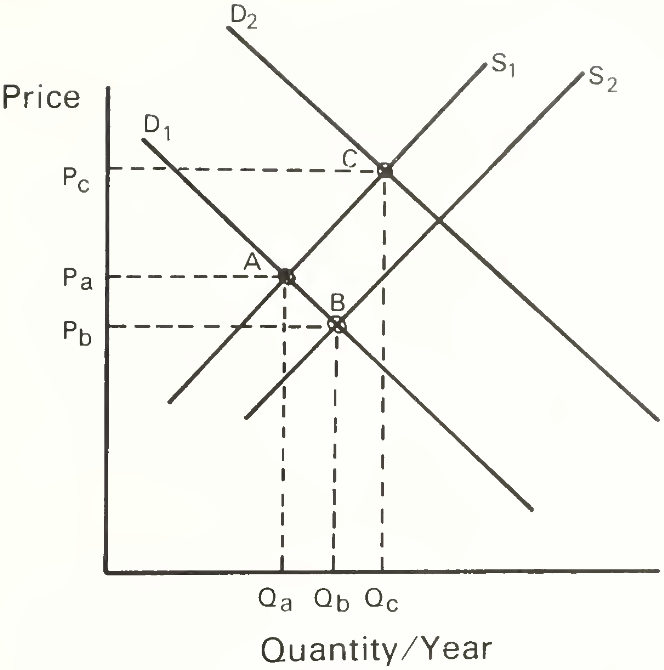

Figure 3.—Demand, supply, and market price determination.

Supply.—Supply is the relationship between price and the quantity that sellers would place on the market. Supply curves are, in general, upward sloping—the higher the price, the greater the quantity sellers would be willing to provide. Curve S_1 in figure 3 is an example of a supply curve. As with demand, supply curves apply to a stated interval of time. Shifts in a supply curve, as from S_1 to S_2 in figure 3, refer to changes in position.

The supply of stumpage from the National Forests is not considered responsive to price since the amount of timber offered is set by agency policies that generally do not consider current or expected future prices.

Market Prices.—Price is determined by the interaction of supply and demand forces. At a price of P_a (fig. 3), consumers are willing to purchase a quantity of Q_a; at the same time, suppliers are willing to provide Q_a at price P_a. Price P_a, therefore, is an equilibrium price in that the quantity demanded is equal to the quantity supplied.

Changes in either supply or demand will bring about a change in equilibrium price and quantity. For example, a shift in demand from D_1 to D_2 leads to a new equilibrium price of P_c for quantity Q_c. Had supply shifted instead as from S_1 to S_2, price would have fallen from P_a to P_b and quantity would have increased to Q_b.

Price Elasticity.—Elasticity is a quantitative measure of the responsiveness of quantity demanded (or the quantity supplied) to changes in price. The price elasticity of demand is the percentage change in quantity divided by the percentage change in price. Price elasticity of supply is similarly defined. Demand or supply is said to be elastic (inelastic) if the percentage change in quantity is greater (less) than the percentage change in price. Demand (supply) is unitary elastic if the percentage change in quantity is equal to the percentage change in price. Elasticities are either computed at a single point on a demand or supply curve (point elasticity) or between two points on the same demand or supply curve (arc elasticity).

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[2] A fixed coefficient production function states that inputs are combined in fixed proportions to produce quantities of output.

Estimates of elasticity vary through time. The relationships in general become more elastic as technological improvements lower processing costs and industry shifts from less competitive regions to regions with greater competitive advantage. An increase in elasticity of stumpage supply from all sources other than the USDA Forest Service would also serve to increase the elasticity of the demand curve for National Forest stumpage, and, therefore, reduce the sensitivity of regional stumpage price to changes in National Forest supply. Finally, changes in the relative prices of substitutes, complements for wood products, and national income would change the elasticity of product demand, and hence the demand relationship for National Forest stumpage.

The Regional Demand for National Forest Stumpage

The regional demand for stumpage on the National Forests is the relationship between price in the regional stumpage market and the level of timber offerings on the National Forests. This relationship cannot be directly observed from market transactions since the National Forests contribute only a portion of the total quantity supplied in each region and it is total quantity that establishes regional prices. We can, however, deduce the relationship between price and National Forest timber offerings. Further, we can do this in a way that allows for simultaneous supply adjustments on other ownerships. The underlying economic model is a combination of the models of derived demand, excess demand (from the international trade literature), and the dominant firm (from oligopoly theory).[3]

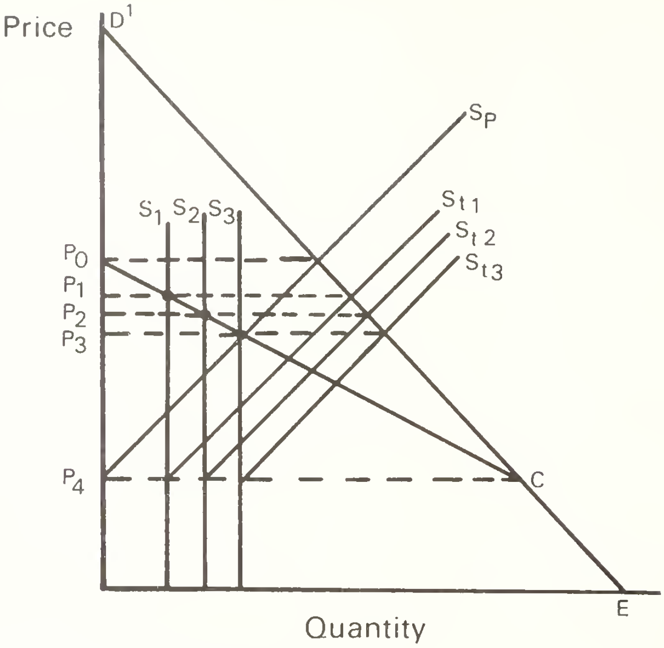

Figure 4.—The regional demand for National Forest stumpage.

Figure 4 displays the elements of demand and supply analysis that are necessary to determine the regional demand for National Forest timber. The supply curves for stumpage for all ownerships other than the National Forests have been consolidated and are represented by the curve S_p. The demand curve for timber (from all ownerships) is D^1E. Three different levels of National Forest harvests are shown: S_1, S_2, and S_3. Total supply is the sum of supply from the National Forests and all other ownerships. Graphically, total supply is the horizontal sum of the two supply components and is labeled S_{t1}, S_{t2}, and S_{t3} for each of the different National Forest harvest levels.

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[3] Further detail on this model and several common alternatives are provided in Connaughton,Kent and Richard W. Haynes. The regional derived demand for stumpage on the National Forests. (In press) USDA For. Serv., Pacific Northwest For. and Range Exp. Station, Portland, Oreg.

Price is determined by the intersection of demand and total supply. If the National Forest harvest level is S_1, price is P_1, if the National Forest harvest level is S_2, price is P_2, and if the National Forest harvest level is S_3, price is P_3. The effect of changing National Forest harvest levels is to shift the total supply curve. The locus of points from the intersection of price and alternative National Forest harvest levels is graphically depicted as P_0CE and is the regional demand for National Forest timber.[4]

The demand for National Forest timber is more elastic than the regional derived demand for timber from all ownerships. This elasticity depends on the elasticity, or slope, of the supply relationships for other ownerships. An increase, for example, in the National Forest harvest level shifts total supply to the right, leading to a lower price and a simultaneous reduction in quantity. Reductions in the quantity supplied from other ownerships offset the increase in National Forest harvest if the supply curve for other ownerships is not totally inelastic. With the reductions in the quantity supplied from other ownerships, the change in the total quantity supplied in the region is less than the change in the quantity offered for sale on the National Forests, and the demand for stumpage on the National Forests is more elastic than the derived demand for stumpage on all ownerships.

The pattern of events traced out in the preceding paragraph depends on the assumption that National Forest timber supply is perfectly inelastic. National Forest timber supply is established by policies which treat the harvest as a schedule of output through time rather than the relationship between output and price in any time period. Therefore, though price projections may affect the temporal schedule of harvests, they do not affect the schedule within a given time period (say 1 year). Budget restrictions or market conditions on the demand side, however, may influence the ability of the National Forests to actually sell the intended volume of timber.

An Example of the Effects of a Change in the Supply of Stumpage from National Forests in a Region.—Figure 5 traces the impacts of a change in the level of National Forest supply on stumpage price, harvest from other ownerships, total harvest from all ownerships, lumber price and lumber production. Lumber demand (DD), derived demand for stumpage (D^1E), demand for National Forest stumpage (P_0CE) and stumpage supply from other ownerships (S_p) are the same as shown in figure 4. National Forest supply is established during the forest planning process and can be represented as a totally inelastic (nonprice responsive) supply curve. Suppose that the supply from the National Forests increases from O to ON. The total supply of stumpage increases from S_p to S^1. The harvest from other ownerships contracts from OA to OA^1 because the increased Federal harvest drives down stumpage price from P_0 to P_2. Total harvest increases from OA to OF, though the magnitude of the change in the total is less than the increase in the National Forest supply because of the offsetting decrease in the harvest from other ownerships. Lumber production increases because of the decrease in stumpage price, and lumber prices fall from P_{L1} to P_{L2}. The magnitude of the impact of changes in the supply of stumpage from the National Forest on prices and quantities in the product and factor markets depends on the product demand relationship, derived demand, and the supply of stumpage from other ownerships.

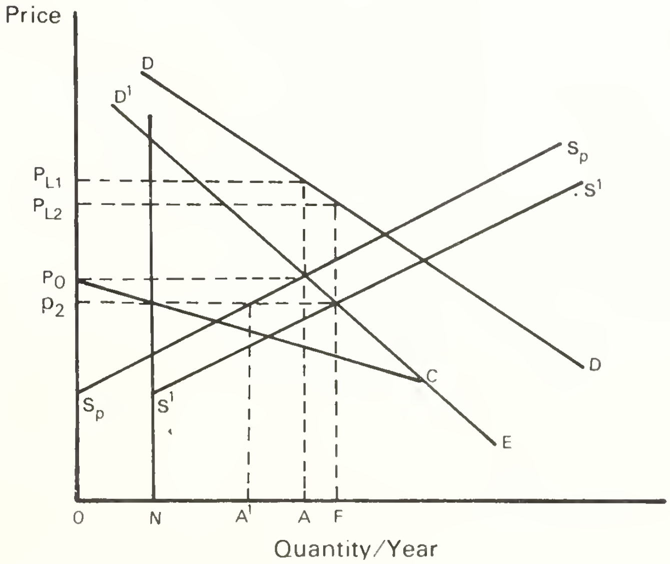

Figure 5.—The effect of a change in National Forest harvest on the price of stumpage, harvest from other ownerships, total harvest, lumber price, and lumber production.

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[4] The kink that occurs are point C is of limited significance since in actual practice it is unlikely to be observed. It represents the point where National Forest harvest levels are high enough to lower prices to such an extent that private supply is zero.

Demand Projections

Table 1—Demand equations for National Forest stumpage, by region and selected years 1980-2030[1]

Region	Selected years[2]											
	1980		1990		2000		2010		2020		2030	
	Intercept	Slope	Intercept	Slope	Intercept	Slope	Intercept	Slope	Intercept	Slope	Intercept	Slope
Pacific Northwest												
West side	122.43	-.091	164.73	-.104	160.10	-.115	191.73	-.126	226.44	-.140	226.59	-.157
East side	102.69	-.275	137.09	-.282	149.95	-.287	174.81	-.293	202.86	-.300	227.97	-.307
Pacific Southwest	93.06	-.161	131.15	-.178	149.35	-.190	177.45	-.201	197.21	-.212	223.81	-.224
Rockies	185.63	-.307	234.18	-.318	263.73	-.331	308.18	-.345	344.41	-.361	403.17	-.380
Northern	100.14	-.307	142.10	-.318	163.73	-.331	204.40	-.345	237.88	-.361	294.58	-.380
Rocky Mountain	48.60	-.307	80.32	-.318	90.22	-.331	113.36	-.345	132.47	-.361	172.90	-.380
Southwestern	51.37	-.307	77.77	-.318	85.59	-.331	108.53	-.345	127.41	-.361	167.96	-.380
Intermountain	52.29	-.307	80.32	-.318	88.57	-.331	111.29	-.345	130.30	-.361	169.86	-.380
Southeast	58.97	-.077	87.71	-.077	107.97	-.078	135.57	-.078	164.86	-.078	198.06	-.079
Southcentral	64.27	-.054	93.99	-.054	114.74	-.054	145.16	-.055	176.42	-.055	211.56	-.056

[1] Equations are of the form: price = intercept + (slope x quantity); where quantity is annual National Forest supply in millions of cubic feet and where annual price is in 1967 dollars per thousand board feet (Scribner).

[2] Equations for nonselected years can be computed by interpolating both the intercept and slope terms.

The regional demand for stumpage on the National Forests is the relationship between the average regional price of stumpage and the volume of timber offered for sale on the National Forests within the Region. Table 1 displays the demand relationship, by Region, for each benchmark year for the decades 1980-2030. The results in table 1 are of the form

$$P = a_0 + a_1S \qquad (1)$$

where P is regional price, a_0 is the price which would prevail if National Forest supply were zero (intercept), a_1 is the rate of change of price with respect to a change in National Forest supply (slope), and S is annual volume of timber offerings on the National Forests (millions of cubic feet).[5] All prices are in 1967 dollars per thousand board feet, short log Scribner scale except for the Pacific Northwest westside which is in long log, Scribner. Therefore, prices are net of inflation. Regional price reflects the volume-weighted average price for all species. The development of regional prices for individual species is discussed in Haynes et al. (1980). Figure 6 is a graphical example of how the demand curves change over time (curves are for the Southwestern Region, Region 3).

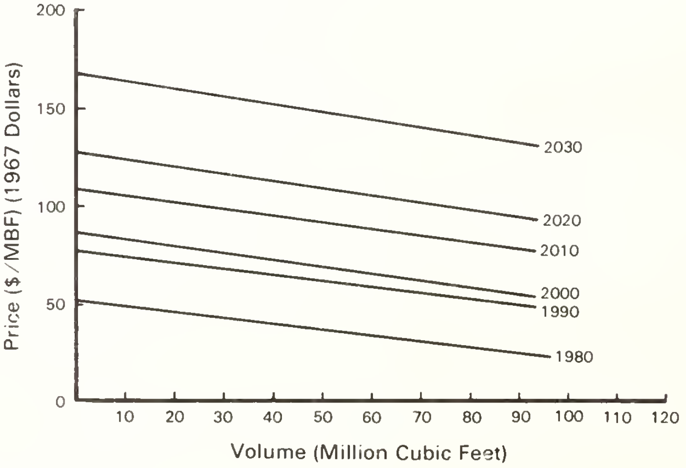

Figure 6.—Demand curves, by selected years, for stumpage from National Forests of the Southwestern Region.

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[5] The equations in table 1 do not represent the kinked relationship shown in figure 3. See footnote 4.

The results in table 1 were calculated from the Timber Assessment Market Model (TAMM) (Adams and Haynes 1980). Our procedure was to calculate the supply curve for all ownerships other than the National Forests and then compute the derived demand for National Forest stumpage, using a mathematical procedure equivalent to the graphical method explained in the previous section. The output from TAMM provided us with the annual supply and derived demand functions for stumpage for each decade for all ownerships. To determine the supply from other ownerships, we subtracted the highbound RPA projections of National Forest harvest from total supply. An additional special procedure was formulated to disaggregate the RPA Rocky Mountain regional demand curve into demand curves for the Northern, Rocky Mountain, Southwestern, and Intermountain Regions (USDA Forest Service Regions 1, 2, 3, and 4). Details of the methods and assumptions used to obtain the results in table 1 are found in appendix 1.

Example

One use of regional demand functions is to quantify the impact of National Forest timber offerings on regional prices. For example, suppose that several Pacific Northwest, westside National Forests adopted a policy of departing in 1990 from nondeclining even flow by 37 million cubic feet. The projected RPA harvest level is 663 million cubic feet (see appendix 1). The price before departure is calculated by substituting 663 million cubic feet into the appropriate equation 1:

$$P = 164.73 - .104\,(663) \qquad (2)$$

The projected 1990 price, before departure, is $95.78 per thousand board feet in 1967 dollars. When the harvest is increased to 700 million cubic feet, price declines by $3.85 to $91.93 per thousand board feet. The latter price would be the expected average annual price which would prevail in the region during the 1990's so long as the annual National Forest supply remained at 700 million cubic feet.

These price impacts do not necessarily have to be expressed in 1967 dollars, nor do they have to be expressed in real terms. For example, the 1990 price in terms of 1979 real dollars is $95.78 times (2.355) = $225.56 where 2.355 is the 1979 wholesale price index (1967 = 100). Another way to express the 1990 price is in terms of the 1979 nominal prices. Suppose, for example, that the average Pacific Northwest region (westside) price in 1979 was $300.31. If we wished to express the price impacts of our departure example in 1979 nominal dollars (prices observed in the market in 1979), we would solve the ratio

$$P_{1990,\,1979} = P_{1979} \times \frac{P_{1990,\,1967}}{P_{1979,\,1967}} \qquad (3)$$

where

$P_{1990,\,1979}$ is the price in 1990 in 1979 dollars

$P_{1990,\,1967}$ is the predicted price in 1990 in 1967 dollars (calculated using the curves in table 1, $91.93 in our example)

P_{1979} is the average price observed in 1979

$P_{1979,\,1967}$ is the predicted price in 1979 in 1967 dollars (calculated using the 1980 curves in table table 1 as a proxy for 1979)

In our example, $P_{1990,\,1979}$ would be $392.78.

To express our results in some other year's dollars, we would change the 1979 subscripts in equation (3) to the desired year and proceed to solve the new equation. Another way of expressing the price impacts would be in 1990 nominal dollars which requires some assumptions regarding the rate of inflation.

Implications for Prices

The price implications of the curves described in table 1 can be demonstrated by comparing the price elasticities of the derived demand for stumpage on all ownerships with the elasticities of the curves for the National Forests. These elasticities for 1980, 2000, and 2030 are shown in table 2.[6] The derived demand curves for all owners are, in the near term, quite close to one another, but regional differences are more pronounced among the elasticities for National Forest stumpage. As a rule of thumb, the elasticity varies inversely with the importance of Forest Service harvest. In the South, where Forest Service harvest is a small component of total harvest, demand is very elastic, especially in the long run.

The estimates of elasticity increase through time. In an earlier section, we discussed the reasons for this from a conceptual viewpoint. Another way to view this change is that, as the equilibrium intersections shift out through time, they also shift upward. Given that our linear demand equations shift outward (up) through time more than our supply curves shift out, the result will be that the equilibrium price and quantity pair will occur in portions of the demand curve which have increasingly higher elasticities.

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[6] All elasticities are computed using the equilibrium quantities and prices shown in tables 4 and 5, appendix 1.

Table 2—Elasticities of derived demand for stumpage for all ownerships and for National Forests by region, for 1980, 2000, and 2030[1]

Region	Year					
	1980		2000		2030	
	All ownerships	National Forests	All ownerships	National Forests	All ownerships	National Forests
Pacific Northwest						
West side	.100	1.343	.122	1.036	.219	1.467
East side	.099	.316	.198	.692	.285	1.055
Pacific Southwest	.099	.761	.152	.920	.214	1.219
Rockies	.044	.136	.091	.262	.183	.499
Northern	[2]—	.285	—	.503	—	.836
Rocky Mountain	—	.842	—	1.546	—	3.458
Southwestern	—	.762	—	1.779	—	3.963
Intermountain	—	.739	—	1.622	—	3.753
Southeast	.041	13.310	.052	20.705	.070	18.843
Southcentral	.110	6.905	.146	8.836	.195	7.814

[1] Computed using the RPA recommended highbound program levels for National Forest Timber supply (table 4, appendix 1), equilibrium prices (table 5, appendix) and the demand curves from table 1 (text) and table 3 (appendix 1).

[2] Values not computed.

We did not compute elasticities for all owners (total derived demand) for the individual Forest Service Regions in the Rockies. Comparisons, however, can be made between the elasticity of derived demand for Forest Service stumpage for each Forest Service Region and the total elasticity for the entire region. In general, the Forest Service has the greatest impact on stumpage prices in the Rockies and in particular the Northern Region.

Market Imperfections and Stumpage Prices

A complete specification of the demand for stumpage would recognize the multitude of market interactions which affect the value of products and factors in the wood products sector. Since pure competition describes or approximates the process through which value is assigned to any unit of timber, it is consistent to view the aggregate of many differentiated markets as a perfectly competitive market. Mead (1966) characterizes the Douglas-fir lumber industry as competitive in the product market and as both competitive and oligopsonistic (small number of buyers) in the stumpage market. Oligopsony might lead to lower prices than would be the case if there were perfect competition in the factor market. Therefore, results based on a perfectly competitive model are likely to overestimate actual observed prices which result from a combination of perfect competition and oligopsony.

Implications for Individual National Forests

The principles of derived demand that apply to a region also apply to local areas, subregions, or individual National Forests. The analysis of the individual Forest is complicated by three important factors: 1) species differentiation, 2) the impact of alternate sources of stumpage on local demand, and 3) local market imperfection. The effect of market imperfections has already been discussed. Though we abstracted from the case of multiple species at the regional level, such a simplification is likely to be misleading on individual National Forests. To complete the link between regional price projections for all species combined and projections for individual species on a National Forest, the reader is referred to Haynes et al. (1980). Their approach is to assume that a simultaneous change in harvest levels throughout a region will be translated into a regional price change which serves as a demand (or price) shifter on individual Forests. The shift in the demand (price) for stumpage which takes place on an individual Forest is conceptually equivalent to a change which would result from a change in the price of a substitute for local stumpage. A rigorous statement of the link between regional and National Forest demand, however, awaits further work.

Literature Cited

Adams, Darius M., and Richard W. Haynes.
1980. The 1980 timber assessment market model: Structure, projections and policy simulations. For. Sci. Monogr. 22. 64 p.

Fight, Roger D., K. Norman Johnson, Kent P. Connaughton, and Robert W. Sassaman.
1978. Roadless area — intensive management tradeoffs on western National Forests. Western Resource Policy Economics Research, USDA For. Serv. 57 p.

Gregory, G. Robinson.
1972. Forest resource economics. The Ronald Press Company, New York. 548 p.

Haynes, Richard W.
1977. A derived demand approach to estimating the linkage between stumpage and lumber markets. For. Sci. 23(2):281-288.

Haynes, Richard W., Kent P. Connaughton, and Darius M. Adams.
1980. Stumpage price projections for selected western species. USDA For. Serv. Res. Note PNW-367, 14 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Mead, Walter J.
1966. Competition and oligopsony in the Douglas-fir lumber industry. Univ. of Calif. Press. 276 p.

U.S. Department of Agriculture, Forest Service.
1979. National Forest System land and resource management planning. Fed. Regist. 44(181):53976-53999.

U.S. Department of Agriculture, Forest Service.
1980a. A recommended renewable resources program — 1980 update. FS-346, 653 p. Washington, D.C.

U.S. Department of Agriculture, Forest Service.
1980b. An assessment of the forest and range land situation in the United States. FS-345, 641 p. Washington, D.C.

U. S. Laws, Statutes, etc.
1974. The Forest and Rangeland Renewable Resources Planning Act of 1974, PL 93-378, August 17, 1974. U. S. Gov. Print. Off., Washington, D.C.

U. S. Laws, Statutes, etc.
1976. National Forest Management Act, PL 94-588, Oct. 22, 1976. U. S. Gov. Print. Off., Washington, D.C.

Appendix 1

Table 3—Coefficients of the derived demand equations for stumpage on all ownerships combined, by region and selected years, 1980-2030[1]

Region	Decade beginning . . .											
	1980		1990		2000		2010		2020		2030	
	Intercept	Slope	Intercept	Slope	Intercept	Slope	Intercept	Slope	Intercept	Slope	Intercept	Slope
Pacific Northwest												
West side	769.76	–.28	801.96	–.28	743.57	–.30	795.59	–.31	838.40	–.32	878.00	–.33
East side	272.87	–.44	343.97	–.46	370.73	–.47	420.30	–.49	466.55	–.51	527.98	–.52
Pacific Southwest	447.89	–.47	514.22	–.49	540.52	–.50	602.63	–.52	643.85	–.54	697.26	–.56
Rockies	527.56	–.49	605.52	–.51	654.70	–.53	726.68	–.55	781.85	–.57	866.76	–.59
Southeast	1,386.49	–.62	1,783.29	–.64	2,064.80	–.66	2,361.26	–.69	2,622.55	–.71	2,866.08	–.74
Southcentral	565.42	–.20	710.36	–.21	810.07	–.21	935.47	–.22	1,049.13	–.23	1,154.38	–.24

[1] Equations are of the form: price = intercept + (slope x quantity); quantity is equilibrium total harvest on all ownerships combined in millions of cubic feet (see table 4), and price is in 1967 dollars per thousand board feet (Scribner).

Computational Methods

The data for computation of the derived demand for stumpage on National Forests were taken from the Timber Assessment Market Model (TAMM) (Adams and Haynes 1980). TAMM is a simulation model that combines a spatial econometric market model with a biological growth model of the resource base. This approach allows for detailed projections of market activity on a regional basis and considers differences in regional resources, production costs, consumer preferences, and transportation costs. It recognizes that over time, competitive economic forces dictate shifts in the location of facilities processing.

In the stumpage sector of TAMM, aggregate derived demand and supply relations interact to determine the level of timber harvests (by owner group) and the price of stumpage. Derived demand is the sum of requirements for each major product category: lumber, plywood, pulp products, miscellaneous products, fuelwood, and log exports. Functionally, derived demand relationships are negatively sloped price quantity relationships where the value for the slope depends on the product supply and demand relationships. The derived demand equations for all ownerships combined are displayed, by region and decade, in table 3.

Stumpage supply relationships are the total of projected harvests from National Forest and other public land and the stumpage supply relationships for forest industry, and farmer and miscellaneous private owners. Our results are based on simulated National Forest harvest levels near those recommended in the 1980 highbound RPA timber program. The projected National Forest harvest levels and the sum of the equilibrium harvest for all other ownerships for each region (table 4) were used to compute the elasticities in table 2. The projected equilibrium prices are determined by the intersection of supply and demand in the stumpage sector of each region (table 5). Historical prices are included to aid in the interpretation of trends. The prices in table 5 were used to calculate the elasticities in table 2 of the text.

Table 4—Projections of equilibrium softwood harvest levels,[1] by region and selected years, 1980-2030

(In million cubic feet)

Region	1980	1990	2000	2010	2020	2030
Northeast						
All public	29	41	52	60	65	68
All private	466	555	610	665	727	779
North Central						
All public	75	87	116	125	123	119
All private	193	228	259	302	356	402
Southeast						
National Forest	53	55	64	89	114	127
Other public	76	72	72	72	72	73
All private	2,023	2,526	2,819	3,082	3,268	3,411
Southcentral						
National Forest	152	185	214	298	382	426
Other public	43	49	51	53	54	54
All private	2,348	2,786	3,025	3,269	3,430	3,545
Rocky Mountains						
National Forest	533	582	631	672	692	707
Other public	84	79	79	79	79	79
All private	412	433	428	439	441	458
Pacific Southwest						
National Forest	327	376	409	446	448	450
Other public	24	16	16	18	18	18
All private	513	530	504	521	533	554
Pacific Northwest-west side						
National Forest	573	663	678	678	685	685
Other public	480	395	400	425	450	475
All private	1,483	1,414	1,158	1,144	1,089	1,016
Pacific Northwest-east side						
National Forest	283	362	372	372	374	374
Other public	102	131	132	135	138	141
All private	179	211	216	238	255	281

[1] The harvest levels necessary to maintain an equilibrium between projected timber demands and supplies.

Table 5—Historical trend,[1] softwood stumpage price levels,[2] and projections of equilibrium prices,[3] for selected years, 1980-2030

($/MBF, Scribner log scale)

Region	1952	1962	1970	1976	1978	1980	1990	2000	2010	2020	2030
Pacific Northwest											
West side[4]	16.64	28.84	44.84	62.40	69.68	69.79	95.19	81.04	105.23	129.64	157.76
East side	15.77	18.22	20.43	22.27	22.92	24.63	53.76	61.35	79.63	94.41	116.98
Pacific Southwest	12.45	19.04	26.73	34.49	37.53	40.22	64.21	71.53	87.66	102.37	122.95
Rockies	6.45	9.29	12.40	15.42	16.58	22.22	48.80	54.79	76.47	94.56	134.12
Southcentral	21.43	30.88	41.37	51.49	55.40	56.13	83.47	103.05	128.79	155.26	188.19
Southeast	21.43	30.88	41.37	51.49	55.40	54.83	83.99	102.96	128.63	155.96	188.13

[1] Prices on a least squares regression line fitted to time series price data for the years 1950-78.

[2] Prices are measured in constant (1967) dollars and are net of inflation or deflation. They measure price changes relative to the producer price index.

[3] Prices which would result from stumpage prices rising enough to maintain an equilibrium between projected timber demands and supplies. These stumpage prices correspond to statistical high bid.

[4] Prices measured with long log Scribner scale.

Supply Curve Adjustments

Computation of the demand for National Forest stumpage begins with an adjustment which subtracts National Forest harvest from the supply curve for all owners combined (from TAMM). Total regional supply functions are conceptually the sum of supply from private and public ownerships. Private stumpage supply relations differ from those for public owners in that private owners are viewed as setting the quantity supplied (Q_s) based on stumpage prices (P) and levels of inventory (I). This latter variable represents the available resource stock. For forest industry or farmer and other private owners, the estimated stumpage supply function for each year is of the form

$$Q_{sk} = B_{k1} + B_{k2}P + B_{k3}I_k \qquad (4)$$

where

k is an ownership subscript and

$B_{1\text{-}3}$ are the estimated coefficients.

Total regional supply functions were computed in a given year by combining with the intercept term the nonprice terms for each private owner and the harvest levels for public owners. This assumes that public harvest shifts the location of the total supply function but does not affect the slope (price responsiveness) of the function. The total supply equation (Q_s) for a region is then expressed as

$$Q_s = [(B_{11} + B_{13}I_1) + (B_{21} + B_{23}I) + H_1 + H_2] + (B_{12} + B_{22})\,P \qquad (5)$$

where

H_1 is the National Forest harvest level and

H_2 is the other public harvest level.

The price variable in both equations is the volume-weighted, all-species average for a particular region. The inventory term, in addition to being owner specific, is also region specific.

Computation of Demand

Price equilibrium is determined by the intersection of supply and demand in the stumpage market. To obtain the demand for National Forest stumpage, therefore, we set derived demand (from table 3) equal to the right-hand side of equation (5) above, while allowing H_1 to remain as a variable. We then solve for price as a function of National Forest supply. For example, the following total stumpage supply, derived demand, and National Forest harvest levels (Q_{nf}) apply to the Pacific Northwest westside region, 1980:

$$Q_s = 2019.003 + 7.399\,P \qquad (6)$$

$$Q_d = 2796.700 - 3.6332\,P \qquad (6a)$$

$$Q_{nf} = 573. \qquad (6b)$$

We subtract (6b) from (6) to obtain the supply from all ownerships other than the National Forests. Total supply, therefore, is

$$Q_s = (1446.003 + Q_{nf}) + 7.399\,P \qquad (7)$$

To obtain the demand for National Forest stumpage we set equation (7) equal to equation (6a) and solve for P as a function of Q_{nf}:

$$P = 122.432 - .091\,Q_{nf} \qquad (8)$$

Equation (8), then, is entered in table 1 (text).

Use of Results

As with any econometric or simulation technique, the equations we derive here are expected to provide the best prediction of price impacts for a range of quantities close to those which have been historically observed. For example, though we have reported the vertical intercept and have interpreted it as the price which would prevail in the absence of any National Forest harvest, we do not have a data set which includes such a point. It and other points outside the range of historical data should, therefore, be used with caution.

Haynes, Richard W., Kent P. Connaughton, and Darius M. Adams.
1981. Projections of the demand for National Forest stumpage, by Region, 1980-2030. USDA For. Serv. Res. Pap. PNW-282, 13 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

The concept of regional demand is described and applied to the demand for National Forest stumpage. Specifically, demand functions for stumpage (price-quantity relationships) are developed by decade for the major National Forest Regions. The demand functions are consistent with the 1980 timber program prepared under requirements of the Renewable Resources Planning Act of 1974 (RPA) and provide forest planners with a mechanism to relate National Forest Regional harvest levels to prices.

Keywords: Projections (demand), supply/demand (forest products), stumpage prices, National Forests.

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Estimating Value and Volume of Ponderosa Pine Trees by Equations

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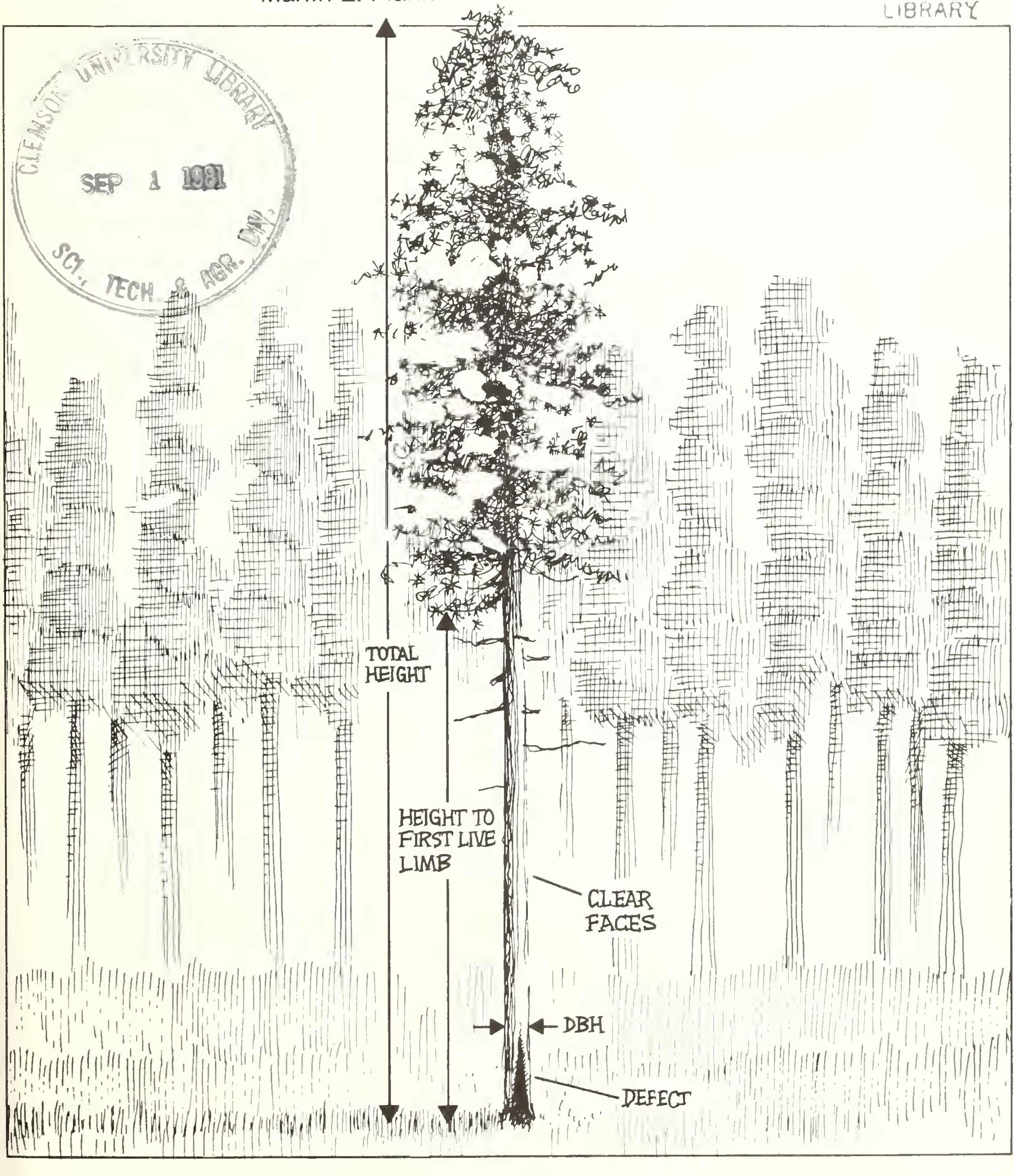

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Abstract

Plank, Marlin E. Estimating value and volume of ponderosa pine trees by equations. USDA For. Serv. Res. Pap. PNW-283, 13 p. Portland, OR: Pac. Northwest For. and Range Exp. Stn.; 1981.

Equations for estimating the selling value and tally volume for ponderosa pine lumber from the standing trees are described. Only five characteristics are required for the equations. Development and application of the system are described.

Keywords: Lumber value, volume estimation, grading systems, ponderosa pine, Pinus ponderosa.

Summary

This paper describes a system for estimating the selling value and lumber volume of ponderosa pine (Pinus ponderosa Dougl. ex Laws.) trees. Similar systems have proved easier and more practical than the conventional method of listing logs by discrete classes.

From a sample of 189 trees selected in western Montana, 154 were used to develop two prediction model equations, one for estimating selling value and one for estimating tally volume of lumber. A subsample of 34 trees was withheld from the analysis to test the equation.

Measurement of five characteristics will enable the user to apply the prediction equations to other samples. The tree characteristics are:

1. Diameter
2. Height
3. Height to the first live limb
4. The number of limb-free and defect-free faces on a butt 32-foot log
5. Total defect

The prediction equations account for 91 percent of the variation in value and 97 percent of the variation in lumber volume as measured by the R^2 values.

When the system was applied to the 34 trees withheld from the original data, the prediction of total dollar value was 7.3 percent more than the actual value and the prediction of volume 7.0 percent higher than the actual volume of lumber recovered.

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Introduction

The State of Montana contains an estimated 11 billion board feet (International 1/4 inch rule) of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) sawtimber (USDA Forest Service 1973). Much of this resource is growing on lands administered by the USDA Forest Service. When offered for sale, stumpage value is determined by a system of five log grades. Although this grading system is reliable, an easier and less costly method has been developed that will work equally well.

The Northern Region (Region 1) of the USDA Forest Service is using equations that estimate the lumber tally volume and value of standing trees for several species. Cruisers have found the method fast and simple to use, and the estimates obtained from the equations are being accepted by timber purchasers. The equations in this paper were developed for ponderosa pine because it is the only major species log-graded in Region 1, and the goal is to get all major species in the Region on the same system.

This paper presents, for timber managers, sellers, and buyers, equations for estimating total value and lumber volume of ponderosa pine trees. It documents the steps in developing the equations, demonstrates their use, and shows how well these equations estimate value and lumber volume for a group of trees.

Study Procedures

Sample and Field Procedures

A sample of 189 trees was selected to represent the range in size and quality of old-growth commercial ponderosa pine sawtimber being used by sawmills in western Montana. The trees were from four areas on the west side of the Lolo National Forest. Diameters ranged from 7 to 37 inches and heights from 42 to 165 feet.[1] The mean diameter was 22 inches and mean height 100 feet.

The surface characteristics of the butt 32-foot portion were recorded for each standing tree. All logs were identified with a tag showing tree and log numbers before they were removed from the woods. In the millyard, they were scaled for board-foot content in the woods length and after they were bucked on the mill deck, they were again scaled. Scaling was done according to procedures in the National Forest Log Scaling Handbook (2409.11, Sept. 1973).

---

[1] To convert inches to centimeters, multiply by 2.54; to convert feet to meters, multiply by 0.304 8.

The logs were then processed at a mill considered representative of mills processing ponderosa pine in the northern Rocky Mountain area. The logs were sawn under normal conditions, with the intent of obtaining the highest value from each log. Lumber produced was either 4/4-inch or 5/4-inch shop or 1-inch boards. The values and volumes were based on kiln-dried, surfaced lumber tally according to general industry practice. All lumber was identified throughout the milling phase so that each piece could be related to the log and tree from which it originated.

Developing the Prediction Model

Before data analysis, 34 of the 189 sample trees were randomly selected as a subsample for testing the prediction equations that would be developed. Of the remaining trees, one was inadequately measured, leaving 154 trees as a base for developing the equations.

Twenty-nine variables were screened with a multiple regression program (Dixon 1964) to determine tree characteristics that would be most highly correlated with value and volume of lumber. The independent variables that were examined are listed in appendix 1. Previous studies (Lane et al. 1970, Plank and Snellgrove 1978, Snellgrove et al. 1973) of other species have indicated that many characteristics are poorly correlated with value or volume, so they were not measured. The forward stepwise regression procedure was used to select the subset of independent variables to be included in the regression model for predicting value or lumber tally volume of the trees.

The screening process indicated that six tree characteristics should be observed and recorded.

These characteristics, described in the next paragraph, together with several transformations of the same characteristics, were selected as the best independent variables to be used in the two models.[2/] These variables were used with lumber yield information to develop the regression equations for predicting total value (dollars) and lumber volume (board feet) per tree. The same set of independent variables did not survive as the best estimator of both value and volume; consequently, separate equations were chosen to estimate the dependent variables. The final variables selected for the models were the ones that were most practical for application in timber appraisals and that statistically accounted for the most variation in volume and value.

[2/] Transformations are used not only for constructing interaction variables but also for changing the form of the individual variables so that more of the variation can be explained.

The following model equations are used for predicting total dollar value and total lumber volume of a tree:

$$\begin{aligned}\text{Total value} = {} & b_0+b_1(\text{LDFF32})+b_2(\text{PADEFT})(D^2H)\\ & +b_3(\text{DEFPER})(D^2H)+b_4(D^2)\\ & +b_5(DH)+b_6(D^2H).\end{aligned}$$

$$\begin{aligned}\text{Total lumber volume} = {} & b_0+b_1(H)+b_2(\text{HTFLL})\\ & +b_3(\text{DEFPER})(D^2H)\\ & +b_4(\text{DEFSQR})(D^2H)+b_5(D^2H);\end{aligned}$$

where:
b_0 is Y intercept constant,
b_1, $b_2 \ldots b_6$ are regression coefficients,
LDFF32 is the number of limb-free and defect-free faces on the butt 32-foot log,
PADEFT is the presence or absence of any defect (1 if present, 0 if absent),
DEFPER is estimated defect expressed as a percentage of gross cruise volume,
D is diameter at breast height (inches),
DEFSQR is estimated defect percent squared,
H is total tree height (feet),
HTFLL is the height to the first live limb.

Coefficients for the volume equation are as follows:

$b_0 = -3.00685$
$b_1 = -0.826482$
$b_2 = 0.422030$
$b_3 = -0.0000843925$
$b_4 = 0.000000829797$
$b_5 = 0.0155223$

Coefficients for the value equation vary as lumber prices vary and can be determined by the steps in the section, "How To Use the System."

The equations account for 91 percent of the variation in dollar value and 97 percent of the variation in lumber volume. The standard error of estimates are $51.89 and 139 board feet.

How the System Performs

From the sample of 189 trees, a subsample of 34 trees was randomly selected to test the performance of the estimating equations. The general characteristics (d.b.h., total height, criteria for the faces, height to first live limb, and defect) were recorded for each of the 34 trees in the subsample. Predictions of selling value and volume of lumber were then calculated using the equations.

Table 1 shows comparisons of estimated and actual values for the 34 subsample trees. Figures 1 and 2 show that the estimates of value and volume are about equally split by the 45-degree line.

Table 1--Comparison of estimated and actual selling value and volume of lumber from 34 ponderosa pine trees

Item	Total value	Difference	Total lumber volume	Difference
	Dollars	Percent	Board feet	Percent
Estimated	6,221.58	+7.3	29,865	+7.0
Actual	5,796.14		27,904	
Mean deviation	+12.51		+58	
Mean absolute deviation	37.13		93	

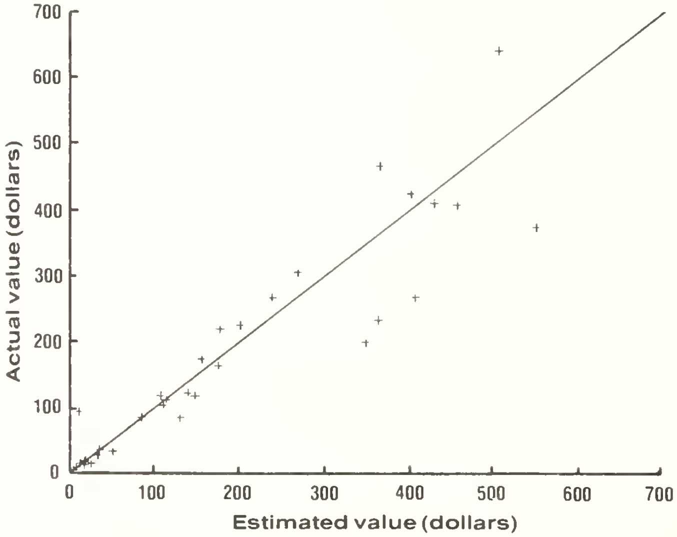

Figure 1.--Actual value versus estimated value of ponderosa pine trees.

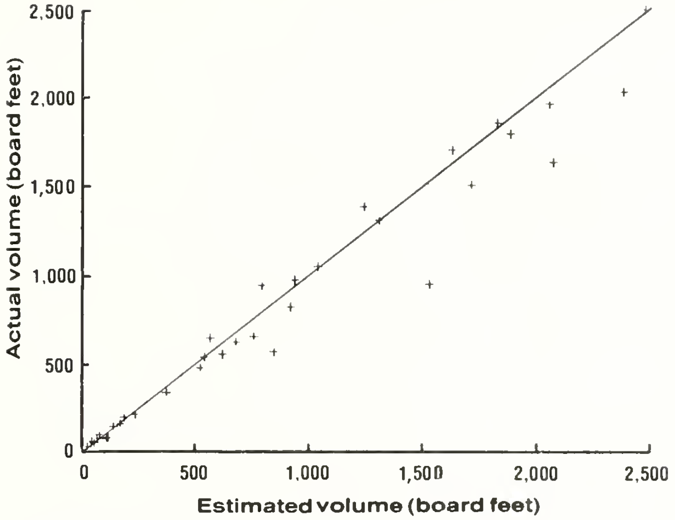

Figure 2.--Actual volume versus estimated volume of ponderosa pine trees.

How To Use the System

Computer facilities for making regression analyses are essential for efficient use of this system. Regression coefficients for tree values are derived from the tree characteristic data, the lumber grade yield data for each tree in the base study, and appropriate lumber prices. These data and the card format for the 154 trees are shown in appendix 2.

The total lumber tally volume of a tree or group of trees may be estimated by solving the following equation using the coefficients shown:[3]

$$\begin{aligned}\text{Total lumber tally volume (board feet)} = {} & 3.00685-0.826482(H)+0.422030(HTFLL)\\ & -0.0000843925(DEFPER)(D^2H)\\ & +0.000000829797(DEFSQR)(D^2H)\\ & +0.0155223(D^2H).\end{aligned}$$

A procedure for developing a value equation for the 154 tree data set and current prices is as follows:

1. Assign current or desired lumber prices to each lumber grade recorded in the base study.

---

[3] Note that this system was developed to predict values and volumes of 4/4- and 5/4-inch lumber. Using this system to predict values and volumes in areas where relatively large amounts of dimension lumber are obtained may not give accurate results.

2. Multiply these prices by the appropriate lumber yield information shown in appendix 2 to obtain a dollar value for each of the 154 trees in the base study.

3. Use an appropriate multiple regression program to develop the value equation coefficients for the 154 trees. Use the computed total dollar value (step 2) and five of the six tree characteristics in the following transformations:

   Dependent variable:
   Total dollars/D^2H

   Independent variables:
   LDFF32/D^2H
   PADEFT
   DEFPER
   D^2/D^2H
   DH/D^2H
   $1/D^2H$

4. Select sample trees.

5. Measure and record for each sample tree the five characteristics: (1) diameter, (2) height, (3) defect, (4) presence or absence of defect, and (5) number of limb- and defect-free faces in the butt 32-foot log.

6. Now apply this equation to a new group of trees using the following steps: Use coefficients developed in step 3 to solve the value equations for the sample trees selected in step 4.

Conclusions

Field tests of this system and similar systems have demonstrated that they have a number of advantages over the conventional log grading method. It is faster to apply in the field and thus more economical. Fewer judgment factors are required than with the log grading system presently used for ponderosa pine. Selling price is calculated easily and more directly than by methods that involve adjusting yield by log overrun estimates. In addition, training and checking of cruisers are easier.

This system is similar to others that have been used successfully by the USDA Forest Service in the northern Rocky Mountains. The performance of these systems and their acceptance by both timber buyers and sellers indicate that they are simple, workable methods of estimating the quality of standing sawtimber.

This system was developed where the major portion of lumber was manufactured into 4/4-inch and 5/4-inch items. Inferences as to the applicability of the system in areas where dimension lumber is a sizable portion of the cut may give misleading results.

Literature Cited

Dixon, W. J., Ed. BMD biomedical computer programs. Health Sci. Comput. Facil. Dep. Prev. Med. and Public Health, Sch. Med., Los Angeles, CA: Univ. Calif.; 1964.

Lane, P. H.; Plank, M. E.; Henley, J. W. A new and easier way to estimate the quality of inland Douglas-fir sawtimber. USDA For. Serv. Res. Pap. PNW-101. Portland, OR: Pac. Northwest For. and Range Exp. Stn.; 1970.

Plank, M. E.; Snellgrove, T. A. An equation for estimating the value and volume of western larch trees. USDA For. Serv. Res. Pap. PNW-231. Portland, OR: Pac. Northwest For. and Range Exp. Stn.; 1978.

Snellgrove, T. A.; Plank, M. E.; Lane, P. H. An improved system for estimating the value of western white pine. USDA For. Serv. Res. Pap. PNW-166. Portland, OR: Pac. Northwest For. and Range Exp. Stn.; 1973.

U.S. Department of Agriculture, Forest Service. The outlook for timber in the United States. For. Resour. Rep. 20. Washington, DC; 1973.

Appendix 1. Independent Variables

Defect related variables:

1. Defect percent.
2. Defect percent squared.
3. Presence or absence of defect.

Quality related variables:

4. Number of limb- and defect-free 8-foot panels on the butt 16-foot log.
5. Number of limb-free 8-foot panels on the butt 16-foot log.
6. Number of limb- and defect-free 8-foot panels on the butt 32-foot log.
7. Number of limb-free 8-foot panels on the butt 32-foot log.
8. Number of limb- and defect-free 16-foot faces on the butt 32-foot log.
9. Number of limb-free 16-foot faces on the butt 32-foot log.
10. Number of limb-free faces with no defect on the butt 16-foot log.
11. Number of limb-free faces on the butt 16-foot log.
12. Number of limb-free faces with no defect on the butt 32-foot log.
13. Number of limb-free faces on the butt 32-foot log.
14. Length of scar.
15. Presence or absence of scar on butt log.
16. Presence or absence of conks.
17. Size of the largest limb on the butt 16-foot log.
18. Size of the largest limb on the butt 32-foot log.
19. Height to the first live limb.

Volume related variables:

20. d.b.h. = D
21. Total height = H
22. D^2
23. DH
24. H^2
25. D/H
26. H/D
27. (H/D^2)
28. D^2H
29. $1/D^2H$

Appendix 2. Tree Quality Characteristics and Lumber Yield Data

The tree quality characteristics and lumber yield data for each of the 154 trees in the base study are listed according to the card format shown below.

Columns	Data
1-3	Tree number
4-6	d.b.h.
7-9	Total height
10	Number of limb- and defect-free (clear) faces on the butt 32-foot log
11-12	Height to the first live limb
13	Presence or absence of defect
14-16	Defect percent
17-20	Volume of B Select lumber
21-24	Volume of C Select lumber
25-28	Volume of D Select lumber
29-32	Volume of Moulding lumber
33-36	Volume of 3 Clear lumber
37-40	Volume of 1 Shop lumber
41-44	Volume of 2 Shop lumber
45-48	Volume of 3 Shop lumber
49-52	Volume of Shop-out lumber
53-56	Volume of 2 Common & Btr lumber
57-60	Volume of 3 Common lumber
61-64	Volume of 4 Common lumber
65-68	Volume of 5 Common lumber
69-72	Volume of Pitch Select lumber

Data Cards

		TOT	CL	HT	P-A	PCT						V O L U M E								
TREE	DBH	HT	FA	LMB	DEF	DEF	B-SEL	C-SEL	D-SEL	MLDG	3-CL	1-SHP	2-SHP	3-SHP	SHP-0	2-COM	3-COM	4-COM	5-COM	P-SEL
1	357	132	3	40		1	28	82	198	419		138	645	208	15	230	252	76	5	144
2	263	123	1	66		2	34	46	64	91		69	214	78		159	348	83		
3	209	90	3	34			13	31	122	32		26	52	17	10	185	210	19	4	
4	266	109	3	41	1	2	20	96	63	231		47	198	79	13	189	241	29		14
6	200	96	3	48		5		53	81	41		8	18			92	111	35	26	7
7	254	133	3	47		3	7	113	120	112		41	212	30		173	174	55	2	
9	195	108	4	44		7	17	73	41	16		16	13			259	69	17		
11	221	98		37				42	69	4		16		27		185	250	18	3	
12	290	118	1	24		2	74	76	114	171		165	390	40		165	243	14	5	
14	243	119	3	35		2		70	75	173		89	254	42		235	86			
15	243	118	1	22				37	98	111		138	275	110	13	163	78	48	17	
16	327	124		47		4		30	66	170		107	562	248	23	105	408	48	10	
22	296	124		28		1	27	44	63	96		67	357	180	77	145	340	30	3	47
23	316	118		30	1	9	19	56	105	124		123	343	168		201	143	29	17	5
25	267	110	1	31	1	4		47	84	103		55	168	93	12	165	139	17	5	24
26	264	118	3	41		1		49	50	178		188	235	185		140	182	30		
27	318	125		36		6		14	131	214		34	405	390	93	176	345	21	3	25
28	307	130	1	36	1	3		29	49	198		91	461	165	19	283	194	20	6	10
29	286	113	3	47	1	12	74	105	96	160		26	157	181	20	139	148	44	27	
31	202	107	4	40		6		109	58	142		9				200	106	23	4	
32	367	151	3	50		27	202	249	116	338		65	586	495	47	25	345	387	185	48
33	330	125	3	40	1	28	163	193	138	354	38	250	182	157	19	20	63	112	45	
34	282	106	1	36	1	7	3	27	193	224		87	183	141		161	107	34	13	
37	349	126	2	22		11	26	80	152	315	38	205	691	262		81	292	138	41	
38	317	131	2	65		34		61	91	365	40	241	672	150	38	14	247	200	8	
40	258	105		25					7	13		13	106	142	78	77	144	206	28	
41	296	125		24		1		18	9	58	17	211	436	168	32	102	183	78	119	
42	180	88		30		80			6	3		16				176	169	15		
43	160	86		30		8				3		6				119	171	7		
44	201	96		34					2	5			90	122		131	241	41	13	
45	126	65		28												75	58	7		
46	111	54		28						3			8			24	41	3		
47	135	88		30					3							60	92	15		
48	99	65		34	1											29	27	7		
51	262	95		39		1		6	4	25		74	307	221	23	97	239	22	17	
52	268	109		27		2		18	10	86		44	538	95	15	53	270	50	11	
53	124	77		19						6						46	47	16		
54	92	69		20												10	13	6		
55	298	110		24		1		13		5	15	193	481	193		66	332	71	9	
57	222	121	1	52	1	4	12	48	64	115		77	116	60	8	79	265	10	9	

TREE	DBH	TOT HT	CL FA	HT LMB	P-A DEF	PCT DEF	V O L U M E													
							B-SEL	C-SEL	D-SEL	MLDG	3-CL	1-SHP	2-SHP	3-SHP	SHP-0	2-COM	3-COM	4-COM	5-COM	P-SEL
58	308	139	1	37	1	4		22	26	177	22	259	565	269	17	245	292	126	4	
59	372	116	4	44		16			15	104		26	119	195	250		324	997	150	
60	312	112		45		13		18	19	53		130	618	397	66	19	257	66	8	
62	291	125	2	39		10	3	47	100	83		60	410	374	12	190	329	129	17	
64	333	127	1	40				55	167	131		55	432	671	143	120	484	52	25	
65	344	119		30		2		17	51	208		164	516	244	75	119	364	46		
66	230	120	2	37		1		32	21	87		136	338	36		254	210	15	5	
67	187	108	2	35				10	24	80		21	10	96		262	70	28	5	
69	240	120	1	38	1	7			16	67		117	289	121		169	114	81	8	
70	154	93		17	1	5		3	5	8						150	40	24		
71	74	64		36												12		3		
72	166	81		27		12										74	100	25	7	
73	140	89	1	29					25							71	47	8		
74	347	128		41		6		22	51	130		95	887	551	132	32	335	161	14	
76	327	117		25	1	3			18	55		116	657	526	53	44	415	212	41	
77	240	108		25	1	6	14	27	46	119		74	97	69		104	189	26	4	
78	287	124	2	21	1	6	8	66	111	100		20	383	182		45	319	237	13	
79	365	128		47	1	27		17	25	80		30	492	569	58	29	287	331	31	55
84	89	60		33					6	3						26	6	4		
85	295	116	4	52		13	24	35	20	154		47	382	318	57	5	273	110	34	
87	195	103	4	55		12		42	56	55		13	8	16	17	135	159	40	7	
89	280	120		60		2		28	43	118		86	360	173	8	104	276	210	6	2
90	328	110	1	36	1	19		63	72	93		70	522	219		44	239	173	26	
91	297	117	3	54		3	14	48	63	197		17	268	252	43	44	210	343	40	
92	307	124	1	39		4			23	85		202	606	242	4	172	284	60	29	
93	302	135	1	33	1	8		5	14	72		30	309	459	45	87	546	243	15	4
95	200	88		42		24			10	37		33	105	42		94	150	16	5	
96	169	92	1	50		3			16	26		27	21	59		57	153	35		
97	250	99		52		2		3		69		51	231	140		135	265	123	3	
98	267	104	3	27		2	136	84	59	161		53	123	20	10	240	102	3		51
99	226	122	1	28		3	3		65	46		11	81	102		148	285	13		10
100	351	113		42		2		15	14	129		254	557	416	123	99	315	50	6	
101	355	110	4	43		4	160	228	92	358		163	427	232		185	241	63	38	48
102	340	128	2	32	1	5	11	94	73	267		186	453	518	46	64	438	41	7	
103	163	53		22		13	5	6	15	3						8	67	29	5	
106	290	109	3	45	1	17		29	62	128		15	63	390		51	171	214	16	118
107	282	106	1	29	1	24	4	5	29	11		65	197	123	39	69	165	186	30	
108	363	109		28	1	4		7	21	202		143	592	598	213	106	227	99	14	27
109	131	44		21		14			8							12	45	22		
110	216	90		24	1	28		14	31	44		19	23	8		78	189	73	26	
111	139	58	1	40	1	22		3	4	12						7	59	4		

		TOT	CL	HT	P-A	PCT						V O L U M E								
TREE	DBH	HT	FA	LMB	DEF	DEF	B-SEL	C-SEL	D-SEL	MLDG	3-CL	1-SHP	2-SHP	3-SHP	SHP-O	2-COM	3-COM	4-COM	5-COM	P-SEL
115	172	111	2	33					15	4		27				154	281	23	8	
116	148	101		44					4				8			87	177	79	5	
118	208	105		43		2			13	5		19				137	349	66		
119	169	110		57					5	5		39	36	10		155	153	45	5	
120	130	101		44					7							75	59	29		
121	103	65		44		14										44	31	17		
123	157	106		37		8			13	2		8				146	115	12		
124	330	152	2	32		8	3	60	33	221		273	680	260	22	153	226	52	16	
125	162	91		38	1					2			6			106	132	53		
127	199	106	1	33	1	2			3	34		27	56	69		216	248	43	3	8
128	180	120		74	1	7		3		8		13				222	143	61		
130	130	103	2	45												159	53	21		
132	92	80		48		14										31	29	6		
133	149	106		40	1	4			7			8				142	147	27		
134	111	101		66						5						64	66	32		
136	145	117	1	53		5			6	3						117	149	15		
137	145	97		46					8							125	100	21	3	
139	119	105	3	65	1	8		3		3						66	55	20	15	
140	299	163		52		3	7	30	87	218	37	466	808	214		167	286	153	69	
142	109	80		20					5							55	12	26		
143	75	77		50												7	6		2	
144	103	84		47	1											34	44	19		
145	79	76		45												5	8	5		
146	136	78		44	1											80	70	27		
147	372	162	3	72	1	7		44	69	389		222	784	444	55		161	385	78	55
148	248	120		64	1	7		18	3	46		41	206	206		81	111	160	49	
149	312	140	3	83	1	40		85	9	156		158	314	310	13	38	200	24		
152	102	42		20												20	23			
153	134	30		10					5							5	39	9		
154	193	66		22		27		3				8				38	178	30	15	
155	199	89		29	1							39	24			167	184	43		
156	280	94		29		4	21	78	71	73		53	220	58		107	260	52	9	
157	270	85	1	28	1	12		79	62	50		34	95	87	17	96	143	120		
158	165	61		22	1	33			19	27						20	132	18	4	
159	245	104	1	56	1	9	31	46	50	227		40	117	54	10	35	110	77	5	
160	275	114		42	1	12		34	53	126		123	437	93	9	46	157	136	28	
162	338	96	2	42		20	113	196	63	206		237	413	95	4	26	201	109	53	
164	226	66		20	1	4			7	6		19	11			23	253	79		
165	289	99		19	1	14	5	70	60	54		94	227	33		78	441	175	8	
166	159	86		34	1	21		3	27	19		14				77	64	24		
167	260	91	2	45	1	13		11	46	28		50	100	22		57	124	195	5	

		TOT	CL	HT	P-A	PCT						VOLUME								
TREE	DBH	HT	FA	LMB	DEF	DEF	B-SEL	C-SEL	D-SEL	MLDG	3-CL	1-SHP	2-SHP	3-SHP	SHP-O	2-COM	3-COM	4-COM	5-COM	P-SEL
168	311	93	2	40		20		7	81	78		8	53	45	105	4	101	223	235	57
169	180	83		13	1	17		3		3		21	8	15		72	132	53	10	
171	115	79		26	1	29	7		12							22	33	7		
173	90	68		20	1	33										5	11	5		
175	160	77		19		6			16			18				85	73	11		
179	304	83	4	36		18	101	112	133	268		56	120	72	31	79	228	95	14	
180	300	130	1	24	1	2		101	268	217		69	198	132	30	90	150	117	16	38
181	85	68		10		50											14	3	8	
182	124	86		49					5	3						123	11	8	2	
183	145	81		22					9							99	70	26	4	
184	250	76		35	1	4		35	33	26		40	84	111	17	9	271	21	28	
187	224	83		37	1	4			14	13			8			43	227	287	18	8
188	199	74		28	1	10			10	24			17	30	10	70	257	29	13	
189	256	85		24	1	5		12	5	66		93	208	122	35	43	266	45	8	
190	208	64		13					2			8	13			55	193	14		
191	80	64		37												7		3	4	
192	90	68		35												9	8	2	3	
195	110	67		15						3						52	12			
196	189	89		36				2	11			6	8			118	187	36		
197	119	83		51		14										24	25	34	8	
198	116	89		22		30										35	46			
250	170	64	1	29		5	4	30	49	39						3	29	38	7	
253	180	77		27	1				12	14			34	43	9	51	109	13	3	
254	310	153	3	85		7	103	156	152	274		86	471	125	15	338	199	29	5	14
255	130	82		18					3							82	62	3	9	
256	150	82		35		5			14	12		6				127	44	6		
257	110	69		31												35	27	5	5	
258	160	77		36		86		3								41	124	26		
259	194	109		35				3	12	22		17	75	26		242	59	9	10	
261	250	130		50		2	2	4	34	29		107	186	55		434	183	25		
262	210	99		31				18	78	12						215	139	12	7	
309	268	110	1	65	1	10		18	20			8	192	250	53	59	304	135	19	

Plank, Marlin E. Estimating value and volume of ponderosa pine trees by equations. USDA For. Serv. Res. Pap. PNW-283, 13 p. Portland, OR: Pac. Northwest For. and Range Exp. Stn.; 1981.

Equations for estimating the selling value and tally volume for ponderosa pine lumber from the standing trees are described. Only five characteristics are required for the equations.
Development and application of the system are described.

Keywords: Lumber value, volume estimation, grading systems, ponderosa pine, *Pinus ponderosa*.

The **Forest Service** of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

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Agriculture

Forest Service

Pacific Northwest
Forest and Range
Experiment Station

Research Paper
PNW-284

July 1981

Regeneration Outlook on BLM Lands in the Southern Oregon Cascades

William I. Stein

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mmary

r more than a decade, various in-
sities of partial cutting have been
ed in the southern Oregon Cas-
des by the Bureau of Land Manage-
nt, U.S. Department of the Interior,
d others to foster establishment of
tural regeneration. Difficulties ex-
rienced in reforesting some clear-
ts were a prime reason for the
ange to partial cutting. This com-
ehensive study was cooperatively
dertaken to evaluate reforestation
ults obtained by both clearcutting
d partial cutting, to identify influ-
cing variables and problems, and to
ommend improvements in silvicul-
al practices.

cking levels, composition of
eneration, and species dominance
re determined from data collected
92 randomly located plots in par-
cuts and clearcuts logged during
1956-70 period in the Dead Indian
Butte Falls areas. Each plot was
npled by twenty 4-milacre (0.00162-
tare) subplots, located systemati-
ly in a 2-acre (0.81-hectare) grid.
st partial cuts were moderately or
l stocked; clearcuts in the Butte
ls area were also well stocked but
ny in the Dead Indian area were
.

artial cuts, regeneration estab-
ed before logging made up about
the total stocking and domi-
ed nearly half the stocked
plots. Many second-year seed-
s were found in partial cuts, few in
arcuts; yet their potential for
nging stocking levels is minor.
urally established true firs,
glas-fir, and incense-cedar were
dominant species in partial cuts,
artificially established ponderosa
was dominant in clearcuts. In
eral, a mix of species was more
nmon in the Butte Falls area than
ne Dead Indian—up to six per
plot.

Comparisons of geographic and vegetative characteristics showed that the Dead Indian and Butte Falls areas are more dissimilar than is first evident. Both areas have much gentle terrain and some plateaulike features, but Butte Falls occupies a midslope position west of the Cascade Range summit, whereas Dead Indian mainly occupies upper slopes. An average difference in elevation of 1,400 feet (427 meters) has important implications for length of growing season, frost occurrence, exposure to storm winds, temperature extremes, and other factors. The Butte Falls area appears to average at least 10 inches (25 centimeters) more annual precipitation and has finer, deeper soils with more water-holding capacity. In clearcuts of both areas, about 90 percent of the soil surface appeared to have been disturbed during harvest; in partial cuts, 50 to 60 percent. Canopy averaged about 45 percent in partial cuts, and ground cover 49 percent. In clearcuts, ground cover averaged 61 percent.

In partial cuts, total and subsequent stocking averaged less in the white fir forest type than in the Douglas-fir, Shasta red fir, and pine types; the reverse was true in clearcuts. Stocking did not differ greatly by soil series, but large differences were found among some locations and drainages. Total and subsequent stocking were lowest in the western part of the Dead Indian area which is also where the white fir type is most fully developed.

Stocking correlated significantly with an array of environmental variables. The associations differed for partial cuts and clearcuts, Butte Falls and Dead Indian areas, forest types, and for classes and species of regeneration. For partials cuts, associations based on data grouped by forest types were judged strongest and most useful; associations for clearcuts were about equally strong whether based on forest type or geographic area. In both partial cuts and clearcuts, stocking generally increased as amount of woody perennials increased, and tended to be less as total ground cover, grass, radiation index, and elevation increased. Regression equations describe present stocking patterns, and others predict future stocking based on variables that can be observed or specified before harvest.

In planning harvests and reforestation, management should give special attention to differences among geographic areas, forest types, and stands. The Dead Indian area has more severe ecological conditions than Butte Falls; thus, reforestation requires commensurately greater caution and attention. Clearcutting should not be ruled out completely in the southern Cascades. Used judiciously in conjunction with the best available planting technology, clearcutting should be appropriate in much of the Butte Falls area and for reestablishment of ponderosa pine and other frost-hardy species in the Dead Indian area. Prudent use of clearcutting requires better identification of locations or situations where the chances for frost damage during the growing season are low.

Seedling establishment is progressing satisfactorily in most partial cuts even before a technical regeneration cut has been made. There are problems to solve however, such as control of density, species, and genetic composition; prevention of disease infection from residual overstory; and acceleration of seedling growth. Planting under shelterwood may prove necessary to achieve prompt establishment, and control of species and genetic quality. Release of advance growth and establishment of new regeneration can be enhanced by preparing and following specific stand prescriptions. Where, how much, and how long to retain overstory are the foremost questions requiring research.

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, William I.
981. Regeneration outlook on
LM lands in the southern Oregon
ascades. USDA For. Serv. Res.
ap. PNW-284, 70 p., illus. Pacific
orthwest Forest and Range
xperiment Station, Portland,
regon.

vey of cutover timberland in the
e Falls and Dead Indian areas
ved that most partial cuts were
erately or well-stocked with
al regeneration. Clearcuts in the
e Falls area were also well-
ked, primarily with planted pon-
sa pine; but many in the Dead
n area were not. Advance regen-
on was an important stocking
onent in partial cuts. Stocking
d by forest type, species, and
age and correlated with an array
vironmental variables. Regres-
equations describe present
ing patterns, and others predict
e stocking based on variables
an be observed or specified
e harvest.

ords: Regeneration (stand),
eration (natural), regeneration
cial), clearcutting systems, par-
utting, stand development,
on (Cascade Range).

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roduction

ests in southwestern Oregon grow
diversity of sites and contain a
able mix of species. After timber
est, intense radiation, high
peratures, summer drought,
ng winds, cold temperatures, and
ts are common obstacles to the
tablishment of conifers. Success
forestation varies greatly, but the
tions and situations where tree
blishment is difficult or easy are
sufficiently identified.

e early 1960's, the primary
hod of timber harvest used by the
ford District of the Bureau of
Management (BLM), U.S. Depart-
t of the Interior, shifted from
rcutting to partial cutting. Diffi-
y experienced in artificially refor-
ng some clearcuts was a key
on for changing cutting prac-
. It was believed the environment
ided by a partial overstory would
nit ready establishment of natural
eneration. But this premise
ired confirmation.

r sufficient time had elapsed to
nit establishment of regeneration,
Pacific Northwest Forest and
ge Experiment Station and the
gon State Office, Bureau of Land
agement, jointly undertook an
uation of reforestation on the
lford District. The study had two
ary objectives: (1) evaluate in
th the results of reforestation
rts and (2) develop improved silvi-
ural guidelines for establishing
ifer regeneration in southwestern
gon. This paper summarizes
rmation obtained by 1973-74 field
eys of cutovers located in Dead
an and Butte Falls, the Cascade
s of the Medford District (fig. 1).

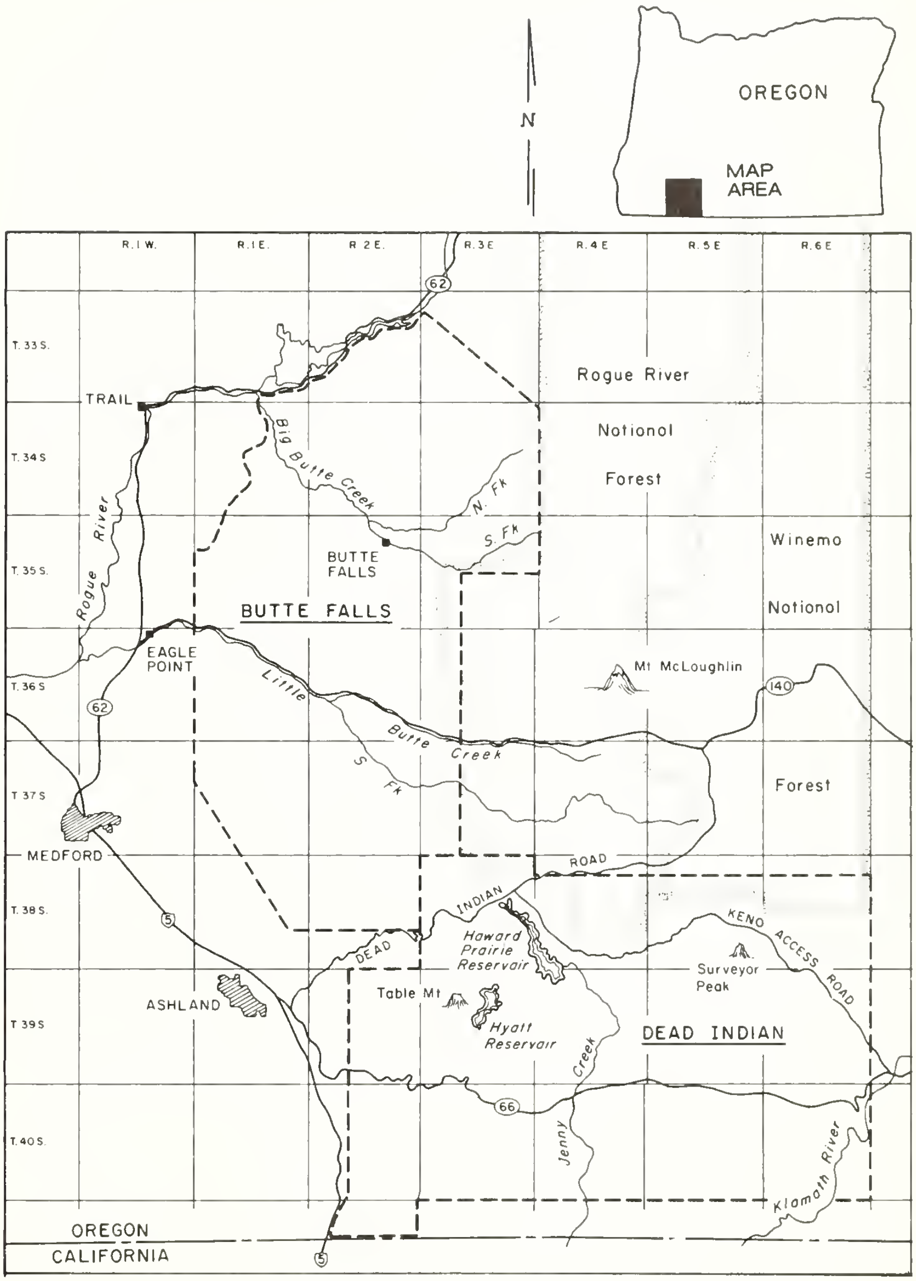


Figure 1.—The Butte Falls and Dead Indian areas are located to the northeast and southeast of Medford, Oregon.

Survey Methods

Survey methods were designed to answer these specific questions:

1. Of the area cut over in the 1956-70 period, what portion is now at least 30, 50, 70, and 90 percent restocked?

2. What is the composition of the stocking?
   a. Percent of area stocked by individual species?
   b. Percent of stocked area dominated by each species?
   c. Comparative stocking by seedlings of preharvest and postharvest origin?
   d. Portion of total stocking naturally established or artifically established?

3. Does stocking vary with changes in observed environmental variables?

4. What are the major regeneration problems?

5. Where are the chief problem areas?

Sample Selection

Sample plots were randomly located within BLM acreages clearcut or partially cut in the Dead Indian and Butte Falls areas during 1956-70. The cutovers were identified by section subdivisions, the forties (40 acres, a sixteenth of a section), in which they occurred. Primarily from photomap information, separate lists were compiled of all BLM forties in which 10 or more acres had been partially cut or clearcut. If a forty contained 10 or more clearcut acres and 10 or more partially cut acres, it was entered in both lists. All forties with sufficient cutting were listed, including those where cutting status or system were in doubt.

After forties in the lists had been numbered consecutively, tentative samples were selected by recording numbers in the order they were drawn from a random number table. Coordinates designating the exact location of the sample point (plot) in chains north and east of the southwest corner were then randomly assigned to each sample forty. When the designated sample point did not occur within cutover acreage, the sample was rejected. In successive random selections, the cutover acreage within a forty might be sampled more than once, each time at a point designated by a new set of randomly chosen coordinates.

These selection procedures resulted in a generous listing of forties and a consequent high rejection rate when sample points were not located in cutover areas or did not meet other criteria. Disposition of the first 214 candidate samples in partial cuts was as follows:

Plots	Percent	
Sampled		30.4
Rejected:		69.6
Uncut	33.2	
Natural openings or scrub	9.4	
Cut over since 1970	12.6	
Cut over before 1956	6.5	
Clearcut	5.1	
Miscellaneous	2.8	
Total	69.6	100.0

Among the first 215 candidate samples in clearcuts, 25.6 percent were valid samples; 47.4 percent were rejected because the sample point was located in an uncut or partially cut stand; 22.8 percent were natural openings; and 4.2 percent were rejected for other reasons.

By the end of the 1973 field season, it became evident that the Butte Falls area was lightly represented among the first 55 plots sampled. It was evident too, that regeneration differed substantially between the Dead Indian and Butte Falls areas. A decision was then made to sample the Butte Falls area more intensively, and applicable samples for this purpose were drawn in sequence from the lists of candidate samples.

Plots and Subplots

Sample plots were found by hand compass and pacing. A land survey corner or section line marker at roadside was the usual starting point; but occasionally an identified road intersection, ownership boundary, or distinct geographic feature was used.

On each qualifying sample plot, circular 4-milacre subplots (1/250-acre; 0.00162-ha) were located at 1-chain intervals along four gridlines. If a subplot was clearly unsuited for establishment of regeneration, it wa not sampled. The affected gridline was then extended a chain in the direction of travel to provide a replacement subplot.

A subplot was considered unsuited for regeneration establishment if an of these conditions prevailed on **mo than half** its area:

1. Streambed up to normal high wat lines.
2. Permanent marsh, swamp, or meadow.
3. Road used since 1970.
4. Gravel pit used since 1970.
5. Solid rock, stump, or live tree ste
6. Area of deep, active erosion.

Subplots were rejected on only 15 o the 92 plots sampled in the Dead Indian and Butte Falls areas. In total 40 of 1,840 subplots were rejected, o 2.2 percent. Occurrence of the subplot on an actively used road wa the cause for all but seven rejection

Data Collected

Each subplot was thoroughly searched for seedlings. Stocking (occurrence) was determined for ea species, but a count for total numb was not made. Stocking was record by class of regeneration: (1) advance—healthy seedlings and saplings up to 8 inches (20 cm) in di meter, that originated before timbe harvest; (2) subsequent—healthy seedlings originating after timber h vest and 2 or more years old; and (3 second-year—healthy seedlings st in their second season of growth. A species could have up to three entr per subplot, one for each class. Stocking was also recorded as bei from natural seed fall, planting, or direct seeding. The species and cla of regeneration most likely to beco dominant on the subplot because size, position, and competitive pot tial were also noted.

Environmental variables observed each subplot were aspect, slope, canopy, total ground cover, domin ground cover, seedbed, and seed source. If one variable—grass, gopher activity, low canopy, cattle damage, etc.— was considered a ary help or hindrance to blishment of regeneration after er harvest, it was also noted. nniques used to collect and sum criptive environmental data are iled in the appendix, page 35.

maries and Analyses

were analyzed by several nods to answer the regeneration stions. Stocking data were med and their means and stan- errors calculated to ascertain ent status of regeneration. ression and correlation analyses ed relationships between king level and various environ- tal factors. The steps involved are ned below; details are given with esults to which they pertain.

king data for each sample plot summarized by counting the plots stocked by any species and ach species of advance, equent, and second-year regenera- Summary tables showing total other stocking classes were piled individually for Dead Indian Butte Falls partial cuts and clear- Plots having more than 30-, 50-, or 90-percent stocking were ted, the totals were expressed as cent of plots in the group, and idence limits were determined he resulting proportions from s prepared by Mainland et al.). Information on species compo- n, dominance, and abundance similarly developed.

aration of environmental data in correlation and multiple ession analyses required the ulation of plot averages for rved variables and those ined from external sources. Tests ssociation between independent ables and the stocking found in d Indian and Butte Falls partial and clearcuts were made by ns of the BMD02R stepwise mul- regression computer program A version of April 13, 1965). ociations between some noncon- ous (discrete) independent ables—forest type, soil type, graphic location, etc.—and plot king were inferred from observed demonstrated differences among pings.

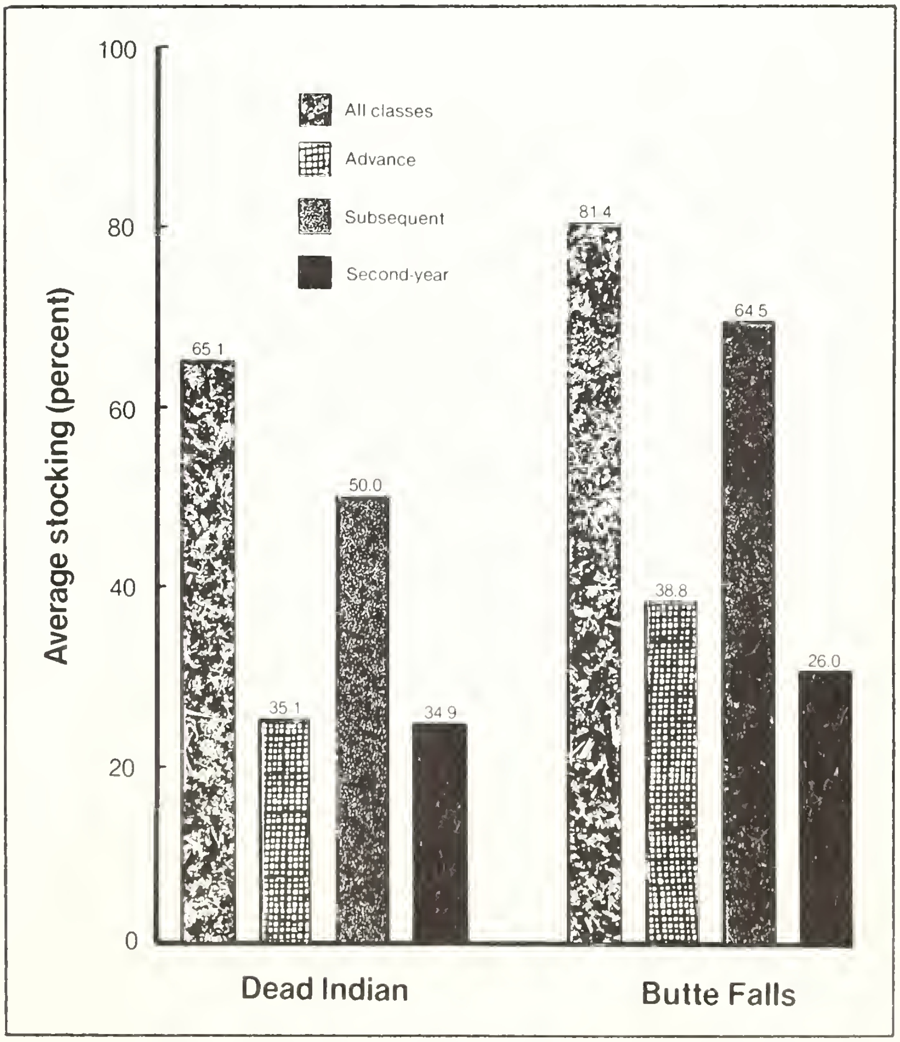
Stocking

Stocking data for plots in partial cuts and clearcuts were summed to show average stocking, proportion of acreage stocked to a given level, and stocking by individual species. Information on species abundance and likely dominance was also developed.

Average Stocking

In broad terms, partial cuts in the Dead Indian area were moderately stocked with regeneration and those in the Butte Falls area were well stocked.[1] Established regeneration averaged 65 percent in the Dead Indian area[2] and 81 percent in the Butte Falls area (fig. 2, and table 12, appendix). Total stocking ranged widely among Dead Indian partial cuts, from a low of 5 percent to 100 percent, and more narrowly for those in Butte Falls, from 50 to 100 percent.

Figure 2.—Regeneration in partial cuts, by class. Data are not additive since more than one class of regeneration was found on many subplots.



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[1] Stocking classes, as defined by the Pacific Northwest Seeding and Planting Committee (Reynolds et al. 1953): well stocked, 70 - 100 percent; moderately stocked, 40 - 69; poorly stocked, 10 - 39; and nonstocked, 0 - 9.

[2] Total stocking also averaged 65 percent for eight Dead Indian partial cuts omitted from all analyses. These sample plots were omitted because elapsed time after logging was not accurately known during sampling; this resulted in uncertain allocation of seedlings to advance and subsequent regeneration classes.

Figure 3.—Regeneration established before logging constituted about half the total stocking found in partial cuts.

Figure 4.—In general, partial cuts were moderately stocked with regeneration that established after logging.

After logging, the amount of advanc regeneration in partial cuts was abo the same in the two areas, averagin 35-percent stocking in Dead Indian and 39-percent in Butte Falls. The amount varied widely on individual plots—from 5 to 85 percent in Dead Indian and from 5 to 75 percent in Butte Falls. Advance regeneration constituted just over half the total stocking in the Dead Indian area an just under half in the Butte Falls are From the standpoint of amount present and size of trees, advance regeneration constituted a highly important component of total stocking in partial cuts (fig. 3).

In both the Dead Indian and Butte Falls areas, partial cuts were moderately stocked with regeneration that established after logging (fig. 4). On the average, 50 percent of the subplots examined i Dead Indian partial cuts were stock with subsequent regeneration; 65 percent in Butte Falls (fig. 2., table 1 appendix). Again, the amount of stocking varied widely among plots from 0 to 95 percent in Dead Indian, to 100 percent in Butte Falls. Postlo ging regeneration constituted a littl over three-fourths of the total stocking found in Dead Indian and Butte Falls partial cuts, if such rege eration is considered the main component rather than a subsidiary com ponent of total stocking.

Substantial numbers of second-yea seedlings were found in both Dead Indian and Butte Falls partial cuts. These were not tallied as part of tot stocking since their survival throug two full growing seasons had not ye been demonstrated. From their appearance, the long-term survival many seemed assured. In only a few instances, however, would the potential of these seedlings materially boost total stocking for t area. For example, potential for increased stocking was found on 26 of the 44 plots examined in Dead Indian, but only on 5 was the potent gain more than 15 percent; on 2 are the potential was sufficient to raise an essentially nonstocked area to moderate stocking and on 2 others from poorly stocked to well stocke In Butte Falls, only four partial cuts had potential for gain in stocking

m second-year seedlings, none
ater than 5 percent. The primary
ect of the continued survival of
ond-year seedlings will be to
rease numbers of seedlings on
plots that are already stocked.

eneral, clearcuts in the Dead
ian area were poorly stocked;
se in the Butte Falls area were well
cked (fig. 5). Total stocking
raged 33 percent on Dead Indian
arcuts; more than twice as much
4 percent—on Butte Falls
arcuts (fig. 6, and table 12,
endix). One clearcut plot in Dead
an had no seedlings at all, and the
nest stocking was 75 percent. In
trast, the lowest stocking on a
te Falls clearcut was 55 percent,
highest 90 percent.

arcuts were not entirely devoid of
ance regeneration. Six of 16 clear-
s sampled in the Dead Indian area
7 of 11 clearcuts in the Butte
s area had minor amounts of
eneration that survived logging
any slash burning. Average
king with advance regeneration
low, 4 percent for Dead Indian, 9
Butte Falls, and constituted about
eighth of total stocking.

tive amounts of regeneration that
blished after logging paralleled
ds in total stocking; on the
age, Dead Indian clearcuts were
ly stocked and Butte Falls
rcuts well stocked with
sequent regeneration. In neither
was there significant potential
ncreased stocking from second-
seedlings. In fact, on only one
lot of one clearcut were second-
seedlings the only regeneration
ent. Clearly, accretion of seed-
s is not occurring on clearcuts in
tities similar to those in partial
t.

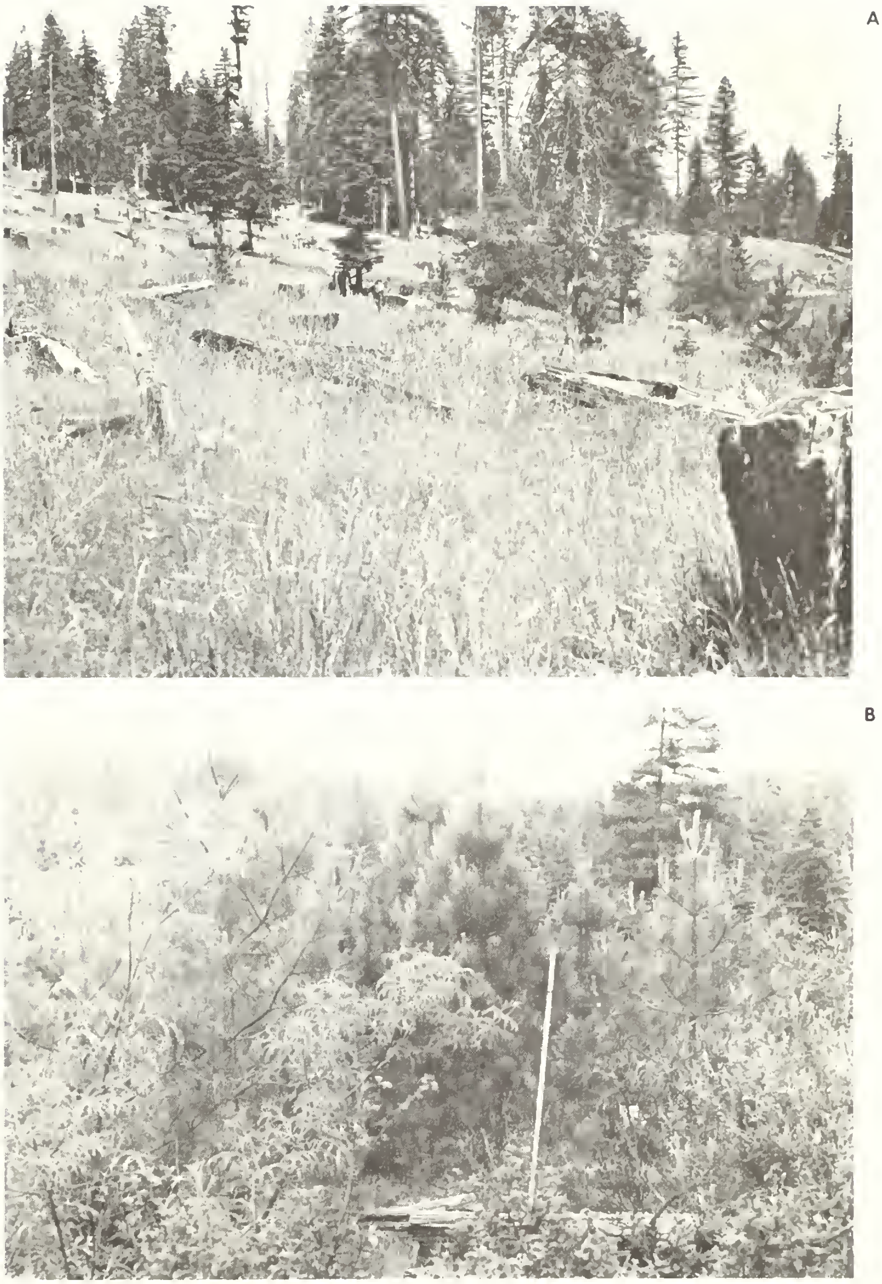

Figure 5.—Clearcuts were generally poorly stocked in the Dead Indian area (**A**), well stocked in the Butte Falls area (**B**).

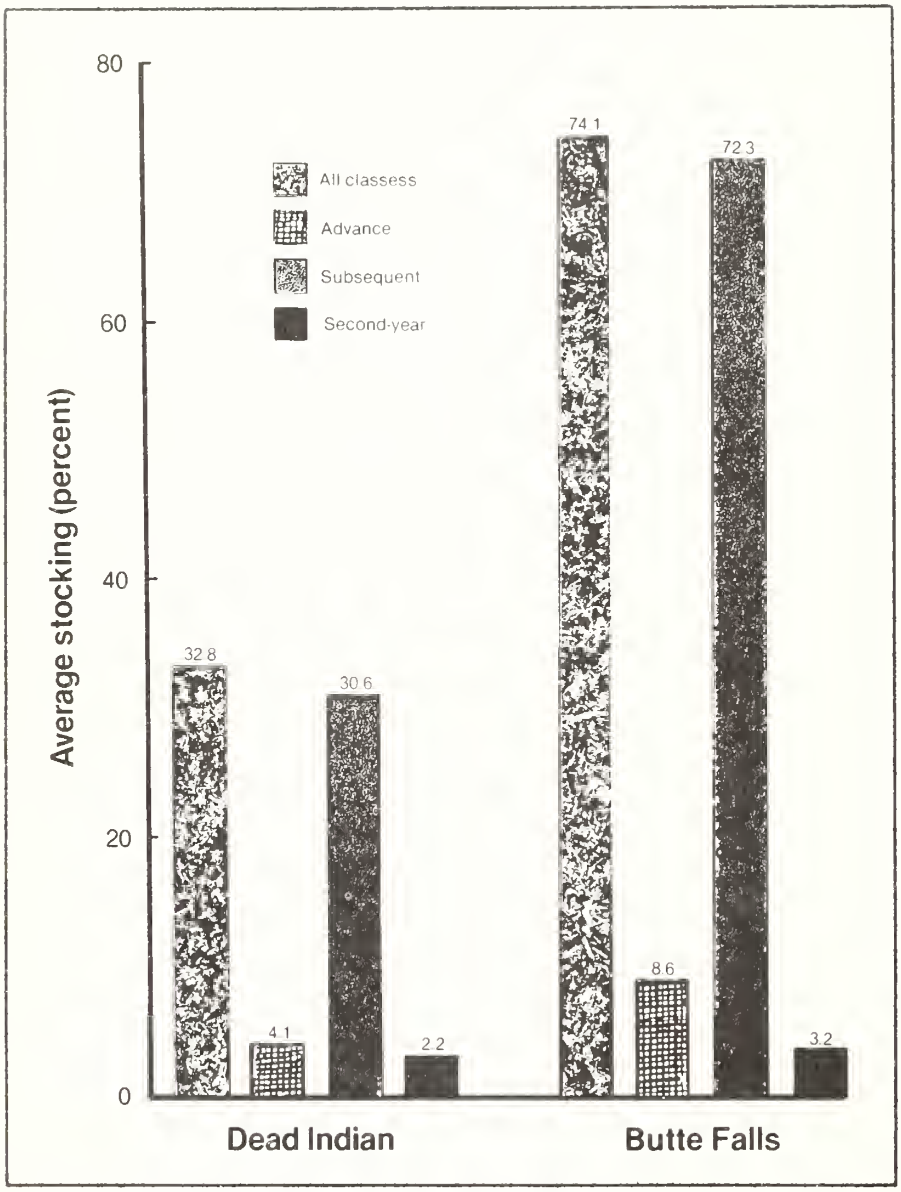

Figure 6.—Regeneration in clearcuts, by class.

Stocking Levels

The proportion of plots stocked to tl 30-, 50-, 70-, and 90-percent levels wa determined to augment information on average stocking. To facilitate presentation and illustrate significance of data on stocking levels, let us assume that 50 percent is the dividing line between acceptable and unacceptable stocking. Are less than 50 percent stocked might then be viewed as requiring addition regeneration effort.

Three-fourths of the acreage partiall cut in the Dead Indian area between 1956 and 1970 now meets the 50-percent or better stocking level (fig. and table 13, appendix). All the partially cut or clearcut acreage in the Butte Falls area meets or exceeds tl 50-percent level, but only one-fourth of the clearcut acreage in Dead Indi does (figs. 7 and 8, and table 13, appendix). In partial cuts, stocking from natural regeneration was so un form and high that a significant amount of the acreage—43 percent Butte Falls, 18 in Dead Indian—mee or exceeds the 90-percent stocking level.

About one-fourth of the partially cut acreage in Dead Indian and four-tenths in Butte Falls was stocked with advance regeneration at the 50-percent level or higher (table 14, appendix). In both Dead Indian and Butte Falls, about one partial cut in eight had as much as 70-percent stocking of advance regeneration after the first or second cut. Little o the clearcut acreage had 30-percent stocking of advance regeneration.

All clearcuts in the Butte Falls area were 50 percent stocked or better with subsequent regeneration, but only one-fourth of those in the Dea Indian area were (table 15, appendi Most partial cuts in Butte Falls had reached the 50-percent level, but in Dead Indian, just over half had attained this level.

king levels for Douglas-fir *eudotsuga menziesii* (Mirb. nco) and true firs, the most com- species to establish naturally r logging, also were different veen Butte Falls and Dead Indian s and between clearcuts and ial cuts (tables 16 and 17, endix). For example, about three- hs of the partial cutting in Butte s had 50-percent or more stocking ouglas-firs but less than a tenth e partial cuts in Dead Indian did. ird of the clearcuts in Butte Falls reached 30-percent or more king of Douglas-fir, but none in d Indian had. Over half the partial in both the Dead Indian and e Falls areas had at least 30- ent stocking of true firs, but few rcuts in either area had reached level.

d Composition

y native conifers and a few woods were found on the plots pled. Douglas-fir and true firs commonly present. True fir neration was not identified by ies; in different parts of the s, it included white fir (*Abies con- r* (Gord. and Glend.) Lindl. ex ebr.), grand fir (*A. grandis* (Dougl. Don) Lindl.), and Shasta red fir *agnifica* var. *shastensis* Lemm.). ifers found in lesser quantities and niversally distributed included derosa pine (*Pinus ponderosa* gl. ex Laws.), sugar pine (*P. lam- ana* Dougl.), western white pine *onticola* Dougl. ex D. Don), epole pine (*P. contorta* Dougl. ex .), western hemlock (*Tsuga rophylla* (Raf.) Sarg.), incense- r (*Libocedrus decurrens* Torr.), Pacific yew (*Taxus brevifolia*). Jeffrey pine (*Pinus jeffreyi* and Balf.), not native in most of utte Falls and Dead Indian areas, planted in mixture with ponder- ine on a few clearcuts. Regener- of large hardwoods found in r quantities included giant apin (*Castanopsis chrysophylla* gl.) A. DC.), western serviceberry *nlanchier alnifolia* (Nutt.) Nutt.) ng aspen (*Populus tremuloides* x.), Pacific madrone (*Arbutus iesii* Pursh), Oregon white oak *cus garryana* Dougl. ex Hook.), bigleaf maple (*Acer macrophyllum* Pursh), red alder (*Alnus rubra* Bong.), and bitter cherry (*Prunus emarginata* Dougl. ex Eaton).

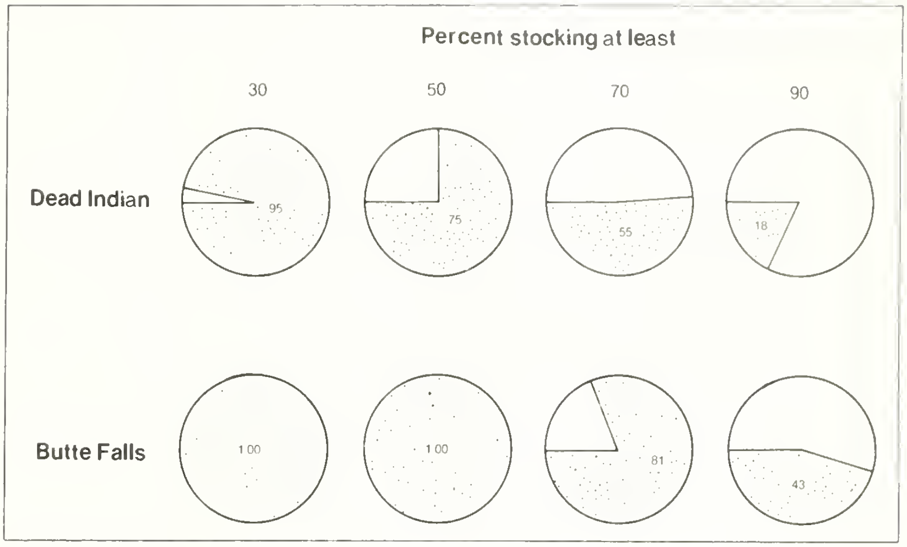

Figure 7.—Proportion of acreage partially cut from 1956 to 1970 that was 30-, 50-, 70-, or 90-percent stocked with regeneration.

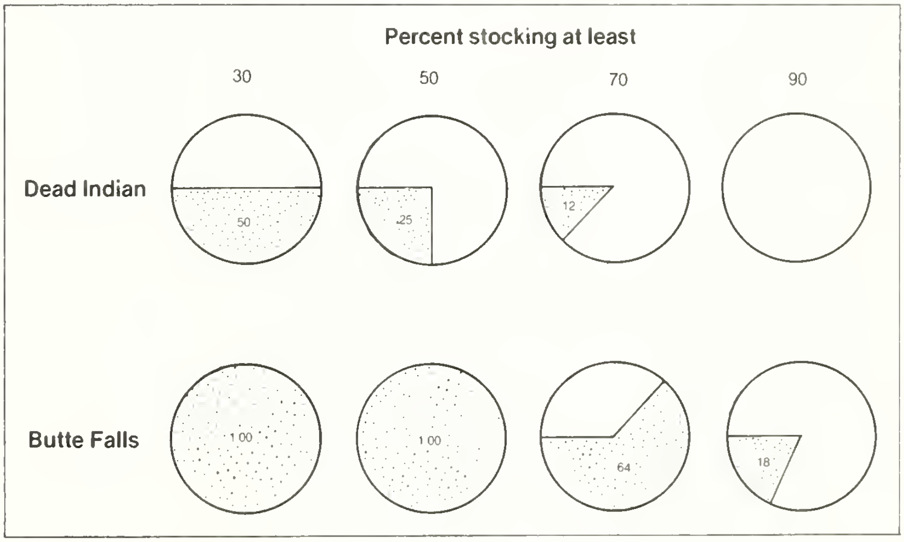

Figure 8.—Proportion of acreage clearcut from 1956 to 1970 that was 30-, 50-, 70-, or 90-percent stocked with regeneration.

True firs predominated among regeneration in partial cuts (fig. 9, and table 18, appendix). They were present on five of every six stocked subplots (54.2 ÷ 65.1 = .833) in the Dead Indian area and on 7 of 10 in the Butte Falls area. Douglas-fir regeneration was next most abundant—found on about 3 of every 10 stocked subplots in Dead Indian and on 6 of 10 in Butte Falls. Incense-cedar was third in abundance, being present on one of five stocked subplots in Dead Indian and on slightly more than half in Butte Falls. Other species were found less frequently than on 1 stocked subplot in 10.

Ponderosa pine was the predominant species in clearcuts in both the Dead Indian and Butte Falls areas (fig. 10, and table 18, appendix). It was present on slightly more than half the

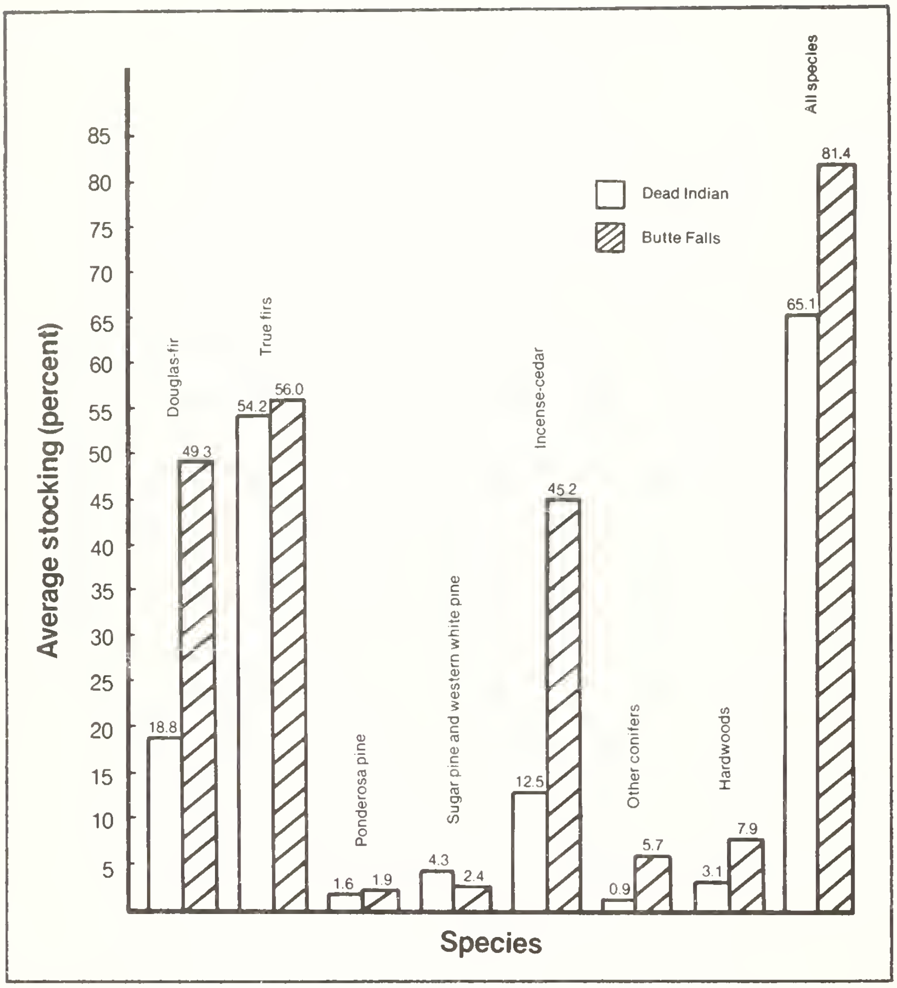

Figure 9.—Average stocking by species in Dead Indian and Butte Falls partial cuts.

stocked subplots in Dead Indian and on four of five in Butte Falls. Douglas-fir was second in frequency of occurrence in Butte Falls clearcuts but was exceeded 3 to 1 by true firs in Dead Indian clearcuts.

Advance true firs were present on five of every six subplots stocked with advance regeneration in Dead Indian partial cuts and on two of every three in Butte Falls (table 19, appendix). Douglas-fir advance regeneration was found on only one of every nine stocked subplots in Dead Indian partial cuts and on less than one of two in Butte Falls. Advance regeneration of other conifers and hardwoods was present only in minor quantities in the Dead Indian area, but incense-cedar was present on about one of every four subplots stocked with advance growth in the Butte Falls area.

True firs also predominated among advance regeneration in clearcuts in both locations (table 19, appendix). I Butte Falls, however, occurrence of Douglas-fir advance regeneration approached that of true firs. No ponderosa pines were found among the sparse advance regeneration in clea cuts, but there were a few five-needl pines and incense-cedars.

Subsequent Douglas-firs and true fi occurred with equal frequency in Butte Falls partial cuts, on 6 of every 10 stocked subplots (table 19, appen dix). In Dead Indian partial cuts, true firs occurred on more than twice as many stocked subplots as did Douglas-fir, 3 of 4 and 3 of 10, respectivel Six-tenths of the subplots stocked with subsequent regeneration in But Falls partial cuts contained incense-cedar; in Dead Indian partial cuts, about one-fourth of the stocked sub plots included incense-cedar. As a proportion of stocking by all specie Douglas-fir, five-needle pines, and incense-cedar were more abundant among subsequent seedlings in partial cuts than they were among advance regeneration. True firs and hardwoods occupied a somewhat smaller proportion of subplots stocked with subsequent regeneration than they did among subplots stocked with advance regeneration.

Ponderosa pine was the most common species established after logging in both Dead Indian and Bu Falls clearcuts (table 19, appendix). was present on 6 of 10 stocked subplots in Dead Indian clearcuts and 8 of 10 in Butte Falls. Predominance ponderosa pine in clearcuts reflect success achieved in planting this species (fig. 11). True firs were seco and Douglas-fir third most common on stocked subplots in Dead Indian and in reverse order in Butte Falls. Incense-cedar occurred on about 1 11 stocked subplots in Butte Falls. Seedlings of all species found exce ponderosa pine, Jeffrey pine, and Douglas-fir were judged to have established naturally from seed.

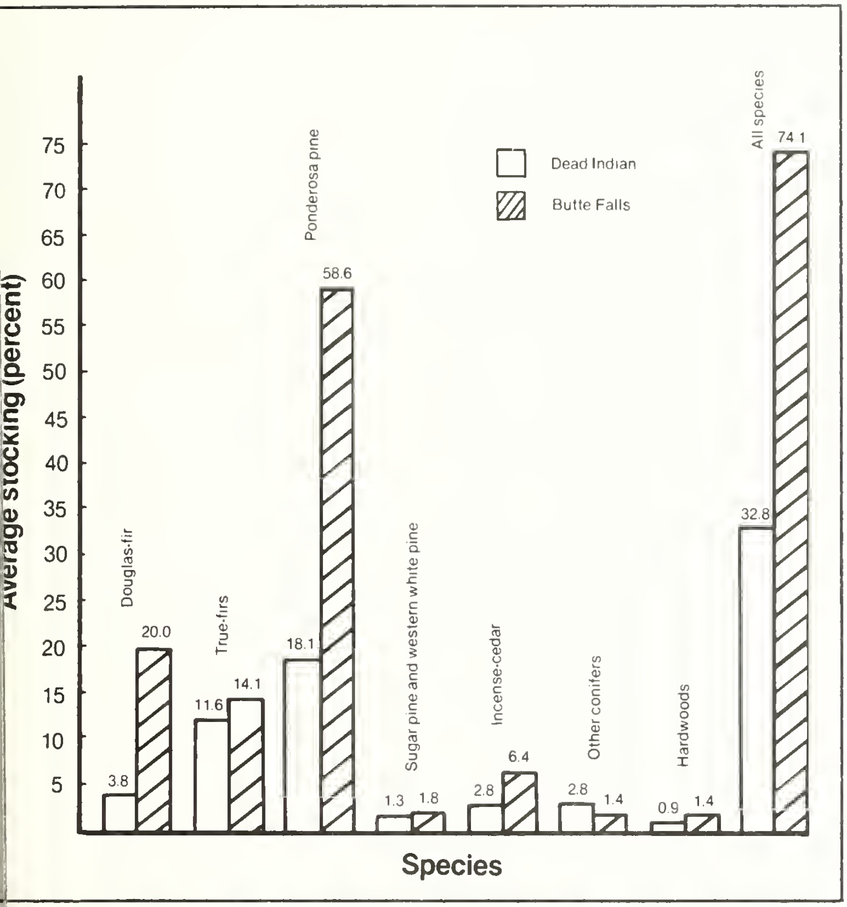

Figure 10.—Average stocking by species in Dead Indian and Butte Falls clearcuts.

Figure 11.—Ponderosa pine was the predominant species in both Dead Indian (**A**) and Butte Falls (**B**) clearcuts.

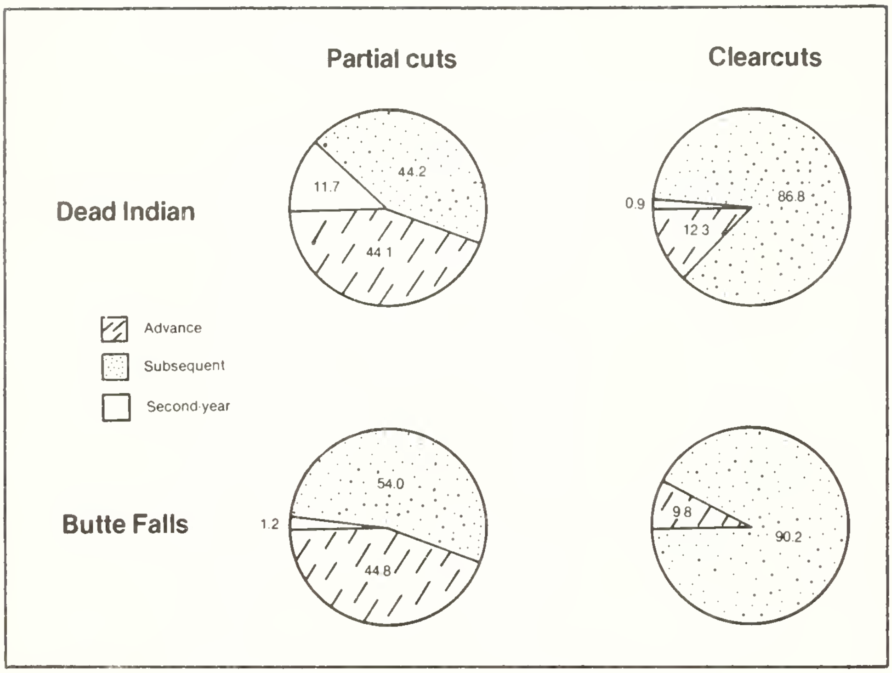

Figure 12.—Advance regeneration dominated nearly half the stocked subplots in partial cuts.

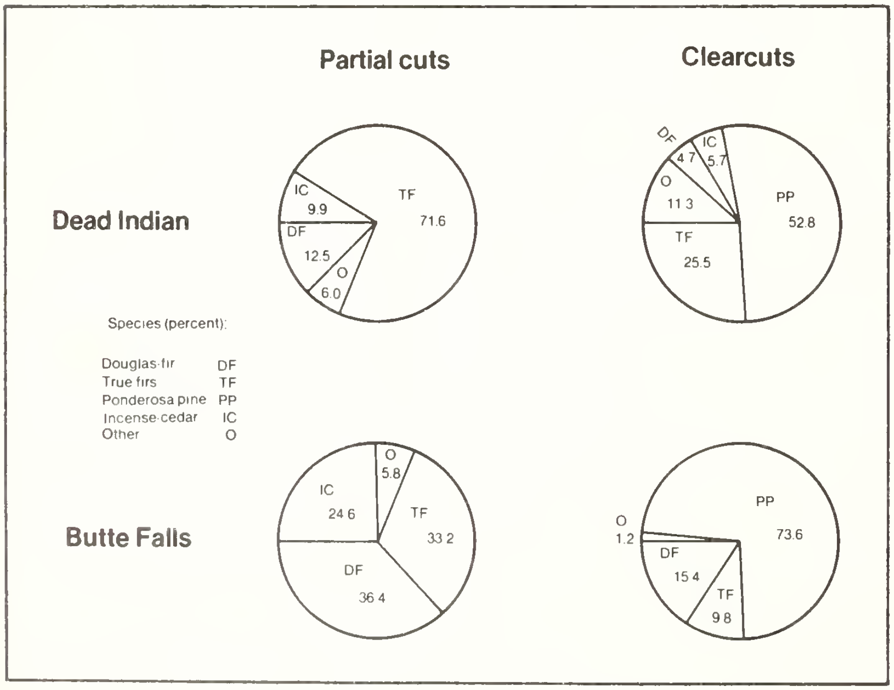

Figure 13.—Species dominant on stocked subplots differed between partial cuts and clearcuts.

Many second-year seedlings were found in partial cuts, very few in cle cuts (table 20, appendix). On a stock ing basis, one-eighth as many youn seedlings were found in Butte Falls and one-sixteenth as many in Dead Indian clearcuts as in respective partial cuts. Young true firs stocked more subplots than any other species, except in Butte Falls partia cuts where incense-cedar was mos common.

Dominance

Future composition of the developi stand may be more closely related t class of regeneration and species that now dominate stocked subplo than to the number of subplots on which each occurs. For this reason the class of regeneration and the species dominant on each subplot were tabulated. Second-year seedlings were included, for these represent potential when nothing older already dominates the subplo

Advance regeneration dominated nearly half the stocked subplots in both Dead Indian and Butte Falls partial cuts; only about 10 percent i clearcuts (fig. 12). Only in Dead Ind partial cuts did second-year seedli constitute an important componen among dominants—12 percent.

True firs, Douglas-fir, and incense-cedar were the dominant species o regeneration in Dead Indian and Bu Falls partial cuts (fig. 13). As individual species, pines, hardwoo and miscellaneous conifers were dominant on 3 percent or less of th total stocked subplots. In clearcut one of two stocked subplots in Dea Indian, and three of four in Butte Fa were dominated by ponderosa pine (fig. 13). True firs and incense-cedar ranked second and third in Dead Indian clearcuts; Douglas-fir and tru firs ranked second and third in Butt Falls clearcuts.

Environmental Relationships

ecies Abundance

his survey, the presence or
ence of seedlings was deter-
ied, not the total number. Since
h subplot was searched for indivi-
l species, however, some
rmation on stand mixtures can be
uced from the stocking data.

eneral, mixed regeneration was
e common in the Butte Falls area
n in the Dead Indian area. Only a
d of the stocked subplots in Butte
s partial cuts contained only one
cies, but nearly two-thirds of
se in Dead Indian did (table 1); dif-
nces were not as great in clear-
s—72 percent for Butte Falls and
ercent for Dead Indian. Both
ial cuts and clearcuts in Butte
s had appreciable numbers of
plots stocked with three or more
cies. Widespread occurrence of
cies mixtures is prerequisite to
ible management of the develop-
stand.

sence of more than one species
provides direct evidence that
y subplots were stocked with
e than one tree. Data in table 1
cate that in the cutovers sampled,
o 68 percent of the subplots were
ked with more than one species.
tainly, the percent of subplots that
more than one tree of the same
cies was even higher.

e 1—Number of species per stocked subplot in partial cuts and clearcuts

ies er lot	Partial cuts		Clearcuts	
	Dead Indian	Butte Falls	Dead Indian	Butte Falls
	- - - - - - Percent of stocked subplots - - - - - -			
	61.2	31.5	79.2	71.8
	31.0	34.1	17.0	16.6
	7.4	27.4	1.9	10.4
	.4	5.8	1.9	.6
	0.	.6	0.	.6
	0.	.6	0.	0.
l	100.0	100.0	100.0	100.0

Regeneration survey objectives included a search for interdependence of environmental factors and seedling stocking and the identification of problem areas. Two kinds of analysis were used: (1) comparison of means after stocking data were sorted on the basis of discontinuous environmental variables—forest type, soil type, etc.; and (2) correlation and regression analyses testing for associations between stocking and independent environmental variables of a continuous nature—elevation, slope, canopy, etc. Environmental information obtained for the Dead Indian and Butte Falls areas is presented before results of the two types of analysis are given.

Geographic Characteristics

Environments in the Dead Indian and Butte Falls areas differ substantially. The differences are somewhat evident from the nature of the forests and other vegetation. The degree of difference, however, is much greater than is evident during casual work or travel in the areas. A systematic comparison of environmental factors determined for sample plots forcefully demonstrates some key differences.

All partial cuts and clearcuts sampled in the Dead Indian and Butte Falls areas were located on gentle terrain. Slopes on plots ranged from flat ground to a maximum of 38 percent (table 2). Slopes averaged 10 percent in Dead Indian and 15 percent in Butte Falls. Although there are prominent hilltops and mountain peaks in both, the Dead Indian and Butte Falls areas have many plateaulike features.

Elevation of these areas, however, is substantially different. Elevation for plots sampled in Butte Falls averaged 3,524 feet (1 074 m), for Dead Indian 4,948 feet (1 508 m), a difference of more than 1,400 feet (427 m). Only elevations of the three highest plots sampled in Butte Falls overlap the lowest elevation sampled in the Dead Indian area. In both areas, clearcuts averaged somewhat lower in elevation than partial cuts.

It is evident from elevation differences alone that growing seasons in the Butte Falls and Dead Indian areas differ substantially in temperature and length. Application of the adiabatic gradient (5.6°F per 1,000 ft or 1°C per 100 m) provides some insight on relative temperatures. When summer temperatures register 100°F (38°C) in the shade at 1,300-foot (396-m) elevation near Medford, temperatures are about 88°F (31°C) in the Butte Falls area and about 80°F (27°C) in the Dead Indian area. Relative to valley temperatures near Medford, neither area is exceptionally hot; and the Dead Indian area is much cooler than the Butte Falls area.

Topographic position of these areas is also quite different. The Butte Falls area, hilltops included, occupies a midslope position relative to the Rogue River Valley to the west and the higher Cascades to the east. In contrast, much of the Dead Indian area occupies upper slope positions. Drainages from the westernmost part of Dead Indian flow westward, then north to the Rogue River via Bear Creek; others flow northwestward to the Rogue via Dead Indian and Little Butte Creeks; but most of the area drains south and southeastward to the Klamath River via Jenny Creek

Table 2—Physical characteristics of sampled areas

Characteristic	Dead Indian		Butte Falls	
	Partial cuts	Clearcuts	Partial cuts	Clearcuts
		Number of areas		
Drainage:				
Jenny Creek	31	7	0	0
Big Butte Creek	0	0	11	7
Klamath River	8	1	0	0
Little Butte Creek	3	7	3	0
Rogue River	0	0	7	4
Bear Creek	2	1	0	0
Total	44	16	21	11
Predominant aspect:				
SE to W	21	9	13	5
NW to E	23	7	8	6
Soil type:[1]				
740	0	0	3	0
750	0	0	11	10
809	30	15	0	0
810	7	1	7	1
840	2	0	0	0
850	1	0	0	0
882	4	0	0	0
Radiation index:				
Average	.4721	.4532	.4626	.4608
Range	.4223-.5315	.3972-.4806	.3457-.5177	.4202-.5006
Elevation:[2]		Feet		
Average	4,965	4,901	3,612	3,355
Range	4,400-5,720	4,560-5,700	2,600-4,840	2,920-4,260
Precipitation:[3]		Inches		
Average annual	29.9	22.6	40.5	38.5
Range	18-40	18-30	30-50	25-50
Slope:		Percent		
Average	9.5	11.0	13.6	16.5
Range	0-35	0-32	0-33	0-38
Seedbed disturbance				
Average	63.0	94.1	50.7	87.7
Range	30-100	85-100	10-95	60-100

[1] Descriptions for numbered soil types are in a compendium on file at Medford District, Bureau of Land Management.

[2] To convert feet to meters, multiply by 0.305.

[3] To convert inches to centimeters, multiply by 2.54.

and adjacent drainages (fig. 1, table 2). Many more sites in the Dead Indian area appear frontally exposed to strong winds and to climatic extremes than in the Butte Falls area.

Limited records indicate that the Butte Falls area receives substantially more precipitation than does the Dead Indian area. As extrapolate from a small-scale isohyet map which probably is only a first approximation of rainfall distribution in the areas, precipitation averages 30 inches (76 cm) per year for the partial cuts sampled in Dead Indian, about 40 inches (103 cm) for those in Butte Falls. Precipitation on the clearcuts sampled is somewhat lower, averaging 23 inches (57 cm) in Dead Indian, 38 inches (98 cm) in Butte Falls. Judged by data for plot locations, precipitation ranges from 18 t 40 inches (46 to 102 cm) in Dead Indian, 25 to 50 inches (64 to 127 cm in Butte Falls.

That midslopes around Butte Falls receive more rainfall than higher slopes only 25 miles (40 km) southward may appear surprising. Undoubt edly, the smoothing and extrapolatio needed to prepare the isohyet map could produce some inconsistencies Broad vegetation patterns, however, support the precipitation levels indicated by the isohyet map. Evergreen brush and forest communities occur substantially lower elevations on the western fringes of the Butte Falls ar than on the Dead Indian area. Perhap the eastern Siskiyou Mountains, whi rise to 7,533-foot elevation (2 296 m) only 15 miles (24 km) to the southwe across the intervening valley, produc a rain shadow effect on the westernmost Dead Indian slopes which rise a maximum of 6,113 feet (1 863 m).

Southerly (SE to W) and northerly (N to E) aspects were about equally represented among sample plots in the Dead Indian and Butte Falls are (table 2). Average radiation indexes were also similar, indicating that slope and aspect combinations we not markedly dissimilar in the two areas. Dead Indian clearcuts averag less radiation (lower radiation inde values) than the rest.

Sample plots in both the Dead India and Butte Falls areas were located well-drained loam soils, originating from basic volcanic rocks of the Cascade Range. Except for their gravel or cobble content and depth descriptions of these soils are not markedly different:

Series	— — Surface — —		— — Depth — —	
	Texture	Color	Surface	Total
			(Inches)[3]	
740	Cobbly loam	Dark brown	24	50
750	Clay loam	Dark reddish brown	14	60
809	Very cobbly loam	Very dark grayish brown	12	36
810	Cobbly loam	Very dark grayish brown	22	45
840	Gravelly loam	Very dark grayish brown	12	55
850	Clay loam	Dark brown	12	36
882	Very cobbly loam	Dark brown	19	45

---

[3] See footnote 3, table 2.

Table 3—Vegetative characteristics of sampled areas

Characteristic	Dead Indian		Butte Falls	
	Partial cuts	Clearcuts	Partial cuts	Clearcuts
	Number of areas			
Forest type:				
White fir	22	9	7	5
Douglas-fir	8	7	13	6
Ponderosa pine	6	0	0	0
Pine mixture	3	0	1	0
Sugar pine	3	0	0	0
Shasta red fir	2	0	0	0
Total	44	16	21	11
Dominant cover:				
Woody perennial	22	3	14	7
Herbaceous	18	3	6	4
Grass	3	10	1	0
Bare	1	0	0	0
Main seed source:				
True fir	31	3	4	0
Douglas-fir	7	13	16	9
Incense-cedar	5	0	1	0
Ponderosa pine	0	0	0	1
Sugar pine	1	0	0	1
	Years			
Time since harvest:				
Average	7.5	12.8	6.6	13.0
Range	2-16	8-16	2-14	9-15
	Percent			
Canopy:				
Average	43.7	9.9	45.6	31.6
Range	21-71	1-25	22-74	15-52
Ground cover:				
Average	49.0	61.0	48.2	61.0
Range	18-83	35-81	17-77	54-69
Seed Source Within 50 feet:				
Average	97.4	33.8	96.2	20.5
Range	55-100	0-70	75-100	0-55

It is likely, but not absolutely certain, that the 2-acre (0.8-ha) plot sampled at each location was on soil typical of the series.

Two-thirds of the plots sampled in the Butte Falls area were located on a dark reddish brown clay loam, the deepest soil represented. Three-fourths of the plots in the Dead Indian area were located on a very dark grayish brown, very cobbly loam of medium depth. Many of the remaining plots in both areas were located on very dark grayish brown cobbly loam (series 810) whose depth is intermediate to series 750 and 809. In broad terms, plots in Butte Falls were located on soils that are finer, deeper, and have greater water-holding capacity than the soils in Dead Indian.

During logging, a high percentage of the seedbed surface on both Butte Falls and Dead Indian clearcuts was disturbed—88 and 94 percent, respectively, as judged by evidence still visible several years later. Much less seedbed was disturbed in the partial cuts, averaging 51 percent for Butte Falls and 63 percent for Dead Indian. Lowest disturbance in partial cuts was 10 percent; in clearcuts, 60.

Vegetation Characteristics

Plots sampled in the Dead Indian or Butte Falls areas occurred in the Douglas-fir, white fir, ponderosa pine, pine mixture, sugar pine, and Shasta red fir forest types. At each plot location, the type was determined from Forest Survey maps prepared in the 1940's. Thus, the classification antedates any compositional changes caused by logging. For study purposes, the mapped subdivisions of each type were not kept separate.

All clearcuts sampled were located in either the Douglas-fir or white fir type (table 3); the two types were equally represented. For partial cuts, white fir type was predominant among Dead Indian samples, Douglas-fir among Butte Falls samples. Pine types were strongly represented among samples from Dead Indian partial cuts, more so than the Douglas-fir type.

On the average, the clearcuts were older than the partial cuts, 13 years compared with 7. By design, all sample areas had been logged at least 2 years earlier and none more than 18.

Dead Indian and Butte Falls partial cuts averaged about the same overstory canopy, 45 percent. The means for 20 ocular estimates of canopy per individual plot ranged from 21 to 74 percent (fig. 14). Scattered residual trees were sometimes present on clearcuts, but young trees and shrubs over waist high constituted most of the canopy. Clearcuts in Dead Indian were relatively open, averaging about 10-percent canopy; those in Butte Falls averaged over 30-percent canopy.

Ground cover averaged 61 percent in clearcuts, 49 percent in partial cuts. Variability in amount of ground cover was greatest in partial cuts, from 17 to 83 percent. Woody perennials and herbaceous types of vegetation were dominant on nearly equal numbers of Dead Indian partial cuts; the majority of clearcuts were dominated by grass. In Butte Falls, woody perennials were the dominant ground cover on a majority of the partial cuts and clearcuts (fig. 15).

Nearly all subplots examined in partial cuts were located within 50 feet (17 m) of a seed tree; but on clearcuts, one-third or less of the subplots were within 50 feet of a seed tree. True firs were the predominant species of seed tree in a majority of Dead Indian partial cuts. Douglas-fir was the predominant seed tree in Butte Falls partial cuts and also adjacent to Dead Indian and Butte Falls clearcuts. Incense-cedar was the predominant seed tree in six instances, ponderosa or sugar pine in only three. On more than 80 percent of the plots examined, at least two species were represented among the closest seed trees.

Figure 14.—Overstory canopy in partial cuts varied greatly in quantity and distribution.

Figure 15.—Woody perennials, such as ceanothus, chinkapin, and manzanita, were the dominant ground cover in Butte Falls clearcuts and partial cuts.

Stocking by Forest Type

Sample plots were sorted by the forest types in which they occurred. Averages for the four classes of regeneration—all, advance, subsequent, and second-year—were then determined for each type, cutting method, and locality. Differences between means representing three or more plots per grouping were tested for significance by analysis of variance and Duncan Multiple Range Tests (Duncan 1955). Although forest types are not represented by an equal number of plots and some groupings have insufficient data, the demonstrated statistical differences and the consistency of various differences provide useful insights.

In partial cuts, both total stocking and subsequent stocking averaged lower in the white fir than in the other forest types sampled (table 4). The difference was substantial—14 percent lower than the next higher average for total stocking and 17 percent lower for subsequent stocking. The same relationship holds for the Dead Indian and Butte Falls areas individually, but differences are not as great.

Advance regeneration tends to be less abundant in the Douglas-fir type than in the white fir, ponderosa pine, and Shasta red fir types. Furthermore, potential for gain in stocking from second-year seedlings was generally less in the Douglas-fir than in the other three types. Scarcity of young seedlings might only reflect timing relative to occurrence of the last seed crop. But good stocking in the type, despite sparse numbers of advance and second-year seedlings, might indicate that seedlings must establish soon after harvest rather than through steady accretion.

Table 4—Average and range of stocking by forest type in Dead Indian and Butte Falls partial cuts

Area and forest type	Sample plots	Regeneration class[1]							
		All		Advance		Subsequent		Second-year	
		Average	Range	Average	Range	Average	Range	Average	Range
	Number	Percent stocking							
Dead Indian:									
White fir	22	58.2a	10- 90	35.5b	5-70	39.8ab	0- 90	37.0	5-75
Douglas-fir	8	63.8	35- 90	17.5bc	5-45	59.4a	25- 90	32.5	15-75
Pine	12	74.6a	5-100	42.5c	5-75	58.8b	0- 95	29.6	5-80
Shasta red fir	2	90.0	80-100	57.5	30-85	72.5	70- 75	52.5	35-70
Total or average	44	65.1	5-100	35.1	5-85	50.0	0- 95	34.9	5-80
Butte Falls:									
White fir	7	74.3	50-100	42.9	20-75	60.0	35- 80	32.1	0-90
Douglas-fir	13	84.6	55-100	37.7	5-70	65.0	5-100	19.6	5-65
Pine	1	90.0	--	25.0	--	90.0	--	65.0	--
Total or average	21	81.4	50-100	38.8	5-75	64.5	5-100	26.0	0-90
Dead Indian and Butte Falls:									
White fir	29	62.1ab	10-100	37.2	5-75	44.7bb_1	0- 90	35.9	0-90
Douglas-fir	21	76.7b	35-100	30.0	5-70	62.9b	5-100	24.5	5-75
Pine	13	75.8a	5-100	41.2	5-85	61.2b_1	0- 95	32.3	5-80
Shasta red fir	2	90.0	80-100	57.5	30-85	72.5	70- 75	52.5	35-70
Total or average	65	70.4	5-100	36.3	5-85	54.7	0-100	32.0	0-90

Means followed by the same letter or letter plus subscript differ significantly--a, at 0-percent probability level; b, 5-percent; and c, 1-percent.

Table 5—Average and range of stocking by forest type in Dead Indian and Butte Falls clearcuts

Area and forest type	Sample plots	Regeneration class[1]							
		All		Advance		Subsequent		Second-year	
		Average	Range	Average	Range	Average	Range	Average	Range
	Number	Percent stocking							
Dead Indian:									
White fir	9	43.3b	20-75	3.3	0-15	41.7b	10-70	2.8	0-15
Douglas-fir	7	19.3b	0-40	5.0	0-25	16.4b	0-40	1.4	0-10
Total or average	16	32.8	0-75	4.1	0-25	30.6	0-70	2.2	0-15
Butte Falls:									
White fir	5	81.0a	75-90	7.0	0-25	80.0b	75-90	2.0	0-5
Douglas-fir	6	68.3a	55-90	10.0	0-30	65.8b	50-80	4.2	0-10
Total or average	11	74.1	50-90	8.6	0-30	72.3	50-90	3.2	0-10
Dead Indian and Butte Falls:									
White fir	14	56.8	20-90	4.6	0-25	55.4	10-90	2.5	0-15
Douglas-fir	13	41.9	0-90	7.3	0-30	39.2	0-80	2.7	0-10
Total or average	27	49.6	0-90	5.9	0-30	47.6	0-90	2.6	0-15

[1] Means followed by the same letter differ significantly--a, at 10-percent probability level; and b, 5-percent.

Stocking levels for clearcuts in the white fir and Douglas-fir types were in reverse order to those for partial cuts (table 5). Total stocking and subsequent stocking averaged one-third higher in the white fir type than in the Douglas-fir type. Advance reproduction and second-year seedlings were scarce on clearcuts; levels were too low to interpret for relative differences. Alone or mixed with other species, ponderosa pine had been spot seeded or planted on all but one of the clearcuts sampled. Differences resulting from species mix, reforestation method, and spacing prevent clear identification of the effects forest type had on regeneration establishment.

Even though there are demonstrated statistical differences in average stocking among forest types and more could be proved at probability levels over 10 percent, it is important to recognize that stocking ranged widely among plots in every type (tables 4 and 5). It varied less in the Butte Falls area than in Dead Indian.

Stocking by Soil Type

Sample plots were sorted by soil type, and the stocking averages for the four classes of regeneration were then determined as for forest type. Plots were even less uniformly distributed among soil types than among forest types. In the Butte Falls area, soil series were represented by plots that were geographically well dispersed; in the Dead Indian area, seven of eight plots on soil series 810 were located in the easternmost part—ranges 5 and 6, Willamette meridian. Most plots on other Dead Indian soils were located in ranges 2, 3, and 4.

Total and subsequent stocking seems to be slightly higher on soil series 810 than on other soil series, but such differences were statistically confirmed only for subsequent stocking at Butte Falls (tables 6 and 7).

Since soil series 810 has depth and other characteristics intermediate to soil series 750 and 809, its characteristics are not likely to be unique enough to differentially influence stocking level. More likely, geographic location, forest type, and other factors associated with this soil are contributing influences. Because both soil development and its classification are linked with such primary environmental variables as slope, aspect, and precipitation, analyzing data for associations between stocking and these environmental variables is more direct and more likely to prove rewarding.

Table 6—Average and range of stocking by soil series in Dead Indian and Butte Falls partial cuts

Area and soil series	Sample plots	Regeneration class[1]							
		All		Advance		Subsequent		Second-year	
		Average	Range	Average	Range	Average	Range	Average	Range
	Number	Percent stocking							
Dead Indian:									
809	30	64.7	10-100	33.3	5-75	51.5	5-95	36.3	5-80
810	7	71.4	35-100	46.4	10-85	47.9	0-75	30.0	5-70
840	2	70.0	60-80	27.5	5-50	52.5	50-55	22.5	5-40
850	1	5.0	-----	5.0	-----	0	-----	45.0	-----
882	4	70.0	45-85	40.0	25-50	53.8	30-70	35.3	15-65
Total or average	44	65.1	10-100	35.1	5-85	50.0	0-95	34.9	5-80
Butte Falls:									
740	3	76.7	55-100	$55.0b_2$	45-70	31.7bc	5-55	23.3	10-30
750	11	79.1	50-100	$44.1b_1$	20-75	65.0b	35-100	26.4	0-90
810	7	87.1	60-100	$23.6b_1b_2$	5-55	77.9c	50-95	26.4	0-65
Total or average	21	81.4	50-100	38.8	5-75	64.5	5-100	26.0	0-90
Dead Indian and Butte Falls:									
810	14	79.3	35-100	35.0	5-85	62.9	0-95	28.2	0-70

Means followed by the same letter or letter plus subscript differ significantly--b, at 5-percent probability level; and c, 1-percent.

Table 7—Average and range of stocking by soil series in Dead Indian and Butte Falls clearcuts

Area and soil series	Sample plots	Regeneration class[1]							
		All		Advance		Subsequent		Second-year	
		Average	Range	Average	Range	Average	Range	Average	Range
	Number	Percent stocking							
Dead Indian:									
809	15	30.0	0-70	3.3	0-25	28.0	0-70	2.0	0-15
810	1	75.0	--	10.0	--	70.0	--	5.0	--
Total or average	16	32.8	0-75	4.1	0-25	30.6	0-70	2.2	0-15
Butte Falls:									
750	10	75.5	55-90	9.5	0-30	73.5	50-90	3.5	0-10
810	1	60.0	--	0	--	60.0	--	0	--
Total or average	11	74.1	55-90	8.6	0-30	72.3	50-90	3.2	0-10
Dead Indian and Butte Falls:									
810	2	67.5	60-75	5.0	0-10	65.0	60-70	2.5	0-5

Stocking by Location

Stocking in Dead Indian partial cuts differed significantly by geographic location. Total and subsequent stocking were lowest for plots in T.39 S., R.3 E., yet stocking with second-year seedlings was substantially above average (table 8). In adjacent townships to the north and northeast, total stocking was about average, and in all other townships it was above average. Subsequent stocking was well below average only in T.39 S., R.3 E. Seven of the 9 sample plots with less than 30-percent subsequent stocking were located in this township; of those with less than 50-percent subsequent stocking, 9 of 18 were in this township.

Clearcuts in T.38 S., R.4 E. had substantially less total and subsequent stocking than those in the adjacent township to the west (table 9). In all, 12 of 16 clearcuts in the Dead Indian area had less than 50-percent stocking.

In the Butte Falls area, partial cuts in T.34 S., R.3 E. had significantly lower stocking of subsequent regeneration than in T.33 S., R.2 E., but higher stocking of advance regeneration. Clearcuts in T.33 S., Rs. 2 and 3 E. had the lowest total and subsequent stocking.

On a drainage basis, total stocking averaged highest for partial cuts and clearcuts located in the eastern part of Dead Indian—in upper side drainages grouped as Klamath River (tables 10 and 11). The next highest averages were for cuttings in Little Butte Creek flowing from the northwest part of Dead Indian to the Rogue River. Total stocking averaged lowest in Jenny Creek and Bear Creek, which drain most of the western and central parts of the Dead Indian area and flow to the Klamath and Rogue Rivers, respectively. Subsequent stocking also tended to be higher in the Klamath River and Little Butte Creek drainages than in the Jenny and Bear Creek drainages.

In Butte Falls, the higher average total and subsequent stocking for partial cuts in Little Butte Creek did not prove statistically significant at the 10-percent level. Among clearcuts, the averages were significantly higher in the Big Butte Creek drainage than in areas draining directly into the Rogue River.

Table 8—Average stocking by township in Dead Indian and Butte Falls partial cuts

Area and township	Sample plots	Regeneration class[1]			
		All	Advance	Subsequent	Second-year
	Number	Percent stocking			
Dead Indian:					
T. 38 S., R. 3 E.	6	62.5	24.2	53.3	26.7ab
T. 38 S., R. 4 E.	7	59.3a	31.4	48.6	18.6c_2c_3
T. 38 S., R. 5 E.	5	84.0ab	41.0	72.0c	48.0ac_1c_3
T. 38 S., R. 6 E.	3	75.0	46.7	51.7	8.3a_1cc_1
T. 39 S., R. 3 E.	14	50.4a_1b	27.1a	32.5ac	50.7$a_2b_1cc_2$
T. 39 S., R. 4 E.	5	74.0a_1	47.0a	58.0a	34.0a_1a_2
T. 39 S., R. 5 E.	2	87.5	42.5	80.0	12.5
T. 39 S., R. 6 E.	1	100.0	85.0	70.0	70.0
T. 40 S., R. 2 E.	1	80.0	50.0	50.0	5.0
Total or average	44	65.1	35.1	50.0	34.9
Butte Falls:					
T. 33 S., R. 2 E.	5	85.0	27.0a_1	77.0a	31.0
T. 34 S., R. 2 E.	3	86.7	23.3$_a$	68.3	21.7
T. 34 S., R. 3 E.	7	72.1	50.7aa_1	51.4a	25.7
T. 35 S., R. 2 E.	5	86.0	46.0	63.0	16.0
T. 36 S., R. 2 E.	1	90.0	25.0	90.0	65.0
Total or average	21	81.4	38.8	64.5	26.0

[1] Means followed by the same letter or letter plus subscript differ significantly--a, at 10-percent probability level; b, 5-percent; and c, 1-percent.

Table 9—Average stocking by township in Dead Indian and Butte Falls clearcuts

Area and township	Sample plots	Regeneration class[1]			
		All	Advance	Subsequent	Second-year
	Number	Percent stocking			
Dead Indian:					
T. 38 S., R. 3 E.	10	35.5	2.0	34.5a	2.0
T. 38 S., R. 4 E.	5	19.0	7.0	15.0a	2.0
T. 38 S., R. 6 E.	1	75.0	10.0	70.0	5.0
Total or average	16	32.8	4.1	30.6	2.2
Butte Falls:					
T. 33 S., R. 2 E.	1	55.0	5.0	50.0	10.0
T. 33 S., R. 3 E.	2	62.5	2.5	62.5	5.0
T. 34 S., R. 2 E.	1	90.0	30.0	80.0	0.
T. 34 S., R. 3 E.	6	78.3	7.5	77.5	2.5
T. 35 S., R. 2 E.	1	75.0	10.0	75.0	0.
Total or average	11	74.1	8.6	72.3	3.2

[1] Means followed by "a" differ significantly at the 10-percent probability level.

Table 10—Average stocking by drainage in Dead Indian and Butte Falls partial cuts

Area and drainage	Sample plots	Regeneration class[1]			
		All	Advance	Subsequent	Second-year
	Number	Percent stocking			
Dead Indian:					
Klamath River	8	80.6b	47.5b	61.3	31.9
Jenny Creek	31	62.1b	34.2	47.3	36.6
Little Butte Creek	3	70.0	16.7b	65.0	31.7
Bear Creek	2	42.5	27.5	25.0	25.0
Total or average	44	65.1	35.1	50.0	34.9
Butte Falls:					
Rogue River	7	80.7	35.0	65.0	24.3
Big Butte Creek	11	79.1	44.1	60.0	25.0
Little Butte Creek	3	91.7	28.3	80.0	33.3
Total or average	21	81.4	38.8	64.5	26.0

[1] Means followed by "b" differ significantly at the 5-percent probability level.

Table 11—Average stocking by drainage in Dead Indian and Butte Falls clearcuts

Area and drainage	Sample plots	Regeneration class[1]			
		All	Advance	Subsequent	Second-year
	Number	Percent stocking			
Dead Indian:					
Klamath River	1	75.0	10.0	70.0	5.0
Jenny Creek	7	21.4a	5.7	18.6a	1.4
Little Butte Creek	7	40.0a	2.1	38.6a	2.1
Bear Creek	1	20.0	0.	20.0	5.0
Total or average	16	32.8	4.1	30.6	2.2
Butte Falls:					
Rogue River	4	61.3c	5.0	60.0c	6.3b
Big Butte Creek	7	81.4c	10.7	79.3c	1.4b
Total or average	11	74.1	8.6	72.3	3.2

[1] Means followed by the same letter differ significantly--a, at 10-percent probability level; b, 5-percent; and c, 1-percent.

sts for Associations

ta on 15 environmental variables re used in both correlation and ression analyses to ascertain cking patterns in partial cuts. The ependent variables or covariates listed below; data source and tinent details on most are given in appendix.

Elevation (feet)
Average annual precipitation (inches)
Aspect index
Average slope (percent)
Radiation index
Canopy (percent)
Time since logging (years)
Total ground cover (percent)
Ground cover primarily grass (percent)
Ground cover primarily woody perennials (percent)
Seedbed primarily duff and litter (percent)
Seedbed primarily logs, wood, and bark (percent)
Seedbed primarily undisturbed, variables 11 and 12 combined (percent)
Nearest seed source Douglas-fir (percent)
Nearest seed source true firs (percent)

teen variables were used for lyses of stocking patterns in rcuts. Distance to seed source substituted for variables 14 and 15 ve, which give seed source ximity for only two individual cies. Although some canopy was sent on clearcuts, variable 6 was ted because it represented a ere mix of independent and endent variables—residual trees high brush and regeneration that eloped after logging.

ables 9 to 15 result from classify- the 20 subplots per plot in different s. For example, variables 9 and 10 fractions (each expressed as a cent of 20) of a four-way classifica- —without cover, grass cover, aceous cover, or woody perennial er. Not all parts of such a classifi- on may validly be included in a ession analysis. The specific frac- s selected were those that appeared most likely to differ from the rest, had the widest range of data, or were of particular interest.

Sufficiently comprehensive regeneration data were available on Dead Indian and Butte Falls partial cuts and clearcuts for these dependent variables:

1. Total stocking
2. Advance stocking, all species
3. Advance stocking, Douglas-fir
4. Advance stocking, true firs
5. Advance stocking, incense-cedar
6. Subsequent stocking, all species
7. Subsequent stocking, Douglas-fir
8. Subsequent stocking, true firs
9. Subsequent stocking, incense-cedar
10. Second-year stocking, all species

Correlation tests between single independent and dependent variables revealed that in neither the Dead Indian nor the Butte Falls areas is stocking distributed at random. There are variations or patterns of stocking significantly associated with changes in independent environmental variables such as elevation, radiation index, or aspect index; and covariates, such as total ground cover, grass, and woody perennials. Correlations identified as significant for different categories of regeneration in the two areas are listed in appendix tables; only highlights are discussed here.

As a broad generalization for data sets combined from Dead Indian and Butte Falls partial cuts, total stocking tended to increase as Douglas-fir became a greater part of the nearest seed source and woody perennials became a larger part of the ground cover (table 21, appendix). Total stocking tended to decrease as elevation, radiation index, and nearby true fir seed source increased. These broad tendencies appear to have split origins, however, for different associations tested significant in the individual areas. In only three instances did stocking for a regeneration category correlate significantly with the same environmental variable for both Dead Indian and Butte Falls partial cuts.

Likewise, total subsequent stocking correlated with different environmental variables in the Butte Falls and Dead Indian areas (table 22, appendix). In Dead Indian, subsequent stocking tended to be higher as aspect index rose (from SSW to NNE) and woody perennials increased. Subsequent stocking was less at higher elevations, as radiation index rose, and as nearby true fir seed source increased. Negative correlations (lower stocking) in Butte Falls involved increases in canopy, duff and litter, and undisturbed seedbed.

Differences in response to environmental variables seem to be indicated by the varying array of correlations significant for individual species in each geographic area. There are also instances where under different circumstances, stocking of a species correlates in the opposite way with a given variable. For example, stocking of Douglas-fir advance growth tended to increase with an increase in duff and litter, but stocking of subsequent Douglas-fir tended to be less with increases in duff and litter.

In clearcuts, total stocking and total subsequent stocking for areas combined tended to increase with increases in woody perennials, duff and litter, precipitation, and undisturbed seedbed and to decrease as elevation or amount of grass increased (tables 23 and 24, appendix). Again, these broad tendencies had split origins. In only four instances did stocking for a regeneration category correlate significantly with the same environmental variable for both Dead Indian and Butte Falls clearcuts.

Stocking appears to have a reasonably consistent correlation with several environmental variables in both partial cuts and clearcuts. For example, stocking generally decreased as elevation or radiation index increased. (The anomaly—increased stocking of second-year seedlings with increasing elevation—appears attributable to the abundance of Shasta red fir seedlings on a few partial cuts at high elevations.) Stocking was also inversely correlated with grass with only one exception—advance stocking of incense-cedar in partial cuts increased with increases in grass.

Stocking was generally less as total ground cover increased but there were a few exceptions—for subsequent true firs in Dead Indian partial cuts and subsequent incense-cedar in Dead Indian clearcuts. Higher stocking was generally associated with increases in aspect index or in the amount of woody perennials present.

Correlation coefficients between stocking and environmental variables were also determined after data had been regrouped by forest type. Because forest types are identifiable ecologic units that often span several geographic areas, there may be more consistent stocking patterns within a forest type than among the mix of types in a geographic area. Tables 25-28 (appendix) list stocking-environmental variable correlations that tested significant in each forest type for which sufficient stocking data were available.

Correlation coefficients for stocking-environmental associations in partial cuts were generally higher if data were analyzed by forest type than by geographic area (tables 25 and 26 vs. tables 21 and 22, appendix). Correlation coefficients for stocking-environmental associations in clearcuts were similar whether compared by forest type or geographic area (tables 27 and 28 vs. 23 and 24, appendix). This indicates that forest type may be a more useful stratification when one is dealing with regeneration in partial cuts than in clearcuts.

Regeneration patterns in partial cuts differed by forest type, as indicated by the dissimilar number and array of correlations found significant per type (tables 25 and 26, appendix). Stocking of advance regeneration was strongly associated with many environmental variables in the Douglas-fir type, substantially fewer in the white fir and pine types. Though still dissimilar, the number of significant associations for subsequent regeneration were nearly equal among forest types.

Some stocking-environmental associations in partial cuts were common to several regeneration categories or forest types. Not unexpectedly, stocking of advance regeneration increased with increases in duff and litter, canopy, and undisturbed seedbed—conditions requisite to or arising from the presence of advance growth. Stocking of advance growth generally tended to be negatively correlated with increases in elevation, true fir seed source, aspect index, total ground cover, grass, and radiation index. Stocking of subsequent regeneration generally increased with increases in Douglas-fir seed source, aspect index, and precipitation, and tended to be less with increases in elevation, undisturbed seedbed, duff and litter, true fir seed source, grass, and radiation index.

For clearcuts, neither the total number nor the array of significant stocking-environmental variable associations were as dissimilar among forest types as in partial cuts. A surprising portion of all environmental variables accounted individually for more than half the variation found in stocking of advance or subsequent regeneration (tables 27 and 28, appendix). Furthermore, stocking was consistently correlated negatively with only two variables—elevation and grass. Among significant variables common to both clearcuts and partial cuts, stocking usually correlated negatively with increases in total ground cover, grass, radiation index, and elevation.

Formulas Describing Stocking

Although an examination of correlation coefficients provides insight on association between paired independent and dependent variables, information is also needed to show how several variables are interacting. For this purpose, stepwise multiple regression analyses were made with data for the environmental variables and regeneration categories already itemized (p. 21). Analyses were made with data sets singly and combined for Dead Indian and Butte Falls partial cuts, and for Dead Indian and Butte Falls clearcuts. Independent variables listed in each formula are generally those which singly had an F value (variance ratio) to enter or remove from the equation equal to or greater than the critical value of the F distribution at 0.10. Occasionally a variable with a smaller F value was included because of its position wit the array of qualifying variables or its contribution to the cumulative R^2 (coefficient of determination), provided the total number of variable remained reasonable for the size of t data base.

The analyses produced for the 10 regeneration categories statistically significant multiple regression formulas relating the variation of existing stocking to changes in one more environmental variables. Formulas for Dead Indian partial cut are listed in table 29 (appendix); for Butte Falls in table 30 (appendix). All regressions for Dead Indian partial cuts but one account for less than ha the total variation in stocking; for Butte Falls all but one account for more than half the variation. Perhaps random variability is greater, or unmeasured variables are influencin stocking more in Dead Indian than in Butte Falls, since over twice as man samples were taken in the Dead Indi area (44 vs. 21).

Combining data from Dead Indian an Butte Falls partial cuts did not produce better regressions. In six formulas, the amount of variation accounted for was only equal to or less than by formulas for the areas singly, and in the other four the cumulative R^2 was intermediate (table 29, 30, and 31, appendix). Moreover, few of the environmental variables in regressions for Dead Indian partial cuts appear in the equivalent regressions for Butte Falls. Thus, the regre sion formulas, as well as the stockin environmental, and correlation data amply demonstrate that regeneratio conditions differ greatly in Dead Indian and Butte Falls partial cuts.

In all but two instances, multiple regressions statistically significant the 5-percent probability level or higher related the variation of stock in clearcuts to changes in one or mo environmental variables (tables 32 a 33, appendix). Significance of the regressions for all advance stocking and for incense-cedar advance stoc ing in Dead Indian clearcuts was at 10- and 10- to 25-percent probability levels, respectively. The amount of stocking variation accounted for is ite high; only regressions for vance stocking in Dead Indian clear- ts account for 50 percent or less of e total variation.

ain, combining Dead Indian and tte Falls data did not prove fruitful. six formulas the stocking variation counted for was less, and in the er four the cumulative R^2 was inter- ediate (tables 32, 33, and 34, pendix). Also, few of the environ- ental variables are common to Dead lian and Butte Falls regressions. As th partial cuts, regeneration condi- ns clearly differ in Dead Indian and tte Falls clearcuts.

gression equations describing cking-environmental relationships artial cuts fit better when the data grouped by forest type (tables 35, and 37, appendix) than by geo- phic area (tables 29 and 30, endix). Quality of fit was judged by nming R^2 values for sets of equa- ns and comparing the average varia- n accounted for per equation.[4] On average, equations based on ographic area accounted for 48.5 cent of the variation in stocking; se based on forest type, 59.5 cent. This difference seems impor- t since it arises primarily from rouping of the same data. Only the plots in the Shasta red fir type are resented in the geographic group- and not in the forest type grouping.

he Douglas-fir and pine types, the cking-environmental relationship every regeneration category is cribed by a strong regression equa- n—one that with two to five ables accounts for over half the al variation in stocking (tables 35 37). Judged by the same criterion, ressions describing relationships he white fir type are weak (table 36). but two account for less than half total variation in stocking. It ears that stocking has less pattern he white fir type, or it is not ngly patterned by the observed ironmental variables.

Grouping data by forest type (tables 38 and 39, appendix) instead of geographic area (tables 32 and 33, appendix) did not change the average fit of regressions for stocking-environmental relationships in clearcuts as it did for partial cuts. The difference in cumulative R,^{2} however, was usually less between equations of the same regeneration category in the two forest types than in the two geographic areas. Such evidence suggests that stocking variations in clearcuts are also best considered in the context of forest type.

Predicting Regeneration

Preceding sections of this report have shown how present stocking associates or changes with observed environmental variables. But such variables as total ground cover, woody perennials, and grass are covariates. They may be absent or of minor consequence at harvest and increase just as tree stocking does with time. For assessing reforestation possibilities before an area is cut, it would be useful to know how prevailing environmental variables, plus those whose levels are regulated by the harvest, influence subsequent regeneration. So prediction equations were developed for subsequent stocking based on environmental variables that can be observed or specified before harvest. Eleven variables—elevation, radiation index, aspect index, slope, canopy, duff and litter, logs and bark, Douglas-fir seed source, true fir seed source, precipitation, and undisturbed seedbed—were used in analyses for partial cuts. Nine variables were used in analyses for clearcuts; canopy, Douglas-fir seed source, and true fir seed source were deleted from the preceding group, and seed source distance was added.

Similar prediction equations for advance regeneration are not needed since the amount present at harvest or immediately after can and should be measured directly.

Prediction equations based on forest types (tables 40 and 41, appendix) appear preferable to those based on geographic area (tables 42 and 43, appendix). Reasonably comparable amounts of the total variation are accounted for by the sets of equations, but those for forest type probably have broader applicability. The origin of a forest type and its perpetuation is directly related to the mix of environmental conditions that prevail. Hence, stocking—environmental relationships found important in one part of a type could reasonably be expected to prevail broadly throughout the type.

In general, more of the total variation is accounted for by prediction equations for clearcuts than those for partial cuts. The equations for clearcuts in the Douglas-fir type and for partial cuts in the pine type are particularly strong; no more than three variables account for over half the total variation in all equations but one. Equations for second-year stocking tend to be weaker than most others, but are also the ones least likely to be needed. Equations for total subsequent regeneration are probably the most useful because they include the response of all species; for clearcuts in particular, they reflect the large influence of planted ponderosa pine which is not in the other equations.

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ect comparison of R^2 values for ations within each stocking category is possible because for forest types the gories include data from both the Dead an and Butte Falls areas.

Forest Management Applications

A comprehensive analysis of reforestation status and relationships provides first approximations for management and serves to clarify or pinpoint problems that need to be solved. The broad implications of study results are emphasized in these interpretations; mention of how results relate to reforestation principles observed elsewhere are mostly incidental.

Silvicultural Units

The Dead Indian and Butte Falls areas differ in geography, climate, forest communities, and reforestation response. Perhaps results of this study bring area differences into focus more comprehensively than ever before. By and large, the territory sampled around the town of Butte Falls is mid-elevational, the 25 to 50 inches (64 to 127 cm) of rainfall is conducive to forest growth, and growing conditions probably do not differ greatly from other mid-elevation locations farther north in the Rogue River and Umpqua drainages. In contrast, Dead Indian is primarily an upper slope area. The lower end of its 18- to 40-inch (46- to 102-cm) rainfall range approaches the margin for commercial tree growth, and growing conditions are more varied and limited. Because of these contrasts, foresters should logically draw from quite different geographic sources for research results and silvicultural experiences that might apply in the Dead Indian or the Butte Falls area.

Study results clearly demonstrate that the environmental differences between the Butte Falls and Dead Indian areas influence reforestation response. In Butte Falls, the stocking is greater, species mix richer, understory development more dense, and the array of factors that correlated with stocking different than for Dead Indian. Moreover, stocking patterns were described best by regressions when data for the two areas were used separately. Identical silvicultural practice is not likely to produce the same result in both areas, and management must recognize area individuality to a greater degree than in the past.

A line or band marking the silvicultural division between Butte Falls and Dead Indian territory needs to be delineated. Currently, both names apply to loosely defined geographic areas. For study purposes, a common boundary was arbitrarily drawn northeast of Ashland (fig. 1). Dead Indian and Conde Creeks, upper drainages that actually flow toward Butte Falls, were included as part of the Dead Indian area. Because of cutover distribution, nearest sample plots of the two areas were separated by a dozen miles (19 km) or more. Somewhere within that span or near its southern edge, a logical silvicultural demarcation should be made.

Elevation, drainage system, or changes in understory community might be used as the basis for this demarcation. There are distinct differences between the two areas in the occurrence of woody perennials and the mix of species in the understory. The delineation could be based on shrub differences observed in this study, or on the detailed vegetation information developed by Minore and Carkin[5] (1978). In a historical summary, Minore (1978) delineated the Dead Indian area's northern limit as the precipitous slopes above (south) of Little Butte Creek.

For intensive application of silvicultural and reforestation practices, recognition of subdivisions within each territory also appears necessary. Forest type seems to be a practical and readily available initial subdivision. Stratification by forest types might prove very useful because these are identifiable ecologic entities whose characteristics and response may be similar in several geographic areas. Types reflect site, elevation, and successional differences that affect reforestation. Eventually, reforestation responses should be related specifically to plant communities or habitat types.

Interpreting Stocking Data

Stocking values generally express actual stocking as a percent of full stocking. Consequently, full stocking must be defined before the true significance of observed stocking value can be assessed. By agreement among participants at the start of thi study, full stocking was set at 250 uniformly distributed trees per acre. This standard can be met if one coun able tree is present on every 4-milacr subplot examined.

In the stocked quadrat sampling system, only one countable tree mus be present for a 4-milacre plot to be stocked (Stein 1978). Hence, a stocking value of 50 percent means that at least 125 well-distributed tree are present per acre (310 per ha). The system produces a minimum figure; is strongly oriented toward evaluatio of tree distribution, not total number Where trees are uniformly distribute as in a plantation, stocking may closely reflect the total number present—not so for natural regenera tion or mixes of artificial and natural regeneration. In natural regeneratior 50-percent stocking might mean nearly 400 trees per acre (990 per ha) 85-percent stocking over 1,200 (2 965 per ha) (Bever and Lavender 1955). Tl conversion curves used in this example were developed from data f natural regeneration in western Oregon clearcuts and may not be ful applicable in partial cuts. The compa sons indicate, however, what stocki data mean in terms of total trees pe acre.

If stocked and nonstocked plots are well interspersed, 50-percent stocki can produce a good stand. If they ar not, part of the sampled area will be well stocked or overstocked and pa of the area will be short of trees.

Regeneration in Partial Cuts

Throughout this paper, forest stand from which some overstory had bee removed through harvest have been called partial cuts, not shelterwood This was done deliberately becaus many partially cut stands did not qualify as shelterwoods in the full technical sense of that term. Instea

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[5] Minore, Don, and Richard E. Carkin. 1975. Relation of environmental factors to regeneration after partial cutting in the Dead Indian Plateau and Butte Falls areas of southwestern Oregon—A report to the Bureau of Land Management. 18 p. Unpublished report on file at the Pacific Northwest Forest and Range Experiment Station, Portland, Oreg.

y were the product of an initial cut
irgin old-growth forest of varied
nposition, density, age class, and
e. Many stands had an open over-
ry for a long time before harvest
ch fostered advance regeneration.
ne stands were cluttered with
rly dense advance regeneration,
ers with more uniform and heavy
opy were relatively bare under-
th. Thus, stocking data reflect the
eneration present in a wide range
tand conditions rather than in
form stands whose nature can be
ined readily.

partial cutting done in both Butte
s and Dead Indian stands between
6 and 1970 has been referred to as
hree-stage shelterwood." A first
to open up the stand is to be fol-
ed by a second cut in 10 years and
al cut in another 10 years. The
ond cut is intended to foster regen-
ion. According to the records, only
the 44 stands sampled in Dead
an and none of those sampled in
te Falls had received a defined
eneration cut. Stocking of seed-
s that established after harvest on
s entered twice averaged 56
cent but included one area with
5-percent stocking. Canopy on
e areas averaged 41 percent,
ilar to the 44-percent average for all
ples. They were not considered
iciently different from areas
red only once to warrant separate
mary and analysis.

ievement of a specified basal area,
position, or distribution of over-
y did not appear to have been
ng primary objectives for the first
In some stands, scattered single
s had been removed, leaving a
onably uniform and rather dense
story; in others, small clearings
interspersed with nearly
inned canopy (fig. 16). Some
ds were opened up drastically; 10
pled in Dead Indian had 30-percent
py or less. A good choice of seed
s was readily evident in some
es; in others, the adequacy of the
aining seed source was much in
t. In summary, the stands
sampled had a large amount of initial variability, were not necessarily made more uniform by the first cut, and most were sampled before the second or "regeneration" cut had been made.

Even though sampling occurred before the "regeneration" cut, substantial regeneration was found in partial cuts. In fact, only one-fourth of the areas sampled in Dead Indian and none of those sampled in Butte Falls were less than 50 percent stocked with 2-year or older regeneration. If stocking were the sole criterion, the regeneration already present could be rated satisfactory in most partial cuts. Such is not the case, however.

Figure 16.—Partial cuts included stands with small clearings and adjacent, unthinned canopy.

In enough instances to cause concern, seedling growth was very slow. There also was evidence that successive crops of new seedlings are not developing as needed for projected timber production. Field notes for about one-quarter of the Dead Indian plots include comments on the lack of seedling vigor or height growth; good vigor or growth is mentioned for about an equal number. Excerpts from the notes illustrate concerns about growth:

> Seedlings have fair to poor health; most are shaded and on rotten wood.
>
> Seedlings found along roadsides were healthier than those in the plot.
>
> Seedlings were tallest in areas where competition was lowest; many seedlings were found on roadbanks and other exposed sites.
>
> This area has been available for seedling establishment for 10 years; but there is a scarcity of seedlings more than 2 years old . . . the largest seedlings were found on some of the more open subplots.
>
> Reproduction is fairly abundant, but most of it is too small for age of the cutting.

Slow growth of seedlings was also noted in some Butte Falls partial cuts; better growth on disturbed than on undisturbed seedbeds was specifically recorded several times.

In many partial cuts, seedling growth must be accelerated to achieve meaningful development. Some obstacles to overcome are discussed in the section, Problems to Solve.

Role of Advance Regeneration

The abundant regeneration often present before harvest begins provides opportunities that have hardly been exploited. The magnitude of these opportunities is highlighted by study data which show that, after harvest, 31 percent of all partial cuts were at least 50 percent stocked with advance regeneration. Before harvest, even more areas might have been stocked at or above that level. Not all advance regeneration has crop tree potential, but many trees do. The stand establishment period may be bypassed and a long step taken into the next rotation if adequate advance regeneration can be protected during a relatively short conversion period.

Efforts to save advance regeneration were evident in some partial cuts; in others, destruction of prime saplings and poles during logging was excessive. Often the pattern of overstory removal was less than optimum for release of advance regeneration. Furthermore, an arbitrary 10-year reentry cycle does not meet the silvical needs of stands with abundant advance regeneration. Complete removal of scattered overstory is desirable in the first cut when an area is already adequately stocked. Felling and skidding direction should be controlled to minimize damage during removal of overstory from regeneration thickets where it no longer serves a useful purpose. Most terrain in Dead Indian and Butte Falls is gentle enough to permit the maneuverability needed to save advance growth.

Some partial cuts were overstocked. Perhaps 43 percent of those in Butte Falls were, since 90-percent stocking of natural regeneration might average 1,400 trees per acre (3 460 per ha) (Bever and Lavender 1955). Some of the poor growth noted was due to excessive numbers of saplings. Since numerous new seedlings are also becoming established in partial cuts, additional areas will soon become overstocked. Adequacy of regeneration should be assessed periodically so that overstory is removed on a timely basis, seedling accretion is halted, and the new stand is fully released.

Only a few instances of exposure damage were observed on advance regeneration released from overstory. Frost occurs in some locations, and newly exposed stems may sunscald. Situations where these dangers exist need to be identified. Where overexposure is not a problem, growth could often be enhanced by thinning advance regeneration as soon as it has stabilized after release.

Overstory mortality from exposure, growth rate of residual trees and stands, spread of mistletoe from mature trees to regeneration, damag caused by successive entries, and other factors are important elements of a decision to foster regeneration through use of shelterwood. Their evaluation was not within the scope this study.

Regeneration in Clearcuts

The reforestation methods used in Butte Falls clearcuts produced moderate stocking or better in every area sampled; in Dead Indian clearcu only 1 in 4 was as satisfactory (fig. 8) Early reforestation attempts involve much trial and error, and the records show distinctly different sequences were tried in Butte Falls and Dead Indian clearcuts. In Butte Falls, slas was spot-burned (sometimes broadcast-burned) and the clearcut was generally spot-seeded the same yea or planted the next year. Required replanting was usually done a year o two after the initial reforestation effort. Clearcuts in Dead Indian were also spot- or broadcast-burned, but then a lengthy period was allowed (averaging more than 4 years) for establishment of natural regenerati Every clearcut was planted eventual over half more than once. How ofte and what kind of site preparation accompanied delayed planting is uncertain. All reforestation delays permitted development of competin vegetation and buildup of animal populations. Consequently, tree establishment was made more difficult than if clearcuts had been planted at the first opportunity.

he reputation of Dead Indian as a eforestation problem area is based rgely on the repeated failure of eforestation efforts in a small number f old clearcuts and burns. Results on uch areas may not be similar to those n fresh clearcuts and certainly do not present best application of modern eforestation technology. When ssessing the difficulty of reforesting earcuts, it is critically important to amine all available evidence.

udy results definitely show that nder past reforestation practices, tablishment of natural regeneration as not adequate in either Butte Falls Dead Indian clearcuts. Those actices generally included laying out e clearcut in a rectangular block, rning some slash, letting grass velop, and permitting unrestricted azing. Gopher activity has often en heavy and control efforts limited. some extent, the cover of woody rennials under which natural generation might start has been held check, particularly in Dead Indian earcuts, by grazing and gophers and metimes by scarification or rbicide spraying. Repeatedly, field tes for plots in both Dead Indian and tte Falls clearcuts included the servation that natural regeneration as found around logs or under brush ver. It appears such regeneration nefited by protection from sun, st, and cattle trampling. Instances here good stocking of natural regenation was found for some distance rth of a timber edge were also ted. Plentiful natural regeneration n be observed in the Dead Indian ea on exposed roadbanks, particuly along the Keno access road, in veral incidental clearings, and near ward Prairie reservoir (fig. 17). ese examples demonstrate that ere are circumstances where natural generation, even of Douglas-fir and ite fir, establish adequately in bare enings. The conditions would have be defined more specifically, hower, before natural regeneration could relied on to restock such openings. ntleness of the terrain would rtainly permit the use of strip clearts or other modified clearings.

ost regeneration found in both Butte lls and Dead Indian clearcuts origated as planted nursery stock.

Figure 17.—Natural regeneration established abundantly on north slopes in a narrow clearing near Howard Prairie Reservoir.

Ponderosa pine was the main species planted. In a few instances, Jeffrey pine, Douglas-fir, white fir, or Shasta red fir were planted or seeded. Without question, clearcuts in Butte Falls can be adequately reforested by planting ponderosa pine. So can clearcuts in Dead Indian provided the plantations are established promptly and given reasonable protection from cattle and gophers. The advisability of establishing plantations heavily dominated by ponderosa pine is discussed later under Species Composition.

Frost occurrence during the growing season is not uncommon in parts of the Dead Indian area. If fully exposed, such nonhardy species as Douglas-fir and white fir may be killed outright or repeatedly set back by untimely frosts. Even such hardy species as ponderosa pine, lodgepole pine, and Jeffrey pine are damaged occasionally but not as severely (Stein 1963, Williamson and Minore 1978). Frost occurrence varies by topographic location and is much less frequent under forest cover than in the open (Williamson and Minore 1978). Successful establishment of nonhardy species in clearcuts requires knowing where frost is uncommon during the growing season.

Judged by the scope of information on record, the clearcut and plant reforestation system has not received enough prudent trials in either the Dead Indian or Butte Falls area. In Dead Indian particularly, most clearcuts were located on gentle terrain not far from open meadows and old homesteads. Such clearcuts served as extensions of natural meadows in frost pockets that had been heavily grazed for decades (Minore 1978). From the start, above average reforestation difficulty could be expected in such locations. Moreover, timeliness of planting, kind and quality of stock, and plantation tending are all much improved today compared with the technology applied over 15 years ago. Widespread use of clearcutting is not advocated now except for regeneration of ponderosa pine. But judicious tests of clearcutting in selected locations and stands seems desirable since there is good evidence that some cleared areas reforest readily. Well-planned comparisons of silvicultural systems are also needed to demonstrate the results possible by alternate means. Prompt planting and sustained tending of plantations should be an integral part of all future harvest-cutting trials.

Figure 18.—Because of location or individual differences, growth potential of one ponderosa pine is excellent (**A**) and for the other nil (**B**) in the same clearcut.

Species Composition

True firs, primarily white fir, are now the dominant regeneration by a wide margin in Dead Indian partial cuts and a major component in Butte Falls partial cuts (fig. 13). Continued light partial cutting will foster white fir's already dominant role in the next rotation, for it is the climax species in and perhaps beyond, the present whit fir type. Instances were noted where Douglas-fir regeneration was not proportionate to the seed source present —where the ground was covered with Douglas-fir cones, yet few Douglas-fir seedlings were found. Pine regeneration also did not appear proportionate to the available seed source, whereas incense-cedar regeneration seemed relatively abundant wherever there was any source of seed. It is likely tha seedeaters feed more heavily on Douglas-fir and pine seed than on see of other tree species. There may also be a tendency to cut first the scattere Douglas-firs and pines since these ar often older, larger, and of higher quality than the white firs. Whatever the reasons, white fir regeneration is pre-eminent. Should or must management settle for the kind of forestry implicit when the climax species establishes naturally and develops slowly under its own heavy shade? What are feasible alternatives? Will more open, uniform stands or stands with interspersed small openings foster natural or artificial establishment of other species and provide faster growth?

Ponderosa pine is dominant now in clearcuts. With a head start and fast juvenile growth, it is likely to remain dominant for a long time if the stock used proves suitable for the site. Son seedlings of Douglas-fir, white fir, an other species are filtering in naturall and in the long run, mixed stands will develop. Ponderosa pine has been planted on several clearcuts where it was absent before, but present in the vicinity. These plantings are vulnerable —the pine may do fine or it may suffe excessive damage from snow or othe causes before it reaches commercial size. In specific instances, planted pines were making exceptional growth, yet others on the same area were useless because of snow-cause deformities (fig. 18). Even though

nderosa pine is native and wide-
read in Dead Indian and has good
aracteristics and potential, placing
le reliance on this species appears
wise.

mix of conifers should be the
orestation goal for much of the
tte Falls and Dead Indian areas.
is recommendation takes into
count the long-term vegetation
nds, the structure of present
nds, and the practical objectives of
nagement.

om geologic and ecologic evidence,
as been inferred that massive
vances and retreats of forest
mmunities have occurred in the
stern United States. A pine-oak
mplex which included most of the
ecies found in the southern
scades reached its most recent
rtherly advance during a drier era
t ended about 6,000 years ago
etling 1968). As the climate has
come cooler and more moist,
nifers are replacing oaks, and
undaries of climax types are
anging. Many examples of such
e replacement can be seen in both
Butte Falls and Dead Indian areas.

e white fir type is just becoming
minant in many parts of the study
as. Fortunately, the seral species
t white fir is replacing are still
dent. Scattered, very large Douglas-
s are found in some predominantly
ite fir stands; scattered sugar pines
common; incense-cedar is found
exposed sites; ponderosa pines are
narchs among white fir and
uglas-fir poles, and they also
avily fringe the open meadows. The
ntainment of wildfire and reduction
grazing in the last 50 years has
bably speeded the natural succes-
n to white fir and has allowed
velopment of dense understories.

nagement for mixed conifers
uires that overstory be opened
ficiently to permit seral species, as
ll as white fir, to become estab-
hed and make good growth. Mixed
nifer stands can probably be estab-
hed through natural regeneration,
results may often be slow and
certain. To achieve intensive
estry, major reliance will have to be
ced on planting. The uneven distribution of desired seed trees, the infrequency and untimeliness of seed crops, the need for reforesting prepared sites immediately, and the desirability of controlling species, genetic quality, and tree spacing all dictate that reforestation not be left solely to "Mother Nature." Underplanting of shelterwoods has been practiced for several years in the southern Cascades; preliminary results look good, and careful evaluation of this reforestation technique should soon be made.

Stand Prescriptions

No single harvesting system should be designated as standard for the varied stands of the Butte Falls and Dead Indian areas. Instead, there is need to apply silvicultural practices almost on an acre-by-acre basis. Some stands need to be left alone for awhile to develop, patches of poles need complete release from overstory, and dense stands may need either a salvage cut or a shelterwood cut to foster regeneration. In selected locations, strip clearings or overstory removal in patches may best fit particular stand conditions. The suitability and vigor of prospective leave trees need careful scrutiny to minimize the scattered, unpredictable mortality that follows every harvest entry. Such scrutiny should include a search for mistletoe in the overstory and advance regeneration to prevent perpetuation of infected stands.

The first step in reaching broad forest management objectives is to define specific goals, area by area. The alternatives available to attain the goals should then be considered, and the most suitable one chosen. The technical basis for that choice should be written out. This facilitates review by subject matter specialists; but more important, it provides the vital communication needed to maintain on-the-ground continuity. A written stand prescription forms the basis for action and provides a means for checking progress periodically.

Use of Correlations and Equations

Many correlations and equations are included in this report. These were the basis for some of the conclusions and recommendations, but their inclusion serves another major purpose. They are working tools the silviculturist can use.

The regression equations describe separately, by regeneration category, stocking patterns that may not be discernible when successive stands are viewed. Each equation shows, for a particular area or forest type, the environmental variables that surfaced as most important in the mathematical analysis of the survey data. The variables are listed in order of importance, and the fraction of total variation accounted for (cumulative R^2) is shown. The numerical values are unique to the equation as listed—delete or add one variable and a different set of values applies. The plus and minus signs in the equation do not indicate whether individual variables had a positive or negative influence on stocking; this information is given by the correlation coefficients for single variables.

Neither regression equations nor correlation coefficients identify actual biological cause-effect relationships between environmental variables and stocking. They constitute tests of association—that a dependent variable (stocking) and one or more independent variables are varying in concert, either directly or inversely. Biological inferences may be drawn from associations found significant, provided the basis for a cause-effect relationship has already been established independently; such relationships are not proved just because certain associations are shown to exist.

The correlation coefficients should prove useful in preparing prescriptions for establishment of particular species or species mixes. The sign of its correlation coefficient indicates whether stocking was positively or negatively associated with each environmental variable listed. For example, stocking of subsequent Douglas-fir in Butte Falls was shown to be negatively associated with increases in canopy, duff, and undisturbed seedbed (table 22, appendix). If the silviculturist wants to favor establishment of Douglas-fir, the prescription for natural regeneration should call for a sparse canopy and good disturbance of seedbed. Perhaps not all applicable, significant variables can be accommodated in a prescription for one species, much less for a mix of species. But by giving attention particularly to associations that are common to more than one species, forest type, or area, the silviculturist has guidance based on past local performance that is much better than guesswork.

In using regressions and correlations, silviculturists must keep in mind limitations of the data base. The data for partial cuts are from stands subjected to one or two entries which left, on the average, about 45-percent canopy. Variability of the original overstory was great, no marking rule was applied systematically, and all regeneration had established naturally. The data for clearcuts are from older areas with a varied history of planting and seeding. Artificial regeneration efforts were often delayed several years. None of the equations reflect what may be possible with the most up-to-date site preparation and reforestation technology, but one might reasonably expect that most of the same variables would have a strong influence.

Problems to Solve

As in every other forested area, there are reforestation problems to solve in the Dead Indian and Butte Falls areas. These problems loom large locally but need to be viewed in perspective. The forest conditions are not any hotter and drier here than they are farther south where the same types grow in northern California, nor so cold and snow burdened as in more northerly upper slope types. Forests have established in abundance naturally, and, by understanding the influencing variables sufficiently, silviculturists should be able to identify ways to speed and otherwise control the process.

Problems to solve are discussed on the premise that reasonably intensive timber management will be practiced —that timber production is a primary objective. Relative importance of the problems would change markedly if management objectives were substantially different. Two additional premises also influence choice of solutions: (1) When desired, an adequate amount of natural regeneration (or of planted trees) can be saved during removal of the initial overstory or shelterwood, and (2) large-scale harvest-system studies are not the best or quickest way to get the kind of answers needed. Skimpy evidence indicates that stocking of seedlings and saplings is not reduced seriously if overstory removal is carefully planned—18 percent of marked trees in ponderosa pine stands of central Oregon (Barrett et al. 1976); 4 percent of milacre stocking in the ponderosa pine type of northern California (McDonald 1969); and 10 percent of 4-milacre stocking in the mixed conifer type of western Oregon (personal observation).

Overstory Required

Survey results and local experiences indicate that natural and planted regeneration of several species establish better, especially in Dead Indian, under the protection of tree canopy than in the open (Minore 1978, Williamson and Minore 1978). Overstory canopy ameliorates strong sunlight, slows wind movement, and reduces outgoing radiation. On the other hand, overstory competes with regeneration for soil moisture and curtails rate of seedling growth. Thus, it is desirable to retain only sufficient overstory to foster establishment of the desired species. The amount of overstory required for different species and circumstances needs much better definition.

Severe frost during the growing season may be a more widespread cause of regeneration failure than drought, particularly in Dead Indian. Ponderosa pine and incense-cedar predominate in clearcuts and other exposed areas because they are more frost and more drought hardy than Douglas-fir and white fir. In clearings occurrence of the latter two species under cover and behind logs may be due as much to their need for protection from frost as for protection from trampling by cattle. Damaging frosts have been observed through the year in both the Butte Falls and Dead Indi areas. Evidence of frost damage was noted during the survey, and for Dead Indian, the differential effects under canopy and in problem openings hav been quantitatively demonstrated by Williamson and Minore (1978).

How to identify frost hazard areas and determine amount of cover needed a key subjects for research. Forestry and meteorological expertise needs be pooled to find answers for such questions as:

1. On cool nights during the growing season, how much do temperatures differ at selected heights above open ground on flats, north and south slopes, and ridgetops?

2. How much are nocturnal temperatures modified by different amounts canopy?

3. How tall must regeneration be in different topographic locations to extend above damaging cold air laye i.e., when may protective canopy be removed?

4. How severe a frost can different species endure during the growing season without damage?

eliminary information on frost
zards can be gained by observing
e geographic location of past and
rrent damage. An adequate under-
anding will require a thorough
arch of applicable literature, use of
cording instruments, and experi-
entation on seedlings. The informa-
n developed would have much wider
plication than just in the Dead
dian and Butte Falls areas.

eventing Moisture Deficiencies

mature forest community depletes
il moisture far more than a seedling
and does (Bethlahmy 1962). Conse-
ently, reduction of overstory
creases the moisture available for
edling establishment, provided
aporation rates from surface layers
not become excessive or competing
v vegetation overly dense. Moisture
ailable to seedlings under different
ounts of overstory and with differ-
t amounts and kinds of competing
getation has never been adequately
fined. An adverse effect of advance
owth on establishment of natural
generation has been reported (Hall
63).

ought has been blamed in the past
regeneration failures in the Dead
lian and Butte Falls areas. The lush-
ss of herbaceous growth under
nse canopies, the density of many
nds, the tall growth of woody
rennials in Butte Falls, and the wide-
ead development of thick grass and
erberry in Dead Indian clearcuts
se questions about the true occur-
ices of drought. Availability of soil
isture in upper soil layers during
growing season could be checked
idly by gravimetric methods or
utron probe, and moisture stress
els in seedlings or associated
getation by pressure bomb readings.

ystematic study of soil moisture
uld define the locations, soils, and
uations where moisture supply is
ly the limiting factor in establish-
nt of regeneration. Intensive
ntrol of vegetation and other
isture-conserving techniques could
n be concentrated where they are
eded most.

Grass and Grazing

Despite claims to the contrary, evidence accumulated over the years shows that grass production and tree establishment are usually not compatible (Cleary 1978, Nolan 1978). Propagation of grass is one of the quickest ways to render a site inhospitable to young trees. The ready availability of moisture in grass-free soil and its drastic depletion in grass-covered soil was demonstrated some years ago at one Dead Indian location (Hallin 1968). In this study, correlation tests demonstrated the negative association between grass and tree stocking for all species. A single positive correlation between advance stocking of incense-cedar and grass does not indicate that incense-cedar benefited from it. Rather, it is probably the only species that established in stand openings where grass predominated.

Either from natural dispersal or from sowing, grass has developed abundantly on many Dead Indian and Butte Falls clearcuts. It has also invaded or become thicker in partial cuts. Wherever it occurs, grass has the capability of occupying the site long before natural conifer regeneration is likely to occur. Once a site is lost to grass, establishment of trees requires extraordinary effort. Quick reestablishment of trees is one of the best ways to minimize problems with all competing vegetation.

The adverse effects of grass on tree establishment are compounded by the uncontrolled grazing of livestock. Young seedlings are trampled or loosened, and older seedlings are damaged or broken. Woody perennials that might furnish cover for natural regeneration are often browsed or mauled. The destruction of blue elder (*Sambucus cerulea* Raf.) clumps 10 to 15 feet (3 to 5 m) tall in the fall by livestock that need or prefer this forage is remarkable (fig. 19).

Figure 19.—In Dead Indian, cattle stripped all foliage and fruits from large clumps of blue elder.

Cattle damage in partial cuts was most common in the open white fir stands of townships 38 and 39 south, ranges 3 and 4 east, Willamette meridian. To fully appreciate severity of grazing damage, areas must be observed before and after it has occurred. Two examples illustrate this point:

Example 1.—Plot 24 on Cottonwood Creek in the Dead Indian area was examined on June 26, 1973. It was 30 percent stocked—25 percent with advance true firs located in tight clumps and 5 percent (a single subplot) with subsequent true firs. Stocking of second-year seedlings was also 30 percent, found mainly on subplots with trash and rotten wood. Five years after harvest, the soil was extremely loose on this northeast slope at 5,700 feet (1 740 m), canopy density of 36 percent looked ideal, and the 63-percent herbaceous cover lush and thriving. Looseness of the soil and lack of subsequent regeneration were ascribed to gophers, which were present. Snows had melted only a few weeks before; the soil surface was humpy but untracked by animals.

On September 19, 1973, the plot was revisited to show a technical group an example of a good site where regeneration was not as plentiful as it should be. The primary cause of low stocking was then obvious; all herbaceous cover was gone and most of the area was covered by hoofprints as in a barnyard. The surface soil was now even looser and the plot hardly recognizable (fig. 20).

Example 2.—Plot 76 on Jenny Creek in Dead Indian was examined on June 27, 1973. It was found to be 75 percent stocked—40-percent advance regeneration, mostly true firs, and 65-percent subsequent stocking, all true firs. Second-year seedlings were found on 75 percent of the subplots. Ten years after harvest the soil appeared stable on this gentle north aspect at 5,320 feet (1 520 m), gopher activity was present but not abundant, and vigorous herbaceous cover averaged 63 percent. Canopy averaged 38 percent; most of the regeneration was young and small. Trees a foot (0.3 m) or more tall, commensurate with age of the cutting, were found primarily on a heavily disturbed skidroad and among a few burned logs near roadside.

In September 1976 this area was revisited to view the contrasts in seedling size. Most of the large seec lings observed before were now mauled or gone, and signs of grazin and trampling by cattle were everywhere.

Figure 20.—Trampling by cattle severely redisturbed an already loose soil in a white fir partial cut.

Although regeneration was found o both plots, seedlings were smaller a younger than expected, and the nev stand was not developing as it shou Cattle were the primary restrictive influence.

Additional research is not needed t solve many problems involving gras competition and grazing damage. T first step in their resolution is to recognize that grass is commonly v unfavorable for tree establishment that cattle are damaging regenerati in significant amounts. The next ste is to decide if and where tree establishment has priority over grazing. Finally, measures must be taken to control grass wherever necessary a to keep cattle out or closely regulat grazing in reforestation areas until new tree crop is well established.

Animal Damage

Many parts of Dead Indian and Butt Falls also have high populations of wild animals that affect reforestati Gopher activity has already been recognized as a problem. The effec of rabbits, deer, and other animals become more evident as marked tr are examined repeatedly.

Gophers have been depleting stan of young trees in these two areas f many years. One study that demonstrated the protracted nature of see ling losses to gophers was already completed in Dead Indian by the ea 1960's (Hermann and Thomas 1963 comparison of methods to control them by manipulating vegetation w recently completed (Black and Hoc 1977).

Gopher control methods are receiv substantial attention throughout th west, so more local studies are probably not critical. Fast establis ment of trees before gopher popul tions build up will help. Population increases that threaten plantation must be recognized and dealt with a timely basis.

and Ecology

and composition in Dead Indian and
itte Falls often differs within short
stances. These differences may be
e to the happenstances of seed crop
currence when sites were ready for
edling establishment; or the
riations may form patterns that
ovide clues on species limitations,
crosite requirements, and
ological trends.

owledge gained from studies of
ecies occurrence and requirements
ould guide the choice of species for
ferent sites. Such studies could
lp demarcate geographic areas to be
naged primarily for white fir, Shasta
I fir, mixed conifers, or ponderosa
ne. They might even indicate where
ster rust hazard is low. Sugar pine is
e of the best growing species in the
xed conifer type and should be
rpetuated wherever rust hazard is
v, or when resistant natural seed-
gs or planting stock are available.
me information on stand age and
ucture was obtained by Minore and
rkin as part of their 1976 field work
the Dead Indian area (Minore 1978).

Growth of Regeneration

Information on growth rate is needed for two important topics that influence choice of reforestation practices: (1) Among advance regeneration, which species and stems have the capability to respond promptly to release and then make normal growth? and (2) What are typical growth rates for regeneration under different densities of canopy? An answer to the first question would identify the advance regeneration worth saving. An answer to the second question would define overstory densities that foster reasonable growth of natural or planted regeneration.

Preliminary information on response of sugar pine seedlings to release in the South Umpqua drainage was developed by Hallin (1959), but information is needed for other species and a range of sites. Such information could be obtained quickly by stem analysis of released trees. Correlations between appearance before release and subsequent response would also be easy to obtain, but several years would be required to observe the response of marked trees.

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Literature Cited

Barrett, James W., Stanley S. Tornbom, and Robert W. Sassaman.
1976. Logging to save ponderosa pine regeneration: A case study. USDA For. Serv. Res. Note PNW-273, 13 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Bethlahmy, Nedavia.
1962. First year effects of timber removal on soil moisture. Int. Assoc. Sci. Hydro. Bull. 7(2):34-38, illus.

Bever, Dale N., and Denis P. Lavender.
1955. Revised "number of trees per acre" curves. Oreg. State Board For. Res. Note 25, 3 p., illus.

Black, Hugh C., and Edward F. Hooven.
1977. Effects of herbicide-induced habitat changes on pocket gophers in southwestern Oregon. *In* Proc. 29th Annu. Calif. Weed Conf. (Sacramento), p. 119-127.

Cleary, Brian D.
1978. Vegetation management and its importance in reforestation. Oreg. State Univ. For. Res. Lab. Res. Note 60, 4 p., illus., Corvallis.

Day, Frank P. Jr., and Carl D. Monk.
1974. Vegetation patterns on a southern Appalachian watershed. Ecology 55(5): 1064-1074, illus.

Detling, Leroy E.
1968. Historical background of the flora of the Pacific Northwest. Univ. Oreg. Mus. Nat. Hist. Bull. 13, 57 p., illus.

Duncan, David B.
1955. Multiple range and multiple F tests. Biometrics 11(1):1-42.

Frank, Ernest C., and Richard Lee.
1966. Potential solar beam irradiation on slopes: Tables for 30° to 50° latitude. USDA For. Serv. Res. Pap. RM-18, 116 p., illus. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Hall, Dale O.
1963. The effect of advance growth on ponderosa pine seedling mortality at Challenge Experimental Forest. USDA For. Serv. Res. Note PSW-8, 7 p., illus. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Hallin, William E.
1959. Release of sugar pine seedlings and saplings by harvest cutting. USDA For. Serv. Pac. Northwest For. and Range Exp. Stn. Res. Note 179, 3 p., illus. Portland, Oreg.

Hallin, William E.
1968. Soil moisture tension variation on cutovers in southwestern Oregon. USDA For. Serv. Res. Pap. PNW-58, 18 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Hermann, Richard K., and Harold A. Thomas.
1963. Observations on the occurrence of pocket gophers in southern Oregon pine plantations. J. For. 61(7):527-529, illus.

Mainland, Donald, Lee Herrera, and Marion I. Sutcliffe.
1956. Statistical tables for use with binomial samples: Contingency tests, confidence limits, and sample size estimates. 83 p., N. Y. Univ. Coll. Med., New York.

McDonald, Philip M.
1969. Ponderosa pine seed-tree removal reduces stocking only slightly. J. For. 67(4):226-228, illus.

Minore, Don.
1978. The Dead Indian Plateau: A historical summary of forestry observations and research in a severe southwestern Oregon environment. USDA For. Serv. Gen. Tech. Rep. PNW-72, 23 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Minore, Don, and Richard E. Carkin.
1978. Vegetative indicators, soils, overstory canopy, and natural regeneration after partial cutting on the Dead Indian Plateau of southwestern Oregon. USDA For. Serv. Res. Note PNW-316, 9 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Nolan, Karen S.
1978. Vegetation management and its importance in reforestation: An annotated bibliography. Oreg. State Univ. For. Res. Lab. Res. Note 61, 4 p., Corvallis.

Reynolds, Charles, Nelson Jeffers, Vincent Bousquet, and Roy Stier.
1953. Reforestation surveys. *In* Reports of the Pacific Northwest Seeding and Planting Committee on various recommended reforestation practices and techniques. Chapter 7, p. 61-69, illus. West. For. and Conserv. Assoc., Portland, Oreg.

Stein, William I.
1963. Comparative juvenile growth of five western conifers. Ph. D. thesis. Yale Univ., New Haven, Conn. 194 p., illus.

Stein, William I.
1978. Chapter 11. Reforestation evaluation. *In* Regenerating Oregon's forests, p. 205-221, illus. Brian D. Cleary, Robert D. Greaves, and Richard K. Hermann, compilers and eds. Oreg. State Univ. Ext. Serv., Corvallis.

Williamson, Denis M., and Don Minore.
1978. Survival and growth of planted conifers on the Dead Indian Plateau east of Ashland, Oregon. USDA For. Serv. Res. Pap. PNW-242, 15 p., illus. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Appendix

Data sources, collection methods, and summation procedures for descriptive and environmental variables.

1. Elevation—height above mean sea level was extrapolated to the nearest 10 feet (3 m) from the plot's location on the applicable U.S. Geological Survey quadrangle map.

2. Average slope—steepness of slope was estimated ocularly to the nearest 10 percent and checked occasionally with a clinometer. Observations for individual subplots were summed and a plot average determined.

3. Aspect index—slope direction was rated to the nearest of eight main compass points. A numerical relative moisture value was then assigned to each subplot from the scale derived by Day and Monk (1974). Values for subplots were summed and a plot average determined.

4. Radiation index—a solar irradiation value was determined for each subplot by entering its slope and aspect in a table of radiation indexes for latitude 42° north calculated by Frank and Lee (1966). Values for subplots were summed and a plot average determined.

5. Average annual precipitation—yearly rainfall was extrapolated to the nearest 2 inches (51 mm) from the plot's approximate location on a small-scale isohyet map of Oregon.

6. Forest type and age class—the general prelogging composition, density, and age of the forest stand were determined from the plot's location on a forest type map. Such maps were prepared in the 1940's as part of the nationwide Forest Survey by the Pacific Northwest Forest and Range Experiment Station, USDA Forest Service.

7. Soil type—soil series were identified from soil inventory maps and descriptions prepared by the Medford District, Bureau of Land Management, in 1973.

8. Years since logging—timber harvest dates were obtained for the cutover area encompassing each plot from cutting reports for individual sales. Years since logging are based on the number of complete growing seasons (ending September 1) between cutting date and examination date. Determined this way, elapsed time data best reflect the actual establishment period available for tree seedlings and fits with the development stage for judging when seedlings are 2 years old or less.

9. Canopy—total vegetative cover present at waist height and above was estimated ocularly to the nearest tenth of the subplot area. Estimates for individual subplots were summed and a plot average determined.

10. Seedbed—the surface condition judged predominant on the subplot immediately after logging was classed as one of five types: bare mineral soil, undisturbed duff and litter; disturbed soil, duff, and litter; mixed soil and rock; or logs, wood, and bark. Duff- and litter-covered subplots and those covered with logs, wood, and bark were counted separately and computed as a percentage of the total subplots on the plot.

11. Seed source—distance to the nearest seed tree was judged as within 50 feet (15.2 m) or over 50 feet in 100-foot (30.5-m) classes. The nearest 16-inch (41-cm) d.b.h. or larger tree with a reasonably full crown was usually considered a source of seed. Trees smaller than 16 inches were recognized if there was evidence they had borne seed in substantial quantities. The species of the nearest seed tree was also recorded. Separately, subplots with a seed tree of any species, of Douglas-fir, or of true fir, within 50 feet were counted and computed as a percentage of the total subplots on the plot.

12. Ground cover—total vegetative cover present below waist height was estimated ocularly to the nearest tenth of the subplot area. Estimates for individual subplots were summed and a plot average determined.

13. Dominant ground cover—vegetative cover was classed as the predominant one of three broad types: grass, herbaceous, or woody perennial. For subplots dominated by woody perennials, the genus or species was recorded if one clearly dominated. Separately, subplots dominated by grass, or woody perennials, were counted and computed as a percentage of the total subplots on the plot.

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Table 12—Average stocking in cutovers in the Dead Indian and Butte Falls areas

Descriptor	Dead Indian	Butte Falls	Combined
	PARTIAL CUTS		
Number of samples	44	21	65
Regeneration class (percent ± standard error):[1]			
All	65.1 ± 3.6	81.4 ± 3.4	70.4 ± 2.8
Advance	35.1 ± 3.2	38.8 ± 4.6	36.3 ± 2.6
Subsequent	50.0 ± 3.9	64.5 ± 5.1	54.7 ± 3.2
Second-year[2]	34.9 ± 3.4	26.0 ± 5.4	32.0 ± 2.9
	CLEARCUTS		
Number of samples	16	11	27
Regeneration class (percent ± standard error):[1]			
All	32.8 ± 5.5	74.1 ± 3.6	46.6 ± 5.3
Advance	4.1 ± 1.8	8.6 ± 3.1	5.9 ± 1.7
Subsequent	30.6 ± 5.7	72.3 ± 3.5	47.6 ± 5.4
Second-year[2]	2.2 ± 1.1	3.2 ± 1.2	2.6 ± .8

[1] Data for regeneration classes are not additive since more than 1 class was found on many subplots.

[2] Not included in the "All" and "Subsequent" classes.

Table 13—Proportion of sample plots stocked at 4 levels with regeneration

Stocking at least	Plots	Proportion of total	Confidence limit[1] Lower	Confidence limit[1] Upper
Percent	Number	-Proportion-		
		44 DEAD INDIAN PARTIAL CUTS		
30	42	0.95	0.85	0.99
50	33	.75	.60	.87
70	24	.55	.39	.70
90	8	.18	.08	.33
		21 BUTTE FALLS PARTIAL CUTS		
30	21	1.00	.84	1.00
50	21	1.00	.84	1.00
70	17	.81	.58	.95
90	9	.43	.22	.66
		16 DEAD INDIAN CLEARCUTS		
30	8	.50	.25	.75
50	4	.25	.07	.52
70	2	.12	.02	.38
90	0	0.	0.	.21
		11 BUTTE FALLS CLEARCUTS		
30	11	1.00	.72	1.00
50	11	1.00	.72	1.00
70	7	.64	.31	.89
90	2	.18	.02	.52

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[1] There is a 95-percent or greater chance that the true proportion is within lower and upper confidence limits.

Table 14—Proportion of sample plots stocked at 4 levels with advance regeneration

Stocking at least	Plots	Proportion of total	Confidence limit[1]	
			Lower	Upper
Percent	Number	Proportion		
		44 DEAD INDIAN PARTIAL CUTS		
30	26	0.59	0.43	0.74
50	12	.27	.15	.43
70	5	.11	.04	.24
90	0	0.	0.	.08
		21 BUTTE FALLS PARTIAL CUTS		
30	13	.62	.38	.82
50	8	.38	.18	.62
70	3	.14	.03	.36
90	0	0.	0.	.16
		16 DEAD INDIAN CLEARCUTS		
30	0	0.	0.	.21
50	0	0.	0.	.21
70	0	0.	0.	.21
90	0	0.	0.	.21
		11 BUTTE FALLS CLEARCUTS		
30	1	.09	0.	.41
50	0	0.	0.	.28
70	0	0.	0.	.28
90	0	0.	0.	.28

[1] There is a 95-percent or greater chance that the true proportion is within lower and upper confidence limits.

Table 15—Proportion of sample plots stocked at 4 levels with subsequent regeneration

Stocking at least	Plots	Proportion of total	Confidence limit[1] Lower	Confidence limit[1] Upper
Percent	Number	Proportion		
		44 DEAD INDIAN PARTIAL CUTS		
30	35	0.80	0.65	0.90
50	26	.59	.43	.74
70	13	.30	.17	.45
90	4	.09	.03	.22
		21 BUTTE FALLS PARTIAL CUTS		
30	20	.95	.76	1.00
50	18	.86	.64	.97
70	10	.48	.26	.70
90	4	.19	.05	.42
		16 DEAD INDIAN CLEARCUTS		
30	7	.44	.20	.70
50	4	.25	.07	.52
70	2	.12	.02	.38
90	0	0.	0.	.21
		11 BUTTE FALLS CLEARCUTS		
30	11	1.00	.72	1.00
50	11	1.00	.72	1.00
70	7	.64	.31	.89
90	1	.09	0.	.41

[1] There is a 95-percent or greater chance that the true proportion is within lower and upper confidence limits.

Table 16—Proportion of sample plots stocked at 4 levels with subsequent Douglas-fir

Stocking at least	Plots	Proportion of total	Confidence limit[1]	
			Lower	Upper
Percent	Number	Proportion		
		44 DEAD INDIAN PARTIAL CUTS		
30	8	0.18	0.08	0.33
50	4	.09	.03	.22
70	0	0.	0.	.08
90	0	0.	0.	.08
		21 BUTTE FALLS PARTIAL CUTS		
30	12	.57	.34	.78
50	6	.29	.11	.52
70	3	.14	.03	.36
90	0	0.	0.	.16
		16 DEAD INDIAN CLEARCUTS		
30	0	0.	0.	.21
50	0	0.	0.	.21
70	0	0.	0.	.21
90	0	0.	0.	.21
		11 BUTTE FALLS CLEARCUTS		
30	4	.36	.11	.69
50	1	.09	0.	.41
70	0	0.	0.	.28
90	0	0.	0.	.28

[1] There is a 95-percent or greater chance that the true proportion is within lower and upper confidence limits.

Table 17—Proportion of sample plots stocked at 4 levels with subsequent true firs

Stocking at least	Plots	Proportion of total	Confidence limit[1]	
			Lower	Upper
Percent	Number	Proportion		
44 DEAD INDIAN PARTIAL CUTS				
30	28	0.64	0.48	0.78
50	17	.39	.25	.55
70	4	.09	.03	.22
90	1	.02	0.	.12
21 BUTTE FALLS PARTIAL CUTS				
30	14	.67	.43	.85
50	6	.29	.11	.52
70	1	.05	0.	.24
90	0	0.	0.	.16
16 DEAD INDIAN CLEARCUTS				
30	1	.06	0.	.30
50	1	.06	0.	.30
70	0	0.	0.	.21
90	0	0.	0.	.21
11 BUTTE FALLS CLEARCUTS				
30	1	.09	0.	.41
50	1	.09	0.	.41
70	0	0.	0.	.28
90	0	0.	0.	.28

[1] There is a 95-percent or greater chance that the true proportion is within lower and upper confidence limits.

Table 18—Average stocking by species in cutovers in the Dead Indian and Butte Falls areas

Descriptor	Dead Indian		Butte Falls	
	Partial cut	Clearcut	Partial cut	Clearcut
Number of samples	44	16	21	11
Species (percent ± standard error):[1]				
Douglas-fir	18.8 ± 2.5	3.8 ± 1.6	49.3 ± 4.5	20.0 ± 5.6
True firs	54.2 ± 3.4	11.6 ± 3.3	56.0 ± 4.7	14.1 ± 5.2
Ponderosa pine	1.6 ± .7	18.1 ± 5.1	1.9 ± 1.1	58.6 ± 6.2
Sugar and western white pine	4.3 ± 1.3	1.3 ± .7	2.4 ± .8	1.8 ± 1.0
Incense-cedar	12.5 ± 3.9	2.8 ± 1.2	45.2 ± 6.0	6.4 ± 1.7
Other conifers	.9 ± .6	2.8 ± 1.6	5.7 ± 2.6	1.4 ± 1.4
Hardwoods	3.1 ± .8	.9 ± .9	7.9 ± 2.7	1.4 ± 1.4
All species	65.1 ± 3.6	32.8 ± 5.5	81.4 ± 3.4	74.1 ± 3.6

[1] Does not include second-year seedlings.

Table 19—Average stocking of advance and subsequent regeneration by species in cutovers in the Dead Indian and Butte Falls areas

Descriptor	Dead Indian		Butte Falls	
	Advance	Subsequent	Advance	Subsequent
PARTIAL CUTS				
Number of samples	44	44	21	21
Species (percent ± standard error):[1]				
Douglas-fir	4.0 ± 0.9	15.5 ± 2.5	17.1 ± 3.6	38.1 ± 4.8
True firs	29.3 ± 3.0	37.8 ± 3.4	25.2 ± 4.1	38.1 ± 4.4
Ponderosa pine	.2 ± .2	1.5 ± .7	1.0 ± .7	1.0 ± .4
Sugar and western white pine	1.5 ± .6	3.1 ± 1.2	.7 ± .4	1.7 ± .8
Incense-cedar	2.3 ± 1.2	11.8 ± 3.8	9.3 ± 2.4	39.5 ± 5.9
Other conifers	.1 ± .1	.8 ± .6	3.1 ± 1.3	3.1 ± 1.5
Hardwoods	2.6 ± .7	1.2 ± .6	3.3 ± 1.4	4.8 ± 2.2
All species	35.1 ± 3.2	50.0 ± 3.9	38.8 ± 4.6	64.5 ± 5.1
CLEARCUTS				
Number of samples	16	16	11	11
Species (percent ± standard error):[1]				
Douglas-fir	.9 ± .7	2.8 ± 1.5	5.0 ± 1.8	17.7 ± 6.0
True firs	3.1 ± 1.6	9.4 ± 3.1	5.9 ± 2.1	10.5 ± 4.3
Ponderosa pine	0.	18.1 ± 5.1	0.	58.6 ± 6.2
Sugar and western white pine	.6 ± .6	.6 ± .4	0.	1.8 ± 1.0
Incense-cedar	.6 ± .6	2.5 ± 1.0	.9 ± .9	6.4 ± 1.7
Other conifers	0.	2.8 ± 1.6	.5 ± .5	.9 ± .9
Hardwoods	0.	.9 ± .9	.5 ± .5	.9 ± .9
All species	4.1 ± 1.8	30.6 ± 5.7	8.6 ± 3.1	72.3 ± 3.5

[1] Does not include second-year seedlings.

Table 20—Average stocking of second-year seedlings by species in cutovers in the Dead Indian and Butte Falls areas

Descriptor	Dead Indian		Butte Falls	
	Partial cut	Clearcut	Partial cut	Clearcut
Number of samples	44	16	21	11
Species (percent ± standard error):				
Douglas-fir	4.5 ± 1.1	0.3 ± 0.3	3.3 ± 0.9	1.4 ± 0.7
True firs	29.5 ± 3.2	1.9 ± .9	8.8 ± 1.9	1.8 ± 1.0
Ponderosa pine	.1 ± .1	0.	.7 ± .5	0.
Sugar and western white pine	.3 ± .3	0.	0.	0.
Incense-cedar	5.3 ± 2.4	.3 ± .3	18.3 ± 5.1	0.
Other conifers	0.	0.	1.0 ± .6	0.
Hardwoods	.1 ± .1	0.	0.	0.
All species	34.9 ± 3.4	2.2 ± 1.1	26.0 ± 5.4	3.2 ± 1.2

Table 21—Significant associations between total or advance stocking in partial cuts and environmental variables by area

Stocking category	Environmental variable and its correlation coefficient (r)[1, 2]					
	Dead Indian		Butte Falls		Areas combined	
Total	Radiation index	-0.33*	Ground cover	-0.54*	Elevation	-0.26*
	Woody perennials	.35*	Grass	-.59**	Radiation index	-.29*
	True fir seed source	-.40**	Duff & litter	-.39	Woody perennials	.29*
			Undisturbed seedbed	-.48*	Douglas-fir seed source	.22
					True fir seed source	-.42**
Advance all species	Woody perennials	.31*	Elevation	-.37	Canopy	.22
	Undisturbed seedbed	.26	Canopy	.68**	Ground cover	-.27*
			Ground cover	-.38	Woody perennials	.26*
			Duff & litter	.53*	Duff & litter	.28*
			Precipitation	-.48*	Undisturbed seedbed	.33**
			Undisturbed seedbed	.45*		
Advance Douglas-fir	Radiation index	-.30*	Elevation	-.40	Elevation	-.59**
	Aspect	.35*	Canopy	.52*	Canopy	.24
			Ground cover	-.40	Duff & litter	.40**
			Duff & litter	.45*	Douglas-fir seed source	.38**
			True fir seed source	-.39	True fir seed source	-.44**
			Precipitation	-.56**	Undisturbed seedbed	.28*
Advance true firs	Ground cover	-.30*	Aspect	-.44*	Canopy	.22
	Woody perennials	.32*	Canopy	.67**	Ground cover	-.35**
	Undisturbed seedbed	.37*	Ground cover	-.52*	Woody perennials	.27*
			Duff & litter	.49*	Duff & litter	.25*
			Precipitation	-.42	Undisturbed seedbed	.35**
			Undisturbed seedbed	.47*		
Advance incense-cedar	Grass	.37*			Elevation	-.32**
	Undisturbed seedbed	-.26			True fir seed source	-.36**
					Precipitation	.23

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[1] Degrees of freedom for the significant correlations in each stocking category are respectively 42, 19, and 63 for Dead Indian, Butte Falls, and combined data sets.

[2] Correlation coefficients with 0, 1, or 2 asterisks are significant at the 10-, 5-, and 1-percent probability levels, respectively. To determine the amount of total variation accounted for by any single independent variable, square its r value.

Table 22—Significant associations between subsequent stocking in partial cuts and environmental variables by area

Stocking category	Environmental variable and its correlation coefficient (r)[1, 2]					
	Dead Indian		Butte Falls		Areas combined	
Total subsequent	Elevation	-0.29	Canopy	-0.40	Elevation	-0.24
	Radiation index	-.40**	Duff & litter	-.59**	Radiation index	-.34**
	Aspect	.29	Undisturbed seedbed	-.69**	Aspect	.23
	Woody perennials	.31*			Canopy	-.21
	True fir seed source	-.52**			Douglas-fir seed source	.27*
					True fir seed source	-.43**
Second-year	Elevation	.33*	Douglas-fir seed source	-.39	Elevation	.25*
	Woody perennials	-.32*			Grass	-.21
	Precipitation	.40**			Woody perennials	-.35**
					Douglas-fir seed source	-.27*
Douglas-fir	Elevation	-.34*	Canopy	-.41	Elevation	-.47**
	Duff & litter	-.27	Duff & litter	-.47*	Radiation index	-.31*
	Douglas-fir seed source	.69**	Undisturbed seedbed	-.47*	Woody perennials	.25*
	True fir seed source	-.40**			Douglas-fir seed source	.68**
	Precipitation	-.49**			True fir seed source	-.49**
					Precipitation	.23
True firs	Radiation index	-.53**	Radiation index	-.46*	Radiation index	-.47**
	Aspect	.38*	Aspect	.44*	Aspect	.39**
	Years	.25	Precipitation	.47*	Years	.25*
	Ground cover	.29				
	Woody perennials	.30*				
	Precipitation	-.37*				
ncense-cedar	Ground cover	-.31*	Elevation	.41	Elevation	-.31*
	True fir seed source	-.43**	Years	.42	Ground cover	-.28*
			Woody perennials	-.42	True fir seed source	-.45**
			Duff & litter	-.45*	Precipitation	.37**
			Undisturbed seedbed	-.55**		

Degrees of freedom for the significant correlations in each stocking category are respectively 42, 19, and 63 for ead Indian, Butte Falls, and combined data sets.

Correlation coefficients with 0, 1, or 2 asterisks are significant at the 10-, 5-, and 1-percent probability evels, respectively. To determine the amount of total variation accounted for by any single independent variable, quare its r value.

Table 23—Significant associations between total or advance stocking in clearcuts and environmental variables by area

Stocking category	Environmental variable and its correlation coefficient (r)[1, 2]					
	Dead Indian		Butte Falls		Areas combined	
Total	Radiation index	-0.43	Elevation	-0.76**	Elevation	-0.72**
	Woody perennials	.58*	Slope	-.54	Grass	-.42*
			Seed source distance	.85**	Woody perennials	.68**
					Duff & litter	.47*
					Precipitation	.53**
					Undisturbed seedbed	.40*
Advance all species	Ground cover	-.47	Duff & litter	.90**	Duff & litter	.66**
			Logs, wood, bark	.58	Logs, wood, bark	.43*
			Seed source distance	.55	Undisturbed seedbed	.67**
			Undisturbed seedbed	.87**		
Advance Douglas-fir	Ground cover	-.65**	Duff & litter	.78**	Elevation	-.43*
			Undisturbed seedbed	.72*	Duff & litter	.72**
					Logs, wood, bark	.35
					Precipitation	.42*
					Undisturbed seedbed	.66**
Advance true firs	Ground cover	-.57*	Years	-.53	Ground cover	-.44*
	Seed source distance	.44	Duff & litter	.89**	Duff & litter	.56**
			Undisturbed seedbed	.80**	Logs, wood, bark	.40*
					Seed source distance	.35
					Undisturbed seedbed	.60**
Advance incense-cedar			Years	-.70*		

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[1] Degrees of freedom for the significant correlations in each stocking category are respectively 14, 9, and 25 for Dead Indian, Butte Falls, and combined data sets.

[2] Correlation coefficients with 0, 1, or 2 asterisks are significant at the 10-, 5-, and 1-percent probability levels, respectively. To determine the amount of total variation accounted for by any single independent variable, square its r value.

Table 24—Significant associations between subsequent stocking in clearcuts and environmental variables by area

Stocking category	Environmental variable and its correlation coefficient (r)[1, 2]					
	Dead Indian		Butte Falls		Areas combined	
Total subsequent	Radiation index	-0.47	Elevation	-0.80**	Elevation	-0.72**
	Woody perennials	.57*	Slope	-.67*	Grass	-.42*
			Seed source distance	.73*	Woody perennials	.67**
			Precipitation	-.61*	Duff & litter	.42*
					Precipitation	.52**
					Undisturbed seedbed	.33
Second-year	Woody perennials	.46	Ground cover	-.57	Radiation index	.37
			Precipitation	.55	Aspect	-.38*
					Woody perennials	.34
Douglas-fir	Grass	-.48	Elevation	.71*	Slope	.53**
	Woody perennials	.68**	Aspect	.53	Grass	-.50**
	Duff & litter	.46	Slope	.56	Woody perennials	.66**
			Grass	-.55	Duff & litter	.36
			Woody perennials	.64*	Precipitation	.76**
			Precipitation	.87**		
True firs	Radiation index	-.62**	Duff & litter	.76**	Radiation index	-.47*
	Woody perennials	.55*	Logs, wood, bark	.65*	Grass	-.33
	Duff & litter	.49	Seed source distance	.58	Woody perennials	.38*
	Undisturbed seedbed	.52*	Undisturbed seedbed	.83**	Duff & litter	.53**
					Logs, wood, bark	.53**
					Undisturbed seedbed	.66**
Incense-cedar	Ground cover	.48	Radiation index	.64*	Elevation	-.34
					Ground cover	.33
					Woody perennials	.40*

[1] Degrees of freedom for the significant correlations in each stocking category are respectively 14, 9, and 25 for Dead Indian, Butte Falls, and combined data sets.

[2] Correlation coefficients with 0, 1, or 2 asterisks are significant at the 10-, 5-, and 1-percent probability levels, respectively. To determine the amount of total variation accounted for by any single independent variable, square its r value.

Table 25—Significant associations between total or advance stocking in partial cuts and environmental variables by forest type

Stocking category	Environmental variable and its correlation coefficient (r)[1], [2]					
	Douglas-fir		White fir		Pine	
Total	Logs, wood, bark	-0.47*	True fir seed source	-0.39*	Radiation index	-0.62*
	True fir seed source	-.42			Aspect	.53
	Precipitation	.48*				
Advance all species	Elevation	-.52*			Aspect	.49
	Aspect	-.37			Duff & litter	.51
	Canopy	.57**			Undisturbed seedbed	.48
	Ground cover	-.45*				
	Grass	-.45*				
	Duff & litter	.64**				
	Undisturbed seedbed	.56**				
Advance Douglas-fir	Elevation	-.52*	Elevation	-.62**	Radiation index	-.55*
	Aspect	-.39	Douglas-fir seed source	.55**		
	Canopy	.48*	True fir seed source	-.47**		
	Ground cover	-.56**				
	Duff & litter	.62**				
	Undisturbed seedbed	.39				
Advance true firs	Elevation	-.40	Elevation	.31	Radiation index	-.48
	Aspect	-.46*	Aspect	-.39*	Woody perennials	.55*
	Canopy	.65**			Duff & litter	.63*
	Ground cover	-.46*			Undisturbed seedbed	.77**
	Duff & litter	.70**				
	Undisturbed seedbed	.62**				
Advance incense-cedar	Ground cover	-.41	Elevation	-.48**		
	Grass	-.38	True fir seed source	-.41*		
	True fir seed source	-.41				
	Precipitation	.40				

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[1] Degrees of freedom for the significant correlations in each stocking category are respectively 19, 27, and 11 for Douglas-fir, white fir, and pine type data sets.

[2] Correlation coefficients with 0, 1, or 2 asterisks are significant at the 10-, 5-, and 1-percent probability levels, respectively. To determine the amount of total variation accounted for by any single independent variable, square its r value.

Table 26—Significant associations between subsequent stocking in partial cuts and environmental variables by forest type

Stocking category	Environmental variable and its correlation coefficient (r)[1, 2]					
	Douglas-fir		White fir		Pine	
Total subsequent	Years	0.41	Elevation	-0.36	Radiation index	-0.53
	Logs, wood, bark	-.39	Douglas-fir seed source	.35		
	Undisturbed seedbed	-.59**	True fir seed source	-.47**		
Second-year	Elevation	.38	Grass	-.47**	Elevation	-.49
	Aspect	.38			Woody perennials	-.64*
					Duff & litter	-.48
					Precipitation	.63*
Douglas-fir	Duff & litter	-.37	Elevation	-.63**	Elevation	-.64*
	Douglas-fir seed source	.38	Woody perennials	.42*	Radiation index	-.51
	Undisturbed seedbed	-.52*	Douglas-fir seed source	.65**	Slope	.80**
			True fir seed source	-.63**	Years	-.52
					Grass	-.53
True firs	Radiation index	-.45*	Radiation index	-.38*		
	Aspect	.54*				
Incense-cedar	Ground cover	-.43*	Elevation	-.32	Elevation	-.70**
	Grass	-.47*	True fir seed source	-.53**	Radiation index	-.54
	Precipitation	.56**			True fir seed source	-.53

[1] Degrees of freedom for the significant correlations in each stocking category are respectively 19, 27, and 11 For Douglas-fir, white fir, and pine type data sets.

[2] Correlation coefficients with 0, 1, or 2 asterisks are significant at the 10-, 5-, and 1-percent probability evels, respectively. To determine the amount of total variation accounted for by any single independent variable, square its r value.

Table 27—Significant associations between total or advance stocking in clearcuts and environmental variables by forest type

Stocking category	Environmental variable and its correlation coefficient (r)[1], [2]			
	Douglas-fir		White fir	
Total	Elevation	-0.88**	Elevation	-0.75**
	Slope	.63*	Ground cover	-.52
	Grass	-.80**	Precipitation	.52
	Woody perennials	.91**	Undisturbed seedbed	.47
	Duff & litter	.58*		
	Precipitation	.77**		
Advance all species	Duff & litter	.61*	Radiation index	.50
	Logs, wood, bark	.81**	Duff & litter	.72**
	Seed source distance	.53	Undisturbed seedbed	.49
	Undisturbed seedbed	.80**		
Advance Douglas-fir	Elevation	-.59*	Radiation index	.47
	Woody perennials	.52	Ground cover	-.47
	Duff & litter	.60*	Duff & litter	.86**
	Logs, wood, bark	.60*	Precipitation	.59*
	Undisturbed seedbed	.67*	Undisturbed seedbed	.66**
Advance true firs	Logs, wood, bark	.75**	Radiation index	.51
	Seed source distance	.58*	Duff & litter	.88**
	Undisturbed seedbed	.60*	Precipitation	.54*
			Undisturbed seedbed	.61*
Advance incense-cedar	Years	-.53		

[1] Degrees of freedom for the significant correlations in each stocking category are respectively 11 and 12 for Douglas-fir and white fir type data sets.

[2] Correlation coefficients with 0, 1, or 2 asterisks are significant at the 10-, 5-, and 1-percent probability levels, respectively. To determine the amount of total variation accounted for by any single independent variable, square its r value.

able 28—Significant associations between subsequent stocking in clearcuts nd environmental variables by forest type

tocking ategory	Environmental variable and its correlation coefficient (r)[1], [2]			
	Douglas-fir		White fir	
otal subsequent	Elevation	-0.88**	Elevation	-0.75**
	Slope	.63*	Ground cover	-.50
	Ground cover	.50	Precipitation	.51
	Grass	-.80**		
	Woody perennials	.90**		
	Duff & litter	.52		
	Precipitation	.77**		
econd-year				
uglas-fir	Elevation	-.58*	Woody perennials	.60*
	Slope	.63*		
	Grass	-.63*		
	Woody perennials	.80**		
	Precipitation	.89**		
ue firs	Duff & litter	.74**	Radiation index	-.50
	Logs, wood, bark	.75**	Undisturbed seedbed	.47
	Undisturbed seedbed	.83**		
cense-cedar	Elevation	-.68**	Duff & litter	.49
	Ground cover	.56*	Undisturbed seedbed	.52
	Woody perennials	.49		

egrees of freedom for the significant correlations in each stocking category e respectively 11 and 12 for Douglas-fir and white fir type data sets.

orrelation coefficients with 0, 1, or 2 asterisks are significant at the 10-, , and 1-percent probability levels, respectively. To determine the amount of tal variation accounted for by any single independent variable, square its r lue.

Table 29—Regressions between stocking and environmental variables for Dead Indian partial cuts

Regression formula				Statistical values		
Stocking =	constant	±	environmental variable	Cumulative R^2	Degrees of freedom	F ratio[1]
Total	221.48	-0.31	(true fir seed source)	0.16	2/41	6.81**
		-289.49	(radiation index)	.25		
Advance all species	30.78	+0.25	(woody perennials)	.10	2/41	4.06*
		-0.27	(Douglas-fir seed source)	.17		
Advance Douglas-fir	-0.38	+0.49	(aspect)	.12	1/42	5.70*
Advance true firs	15.53	+0.30	(undisturbed seedbed)	.14	3/40	4.37**
		+0.19	(woody perennials)	.19		
		-0.23	(Douglas-fir seed source)	.25		
Advance incense-cedar	-0.98	+0.20	(grass)	.14	1/42	6.60*
Total subsequent	252.51	-0.45	(true fir seed source)	.27	2/41	13.89***
		-369.49	(radiation index)	.40		
Second-year	-21.10	+1.63	(precipitation)	.16	6/37	4.49**
		-0.24	(woody perennials)	.25		
		-0.30	(grass)	.29		
		+1.76	(aspect)	.34		
		+0.42	(canopy)	.38		
		-0.18	(true fir seed source)	.42		
Subsequent Douglas-fir	7.27	+0.56	(Douglas-fir seed source)	.47	2/41	21.40***
		-0.44	(slope)	.51		
Subsequent true firs	264.95	-426.41	(radiation index)	.28	3/40	9.83***
		-1.19	(precipitation)	.38		
		+1.32	(years)	.42		
Subsequent incense-cedar	88.69	-0.77	(true fir seed source)	.19	3/40	10.52***
		-0.79	(Douglas-fir seed source)	.40		
		-1.48	(years)	.44		

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[1] 1 asterisk denotes significance of the regression F ratio at the 5-percent probability level; 2 asterisks, 1-percent; 3, 0.1-percent.

Table 30—Regressions between stocking and environmental variables for Butte Falls partial cuts

Regression formula					Statistical values		
Stocking	=	constant	±	environmental variable	Cumulative R^2	Degrees of freedom	F ratio[1]
Total		90.14	-0.70	(grass)	0.35	3/17	10.78***
			-0.28	(woody perennials)	.55		
			+1.94	(years)	.66		
Advance all species		72.29	+0.78	(canopy)	.46	3/17	10.37***
			-0.012	(elevation)	.54		
			-0.54	(ground cover)	.65		
Advance Douglas-fir		67.85	-1.31	(precipitation)	.32	4/16	6.01**
			-0.46	(grass)	.46		
			+0.23	(undisturbed seedbed)	.53		
			-0.23	(true fir seed source)	.60		
Advance true firs		19.02	+0.73	(canopy)	.45	2/18	13.81***
			-0.56	(ground cover)	.61		
Advance incense-cedar		21.16	-0.77	(true fir seed source)	.09	6/14	6.35**
			0.47	(Douglas-fir seed source)	.41		
			-0.42	(grass)	.52		
			+0.25	(canopy)	.59		
			+1.59	(years)	.66		
			+0.31	(ground cover)	.73		
otal subsequent		69.51	-0.60	(undisturbed seedbed)	.47	5/15	11.97***
			+0.90	(true fir seed source)	.52		
			+0.70	(Douglas-fir seed source)	.57		
			-0.60	(woody perennials)	.70		
			-0.47	(grass)	.80		
econd-year		155.79	-0.57	(Douglas-fir seed source)	.16	4/16	3.00*
			-0.34	(undisturbed seedbed)	.25		
			-0.020	(elevation)	.32		
			-0.54	(grass)	.43		
ubsequent Douglas-fir		-24.05	-0.49	(undisturbed seedbed)	.22	4/16	5.90**
			+0.65	(Douglas-fir seed source)	.35		
			+0.55	(true fir seed source)	.52		
			+0.86	(precipitation)	.60		
ubsequent true firs		184.18	+2.51	(precipitation)	.22	7/13	7.73***
			+5.23	(years)	.33		
			-520.48	(radiation index)	.46		
			+0.93	(canopy)	.62		
			-0.35	(woody perennials)	.68		
			-3.34	(aspect)	.75		
			-0.011	(elevation)	.81		
ubsequent incense-cedar		84.88	-0.63	(undisturbed seedbed)	.30	5/15	6.39**
			+0.019	(elevation)	.44		
			-1.41	(precipitation)	.55		
			-0.39	(woody perennials)	.60		
			-0.54	(grass)	.68		

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[1] asterisk denotes significance of the regression F ratio at the 5-percent probability level; 2 asterisks, -percent; 3, 0.1-percent.

Table 31—Regressions between stocking and environmental variables for combined data from Dead Indian and Butte Falls partial cuts

Regression formula				Statistical values		
Stocking =	constant	±	environmental variable	Cumulative R^2	Degrees of freedom	F ratio[1]
Total	169.99	-0.28	(true fir seed source)	0.18	2/62	10.09***
		-182.78	(radiation index)	.25		
Advance all species	36.47	+0.31	(undisturbed seedbed)	.11	2/62	5.50**
		-0.27	(ground cover)	.15		
Advance Douglas-fir	57.00	-0.009	(elevation)	.34	2/62	19.27***
		-0.15	(ground cover)	.38		
Advance true firs	46.55	+0.29	(undisturbed seedbed)	.13	5/59	6.13***
		-0.32	(ground cover)	.21		
		-0.49	(precipitation)	.26		
		-0.17	(Douglas-fir seed source)	.29		
		+0.17	(woody perennials)	.34		
Advance incense-cedar	39.25	-0.17	(true fir seed source)	.13	3/61	6.85***
		-0.19	(Douglas-fir seed source)	.20		
		-0.004	(elevation)	.25		
Total subsequent	177.92	-0.31	(true fir seed source)	.18	3/61	9.32***
		-251.65	(radiation index)	.28		
		+1.42	(years)	.31		
Second-year	55.16	-0.26	(woody perennials)	.12	3/61	6.01**
		-0.42	(grass)	.19		
		-0.16	(Douglas-fir seed source)	.23		
Subsequent Douglas-fir	96.60	+0.50	(Douglas-fir seed source)	.46	3/61	27.87***
		-175.91	(radiation index)	.54		
		-0.21	(undisturbed seedbed)	.58		
Subsequent true firs	176.59	-321.81	(radiation index)	.22	2/62	12.82***
		+1.70	(years)	.29		
Subsequent incense-cedar	30.60	-0.63	(true fir seed source)	.20	3/61	11.34***
		+1.06	(precipitation)	.29		
		-0.40	(Douglas-fir seed source)	.36		

[1] 2 asterisks denote significance of the regression F ratio at the 1-percent probability level; 3, 0.1-percent.

able 32—Regressions between stocking and environmental variables for Dead Indian clearcuts

Regression formula					Statistical values		
tocking	=	constant	±	environmental variable	Cumulative R^2	Degrees of freedom	F ratio[1]
otal		291.98	+0.65	(woody perennials)	0.34	4/11	6.51**
			+5.45	(precipitation)	.43		
			-453.30	(radiation index)	.58		
			-0.039	(elevation)	.70		
dvance all species		20.98	-0.28	(ground cover)	.22	1/14	[2]3.88
dvance Douglas-fir		9.89	-0.15	(ground cover)	.42	1/14	10.00**
dvance true firs		31.32	-0.31	(ground cover)	.32	3/12	4.07*
			+0.09	(seed source distance)	.41		
			-0.96	(years)	.50		
dvance incense-cedar		-28.66	+0.005	(elevation)	.06	3/12	[3]1.72
			-0.49	(precipitation)	.22		
			+36.87	(radiation index)	.30		
otal subsequent		322.85	+0.65	(woody perennials)	.33	4/11	7.40**
			+5.73	(precipitation)	.41		
			-530.92	(radiation index)	.61		
			-0.040	(elevation)	.73		
econd-year		-62.12	+0.10	(woody perennials)	.21	4/11	6.11**
			+126.86	(radiation index)	.53		
			+0.07	(seed source distance)	.58		
			+0.22	(slope)	.69		
ubsequent Douglas-fir		50.18	+0.19	(woody perennials)	.47	4/11	13.21***
			-0.021	(elevation)	.60		
			+0.62	(slope)	.76		
			+102.32	(radiation index)	.83		
ubsequent true firs		375.07	-752.43	(radiation index)	.39	3/12	9.84**
			-3.12	(aspect)	.64		
			+0.64	(undisturbed seedbed)	.71		
ubsequent incense-cedar		16.26	+0.06	(ground cover)	.23	4/11	4.20*
			-0.71	(precipitation)	.36		
			-0.44	(undisturbed seedbed)	.49		
			+0.06	(woody perennials)	.60		

asterisk denotes significance of the regression F ratio at the 5-percent probability level; 2 asterisks, -percent; 3, 0.1-percent.

ignificant at the 10-percent level.

ignificant between the 10- and 25-percent level.

Table 33—Regressions between stocking and environmental variables for Butte Falls clearcuts

Regression formula				Statistical values		
Stocking =	constant	±	environmental variable	Cumulative R^2	Degrees of freedom	F ratio[1]
Total	84.69	+0.49	(seed source distance)	0.72	2/8	33.19***
		-0.54	(precipitation)	.89		
Advance all species	-41.62	+0.73	(undisturbed seedbed)	.76	2/8	18.08**
		+89.66	(radiation index)	.82		
Advance Douglas-fir	-164.89	+0.54	(undisturbed seedbed)	.52	4/6	6.83*
		+283.36	(radiation index)	.65		
		+1.79	(aspect)	.71		
		+1.30	(years)	.82		
Advance true firs	-151.37	+0.55	(undisturbed seedbed)	.65	4/6	23.12***
		+317.55	(radiation index)	.73		
		+2.54	(aspect)	.89		
		-0.30	(ground cover)	.94		
Advance incense-cedar	22.87	-1.57	(years)	.49	2/8	10.37**
		-0.13	(undisturbed seedbed)	.72		
Total subsequent	101.19	-0.012	(elevation)	.65	4/6	28.03***
		+1.50	(aspect)	.84		
		+0.21	(seed source distance)	.89		
		-0.41	(slope)	.95		
Second-year	6.36	-0.09	(ground cover)	.33	5/5	37.26***
		+0.75	(precipitation)	.59		
		-0.16	(seed source distance)	.77		
		-0.013	(elevation)	.91		
		+43.48	(radiation index)	.97		
Subsequent Douglas-fir	-64.11	+1.68	(precipitation)	.75	2/8	19.97***
		+1.97	(aspect)	.83		
Subsequent true firs	-88.97	+0.89	(undisturbed seedbed)	.68	4/6	21.90***
		+0.027	(elevation)	.78		
		+0.35	(seed source distance)	.89		
		-0.47	(slope)	.94		
Subsequent incense-cedar	-116.39	+195.85	(radiation index)	.41	3/7	6.18*
		+0.42	(ground cover)	.57		
		+0.12	(woody perennials)	.73		

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[1] 1 asterisk denotes significance of the regression F ratio at the 5-percent probability level; 2 asterisks, 1-percent; 3, 0.1-percent.

Table 34—Regressions between stocking and environmental variables for combined data from Dead Indian and Butte Falls clearcuts

Regression formula					Statistical values		
tocking	=	constant	±	environmental variable	Cumulative R^2	Degrees of freedom	F ratio[1]
otal		108.33	-0.017	(elevation)	0.52	2/24	26.90***
			+0.42	(woody perennials)	.69		
dvance all species		-52.92	+0.65	(undisturbed seedbed)	.45	2/24	14.92***
			+116.78	(radiation index)	.55		
dvance Douglas-fir		-35.42	+0.33	(undisturbed seedbed)	.44	3/23	14.34***
			+69.75	(radiation index)	.59		
			+0.12	(precipitation)	.65		
dvance true firs		17.56	+0.39	(undisturbed seedbed)	.36	2/24	12.87***
			-0.27	(ground cover)	.52		
dvance incense-cedar		-45.73	-0.33	(years)	.10	3/23	3.68*
			+98.50	(radiation index)	.13		
			+0.64	(aspect)	.32		
otal subsequent		108.21	-0.018	(elevation)	.52	2/24	25.29***
			+0.41	(woody perennials)	.68		
econd-year		3.94	-0.57	(aspect)	.15	4/22	5.95**
			+0.10	(woody perennials)	.35		
			+0.002	(elevation)	.44		
			-0.14	(ground cover)	.52		
ubsequent Douglas-fir		15.85	+1.18	(precipitation)	.58	5/21	16.30***
			-146.66	(radiation index)	.70		
			+0.16	(woody perennials)	.74		
			+0.13	(seed source distance)	.76		
			+0.004	(elevation)	.80		
ubsequent true firs		82.97	+0.66	(undisturbed seedbed)	.43	4/22	11.24***
			-171.16	(radiation index)	.56		
			+0.18	(seed source distance)	.60		
			-0.12	(grass)	.67		
ubsequent incense-cedar		-113.17	+0.06	(woody perennials)	.16	4/22	6.28**
			+209.97	(radiation index)	.29		
			+0.93	(aspect)	.43		
			+0.18	(ground cover)	.53		

1 asterisk denotes significance of the regression F ratio at the 5-percent probability level; 2 asterisks, -percent; 3, 0.1-percent.

Table 35—Regressions between stocking and environmental variables for partial cuts in the Douglas-fir type

Regression formula					Statistical values		
Stocking	=	constant	±	environmental variable	Cumulative R^2	Degrees of freedom	F ratio[1]
Total		-2.17	+1.26	(precipitation)	0.23	4/16	7.05**
			+3.76	(years)	.44		
			+0.59	(canopy)	.52		
			-0.36	(undisturbed seedbed)	.64		
Advance all species		25.39	+0.94	(canopy)	.32	3/17	10.54***
			-0.012	(elevation)	.54		
			+0.76	(slope)	.65		
Advance Douglas-fir		34.51	-0.33	(ground cover)	.31	4/16	9.57***
			-0.009	(elevation)	.45		
			+2.33	(years)	.60		
			+0.32	(canopy)	.71		
Advance true firs		-34.57	+0.83	(canopy)	.42	4/16	11.08***
			+0.35	(undisturbed seedbed)	.59		
			-0.20	(true fir seed source)	.68		
			+0.18	(woody perennials)	.73		
Advance incense-cedar		0.10	-0.43	(true fir seed source)	.17	4/16	6.54**
			-0.43	(Douglas-fir seed source)	.51		
			+0.32	(precipitation)	.55		
			+73.45	(radiation index)	.62		
Total subsequent		19.07	-0.68	(undisturbed seedbed)	.35	4/16	10.00***
			+1.52	(precipitation)	.47		
			+5.19	(years)	.63		
			-1.06	(slope)	.71		
Second-year		75.80	+0.019	(elevation)	.14	5/15	3.73*
			-275.82	(radiation index)	.24		
			-0.43	(true fir seed source)	.34		
			-0.25	(woody perennials)	.45		
			+0.55	(canopy)	.55		
Subsequent Douglas-fir		80.07	-0.47	(undisturbed seedbed)	.27	5/15	5.66**
			+1.53	(precipitation)	.46		
			-1.37	(slope)	.52		
			+3.09	(years)	.59		
			-163.94	(radiation index)	.65		
Subsequent true firs		-28.99	+4.27	(aspect)	.29	5/15	4.37*
			-0.27	(woody perennials)	.41		
			+0.61	(canopy)	.47		
			+1.00	(precipitation)	.54		
			-0.85	(slope)	.59		
Subsequent incense-cedar		-48.94	+1.89	(precipitation)	.31	4/16	12.14***
			+7.19	(years)	.53		
			-2.61	(aspect)	.68		
			-0.29	(woody perennials)	.75		

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[1] 1 asterisk denotes significance of the regression F ratio at the 5-percent probability level; 2 asterisks, 1-percent; 3, 0.1-percent.

ble 36—Regressions between stocking and environmental variables for partial cuts in the white fir type

Regression formula					Statistical values		
ocking	=	constant	±	environmental variable	Cumulative R^2	Degrees of freedom	F ratio[1]
tal		111.48	-0.44	(true fir seed source)	0.15	3/25	4.38*
			-0.53	(grass)	.27		
			-0.32	(undisturbed seedbed)	.34		
vance		31.80	+0.21	(Douglas-fir seed source)	.09	1/27	[2]2.77
ll species							
vance		59.64	-0.011	(elevation)	.38	2/26	9.84***
ouglas-fir			-0.18	(grass)	.43		
vance		153.78	-2.64	(aspect)	.15	3/25	4.51*
rue firs			+0.007	(elevation)	.25		
			-282.23	(radiation index)	.35		
vance		38.83	-0.007	(elevation)	.23	2/26	5.18*
ncense-cedar			-0.12	(Douglas-fir seed source)	.29		
tal		121.34	-0.52	(true fir seed source)	.22	3/25	6.87**
ubsequent			-0.67	(grass)	.31		
			-0.71	(canopy)	.45		
cond-year		30.91	-0.71	(grass)	.22	2/26	6.28**
			+2.34	(years)	.33		
bsequent		36.94	+0.15	(Douglas-fir seed source)	.42	5/23	8.94***
uglas-fir			-0.28	(grass)	.50		
			-0.007	(elevation)	.57		
			+0.12	(woody perennials)	.61		
			+0.95	(years)	.66		
sequent		139.25	-265.05	(radiation index)	.15	3/25	3.67*
ue firs			+1.84	(years)	.22		
			+0.20	(woody perennials)	.31		
sequent		60.24	-0.70	(true fir seed source)	.28	4/24	10.70***
cense-cedar			-0.65	(grass)	.43		
			-0.56	(undisturbed seedbed)	.56		
			+1.02	(precipitation)	.64		

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[1] asterisk denotes significance of the regression F ratio at the 5-percent probability level; 2 asterisks, ercent; 3, 0.1-percent.

Sgnificant near the 10-percent level.

Table 37—Regressions between stocking and environmental variables for partial cuts in the pine type

Regression formula				Statistical values		
Stocking =	constant	±	environmental variable	Cumulative R^2	Degrees of freedom	F ratio[1]
Total	444.97	-840.42	(radiation index)	0.38	4/8	6.04*
		+0.52	(woody perennials)	.51		
		+0.58	(grass)	.63		
		-0.35	(true fir seed source)	.75		
Advance all species	11.87	+4.15	(aspect)	.24	4/8	7.22**
		+0.82	(undisturbed seedbed)	.54		
		-0.42	(true fir seed source)	.69		
		-1.23	(slope)	.78		
Advance Douglas-fir	73.84	-156.26	(radiation index)	.30	4/8	[2]3.68
		-0.26	(Douglas-fir seed source)	.47		
		+0.16	(undisturbed seedbed)	.56		
		-0.08	(true fir seed source)	.65		
Advance true firs	-30.42	+1.04	(undisturbed seedbed)	.59	2/10	24.54**
		+3.13	(aspect)	.83		
Advance incense-cedar	123.90	+0.41	(grass)	.20	4/8	[2]3.04
		-0.38	(undisturbed seedbed)	.41		
		-271.86	(radiation index)	.52		
		+0.23	(ground cover)	.60		
Total subsequent	369.64	-618.88	(radiation index)	.28	4/8	4.77*
		-0.51	(true fir seed source)	.43		
		-0.89	(Douglas-fir seed source)	.59		
		+0.34	(woody perennials)	.70		
Second-year	64.57	-0.96	(woody perennials)	.40	4/8	6.81*
		-2.59	(years)	.63		
		+1.61	(slope)	.68		
		+0.64	(undisturbed seedbed)	.77		
Subsequent Douglas-fir	-19.69	+1.21	(slope)	.64	3/9	28.88**
		+1.08	(aspect)	.81		
		+0.11	(true fir seed source)	.91		
Subsequent true firs	-24.19	+0.42	(woody perennials)	.20	4/8	[2]2.82
		-0.43	(Douglas-fir seed source)	.36		
		+2.88	(aspect)	.45		
		+0.51	(ground cover)	.59		
Subsequent incense-cedar	528.30	-0.093	(elevation)	.49	3/9	10.58**
		-0.68	(true fir seed source)	.67		
		-2.09	(slope)	.78		

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[1] 1 asterisk denotes significance of the regression F ratio at the 5-percent probability level; 2 asterisks, 1-percent; 3, 0.1-percent.

[2] Significant at the 10-percent level.

able 38—Regressions between stocking and environmental variables for clearcuts in the Douglas-fir type

Regression formula				Statistical values		
tocking =	constant	±	environmental variable	Cumulative R^2	Degrees of freedom	F ratio[1]
tal	18.41	+0.72	(woody perennials)	0.84	1/11	56.05***
vance	-4.79	+0.39	(undisturbed seedbed)	.64	3/9	10.29**
ll species		+0.19	(seed source distance)	.69		
		+0.11	(woody perennials)	.77		
vance	23.15	+0.11	(undisturbed seedbed)	.45	3/9	6.60*
ouglas-fir		-0.005	(elevation)	.58		
		+0.09	(seed source distance)	.69		
vance	-0.52	+0.30	(undisturbed seedbed)	.36	2/10	4.80*
rue firs		+0.12	(seed source distance)	.49		
vance	12.44	-0.84	(years)	.28	2/10	[2]3.38
ncense-cedar		-0.04	(seed source distance)	.40		
tal	-24.18	+0.64	(woody perennials)	.80	2/10	35.22***
ubsequent		+0.73	(ground cover)	.88		
cond-year	10.39	+0.21	(precipitation)	.20	2/10	5.94*
		-0.25	(ground cover)	.54		
bsequent	133.43	+1.84	(precipitation)	.79	3/9	34.81***
ouglas-fir		-362.91	(radiation index)	.86		
		-0.83	(slope)	.92		
bsequent	78.46	+0.94	(undisturbed seedbed)	.70	2/10	18.64***
rue firs		-168.23	(radiation index)	.79		
bsequent	62.33	-0.011	(elevation)	.46	3/9	7.81**
ncense-cedar		-0.26	(undisturbed seedbed)	.62		
		-0.21	(precipitation)	.72		

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asterisk denotes significance of the regression F ratio at the 5-percent probability level; 2 asterisks, ercent; 3, 0.1-percent.

[2]gnificant at 10-percent level.

Table 39—Regressions between stocking and environmental variables for clearcuts in the white fir type

Regression formula				Statistical values		
Stocking =	constant	±	environmental variable	Cumulative R^2	Degrees of freedom	F ratio[1]
Total	195.91	-0.012	(elevation)	0.56	3/10	17.06**
		+4.06	(aspect)	.64		
		-1.93	(ground cover)	.84		
Advance all species	-85.21	+187.10	(radiation index)	.25	2/11	9.40**
		+0.54	(undisturbed seedbed)	.63		
Advance Douglas-fir	-26.62	+0.37	(undisturbed seedbed)	.43	3/10	25.74**
		+77.41	(radiation index)	.82		
		-0.16	(ground cover)	.89		
Advance true firs	-67.44	+0.48	(undisturbed seedbed)	.37	2/11	21.24**
		+146.10	(radiation index)	.79		
Advance incense-cedar	-56.07	-0.22	(precipitation)	.10	3/10	[2]2.33
		+123.38	(radiation index)	.15		
		+0.74	(aspect)	.41		
Total subsequent	192.48	-0.013	(elevation)	.55	3/10	13.96**
		+3.99	(aspect)	.64		
		-1.83	(ground cover)	.81		
Second-year	-80.07	+153.30	(radiation index)	.16	3/10	8.37**
		+0.15	(woody perennials)	.57		
		+0.002	(elevation)	.72		
Subsequent Douglas-fir	-5.60	+0.16	(woody perennials)	.36	2/11	7.41**
		+0.13	(seed source distance)	.57		
Subsequent true firs	156.96	-306.08	(radiation index)	.25	5/8	4.60*
		+1.13	(undisturbed seedbed)	.39		
		+0.20	(seed source distance)	.49		
		+0.008	(elevation)	.59		
		-0.91	(ground cover)	.74		
Subsequent incense-cedar	-51.78	+0.32	(undisturbed seedbed)	.27	4/9	5.19*
		+129.98	(radiation index)	.34		
		-0.38	(precipitation)	.53		
		+0.09	(woody perennials)	.70		

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[1] 1 asterisk denotes significance of the regression F ratio at the 5-percent probability level; 2 asterisks, 1-percent; 3, 0.1-percent.

[2] Significant near 15-percent level.

Table 40—Prediction equations for subsequent stocking in partial cuts by forest type

Regression formula					Statistical values		
Stocking	=	constant	±	environmental variable	Cumulative R^2	Degrees of freedom	F ratio[1]
				DOUGLAS-FIR TYPE			
Total		72.06	-0.81	(undisturbed seedbed)	0.35	2/18	7.91**
			+0.73	(precipitation)	.47		
Second-year		45.76	+0.020	(elevation)	.14	4/16	3.07*
			-245.46	(radiation index)	.24		
			-0.39	(true fir seed source)	.34		
			+0.53	(canopy)	.43		
Douglas-fir		40.05	-0.69	(undisturbed seedbed)	.27	2/18	7.74**
			+0.87	(precipitation)	.46		
True firs		-11.55	+3.67	(aspect)	.29	2/18	5.35*
			+0.52	(canopy)	.37		
ncense-cedar		-117.39	+1.52	(precipitation)	.31	3/17	5.67**
			+214.44	(radiation index)	.42		
			-0.59	(logs, wood, bark)	.50		
				WHITE FIR TYPE			
otal		198.08	-0.38	(true fir seed source)	.22	2/26	5.52**
			-268.35	(radiation index)	.30		
econd-year		17.72	-0.32	(Douglas-fir seed source)	.08	2/26	[2]2.84
			+0.55	(canopy)	.18		
ouglas-fir		6.32	+0.34	(Douglas-fir seed source)	.42	1/27	19.64***
rue firs		170.36	-290.43	(radiation index)	.15	1/27	4.67*
ncense-cedar		30.46	-0.56	(true fir seed source)	.28	3/25	7.55***
			+1.23	(precipitation)	.37		
			-0.45	(undisturbed seedbed)	.48		
				PINE TYPE			
tal		399.22	-653.65	(radiation index)	.28	3/9	4.26*
			-0.46	(true fir seed source)	.43		
			-0.81	(Douglas-fir seed source)	.59		
econd-year		-420.03	+5.80	(precipitation)	.40	3/9	4.34*
			+4.73	(aspect)	.52		
			+493.62	(radiation index)	.59		
uglas-fir		-19.69	+1.21	(slope)	.64	3/9	28.88***
			+1.08	(aspect)	.81		
			+0.11	(true fir seed source)	.91		
ue firs		217.40	-0.52	(Douglas-fir seed source)	.13	3/9	[2]3.20
			-1023.69	(radiation index)	.22		
			+0.064	(elevation)	.52		
cense-cedar		528.30	-0.093	(elevation)	.49	3/9	10.58**
			-0.68	(true fir seed source)	.67		
			-2.09	(slope)	.78		

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asterisk denotes significance of the regression F ratio at the 5-percent probability level; 2 asterisks, percent; 3, 0.1-percent.

ignificant at the 10-percent level.

Table 41—Prediction equations for subsequent stocking in clearcuts by forest type

Regression formula				Statistical values		
Stocking =	constant	±	environmental variable	Cumulative R^2	Degrees of freedom	F ratio[1]
			DOUGLAS-FIR TYPE			
Total	197.99	-0.045	(elevation)	0.78	2/10	54.13**
		+3.22	(aspect)	.92		
Second-year	2.68	+0.16	(precipitation)	.20	2/10	[2]2.75
		-0.53	(aspect)	.36		
Douglas-fir	133.43	+1.84	(precipitation)	.79	3/9	34.81**
		-362.91	(radiation index)	.86		
		-0.83	(slope)	.92		
True firs	78.46	+0.94	(undisturbed seedbed)	.70	2/10	18.64**
		-168.23	(radiation index)	.79		
Incense-cedar	62.33	-0.011	(elevation)	.46	3/9	7.81**
		-0.26	(undisturbed seedbed)	.62		
		-0.21	(precipitation)	.72		
			WHITE FIR TYPE			
Total	120.54	-0.019	(elevation)	.55	2/11	9.86**
		+2.04	(aspect)	.64		
Second-year	-27.91	+66.64	(radiation index)	.17	1/12	[2]2.41
Douglas-fir	33.63	+0.15	(seed source distance)	.19	3/10	[2]2.40
		-78.14	(radiation index)	.33		
		+0.23	(undisturbed seedbed)	.42		
True firs	103.97	-231.41	(radiation index)	.25	3/10	[2]3.27
		+0.67	(undisturbed seedbed)	.39		
		+0.19	(seed source distance)	.49		
Incense-cedar	-28.73	+0.34	(undisturbed seedbed)	.27	3/10	3.71*
		+85.43	(radiation index)	.34		
		-0.37	(precipitation)	.53		

[1] 1 asterisk denotes significance of the regression F ratio at the 5-percent probability level; 2 asterisks, 1-percent; 3, 0.1-percent.

[2] Significant at or near the 10-percent level.

Table 42—Prediction equations for subsequent stocking in partial cuts by geographic area

Regression formula					Statistical values		
tocking	=	constant	±	environmental variable	Cumulative R^2	Degrees of freedom	F ratio[1]
				DEAD INDIAN			
otal		252.51	-0.45	(true fir seed source)	0.27	2/41	13.89***
			-369.49	(radiation index)	.40		
econd-year		-48.94	+1.53	(precipitation)	.16	3/40	5.12**
			+1.73	(aspect)	.20		
			+0.52	(canopy)	.28		
ouglas-fir		7.27	+0.56	(Douglas-fir seed source)	.47	2/41	21.40***
			-0.44	(slope)	.51		
rue firs		282.48	-444.41	(radiation index)	.28	2/41	12.37***
			-1.16	(precipitation)	.38		
ncense-cedar		70.35	-0.69	(true fir seed source)	.19	2/41	13.52***
			-0.69	(Douglas-fir seed source)	.40		
				BUTTE FALLS			
otal		104.24	-0.81	(undisturbed seedbed)	.47	1/19	16.80***
econd-year		47.08	-0.34	(Douglas-fir seed source)	.16	1/19	[2]3.49
ouglas-fir		-24.05	-0.49	(undisturbed seedbed)	.22	4/16	5.90**
			+0.65	(Douglas-fir seed source)	.35		
			+0.55	(true fir seed source)	.52		
			+0.86	(precipitation)	.60		
ue firs		-11.71	+1.23	(precipitation)	.22	1/19	5.47*
cense-cedar		42.89	-0.79	(undisturbed seedbed)	.30	3/17	7.03**
			+0.027	(elevation)	.44		
			-1.49	(precipitation)	.55		

---

[1] asterisk denotes significance of the regression F ratio at the 5-percent probability level; 2 asterisks, 1percent; 3, 0.1-percent.

[2] ignificant at the 10-percent level.

Table 43—Prediction equations for subsequent stocking in clearcuts by geographic area

Regression formula				Statistical values		
Stocking =	constant	±	environmental variable	Cumulative R^2	Degrees of freedom	F ratio[1]
			DEAD INDIAN			
Total	275.51	-690.83	(radiation index)	0.22	2/13	4.06*
		+3.01	(precipitation)	.38		
Second-year	4.56	-0.77	(aspect)	.15	3/12	[2]2.43
		+0.27	(slope)	.27		
		+0.28	(undisturbed seedbed)	.38		
Douglas-fir	155.23	-309.80	(radiation index)	.16	2/13	[2]3.36
		-1.32	(aspect)	.34		
True firs	413.02	-826.69	(radiation index)	.39	2/13	11.32**
		-3.18	(aspect)	.64		
Incense-cedar	-23.44	-1.25	(precipitation)	.16	4/11	5.04*
		-0.39	(undisturbed seedbed)	.37		
		+0.011	(elevation)	.54		
		+0.07	(seed source distance)	.65		
			BUTTE FALLS			
Total	101.19	-0.012	(elevation)	.65	4/6	28.03**
		+1.50	(aspect)	.84		
		+0.21	(seed source distance)	.89		
		-0.41	(slope)	.95		
Second-year	-48.86	+0.32	(precipitation)	.30	2/8	6.36*
		+86.42	(radiation index)	.61		
Douglas-fir	-64.11	+1.68	(precipitation)	.75	2/8	19.97**
		+1.97	(aspect)	.83		
True firs	-88.97	+0.89	(undisturbed seedbed)	.68	4/6	21.90**
		+0.027	(elevation)	.78		
		+0.35	(seed source distance)	.89		
		-0.47	(slope)	.94		
Incense-cedar	-171.93	+343.47	(radiation index)	.41	3/7	4.79*
		+2.01	(aspect)	.52		
		+0.19	(undisturbed seedbed)	.67		

[1] 1 asterisk denotes significance of the regression F ratio at the 5-percent probability level; 2 asterisks, 1-percent; 3, 0.1-percent.

[2] Significant at or near the 10-percent level.

Stein, William I.
1981. Regeneration outlook on BLM lands in the southern Oregon Cascades. USDA For. Serv. Res. Pap. PNW-284, 70 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

A survey of cutover timberland in the Butte Falls and Dead Indian areas showed that most partial cuts were moderately or well-stocked with natural regeneration. Clearcuts in the Butte Falls area were also well-stocked, primarily with planted ponderosa pine; but many in the Dead Indian area were not. Advance regeneration was an important stocking component in partial cuts. Stocking varied by forest type, species, and drainage and correlated with an array of environmental variables. Regression equations describe present stocking patterns, and others predict future stocking based on variables that can be observed or specified before harvest.

Keywords: Regeneration (stand), regeneration (natural), regeneration (artificial), clearcutting systems, partial cutting, stand development, Oregon (Cascade Range).

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Research Paper
PNW-286
July 1981

Twenty-Year Growth of Thinned and Unthinned Ponderosa Pine in the Methow Valley of Northern Washington

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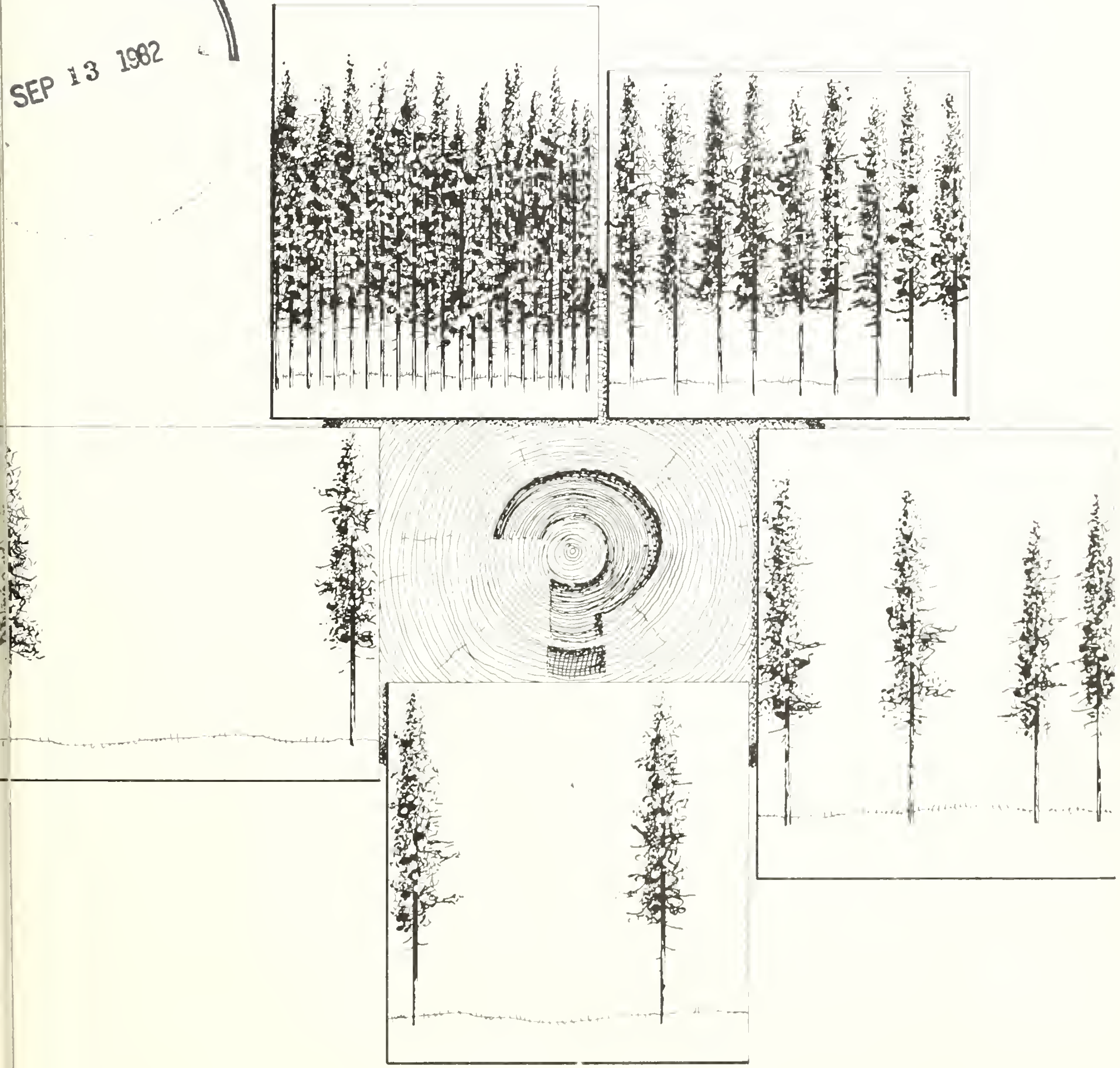
James W. Barrett



Author

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rett, James W. Twenty-year growth
of thinned and unthinned ponderosa
pine in the Methow Valley of northern
Vashington. USDA For. Serv. Res.
Pap. PNW-286, Portland, OR: Pacific
Northwest Forest and Range Experi-
ment Station; 1981. 13 p.

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ches in diameter and 23 feet tall before
ning. Considerations are discussed
choosing tree spacing in a
commercial thinning.

words: Thinning effects, increment,
d density, improvement cutting,
derosa pine, *Pinus ponderosa*.

Summary

Tree spacing had a profound effect on diameter, height, and volume increment in a suppressed, 47-year-old, low-site stand of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) in the Methow Valley of northern Washington that averaged about 3 inches in diameter and 23 feet tall before thinning. Trees at the widest spacing grew at an average rate per decade of 2.6 inches in diameter, compared to 1.4 inches at the narrowest spacing; trees in the unthinned plots grew only 0.4 inches per decade. Twenty years after thinning, the mean height of all trees on the low-density plot was greater than those on the high-density plot.

Although widely spaced trees grew faster in height and diameter than narrowly spaced trees, the low-density plots collectively yielded much less wood fiber than the high-density plots 20 years after thinning.

The major advantages of wide spacing in ponderosa pine in the pine-grass areas of central Washington appear to be that trees grow rapidly to merchantable size and forage production is increased.

Basal areas on unthinned plots in this study have exceeded 160 square feet per acre. These unthinned plots are now accumulating additional basal area at the rate of about 3 square feet per acre per year.

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troduction

e spacing of ponderosa pine (*Pinus* *nderosa* Dougl. ex Laws.) can have an pressive effect upon the eventual size ne trees, wood quality, the time to grow desired product, and—frequently— quantity and quality of the understory getation. Selection of spacing is one of most significant decisions the forest nager makes, because it sets the ge for the dimensions of future vests and interim value of other ources.

st research has shown that widely ced ponderosa pine trees in the cific Northwest maintain rapid vidual tree growth longer than closely ced trees (Barrett 1973). Wide cing, however, is usually accom- ied by losses in stand production until area between trees is fully used.

rett (1971) found some evidence to gest that stands originating on similar s and allowed to develop full crowns yield almost the same amount of ume over a wide range of densities. If is true, then the question is whether manager wants the wood in large or ll trees. In most stands of ponderosa in the Pacific Northwest—as with ny other species throughout the West tand regulation is not that simple; nds that develop from natural seedings ly have crowns that are free to and. If they are widely spaced, the site ometimes invaded by competing, shy vegetation. In many natural nds, poor crown ratios and poor vigor common because of high density and rstory suppression. As a result, the to reach maximum production of ful wood is lengthened. This reduction owth may be so subtle that the ager is unaware of the loss. Even if oss is suspected, dealing effectively it may be impossible because other ource values may be in jeopardy.

earch objectives in this study were:

- o provide estimates of stand growth r specified spacings, including no innings, for ponderosa pine in the ethow Valley.
- o compare tree growth and develop- ent of understory vegetation for the rious treatments.
- To provide some interim guidelines for selecting tree spacing.

My purpose is not to suggest appropriate spacing, but by presenting results of studies on growth and spacing of ponderosa pine in the Methow Valley, to guide forest managers through the thought process of choosing the spacing compatible with their management objectives.

This study is one of several on spacing and levels of growing stock established in the Pacific Northwest in the late 1950's and early 1960's. Only the timber growth aspects of the study are included in this paper. Earlier reports on growth of timber stands were made by Barrett (1968); Sassaman et al. (1973) made an economic analysis of timber and forage returns. McConnell and Smith (1965, 1970) reported on understory responses after thinning.

The Study Area

The study area is in the upper Methow River Valley near Winthrop, Washington, on land owned and administered by the Washington State Department of Game. A combination pine-spacing and forage-production study was established in 1959 by the Washington Department of Game, U.S. Soil Conservation Service, Okanogan National Forest, and Pacific Northwest Forest and Range Experiment Station of the U.S. Department of Agriculture.

The ponderosa pine stand in which the study plots were established originated from natural seeding about 1911 after logging and fire. The stand is on a bench about 600 feet above the Methow River at an elevation of 2,350 feet (fig. 1), where precipitation averages about 14.5 inches annually. The soil is a well-drained Katar sandy loam formed from glacial till and is classified as Typic Xerochrept, coarse-loamy over sandy or sandy skeletal, mixed, mesic.

Figure 1.—The study area is on a bench in the Methow River Valley at an elevation of 2,350 feet.

The Timber Stand and Understory Vegetation

The stand in which plots were established had stagnated, with over 2,300 stems per acre, averaging only 3 inches in diameter and 23 feet high. Ten years later, the unthinned plots appeared unchanged (fig. 2). Although the stand was 47 years old, the trees were remarkably healthy and had none of the diseases common to some dense ponderosa pine stands east of the Cascade Range. Even though growth in height and diameter was slow, crowns of the dominants occupied about 50 percent of total tree height, but branches and needles were short. At the time of thinning, trees were growing only 0.6 inch per decade in diameter and 3.5 feet in height.

Estimating site index was difficult because the stand was stagnated, and density had probably inhibited height growth of dominant and codominant trees. In a nearby stand where stand dimensions appeared to be normal, as defined by Meyer (1961), site index was estimated to be site quality class V, or about 62 feet at 100 years of age.

Mortality, as evidenced by some dead stems throughout the stand, was light; only a few trees per acre died each decade. No beetle activity was evident, and mortality was attributed to gradual suppression.

Before thinning, the understory was a sparse stand of spindly shrubs and scattered forbs and grasses having a usable forage yield of only 0.06 animal unit month[1] per acre per year—". . . a level of forage production that requires 17 acres per month or 68 acres per summer grazing season to provide the necessary forage for one cow" (Sassaman et al. 1973).

Pinegrass (*Calamagrostis rubescens* Buckl.) is the predominant grass in the area and balsamroot (*Balsamorhiza sagittata* (Pursh) Nutt.) the dominant forb (fig. 3). Scattered clumps and individual plants of antelope bitterbrush (*Purshia tridentata* (Pursh) DC.) were found throughout the stand.

---

[1] One animal unit month (AUM) equals 730 pounds of air-dry forage for cattle (the amount of forage consumed by a 1,000-pound animal in 30.5 days).

Figure 2.—An unthinned plot about 10 years after the study began.

Figure 3.—Wide spacing of ponderosa pine and complete slash disposal has encouraged the development of forage.

Experimental Design and Methods

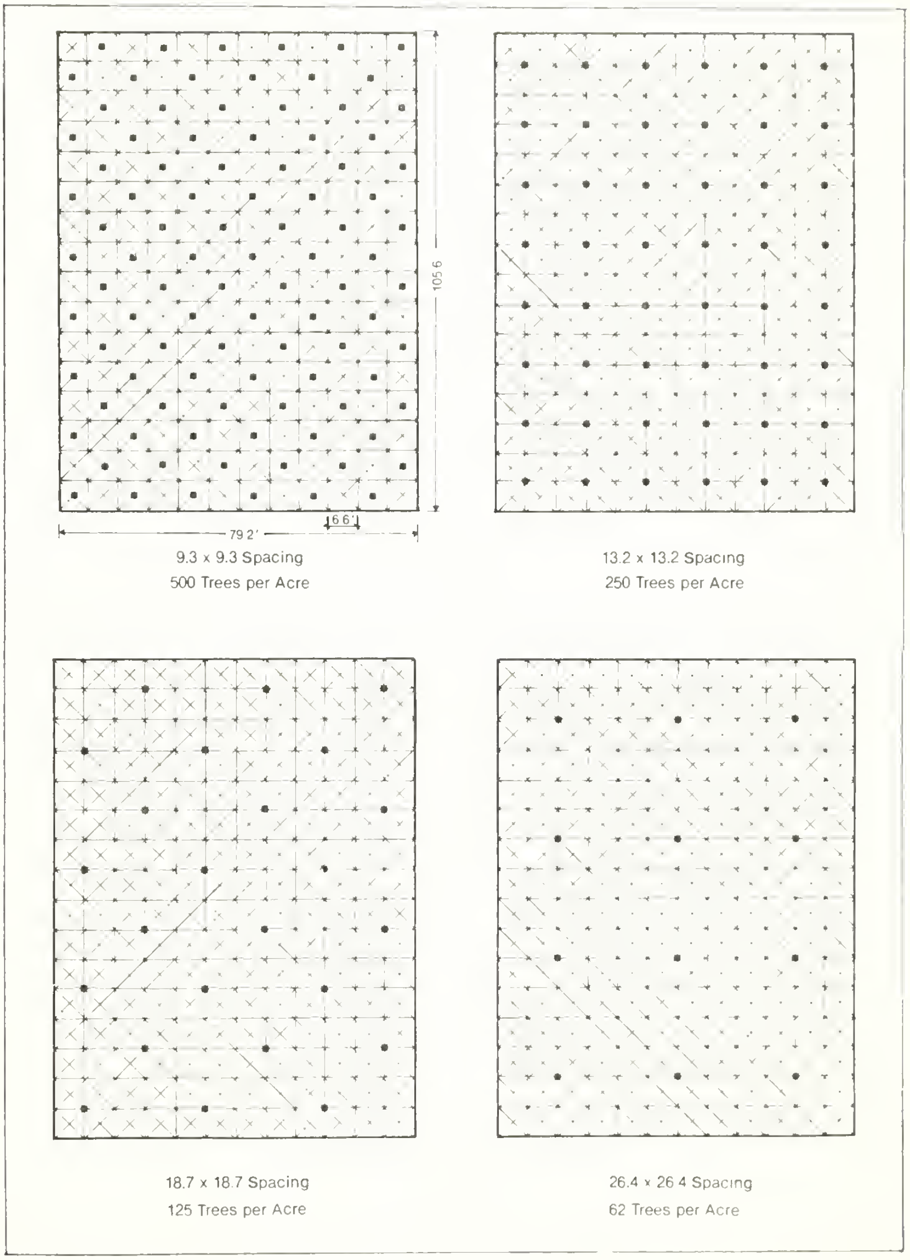
The study was conducted on 13 ectangular 0.192-acre plots, 79.2 by 105.6 feet (fig. 4). Each plot is surounded by a buffer strip 33 feet wide that vas treated the same as the inner plot. The plot, therefore, contained 192 nilacres and could be conveniently livided into 12 subplots, each containing 16 milacres. This plot subdivision aided n selecting leave trees that were evenly listributed throughout the plot. In addition, it easily allowed growth comparisons of the largest, evenly listributed trees within a plot.

Treatments applied to plots were thinning o average spacings of 13.2 feet (250 ees per acre), 18.7 feet (125 trees per cre), and 26.4 feet (62 trees per acre), nd no thinning. Thus, each treatment ontained the following measured trees n each plot:

3.2 x 13.2 feet (250 trees per acre) = 48 trees per plot;
8.7 x 18.7 feet (125 trees per acre) = 24 trees per plot;
6.4 x 26.4 feet (62 trees per acre) = 12 trees per plot.

he stand was divided into three regions ith each treatment occurring in one egion. The experimental design is a andomized block, split plot in time. The eriod effects were partitioned into rthogonal polynomial effects to look at e relations of the responses over time. ne plot was thinned to an average pacing of 9.3 feet (500 trees per acre); itable plots for two additional replicaons could not be found, but the single eatment is included to illustrate points the discussion.

ne 0.192-acre plots are small to present stand growth, thus the inherent riability will be perhaps greater than ight be expected. In light of the stricted scope of inference because of e limited population, results should be terpreted conservatively.



9.3 x 9.3 Spacing
500 Trees per Acre

13.2 x 13.2 Spacing
250 Trees per Acre

18.7 x 18.7 Spacing
125 Trees per Acre

26.4 x 26.4 Spacing
62 Trees per Acre

Figure 4.—Plot layout showing systematic location of trees (black dots) for a given spacing. Plots are 79.2 by 105.6 feet or 0.192 acres, containing 192 milacres (1 milacre 6.6 x 6.6 feet). Each plot was surrounded by a buffer strip 33 feet wide that was treated the same as the inner plot. Trees were selected for thinning as close to this theoretical spacing as possible.

Results

At each measurement, all trees on thinned and unthinned plots were measured to the nearest 0.1 inch in diameter, breast high. Every tree in the thinned plots was measured, to the nearest 0.1 foot in height, with a jointed aluminum pole. Twelve trees in each thinned plot were climbed and diameter measured at 5-foot intervals up the tree. Bark thickness was measured at breast height and stump height. About 20 trees in each unthinned plot were climbed and measured. Trees were climbed that represented the complete range of diameters and heights, but sampling was heavier in the larger size classes. These trees contributed to construction of a general volume equation for second-growth ponderosa pine that was used in this study.[2] Trees on the unthinned plots were not tagged until 5 years after thinning, so no estimates of volume increment were made for the unthinned plots during the first 5 years. Periodic measurements were made initially and then every 5 years for 20 years.

Note that data from the treatment that left 500 trees per acre were from only one plot (compared to three plots for the other treatments).

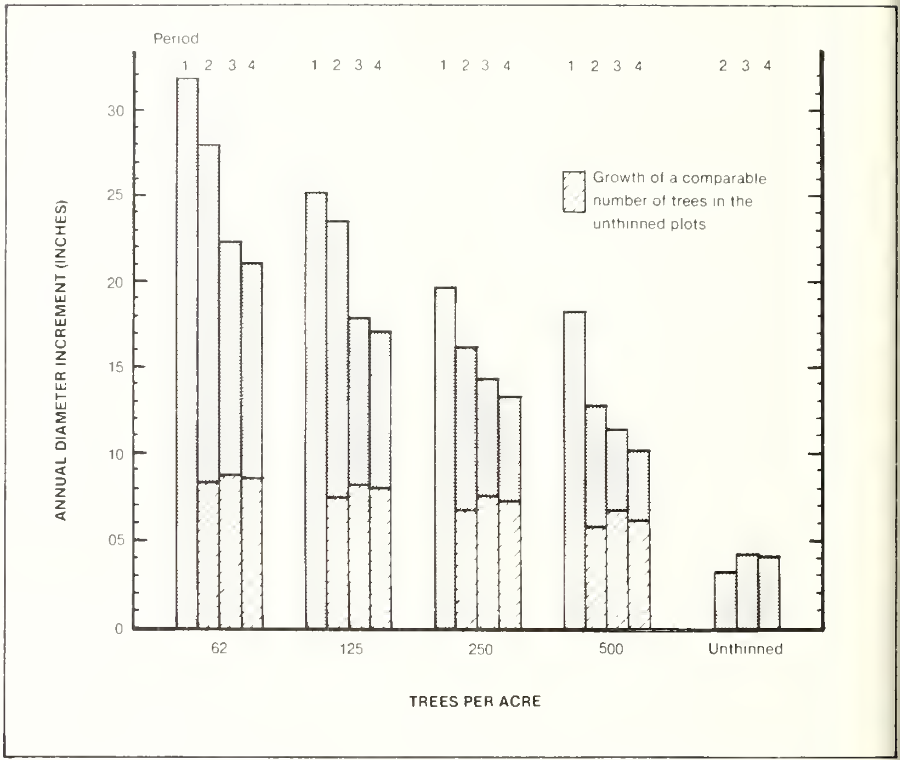


Figure 5.—Average annual diameter increment of ponderosa pine during the first, second, third, and fourth 5-year growth periods after thinning, and growth of a comparable number of trees in the unthinned plots.

Diameter Growth and Average Diameter

Widely spaced trees in the thinned plots grew significantly better in diameter (table 1) than closely spaced trees (fig. 5). Trees at the widest spacing grew at an average rate per decade of 2.6 inches compared to 1.4 inches at the narrowest spacing.

In comparison, trees in the unthinned stand averaged only 0.4-inch growth per decade. In 1978, the unthinned plots were divided on the ground by strings into 12, 16-milacre subplots as shown in figure 4. Growth of the "best" trees—those that would be selected for leaving in a precommercial thinning—were examined. All trees in the unthinned plots were tagged in 1964, so growth could be determined from this date through growth periods 2, 3, and 4. Tag numbers of 12, 24, 48, and 96 trees per plot were chosen. First, for example, the 12 best trees per plot—one for each 16-milacre subplot—were chosen, and their tag numbers recorded.

Then the next best 12 trees were selected, or two per subplot, and so on. Appropriate tree numbers and dimensions were run on the computer to calculate growth of trees and plot averages.

This analysis, where average annual growth in diameter of the 12 best well-distributed trees per plot (62 trees per acre) were compared with the 96 best trees per plot (500 trees per acre), showed only a 0.03-inch difference (fig. 5). Even the best dominants in the stand are suffering from severe competition. Such a small difference occurred from one extreme of tree density to another that no statistical test was done.

---

[2] "Volume equations for second-growth ponderosa pine in the Pacific Northwest," by Donald DeMars and James W. Barrett. Manuscript in preparation.

able 1—Results of analysis of variance[1]

ariable	Blocks	Spacing	Periods Linear[2]	 Quadratic[3]	Lack of fit[4]	Spacing x period interaction
iameter increment	n.s.	**	**	**	n.s.	**
leight increment	n.s.	**	**	**	n.s.	n.s.
olume increment	*	*	**	n.s.	**	**
asal area increment	n.s.	**	n.s.	n.s.	n.s.	**
iameter	**	**	**	**	**	Linear **
leight	**	**	**	*	*	Linear **
olume	**	**	**	n.s.	*	Linear **
asal area	**	**	**	n.s.	n.s.	Linear **

Symbols are: n.s. = not significant; * = significant, 5 percent level of probability; and ** = significant, 1 percent level of probability.
"Linear" isolates the variation accounted for if a straight line is fit through the data points.
"Quadratic" isolates the variation accounted for if a second degree curve is fit through the data points.
"Lack of fit" isolates additional variation not accounted for by linear and quadratic.

ate of growth in diameter has declined[3] ithin thinned treatments throughout the) years of observations (fig. 5), although, ; discussed later in the paper, basal-ea increment has remained rather able. Diameter growth at the widest pacing (26.4 feet) has dropped from an nnual rate of 0.32 inch during the first 5 ears to 0.21 inch during the last 5 years. he percentage decrease appears to ive diminished during the last decade ompared to the first; i.e., the great flush growth after thinning may be bsiding.

venty years after thinning, average iameter of the stands thinned to 62 trees er acre is 11 inches compared to 7.5 ches where 250 trees per acre were left g. 6).[4] Also, note that 20 years after nning, most are from 9 to 13 inches here 62 trees per acre were left and from o 9 inches where 250 trees were left

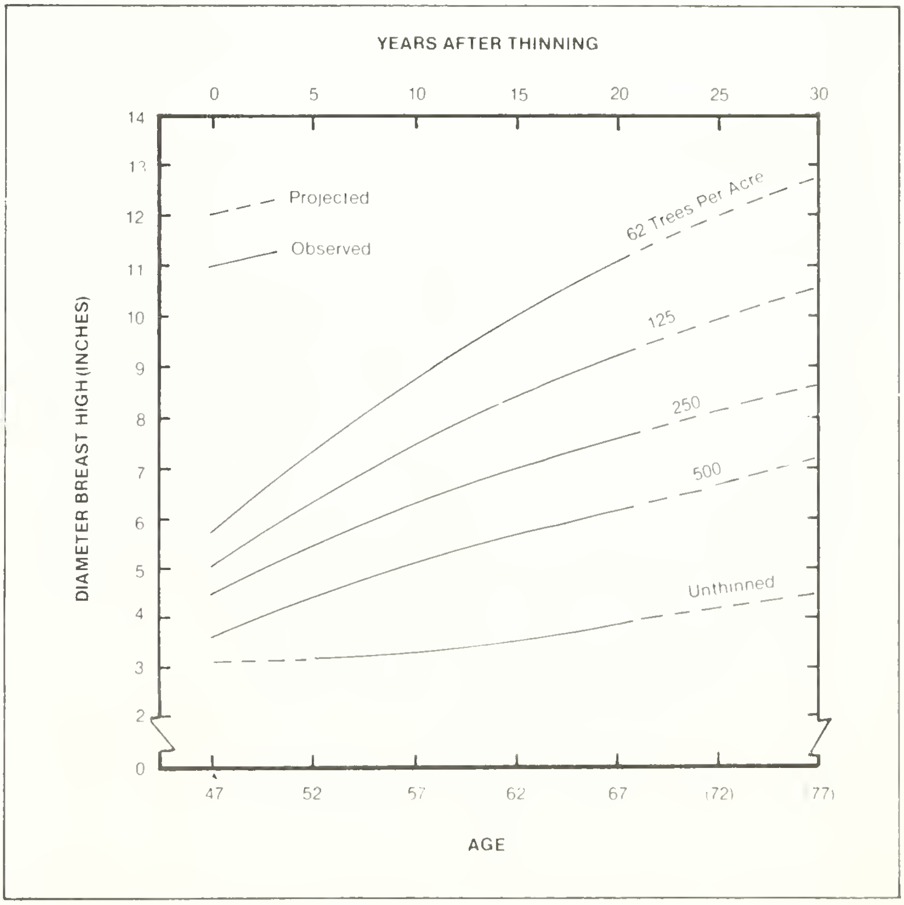


Figure 6.—Average stand diameter under various treatments during the 20 years of observation and estimates projected 10 years in the future.

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[3] he significant interaction between spacing d linear periods indicate that this decline is t consistent from treatment to treatment.

[4] hese curves of diameter (fig. 5), height (. 7), basal area (fig. 8), and volume (fig. 11) tted over periods of time illustrate the ression equations fitted through the data s. The main effects of spacing were nificant for all of these response variables. e interaction effect of spacing by linear iod was also signficiant for all response iables, indicating the curves differ in their pe.

Table 2—Number of trees in each diameter class at the beginning and end[1] of the observation period

Diameter class	Thinning treatment—trees per acre									
	62		125		250		500		Unthinned	
	Start	End	Start	End	Start	End	Start	End	Start	End
Inches	*Trees per acre*									
1					2				451	281
2			4		15	2	125		804	621
3	1		14		47		198	10	577	548
4	14		36		94	10	136	84	307	375
5	19		38	2	59	17	31	125	150	213
6	9	1	23	7	28	38	5	115	57	134
7	14		3	14	2	56		104	24	42
8	5		3	26	3	63	5	47	10	26
9		10	2	28		49		10	5	12
10		14	2	33		10				9
11		12		5		3				2
12		14		5				5		
13		7		2						
14		2		3						
Total	62	60	125	125	250	248	500	500	2385	2263
Average[2] d.b.h.	5.8	11.1	5.1	9.2	4.4	7.6	3.4	6.1	3.1	3.6
Basal area	11.4	40.3	17.4	57.7	26.8	77.9	32.4	100.7	122.2	164.4

---

[1] The stand was 47 years old at the beginning and 67 years old at the end of the observation period.

[2] Quadratic mean diameter.

(table 2). A wide range of diameters occurred where 125 trees per acre were left. Effects of spacing are somewhat confounded by initial differences in size. Denser spacings were somewhat poorer initially than unthinned. Also, when trees to be left were chosen, initial diameters for each treatment were larger as tree spacing increased. For example, initial diameters at age 47 were as follows:

Trees per acre	Spacing	Diameter breast high
Number	*Feet*	*Inches*
62	26.4	5.8
125	18.7	5.1
250	13.2	4.4
500	9.3	3.4
Unthinned		3.1

ameters are projected to 30 years after e initial thinning.[5] Although commercial nning at age 77 would seem doubtful, nay be possible in the two widest acings. Average diameters at this time e estimated to be (fig. 6):

Trees per acre	Diameter breast high
Number	*Inches*
62	12.7
125	10.5
250	8.6
500	7.1

en though some trees are merchant-le where 62 and 125 trees per acre re left, there is little reason to thin. ees are growing well in diameter and ght, and basal area is well below the level for bark beetles. A thinning at time in the two closer spacings is bably not practical, because meters are too small.

ight Growth

eased trees in this study required ut 15 years to reach their maximum of growth in height (fig. 7). During this e, height growth gradually increased ees on each thinned treatment; during fourth growth period (15 to 20 years r thinning), however, rates decreased all thinned densities. This may have n caused by serious drought, ough diameter growth did not rease markedly during the last od.

cing significantly affected height vth (table 1). For example, during the il 5-year growth period, trees at the est density grew about 1.25 feet per r, but only 0.7 foot at the highest sity. The effect of density on height vth of the 62 trees of largest diameter ss all spacings is questionable 7). A trend of reduced height growth with increasing density is suggested, but was not tested statistically because of study design, within-treatment variation, and the slight difference in height growth between the two densities fully replicated. All trees in the unthinned stand were estimated to have averaged only about 0.2 foot of height growth per year.

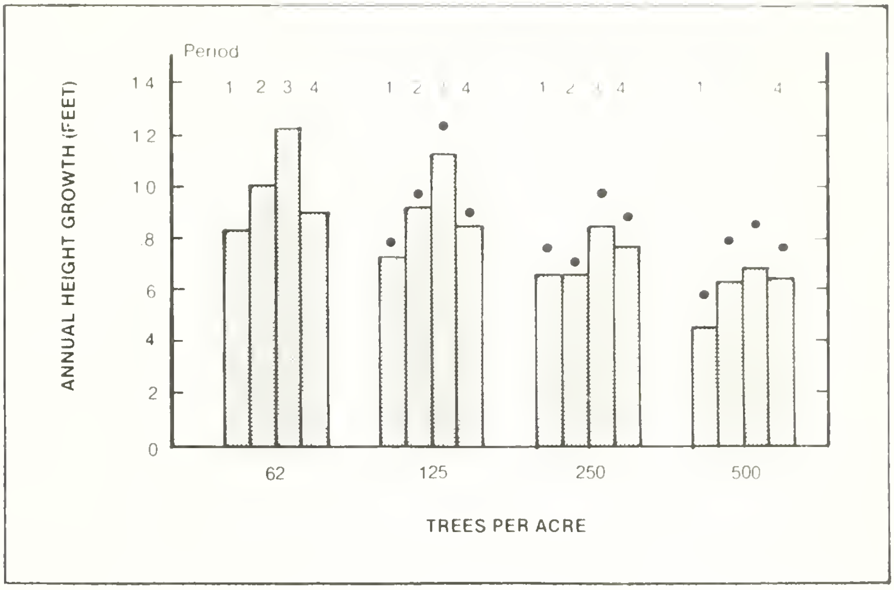

Figure 7.—Average annual height growth during the first, second, third, and fourth 5-year growth periods since thinning. Dots above bars indicate growth of the 62 largest diameter trees.

Twenty years after thinning, considerably taller trees are present on low-density plots than on higher-density plots. For example, trees averaged almost 50 feet tall at the widest spacing 20 years after thinning and about 39 feet where 250 trees per acre were left (fig. 8). Average heights of these trees 30 years after thinning are estimated to be about 65 and 45 feet, respectively. Note that when leave trees were selected in the pre-commercial thinning, the average initial height of the stand (means of field data) increased as spacing increased; for 500, 250, 125, and 62 trees per acre, they were 18.6, 23.5, 25.7, and 28.4 feet.

The limited sample of heights did not permit a reliable picture of individual height increment on the unthinned plots, so this is not shown in figure 7. Average height of unthinned plots shown in figure 8 is based on the relation of height to diameter of about 20 measured trees on each unthinned plot.

Height growth declined during the last measurement period (fig. 7), therefore the curves of average height with time shown in figure 8 should also decline. Note, however, that the relationships shown in figure 8 represent curves that estimate maintaining the present rate of height growth for a decade. I would not expect a marked decline in height growth at this stage of stand development, except from some short, periodic climatic influence.

P jections of tree diameter, height, and ta volume beyond 20 years after thinning re made by equations fitted to the data and y amining trends of periodic diameter and ei t increment. Unforeseen climatic ha ges during the next decade could ffl nce these estimates.

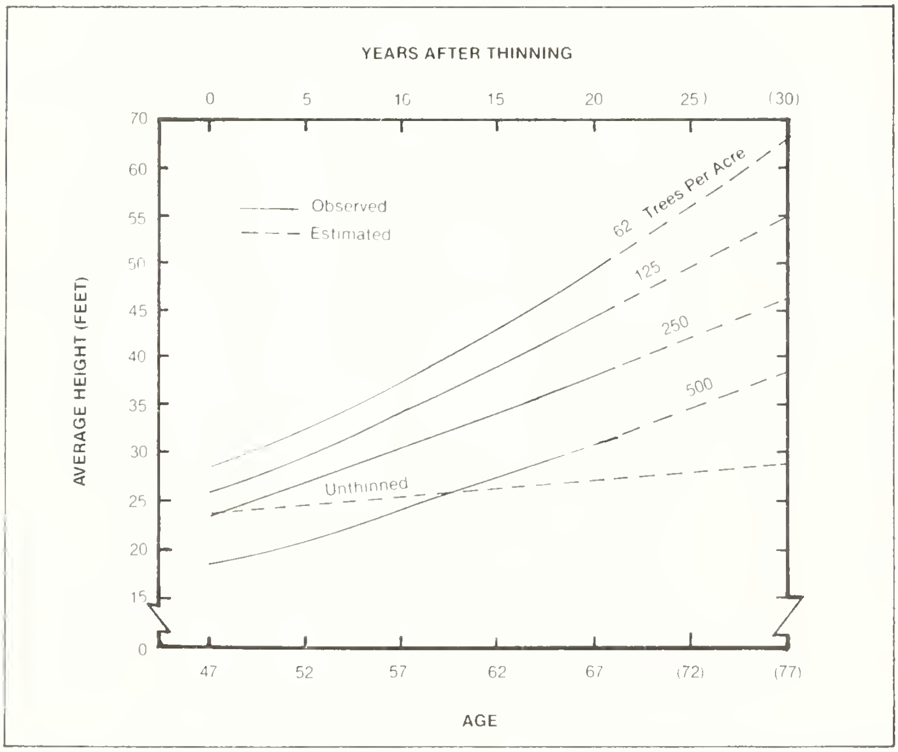

Figure 8.—Average tree height under various stand densities during 20 years of observation, and estimates projected 10 years in the future.

Basal Area

Accumulation of basal area is important in thinned stands, but it is also of concern in unthinned stands, because it gives us a clue to excessive density that may be conducive to beetle attack (Sartwell 1971). The unthinned plot in this study has some characteristics of a stand subject to mountain pine beetle attack, because it now has over 160 square feet of basal area per acre (fig. 9) and is accumulating additional basal area at about 3 square feet per year (fig. 10). Trees are growing slowly because of competition, they are on a low site, and they are about the right size for development of insect broods.

Basal-area increment was significantly and positively correlated with spacing (table 1). Basal area is accumulating at the rate of about 1.5 square feet per acre per year at the lowest density and about 3.25 square feet where 500 trees were left (fig. 10). The greater the growing stock the greater the basal-area increment in the thinned stands. Note that the stand thinned to 500 trees per acre now has 100 square feet per acre. In 10 years, this plot will have over 130 square feet.

The odd high basal-area increment during the first period where 500 trees per acre were left (fig. 10) may result from the exceptional response of some of the larger trees directly after thinning. A decided decrease in growth in these same trees took place during the second period, when competition from other trees probably had an effect.

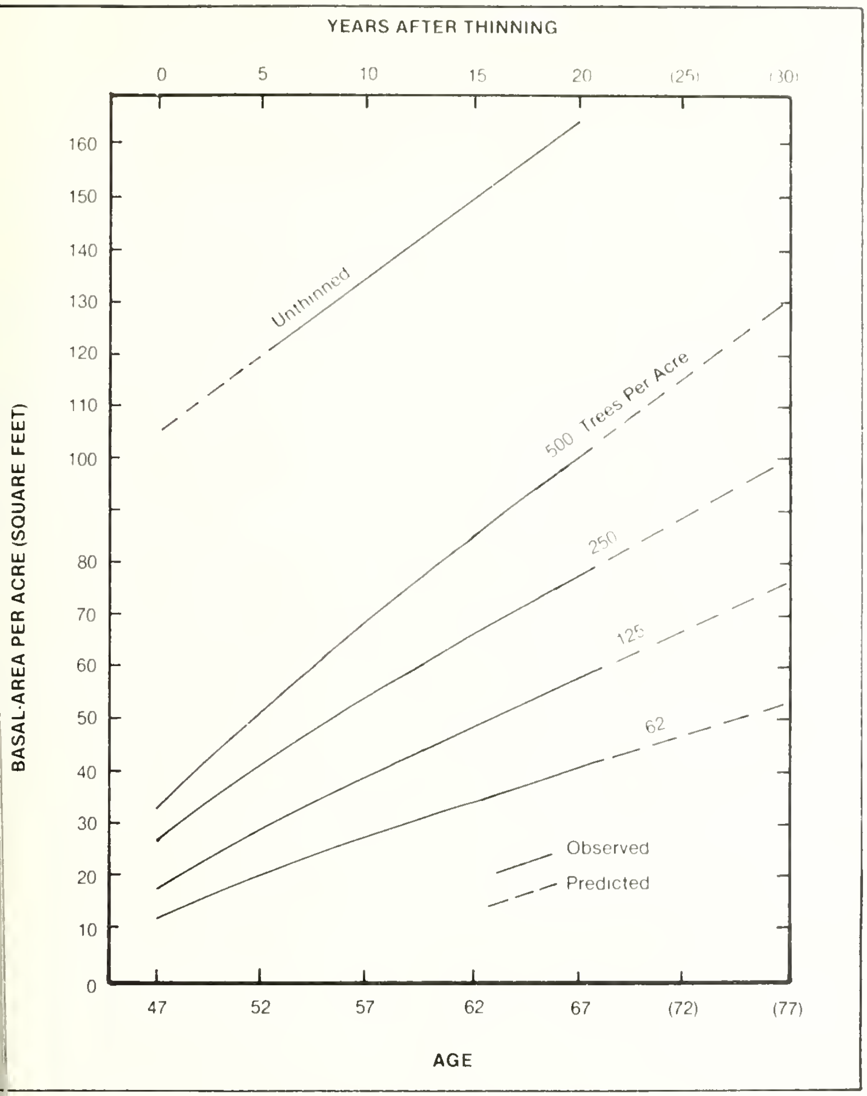

Figure 9.—Net basal area attained during the first, second, third, and fourth 5-year periods, and predicted values 10 years in the future.

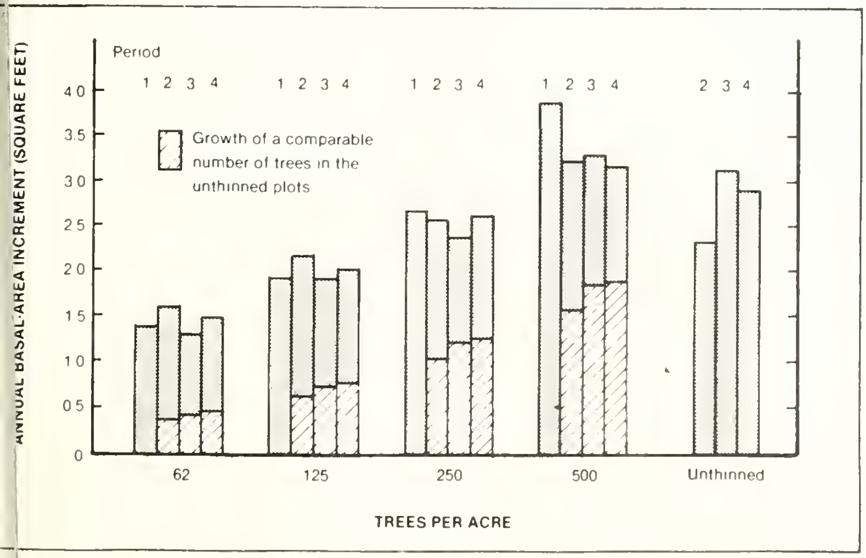

Figure 10.—Average annual net basal-area increment of ponderosa pine during the first, second, third, and fourth 5-year growth periods after thinning, and increment of a comparable number of trees in the unthinned stand.

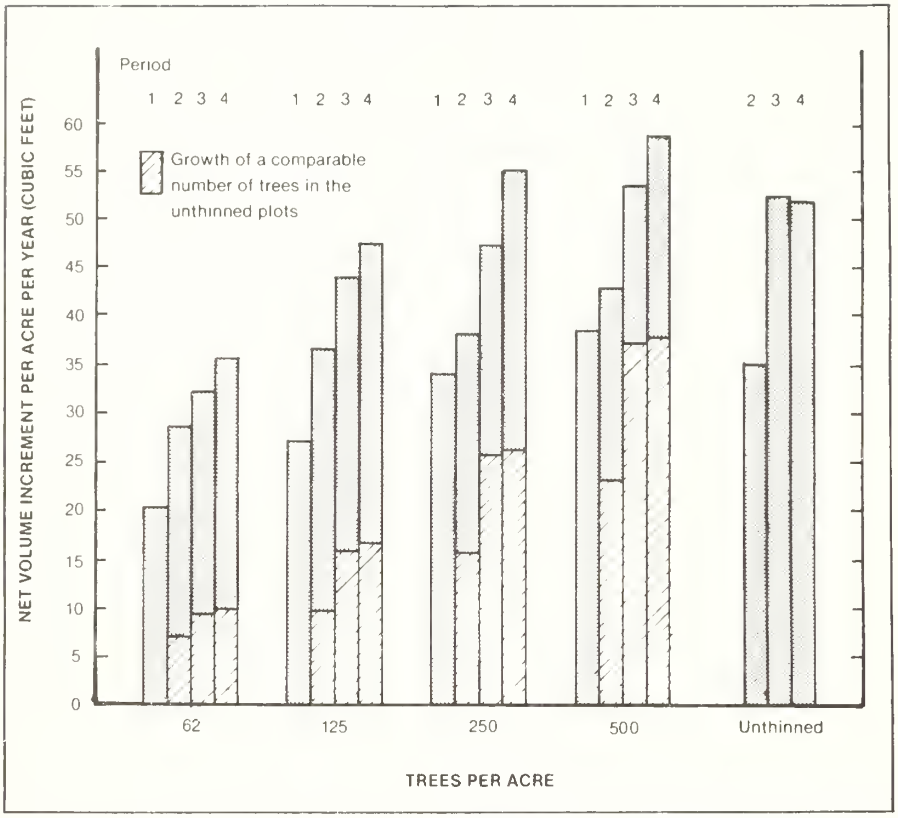

Figure 11.—Average annual net cubic-volume increment of ponderosa pine during the first, second, third, and fourth 5-year growth periods, and increment on a comparable number of the best well-distributed trees in the unthinned stand.

Volume Increment and Yield

The effect of spacing on volume increment was significant (table 1). Periodic volume increment also showed a trend toward increase with time in all thinned treatments (fig. 11). Trees on plots at various densities of 62, 125, 250, and 500 trees per acre produced 62, 92, 107, and 114 percent of the volume produced by the unthinned plots during the last period. This annual increment wil probably increase until maximum capacity for growth for a given density is reached.

The larger, dominant trees in the unthinned stand are not contributing much volume increment. For example, the 125 largest trees in the unthinned stand produced only 16 percent of the volume grown by all the trees in the unthinned stand (fig. 11), indicating that even the dominants are suffering severe competition from other trees in this natural, dense stand.

Although the unthinned stand presently contains the highest amount of wood fibe (fig. 12), the volume is distributed on trees that have an average diameter of a little less than 4 inches. Compare this to trees at the widest spacing that now average 1 inches in diameter.

The relation of volume increment to stan density for ponderosa pine, over a range of sites and plant communities in the Pacific Northwest, needs to be determined. As a beginning, volume incremen related to basal area and stand-density index (SDI) (Reineke 1933)[6] in this stud are presented in figures 13 and 14.

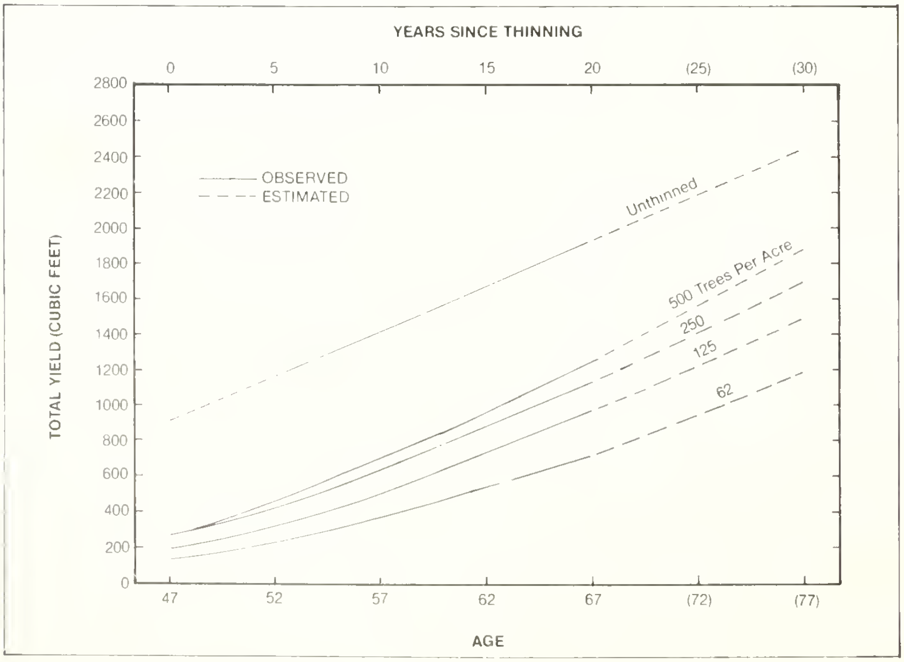

Figure 12.—Net yield of ponderosa pine thinned to densities of 62, 125, 250, and 500 trees per acre and of the unthinned stand.

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[6] Personal communication with Donald DeMars, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

DeMars computed the basic Reineke type equation Log_{10} TPA = 4.32807 – 1.76533 Log_{10} DBH from plot data accumulated by Meyer (1961) for ponderosa pine. Thus:
Log_{10} SDI = Log_{10} TPA – 1.76533 + 1.7653 Log_{10} DBH, where
SDI = stand density index;
TPA = trees per acre;
DBH = average diameter of stand.

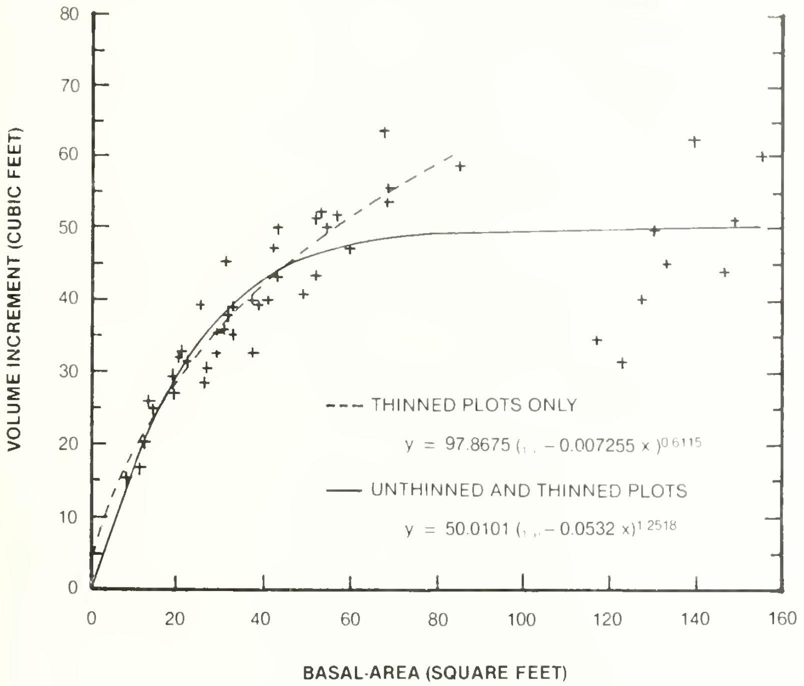

Figure 13.—The relation of annual volume increment to initial basal area. Each point on the figure represents the periodic volume increment relative to basal area for a plot at the beginning of the 5-year period.

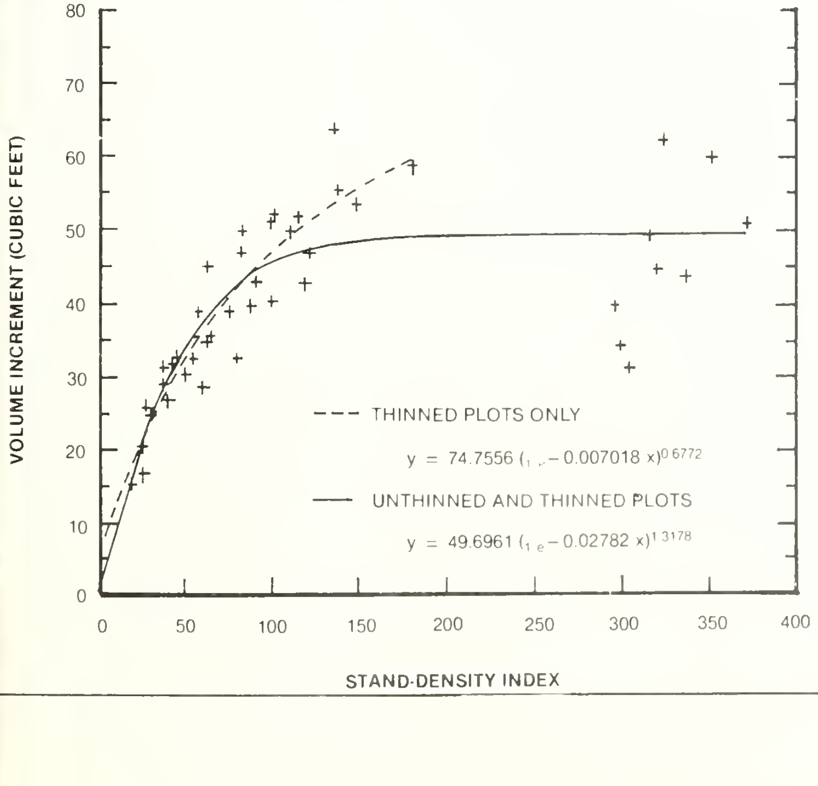

Figure 14.—The relation of annual volume increment to initial stand-density index (Reineke 1933). Each point on the figure represents the periodic volume increment relative to the stand-density index of a plot at the beginning of the 5-year period.

Discussion and Application

Mortality

Only two trees of 348 died on the thinned plots in 20 years of observation. One tree died in the 250-tree-per-acre treatment and one where 125 trees per acre were left. This is a loss in yield of about 6 and 9 cubic feet per acre. Both trees died 10 to 15 years after thinning.

On the three unthinned plots, 70 trees of 1,374 died during the last 15 years of observation. Most trees were less than 2 inches in diameter, but occasionally, a 3- or 4-inch tree died. Only intermediate or suppressed trees died, and mortality accounted for less than 3 percent of gross annual increment on a plot for any one period and averaged 1.5 percent. Thus, mortality had a minor influence on increment and yield in the unthinned plots and practically no effect on the thinned plots.

Applying quantitative data from a study of this kind to similar sites on different soils and plant communities is tempting, because they may be the only data available. If this study were replicated in other places in northern Washington and results were consistent, the geographical and quantitative inference could be expanded; with only one installation, conservative application is appropriate.

Much can be gained from this study by looking at the magnitude of the effects of spacing and tree selection on growth and eventual yield, rather than applying quantitive results. The study provides actual data on wood-volume production of thinned stands in this part of Washington. It also provides a clue as to the time needed to grow trees to commercial sawlog size.

Mortality figures for managed and unmanaged stands are compared. The study also adds strength to the concept that mortality in thinned, ponderosa pine stands is minor during the first 20 years after thinning. Past experience suggests that when mortality is major, it is usually catastrophic—from wildfire or insects. Unthinned sapling stands in the area are now growing rapidly into overdense, small-pole stands that could be subject to insect attack if left unthinned.

Spacing affects the size of products produced, their quality, and the cost of harvesting the wood. In most areas, spacing of ponderosa pine can also have a profound effect on the development of understory vegetation (McConnell and Smith 1970, Barrett 1973). Leaving excessive numbers of trees in an initial thinning to allow for mortality and prepare for a highly questionable round-wood market may not be the logical approach in this area. Evidence from this study and others in Oregon indicate little mortality occurs in healthy, thinned stands. Also, lower density stands enhance the production of forage for game and red-meat production, which is important in north-central Washington. Leaving too many trees will prevent the stand from attaining the size necessary for sawlog marketability and may necessitate another costly precommercial thinning.

Thinning dense stands of ponderosa pine results in a temporary loss in the total capacity of the timber site to produce wood fiber, but the thinning is usually needed to produce a salable product. After a stand is thinned, time is needed for the remaining live tree roots to grow and invade the soil formerly occupied by the trees that were cut. The greater the spacing distance, the greater the time needed to occupy the space between trees with roots and crown. Final yield can be notably reduced as a consequence of excessive spacing. But this sacrifice in production early in the rotation can sometimes be justified by the objectives of resource management.

Managers in north-central Washington might consider the following points in selecting a spacing. If 500 trees per acre is the highest density that will be considered, then we may examine the consequences of further density reduction. From figure 15, we find that total cubic yield in the Methow study 20 and 30 years after thinning falls off slowly as density is lowered to 250 trees per acre, but it falls more rapidly with further density reduction. For example, I estimate a loss of about 10 percent in yield at 30 years after thinning from 500 trees per acre to 250. But this loss reaches about 21 percent if trees are reduced to 125. If the objective is a commercial thinning of sawlogs in the shortest time, wider spacing offers a distinct advantage in product size. Trees at 125 trees per acre would have an average diameter of about 10.5 inches 30 years after thinning, compared to only 7.1 inches if 500 trees were left (figs. 6 and 15). Even with the impressive reduction in yield by going to the wider spacing, note that—during the last period—plots thinned to 125 trees per acre grew almost 81 percent of the volume increment grown where 500 trees per acre were left (fig. 11). During the next decade, 125 trees per acre might produce as much volume annually as 500 trees per acre. From figures 6, 8, 12, and table 2, various combinations of yield and product size can be estimated. These estimates thus provide an interim guide for spacing selection. Alternatives for producing various wood products should eventually be examined using an appropriate stand-growth simulator for ponderosa pine. Such a simulator is now being developed at the Pacific Northwest Forest and Range Experiment Station.

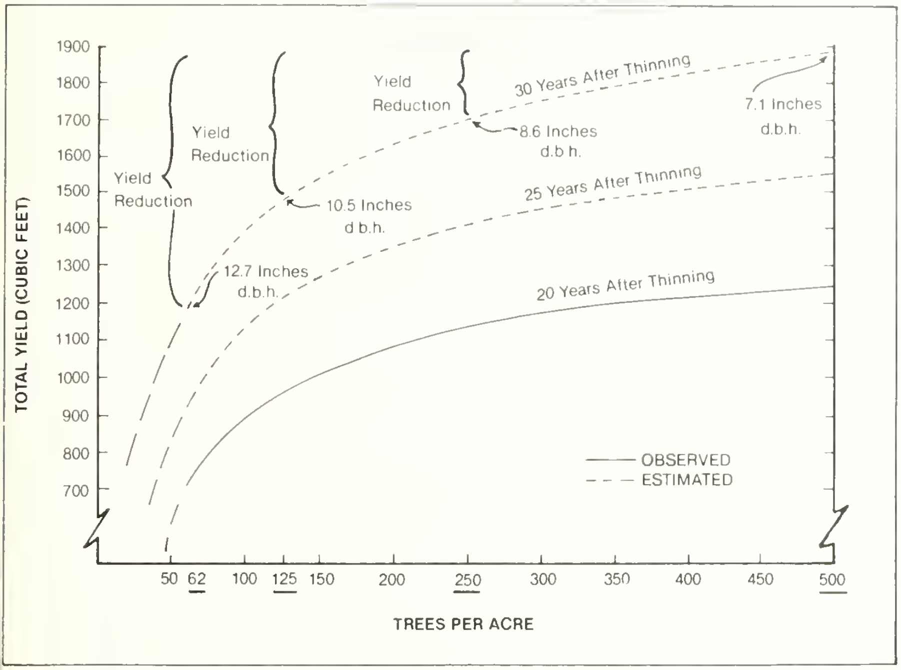

Figure 15.—Yield of ponderosa pine 20, 25, and 30 years after thinning to various tree densities.

Choice of initial spacing on public land is usually not based on wood yield alone. Many thinned stands are also potential sources of forage for big game and ivestock. McConnell et al.[7] found substantial increases in forage production at the wider spacings in the study reported here. Thus, even though the wider spacing temporarily reduced production of wood fiber, it increased the potential for production of red meat, with possibly a greater resource appeal than for wood alone. As shown in figure 6, 12-inch sawlogs might be produced in 30 years by leaving only 62 trees per acre. Low ree-density may be an appropriate practice on some deer winter ranges where maximum forage production is the principal concern.

Finally, I would like to stress that this study was made in a typical stagnated stand of ponderosa pine on a poor site. Precommercial thinning should have been done much earlier, but trees responded quickly and well to such late release. Apparent gains from the thinning are impressive, because the alternative of stagnation offers little hope of useful wood production for many years.

Metric Equivalents

1 inch = 2.54 centimeters
1 foot = 0.3048 meter
1 acre = 0.405 hectare
1 square foot/acre =
  0.2296 square meter/hectare
1 cubic foot/acre =
  0.06997 cubic meter/hectare
1 tree/acre = 2.471 trees/hectare

Literature Cited

Barrett, James W. Response of ponderosa pine pole stands to thinning. USDA For. Serv. Res. Note PNW-77. Portland, OR: Pac. Northwest For. and Range Exp. Stn.; 1968. 11 p.

Barrett, James W. Ponderosa pine growth and stand management. *In* Precommercial thinning of coastal and intermountain forests in the Pacific Northwest. Pullman, WA: Wash. State Univ.; 1971:5-9.

Barrett, James W. Latest results from the Pringle Falls ponderosa pine spacing study. USDA For. Serv. Res. Note PNW-209. Portland, OR: Pac. Northwest For. and Range Exp. Stn.; 1973. 22 p.

McConnell, Burt R.; Smith, Justin G. Understory response three years after thinning pine. J. Range Manage. 18(3):129-132; 1965.

McConnell, Burt R.; Smith, Justin G. Response of understory vegetation to ponderosa pine thinning in eastern Washington. J. Range Manage. 23(3):208-212; 1970.

Meyer, Walter H. Yield of even-aged stands of ponderosa pine. U.S. Agric. Tech. Bull. 630; 1961. 59 p.

Reineke, L. H. Perfecting a stand-density index for even-aged forests. J. Agric. Res. 46(7):627-638; 1933.

Sartwell, Charles. Thinning ponderosa pine to prevent outbreaks of mountain pine beetle. *In* Precommercial thinning of coastal and intermountain forests in the Pacific Northwest. Pullman, WA; Wash. State Univ.; 1971:41-52.

Sassaman, Robert W.; Barrett, James W.; Smith, Justin G. Economics of thinning stagnated ponderosa pine sapling stands in the pine-grass areas of central Washington. USDA For. Serv. Res. Pap. PNW-144. Portland, OR: Pac. Northwest For. and Range Exp. Stn.; 1973. 17 p.

Response of understory vegetation to ponderosa pine thinning in eastern Washington, by Paul J. Edgerton, Burt R. McConnell and Jon M. Skovlin. Manuscript in preparation.

Barrett, James W. Twenty-year growth of thinned and unthinned ponderosa pine in the Methow Valley of northern Washington. USDA For. Serv. Res. Pap. PNW-286, Portland, OR: Pacific Northwest Forest and Range Experiment Station; 1981. 13 p.

Diameter, height and volume growth, and yield of thinned and unthinned plots are given for a suppressed, 47-year-old stand of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) in the Methow Valley of northern Washington that averaged about 3 inches in diameter and 23 feet tall before thinning. Considerations are discussed for choosing tree spacing in a precommercial thinning.

Keywords: Thinning effects, increment, stand density, improvement cutting, ponderosa pine, *Pinus ponderosa*.

The **Forest Service** of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

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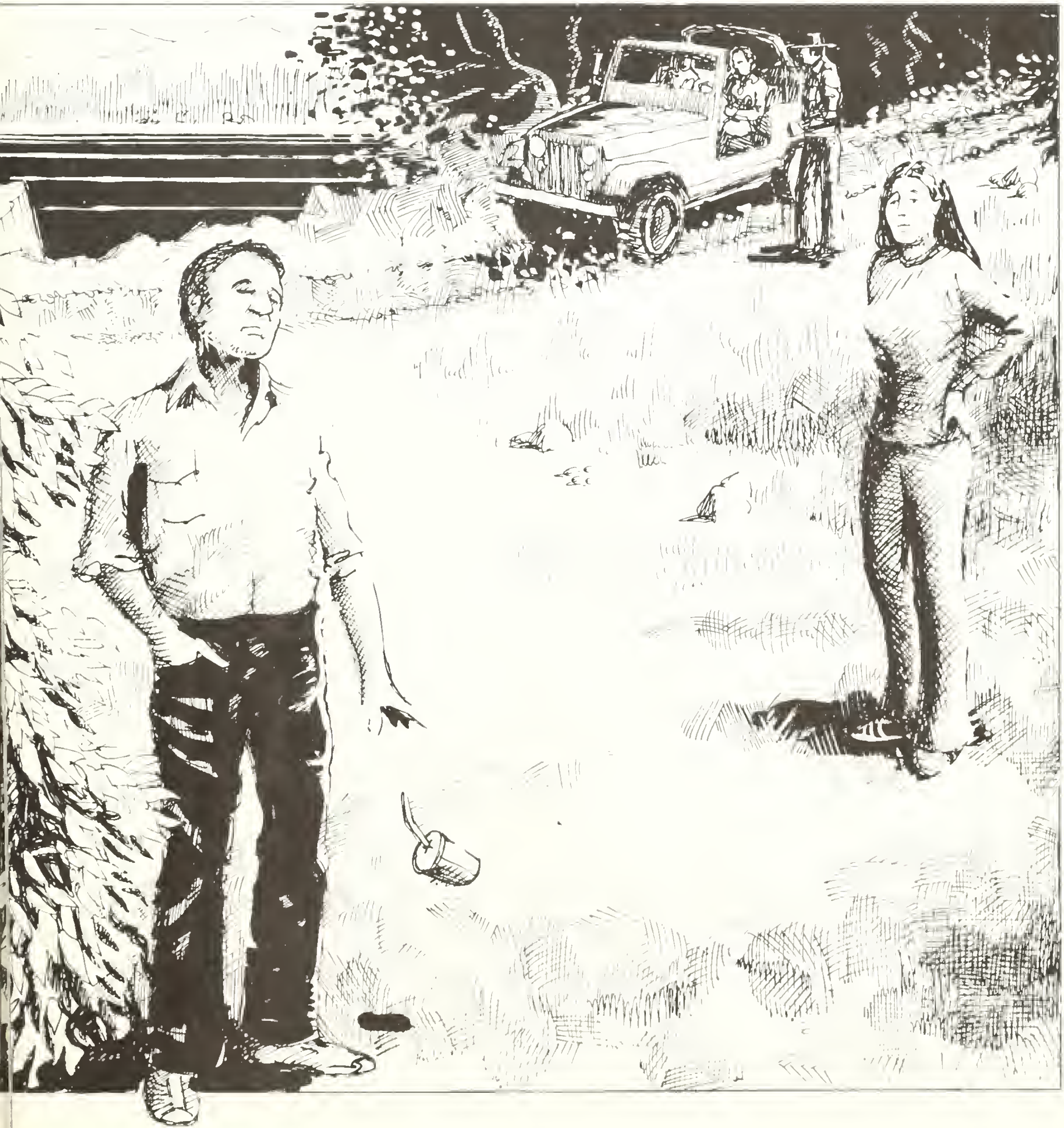
Bystander Intervention and Litter Control: Evaluation of an Appeal-To-Help Program

CLEMSON UNIVERSITY
OCT 18 1982
PUBLIC DOCUMENTS

Harriet H. Christensen



Author

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bstract

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1981. Bystander intervention and litter control: Evaluation of an appeal-to-help program. USDA For. Serv. Res. Pap. PNW-287, 25 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

lanagers of public recreation areas are oncerned about increases in vandalism nd disregard for regulations and the ghts of others by some users. Other than ie litter incentive program, none of the pproaches for reducing violations have een evaluated or proved effective. The resent study evaluated a program to icrease involvement of campers in the ianagement of depreciative behavior by eporting violations they witness. Results iggest that users who witness littering ill help, by reporting infractions to ithorities, dealing with the litterer, or cking up the litter.

eywords: Appeal to help, public volvement, litter, recreation research, epreciative behavior, bystander tervention, recreation management, kperimental analysis.

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Introd

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ntroduction

range of depreciative behaviors such s vandalism and theft occurs in recreaon settings. Managers and users are ncerned over such behavior and its pact on the enjoyment of others, the atural environment, and public and ivate property (Clark et al. 1971b, fano and Magill 1976, Downing and outsinas 1978, Driessen 1978, and U.S. epartment of the Interior 1978). The SDA Forest Service (1975) reported at vandalism and littering in the National orests cost taxpayers over $7 million in 974. The Bureau of Land Management, th fewer and more widely dispersed cilities, reported that vandalism costs 250,000 per year (Alfano and Magill 976). The National Park Service ported 8,251 incidents of crime during 978, an increase of 6 percent from the evious year (U.S. Department of the terior 1979). The Seattle, Washington, arks and Recreation Department timated that vandalism cost $236,000 ring 1976 (U.S. Department of the erior 1977). Vandalism and other olations of rules are found throughout e recreation opportunity spectrum, from ban parks to wilderness areas (Clark al. 1971b, Boston Parks and ecreation Commission 1978, Hendee al. 1978, and Shafer and Lucas 1978).

anagers have used a variety of straties to mitigate or prevent vandalism d other rule violations (Clark 1976a, ristensen and Clark 1978). Currently ese include site planning, architectural sign, construction material specificans, landscape design, education of ers, charging fees, increased surveilce, frequent maintenance, and public olvement—as well as adding rules and ulations. Although they are often cessary, rules can contribute to deeciative behavior — particularly if they erfere with users' activities, if users do understand the reasons for them, or hey are ineffectively communicated. her than the litter incentive program, ere people are rewarded for picking up er, no strategy has been tested and aluated for its effect on reducing blem behavior (Burgess et al. 1971, rk et al. 1972a, Clark et al. 1972b, and rk 1976b).

Involving the public in the management of depreciative behavior has been identified by users, managers, and researchers as a potential solution to the problem. Ways must be found, however, to identify how and under what conditions users will become involved (Clark et al. 1971a, Clark 1976a, and Flickinger 1976). In the survey by Keep America Beautiful (1968), people reported they would not complain to a litterer or report littering to authorities. Heberlein (1971) found that people would not reprimand their friends for littering. Flickinger's (1976) survey in Ohio found that campers said they would do nothing if they observed littering, but they would report theft or vandalism. Clark et al. (1971b), in a study in Washington, found that campers said they would report witnessed rule infractions immediately. But what people say they will do is not necessarily what they will do (Campbell et al. 1968, Clark et al. 1971a). Regardless of the act witnessed, when actual behavior is observed, people normally do not become involved. In a study of campers in a developed campground, Clark et al. (1971a) found that 90 percent of the depreciative acts produced little or no reaction from witnesses. Controlling rule violations is unlikely unless witnesses can be induced to become involved.

Clinard (1974, p. 35) noted, "Where only the general public or the government is a victim, private citizens are less likely to report the offenses." Noninvolvement is a factor in our entire social system (Latané and Darley 1970).

Why do people say they will intervene, when research shows they do not? They are afraid of retribution, do not know how to report, believe others will report, or do not understand an act is illegal or a problem. They also may feel they do not have time to get involved, or that it will not make any difference if they do (Bickman et al. 1977). Early teaching not to tattle or snitch on others also seems to play a role. Ways must be found to change noninvolvement into prosocial behavior (also called altruism) to help reduce or control depreciative behavior. There is some evidence that people help others because they believe it is right, regardless of rewards (Berkowitz 1972).

Latané and Darley (1970) suggested that the witness to an illegal act goes through a process of questioning and decision-making: "What's going on? What should I do? Should I take responsibility?" Five distinctive steps characterize this process: 1, person notices something; 2, person interprets the situation; 3, person decides to assume personal responsibility and do something; 4, person decides what to do; and, finally, 5, person engages in the behavior decided upon. The authors suggest that people may not decide not to act, but, rather, refrain from making decisions. They are in a state of conflict over steps 2, 3, and 4.

Baron and Byrne (1976, p. 397-398) noted:

> Research on prosocial behavior repeatedly indicated that the indifferent bystander actually is one of several very concerned bystanders trying to figure out what is happening. Among the variables identified as having a positive effect on prosocial behavior, the most pervasive seems to be the ambiguity of the situation. Individuals hesitate to take action when the situation is ambiguous; they are afraid of making a mistake and becoming objects of ridicule. This suggests that society could benefit from educational efforts that expose each of us to varied settings and to the types of emergencies likely to arise there. Another important variable is the perceived responsibility of the bystander—which may simply mean that there is sometimes ambiguity about what to do. That, too, can be taught.

Procedures

Baron and Byrne point out that minimizing ambiguity may cause users to intervene, which could help mitigate or reduce rule violations in recreation areas. Perhaps users would intervene by reporting an act or speaking to an offender if they were aware of problems in a campground. Would bystander behavior change if they were told that we must all take personal responsibility for the recreational area and told what actions they should take? Heberlein (1971) found that people littered less if they were aware of the consequences and felt responsible for them.

For the purposes of the current study, establishing a link between recognition of the problem and doing something about it was important.

The premise of the study is that nonintervention is caused by uncertainty and ambiguity—not by indifference. It further suggests that a program in which managers ask recreation visitors to report offenses could reduce littering. Visitors, when confronted with depreciative behavior, can learn to ask three key questions: What is going on? Who is responsible for redirecting this antisocial action? What can I do to help?

This study was conducted on weekends from August 6 to September 5, 1977, in a developed campground on the Wenatchee National Forest, Washington. It focused on campers and their reactions to staged littering. Control of rule violations was sought through intervention by campers and reporting of illegal acts to authorities. Because prevention was not a focus of this study, we can only speculate that a similar program could minimize littering, and potential offenders might be deterred by observing other campers intervening with violators.

Overview of the Study

Camper groups at randomly selected campsites received an appeal-to-help message asking them to report to an authority any illegal acts they witnessed. The message—delivered either by a ranger, a Forest Service volunteer, or a campground host—was either oral or a printed cartoon. Control groups did not receive the message. Two hours after the appeal, littering was staged in view of the subjects, by a man or woman driving past a selected campsite. Two observers following in a second car measured two specific reactions: direct intervention with the litterer and picking up the litter. Ten minutes after the staged littering, a ranger walked through the campground to measure reporting by witnesses. The major dependent variables were reporting, direct intervention, antilittering, and no reaction. Treatments were assigned at random to the campsites. The appeal deliverers and type of litter (soda can or beer can) were assigned to clusters of campsites. The social characteristics and behavior of campers were unobtrusively measured by the appeal deliverers, the litterers, the observers in the second car, and the ranger patrol.

Study Area

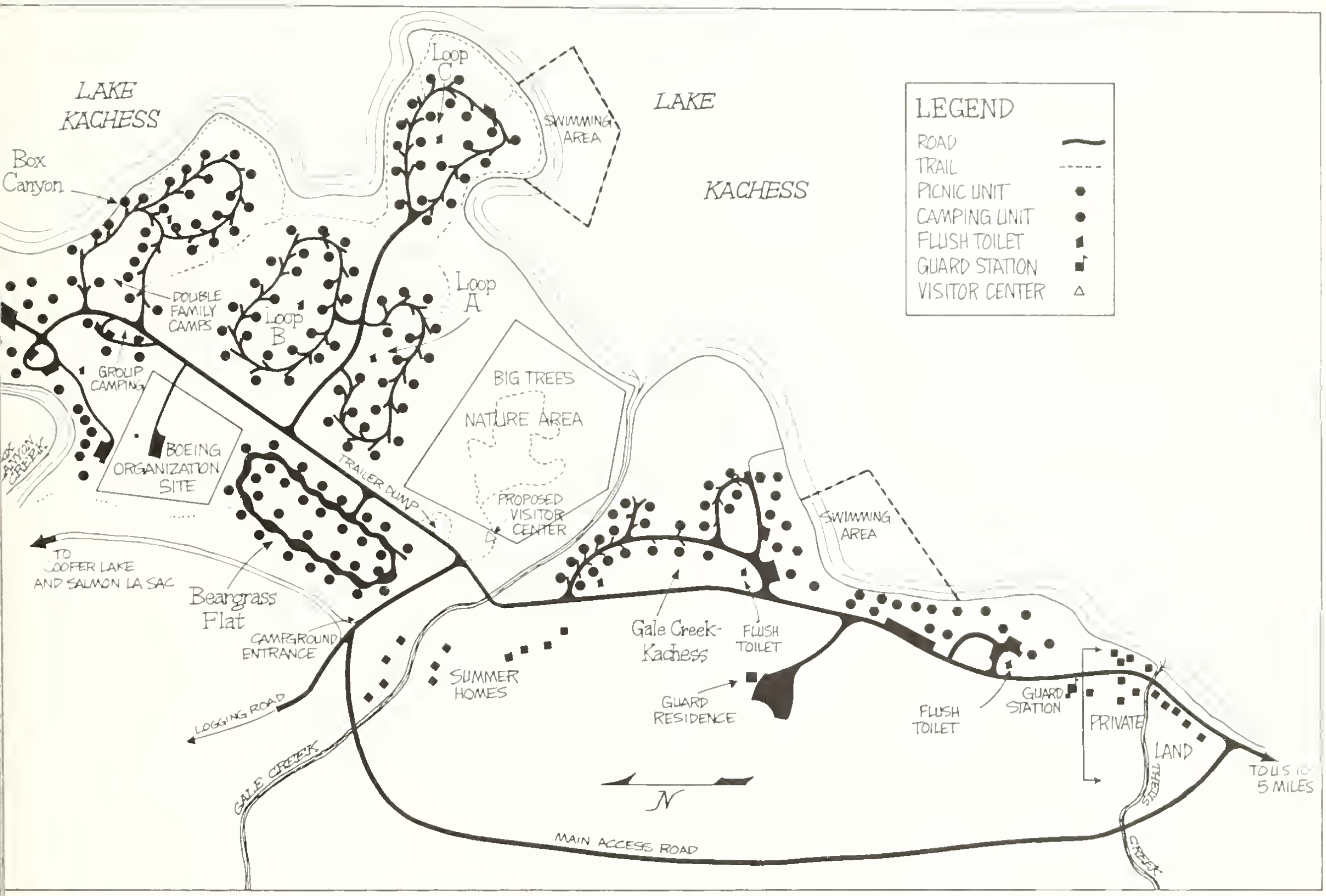
The study area was at Lake Kachess, Cle Elum District, Wenatchee National Forest (fig. 1). During the past decade, this area has been the site of other studies of depreciative behavior — on littering, the nature and extent of depreciative behavior in the campground, and user perceptions of problems and control strategies (Clark et al. 1971a, Clark et al. 1971b, Clark et al. 1972a). In fact, Lake Kachess has become a case-study area for understanding depreciative behavior in developed campgrounds. The layout of the campground also met special requirements of this study.

The campground has well-developed facilities, which include nature and swimming areas, picnic tables and firegrills, and six overnight areas. It is heavily used and supervised by on-site rangers.

Objectives

The nine objectives of the study were:

- To determine camper response to an appeal to help and measure differences in reactions to a rule violation.
- To determine the response of campers to different media (oral appeal and printed flyer).
- To determine the nature and extent of different types of reaction — such as whether campers would report offenses to the ranger, intervene directly, or pick up litter.
- To evaluate two types of reporting: filling out a card and dropping it in the fee box, or reporting directly to the ranger patrol.
- To determine the response of campers to appeals made by a ranger, a volunteer, and a campground host.
- To find out to what extent campers follow through on commitments to report.
- To determine the effects of group size on intervention.
- To examine the effects of selected social, situational, and rule-violation characteristics on intervention.
- To determine the effect of appeals on campers' own behavior in terms of campsite litter, and nails hammered into trees or removed.



ure 1.—Lake Kachess Campground, natchee National Forest, Washington.

tionale for Selecting Littering the Illegal Act

iering was selected as the illegal act to simulated because it is relatively ocuous and nonthreatening. asuring natural littering was sidered impractical.

Most people perceive littering as illegal. Millions of dollars have been spent on antilitter education, invoking fines, and providing trash cans and litter bags. Research has shown the relative effectiveness of education, litter cans and bags, incentives, and involving the public (Burgess et al. 1971; Clark et al. 1972a, 1972b, 1972c; Clark 1976a, 1976b; Christensen 1978; Muth and Clark 1978). Others have studied the effectiveness of sanctions and signs (Heberlein 1971). No one strategy has solved the litter problem, but, taken together, the strategies make a fairly complete solution possible. This study of public involvement and the appeal-to-help program contributes to the systems approach for litter prevention and control.

Definition of Terms

Four reactions to witnessed illegal littering were measured: doing nothing (nonintervention); picking up the litter (antilittering, indirect intervention); reporting (complying with a request for a written or oral report to an authority, indirect intervention); and dealing directly with the offender (direct intervention).

Figure 2.—Printed message distributed to some campers.

Selection of Subjects

A random sample of clusters and of campsites within a cluster were selected for the study. A cluster included campsites both visible to one another and out of sight. Most campsites could be viewed by campers in from one to three other sites. Each camp loop had 12 to 22 clusters that could be selected. Subjects were a camping party at a campsite. After subject campsites were selected within a cluster, they were randomly assigned to the experimental conditions. Campsites were assumed to be independent of each other, even though samples were drawn in clusters.

Camping parties were assumed to be randomly distributed to campsites. Campers were randomly assigned to receive report cards, oral appeals, printed appeals, or no appeal, or to serve as controls.

Experimental Controls

A ranger, host, or volunteer visited all campers, so those not in the experiment would not be curious about what was going on, and explained, "We're trying to get an idea of the number of people at the campground this weekend." Each campsite was provided with a litter bag and the children with Smokey-the-Bear fire-prevention balloons or comic books. Information on individual and group characteristics was collected. Then, depending on the group's assignment in the experiment, the ranger/host/volunteer delivered a printed message, an oral message, or no message; passed out report cards; thanked the people; and left.

The control subjects were visited by the authorities as outlined above, but no message was delivered. Their reactions to the staged littering were measured later.

Subjects chosen to receive printed appeals were given cartoon flyers printed on orange paper (fig. 2). They included two major messages: Lake Kachess has problems with violations of rules, such as littering and hammering nails into trees; and, witnesses should report violations to the authorities. The first message was a specific example of telling "What's going on," the second suggested a particular way to deal with the problem. Personal responsibility was implied.

ral messages were given by the ranger, st, or volunteer as follows:

We're having problems with rule plations — people on motorbikes, nails trees, littering, campfires left burning — d we need your help. (The problem.)

f you see any of these activities or ners that concern you, we would really opreciate your letting us know so that we n talk to these individuals, explain the oblem, and ask for their cooperation. eporting.)

We would like to encourage everyone take personal responsibility for porting problems to us so that we can t a handle on the kinds and frequency problems and talk with the individuals ncerned. (Personal responsibility.)

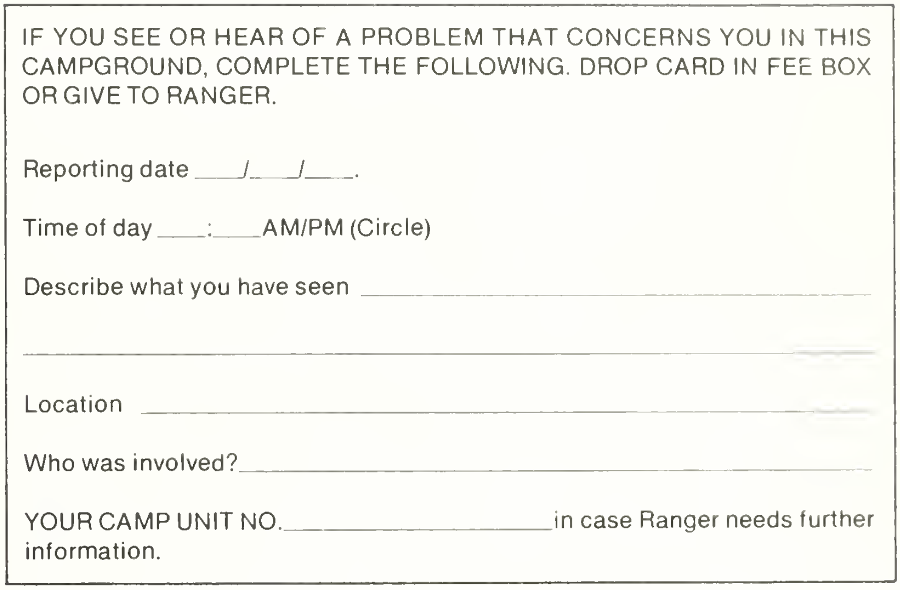
So if you see a violation, will you tell me someone designated who did it? eport the campsite number or car ense number and where they went. ommitment.)

bjects were asked to spread the word the rest of their parties, and not to deal h the offender.

me of the appeals were delivered by a rest Service ranger (actually a creation guard or a member of the search team), dressed in the authorized rest Service uniform.

me of the appeals were delivered by a unteer or campground host to ermine whether the Forest Service uld use volunteers and campground sts in this capacity. The volunteer was ssed as a camper with a Forest vice volunteer patch on his shirt. Both host and the volunteer were males wore nametags that included their s.

me campers received 3-by-5 pre- nted cards (see fig. 3) on which to ort offenses anonymously. They were they could drop the cards in the pground fee box or give them to the ger. Campers who did not receive ds could report rule violations orally.



IF YOU SEE OR HEAR OF A PROBLEM THAT CONCERNS YOU IN THIS CAMPGROUND, COMPLETE THE FOLLOWING. DROP CARD IN FEE BOX OR GIVE TO RANGER.

Reporting date ____/____/____.

Time of day ____:____AM/PM (Circle)

Describe what you have seen ____________________

Location ____________________

Who was involved?____________________

YOUR CAMP UNIT NO.____________________in case Ranger needs further information.

Figure 3.—Card for reporting witnessed rule violations.

To determine whether campers not in the experiment would report violations, cards were placed in fee boxes at several locations. Signs, which read "Report Violations Here," measuring 8 by 10 inches were placed on bulletin boards adjacent to the fee boxes.

Study Phases and Measurement Procedures

Each appeal deliverer was randomly assigned a camp area. Assigned areas did not overlap. Appeal deliverers were provided schedules that indicated the place and time to contact campers. All occupied campsites in the camp area were listed and scheduled to receive printed or oral appeals or identified as controls. Appeal deliverers were trained and did not refer to notes in delivering the appeal.

Information gathered about campers included: Style of camping (number of pickup campers and tents); group composition (number of men, women, boys, and girls); problems reported by campers; amount of spoken commitment (number of men, women, boys, and girls who agreed to report offenses); and license numbers of vehicles. (License numbers were also recorded later by the patrol to determine whether the campsite was occupied by same people during all phases of the test.) The appeal deliverer was not in the area during the litter simulation.

The second phase of the study was the staged littering. Two hours after appeals began a man and woman in their early 20's drove 2 to 5 miles per hour past the experimental campsite. Loud rock music was played on a cassette recorder in the vehicle to attract attention. One can was dropped on the asphalt pavement in front of the selected campsite. The type of can (beer or soda) had been randomly assigned.

Information gathered by the litterers included: Whether experimental subjects witnessed the staged littering and, if so, who; total number of campers in the camp site; and general activities (camp chores, table and nontable activities). Ten minutes was allocated to the litterers to complete their task and leave the area.

Two observers in a car following about 50 feet behind the litterers' vehicle measured subjects' reactions to the staged littering. The observers drove through the camp area twice. They were not aware which sites had received which kinds of appeal. They used a cassette tape recorder to record their observations; the tape was transcribed immediately after the run.

The observers recorded four reactions to littering:

- Camper looked at the car and did nothing.
- Camper pointed a finger at the litterer or placed hands on hips and faced the litterer.
- Camper spoke to the litterer.
- Camper left the campsite and followed the litterer.

At the end of the first run, the observers immediately re-entered the camp loop and recorded the age and sex of campers, whether the can was picked up by the campers or left on the ground, and the total number of bystanders.

The third phase of the study was the patrol. Ten minutes after the staged littering the Forest Service ranger walked through the camp to determine whether campers would report the littering. The ranger did not know which sites had received the oral, the printed, or no appeal. She had a schedule indicating the camp area and sites to patrol and a form for recording reports of littering or other problems.

The ranger recorded: Vehicle license numbers; temperature and weather; number of men, women, boys, and girls who observed her on patrol; and camp activities. If more than one activity was going on, all were recorded.

Measuring Litter and Nails Before and After Campsite Use

Litter was measured at unoccupied camp sites on Thursday, and on the following Monday an after-use count was taken. Included in the count were cigarette butts, matches, pull tabs, and anything larger than a quarter. Orange peels and other garbage were excluded. The number of pieces of litter within 4 feet of each campsite's parking pad for vehicles was recorded.

Nails were also counted at unused campsites on Thursdays and Mondays. Nails in all trees within 20 feet of picnic tables, from ground level to 8 feet, were counted.

Pretest

A pretest the weekend before the study began consisted of training the research team in sampling sites, selecting camper subjects, delivering appeals, staging littering, and measuring campers' reactions.

Data Base

At the end of the study, 128 of 215 trials were usable; 87 were discarded because the camper subjects missed one or more of the three stages — the appeal, the staged littering, or the patrol.

In the 128 trials, 40 groups received the oral appeal, 52 the printed appeal, and 36 were controls. A Forest Service ranger delivered 68 of the appeals, the Forest Service volunteer 15, and the campground host 9. Twenty-seven of the trials (table 1) used report cards, 65 did not, and 36 were controls. (All tables are grouped in the Appendix.)

Campers who received appeals were not always the same ones who witnessed the littering or the patrol. For instance, two people in a party could have received the message while a third person was out of camp, but the third person could have seen the littering while the other two were out of camp. The oral message dealt with this possibility, by asking campers to spread the message to the rest of the party.

Reliability

Reliability checks of the appeal deliverer and patrol observer were conducted one weekend. Interobserver agreement was 97 percent for the appeal deliverer and 95 percent for the patrol observer. The driver and passenger of both cars were in agreement with each other. Reliability measures were determined for counts of litter and nails for 20 campsites. Interobserver agreement was 92 percent for litter and 95 percent for nails.

Significance

Significance levels of .05 are reported in this paper. Discussions, however, sometimes focus on relations that approached significance, but not to the .05 level. Research on bystander intervention is generally in its infancy, and reporting these potentially important relations among variables seems useful. The study was small; with a larger sample size significance would likely be obtained.

Characteristics of Sample

This study included 128 groups of campers consisting of 674 men, women, and children camping together as family, friends, or family and friends. The mean number of people in camping groups witnessing the staged littering was five. Of this group, three were adults and two under age 18.

esults and Discussion

ature and Extent of Reaction

major objective of this study was to etermine how an appeal for help affected ampers' reactions to a rule violation; how uch reaction occurred, and what effect e appeal had on the reaction. Explain- g problems with rule violations and iggesting that campers could help by eporting them was expected to increase volvement by campers.

able 2 summarizes the extent of camper eaction. In over 75 percent of the litter- g trials, some type of reaction was bserved; in 23 percent, campers did not eact in any manner.

able 2 demonstrates a difference in esponse between the treatment and ontrol groups of 22 percentage points 2.6 versus 61.1 percent). This suggests at appealing for the help of campers oes have a significant effect and emonstrates that behavior can be icited through a particular appeal.

atané and Darley (1970) developed a odel of decisionmaking during an nergency (see page 1 and table 3). e 22-percent difference in behavior this study apparently demonstrates at defining the problem and suggesting ays to deal with it increased campers' volvement. Other studies have found milar results. Bickman and Green 977), in their study of shoplifting and porting behavior, also found that ervention increased when witnesses ere educated to take action. Moriarty 975) and Shaffer et al. (1975) found creased intervention to prevent theft en subjects had been asked to help. milar results were found by Bickman 972, 1976), Clark and Word (1972, 74), and Muth and Clark (1978). We do t know which of the components in the peal message were effective in anging behavior. The 22-percent dif- ence may be the result of one or a mbination of cues to the problem: mmitment, personal responsibility, or influence of the ranger, host, or unteer. But results indicate that this proach has promise as part of a mprehensive approach to controlling violations in recreational settings.

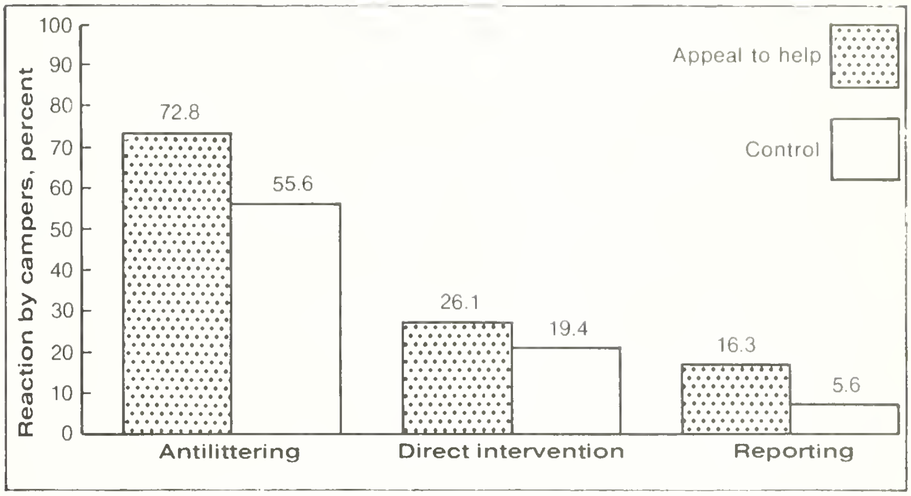


Figure 4.—Three types of reactions by 128 camping parties to staged littering after an appeal to help: for antilittering, $\tau_b = .17$, $p = < .03$, gamma = .36, n.s.; direct intervention, $\tau_b = .07$, gamma = .19, n.s.; reporting, $\tau_b = .14$, $p. = < .05$, gamma = .54, n.s.

Three types of reaction by campers to staged littering were observed: antilittering (campers immediately picked up the litter and placed it in a garbage can); direct intervention (campers overtly intervened with the litterers); and reporting (campers reported the littering to the ranger) (fig. 4). Campers could react in more than one way; they could pick up a can and also report the violator, or they could pick up the can and deal directly with the litterer.

Picking up the litter was the primary reaction of most campers. The appeal resulted in a 17-percent increase in antilittering behavior (72.8 versus 55.6 percent). But 56 percent of the control group picked up cans without any appeal — not surprising, considering that millions of dollars have been spent on programs to prevent littering. Future studies should determine what campers do when the littering is along a trail designated as community property, compared to this study, where cans were dropped at their own campsites.

Twenty-six percent of the subjects receiving the appeal intervened directly with the litterers, 7 percent more than the control group. This was an apparent consequence of the appeal. Subjects who intervened directly evidently decided on that action rather than turn the responsibility over to an authority. Also, campers might have preferred to intervene rather than turn the matter over to a female authority (Maier 1970, Broverman et al. 1972). Future research might focus on how sex of the authority figure affects campers' actions.

In 128 trials, 16 percent of the subjects receiving appeals reported the staged littering, 10 percent more than the control group. The appeal to help was an attempt to elicit behavior that some campers might interpret as snitching or tattling, which may explain why only a handful of campers reported the rule violations. It does not suggest that reporting cannot be produced, however. Results of this study demonstrate that campers sometimes will report a violation; but further research is needed to discover ways to increase reporting.

Campers' perceptions of the costs of intervention — such as embarrassment and verbal or physical abuse — may explain the low rate of this type of response. The cost-reward model of intervention (Piliavin and Piliavin 1972, p. 353) states: "As costs for helping increase, the probability of direct intervention decreases and the probability of indirect help increases." Bleda et al. (1976) suggested that reporting shifts responsibility for corrective action to someone who holds a position of authority. Direct intervention requires personal involvement. The data reported here imply that campers perceived direct intervention as less costly than reporting, although direct intervention would appear to be more risky. Possible explanations for this behavior are that reporting to the ranger was not sufficiently convenient or that direct intervention against littering was not considered a high-risk action.

A direct comparison of oral and printed appeals show that they were similarly effective (table 4). In antilittering responses, for instance, the difference was less than one percentage point.

Direct intervention by those who received flyers was only 1.9 percent more than intervention by those who received oral appeals (25.0 versus 26.9 percent). This was expected, however, because the flyer did not refer to dealing with the litterer; it only asked campers to report violations. The lower rate of direct intervention by campers who received oral appeals may be explained by the fact that they were specifically told *not* to deal with the offender but to report violations to the ranger.

Littering was reported by 20 percent of the campers who received the oral appeal and 13.5 percent of those who received the printed appeal. The difference of 6.5 percentage points may be explained by the method of the appeal. The deliverer of oral appeals interacted longer with the subjects, because the explanation took longer than handing out printed flyers. The difference in response to oral and printed messages might also be explained by the fact that some campers may not have read the flyer.

The role of the person who delivered the appeal to campers was expected to affect the behavior of camping groups. Determining the relative effectiveness of the ranger, Forest Service volunteer or camp ground host is important for administrative purposes. Two rangers were used in the study, both female — the recreation guard at Lake Kachess campground and a researcher dressed in a ranger uniform. Only female rangers and male volunteers were used, not male rangers or female volunteers; thus, any effects related to sex cannot be differentiated.

Among subjects who received the antilitter appeal from a volunteer, 86 percent responded in some way to the illegal act, but only 44 percent of the control group reacted — a difference of 42 percentage points (table 5). This suggests that trained volunteers, such as members of citizen-band radio clubs or 4-wheel drive clubs, could be used in such a program.

The recreation guard delivered appeals during the normal course of her duties. Nearly 90 percent of the campers who received an appeal from her reacted to the littering compared to 82 percent of the subjects who received an appeal by a researcher in ranger uniform. No differences between commitment to report a problem and reporting were found.

In past research, group size has been a major variable in explaining bystander intervention. Several studies have shown that intervention decreases as the number of witnesses to an event increases (Latané and Darley 1968, Latané and Rodin 1969). As the number of bystanders increases, the responsibility felt by any one individual to help decreases — responsibility is diffused — an individual does not bear 100 percent of it. When the bystander is alone, the probability of action increases. But Piliavin et al. (1969) have demonstrated the opposite effect; that is, intervention increases as the number of people witnessing the event increases, possibly because they feel there is safety in numbers. They demonstrated that reaction is less in groups of up to five witnesses than with groups of more than five. Morgan (1976, 1978) suggested that responsibility at one point may be diffused but, as the number of witnesses increases, the probability that some individual will intervene increases.

Table 6 summarizes the effects of group size on reaction. More reaction was observed when a camper was alone than when three or more campers witnessed the staged littering. The findings of the present study on group size seem to support Latané and Darley (1968) and other studies that found less reaction as the number of witnesses increased.

The tendency to report littering was also affected by size of camping party (table 7). When the camping party was small, 30 percent of the subjects reported the littering, but only 5 percent of campers in groups of six or more reported. Small groups appear more likely to turn problems over to authorities rather than deal directly with them. No relations were found between group size and direct intervention and antilitter behavior.

Table 8 summarizes reactions of subjects according to the number of other occupied campsites in their view. What effect would other campers (strangers) have on a subjects' reactions? Is a camping party inclined to react more when strangers are around? Reaction by subjects increased as the number of sites occupied by strangers in view of the subjects' campsites increased. When no strangers were watching, reaction was observed in only 73 percent of the trials, but reaction was observed in all trials where three or more nearby sites were occupied.

Campers' reactions to staged littering are summarized as follows:

- Earlier studies found that campers did nothing and were passive bystanders to rule violations. In this study, some type of reaction by campers occurred in 77 percent of all littering trials.
- The three types of reactions were: Campers picked up the staged litter; campers directly intervened with the litterers; and campers reported violations to the ranger. Many campers reacted in more than one way.

Appeals made to campers by the nger, campground host, or Forest ervice volunteer apparently increased ampers' reactions: picking up litter by 17 ercent, reporting littering by 11 percent, nd intervening directly with the litterer by percent. Overall, the appeal changed 22 ercent of the behavior because users ould have reacted in more than one ay.

The appeal was equally effective when elivered orally or as a cartoon flyer.

The male Forest Service volunteer was e most effective appeal-deliverer, but fects of role were not separable from ose of sex.

As the number of witnesses to the aged littering increased, reactions to the le violation decreased. Similarly, larger amping parties reported the littering less equently. Reactions increased as the umber of occupied sites nearby and sible to the subjects increased, owever.

eporting

hirteen percent of 128 acts of littering ere reported during the course of this udy (table 9).[1] The difference in porting by treatment (16.3 percent) and ntrol (5.6 percent) groups suggests that e appeal to help changed 10 percent of e reporting behavior (fig. 4). Other oblems, such as illegal use of vehicles d chainsaws were also reported by mpers not included in either experi- ental or control groups.

olations other than the staged littering re reported in only 7 percent of the mple (table 9). Some campers reported h unstaged violations and staged ering. Illegal behavior reported luded: speeding in a car, driving a torcycle through the campground, ving a motorcycle without a muffler, ving a vehicle on plants; illegal use of ainsaws in the campground; making se; and a swimming-boating conflict at beach. Litterers other than the two in study were not reported.

All of the illegal behavior was reported while the authority was delivering the appeal (table 9), and over half was reported by campers receiving spoken appeals. Oral appeals produced more contact with campers and allowed more time for subjects to express their concerns. Also, the appeal to report was given at a time the authority was available to take reports.

Campers not given cards had the opportunity to report littering only during the patrol 10 minutes after the staged littering. In 20 percent of trials campers without cards reported the violation to the patrol (table 10).

Campers with cards had three opportunities to report: orally to the ranger; with a filled-in card to the ranger; or with a card in the fee box. Only 10 percent of the staged littering was reported on cards. Of the nine campers given cards, only three wrote reports, and two of these also reported orally. Most subjects given the opportunity to fill in report cards preferred to report orally to the ranger, perhaps because telling the ranger was simply more convenient or perhaps reporting directly enhanced their self-esteem. People are apparently more likely to report problems if a ranger is present. Thus, the presence of a ranger seems important.

Campers not in the sample could report problems on cards available at the campground fee box. Of 173 camping parties not in the sample, 3.5 percent used the card to report problems. One party complimented management on the nature area.

Most of the reporters were adult males. Although they reported 30 percent of the violations, they reported only staged littering (table 11).[2] Twenty-six percent of the time, male and female adults responded together, mostly about unstaged illegal behavior. In fact, all rule violations were reported orally by adults. Reporting by children focused on the staged littering. Children knew littering was illegal; some of them asked what would be done if the culprit were apprehended, and some immediately picked up the thrown can and took it to the ranger. The person patrolling always answered the children's questions, overtly disapproved of the litterers' behavior, and thanked the children for picking up the cans.

People mentioned make and color of vehicle in half the reports concerning automobiles. License numbers were reported less frequently (table 12).[3] The following examples of reports indicate the need to be fairly specific in telling people what to report: An adult male reported, "A little red car littered here . . . should have taken the license number . . . should have picked up the can." Another adult male added questions and comments to his report: "A red Pinto littered here, license number Washington . . . . . young blonde did it . . . What is the fine? What do you do? . . . male and female were in the car . . . they should have stayed in the city." A woman and boy reported: "A green-moss (moss green?) car passed by and threw a beer can in front of our campsite . . . car load of people. We don't want to be identified for fear they'll come back and get us."

Nineteen percent of the morning trials were reported but only 11 percent of the afternoon trials and 6 percent of the evening trials were reported (table 13). Higher rates of response in the morning might be expected because campers were generally in camp; activities were usually quiet—eating breakfast, drinking coffee, or playing table games. In the afternoon, however, most people were at the beach, hiking, or boating. Still fewer trials were reported during the evening when activities such as socializing, eating, and playing were prominent. Reporting apparently increases when more people are in camp and activities are passive.

Beer and soda cans were randomly selected for littering each camp area. Each area tested received all beer cans or all soda cans. More reports were made (16.7 percent) when beer cans were used. If campers differentiated between beer and soda cans, they may have perceived beer cans as more objectionable. Or, campers may have perceived

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[1] wenty-six subjects reported the staged littering or other violations. Two reported the littering both during the patrol and later with a written card. One used only the report card.

[2] A total of 26 cases reported. Data displayed in the table include only oral reports. The other three reports were made on cards.

[3] Nineteen of the reports involved automobiles; 17 were vehicles used in the study; and the other two were involved in other rule violations.

beer drinkers who tossed cans as rowdy types likely to cause trouble, and wanted to prevent more offensive acts. Contacting the ranger when a can was tossed may have seemed a way to short-circuit trouble. This raises questions that could be asked about other rule violations. For example, does reporting by campers depend on the nature of the offense? Might campers report the theft of a Smokey Bear sign and not report the carving of a picnic table?

The sex of the litterer may also have influenced the tendency to report the violator. Two people staged the littering — a man and woman. The female litterer was reported more often than the male, which tentatively supports earlier findings by Bleda et al. (1976). Fifteen percent of the trials with the female were reported, but only 11 percent with the male (table 13). One possible explanation for this difference, according to previous studies (Chesney-Lind 1973, 1974), is that females are not expected to perform such blatant acts and should not be allowed to get away with them. Also, the perceived costs of reporting the female's behavior may be lower because the threat of retaliation is less.

Briefly, major findings of reporting behavior were:

- Staged littering was reported in 13 percent of the trials and other illegal behavior in 7 percent. Some campers reported both types of behavior.

- Campers usually reported unstaged illegal behavior when the ranger was describing problems with rule violations and asking for help. Staged littering was reported predominately during the patrol.

- Only three parties in the sample turned in cards.

- Male adults or men and women together did most of the reporting. Men reported the staged littering, but both men and women reported other illegal behavior.

- Campers who reported automobile violations tended to give color and make of the vehicles, but not license numbers.

- More violations were reported during the morning trials when camp activities were passive than during afternoon or evening trials when competing activities took precedence.

Direct Intervention

Some type of direct intervention was observed in 24 percent of the 128 trials. Appeals for help apparently changed 7 percent of the behavior (fig. 4). Three types of direct intervention by men and women were observed (table 14): Physical gestures (pointed fingers, placed hands on hips, or nodded heads); words; or following the litterer to the camp entrance, and talking to him or her. Some campers reacted in more than one way.

If a man reacted, he usually said something (table 14), such as: "Hey, pick up that can;" "Hey, knock that off;" "Dummy . . . ;" "Hey, come get that back;" or "Get their license number." Some campers followed the litterers. In one instance, three men chased the offenders and told them, "Take your beer can with you . . . find a garbage can."

Women intervened less frequently than men. When they did, the response was usually spoken: "You pick up that can;" "Somebody threw a can;" or "Litterbugs!" Children were rarely observed dealing with the litterers and were excluded from the analysis. If boys did anything, they responded in words. Responses by children were in the presence of adults.

The type of can thrown was found to influence intervention (table 15). More intervention occurred when beer cans were used (33.3 percent) than when soda cans were used (12.5 percent). Similarly, littering with beer cans was reported more often. Campers may feel beer cans are more objectionable than soda cans.

The male litterer produced higher intervention rates (29.1 percent) than the female (20.5 percent). This differs from the reporting response, where littering by the female produced a higher reporting rate than littering by the male.

Direct intervention by campers was evaluated according to style of camping — that is, whether they used more than one type of recreational unit, such as a trailer and tents; a pickup camper and tents; or two pickup campers and trailer (table 16). More intervention was observed in trials at sites with multiple camping styles (38.9 percent) than at sites with one type of vehicle or tent (21.4 percent).

Intervention was also influenced by whether campsites were single or double (table 16). Trials at double campsites where more than one party was camped produced higher intervention rates than trials at single campsites. Double campsites also imply larger groups.

Major findings on direct intervention can be summarized as follows:

- Nearly one-quarter (24 percent) of the camping parties dealt directly with the litterer. The appeal apparently produced a 7-percent increase in direct intervention.

- Three types of intervention were found: physical gestures, spoken expressions, and following the litterer.

- Although both men and women intervened, men responded more frequently and usually by speaking; women also reacted by speaking, but less frequently than men. Children rarely intervened.

- More intervention occurred when a beer can was thrown than when a soda can was thrown.

- More intervention came from sites with more than one vehicle and from sites with more than one style of camping. This may imply there is safety in numbers and intervention increases with the size of camping party. More reporting was done by small camping parties, suggesting that small parties may prefer to turn matters over to authorities.

w costs of intervening were perceived unclear. The major reaction was to pick the can, a low-cost reaction that poses e or no threat. Reporting the problem an authority could be perceived as a edium-cost reaction. Direct intervention s expected to be the high-cost action, and less direct intervention than porting had been expected. But direct ervention occurred more (24 percent) in reporting (13 percent). Does this ean campers perceive direct interven- n as less threatening than reporting? is seems unlikely. Explanations may pend on the nature of the offense, age the offenders, and the number of enses. Direct intervention may be eferred when the illegal act is littering, not if it is throwing a knife at a tree, for ample.

e age of the offenders may also be a terminant. Adults might intervene if ldren are the offenders, but not when er adults commit a violation. The mber of offenders may also be a erminant. A witness might intervene h one offender, but not with three or r. Appearance and sex of the offender y also be a determinant.

najor implication is that, for reasons of ety, managers should not encourage rs to deal directly with offenders.

tilittering

king up staged litter was the most quent response. Over two-thirds was ked up (68 percent). Direct interven- and reporting littering occurred less quently. The effect of the appeal peared to be significant and respon- e for a 17-percent change of behavior . 4).

of the litterer was the only variable ted to picking up litter (table 17). Cans n trials with female litterers were ked up more often (74 percent) than n trials with male litterers (60 cent).

The appeal did help with the problem of littering. But did campers generalize the message and apply it to others situations by, for example, policing their own sites? Litter and nails were measured in campsites before and after use. Nearly half (43 percent) of the sites showed decreases in litter; 33 percent of the sites remained the same (table 18). Counts of nails in trees remained the same in about 75 percent of the sites. Campers' reactions (direct intervention, reporting, or antilittering) were subdivided with campers' litter counts. The data show that regardless of reaction to staged littering more campers picked up their own campsite litter than contributed to it. For instance, among campers who directly intervened, 38.1 percent more picked up their own litter than contributed to it (table 19). Of those who reported the littering, 28.6 percent more picked up their own litter than added to it. Campers who picked up the staged litter also picked up their own campsite litter (90.5 percent).

These findings suggest that campers, seeing the staged littering and reacting in one or more ways, later realized that the campground really had a littering problem and cleaned up their own campsites. They may also see picking up campsite litter as low-cost, helping behavior.

Antilittering activities can be summarized as follows:

- Over two-thirds of the staged litter was picked up. The appeal to help changed behavior among 17 percent of the experimental group.
- More cans discarded by female litterers were picked up than those discarded by males.
- The majority of campers who reacted to the staged littering also cleaned up their own sites; this suggests that the appeal was generalized by users to other situations. But the number of nails in trees was not reduced, possibly because campers were not aware of them or the damage they cause.

Conclusions

The study showed that when an appeal to help was delivered, most campers were willing to become involved. The most frequent response was to pick up the litter; direct intervention was less frequent; reporting to authorities was least. Involvement by campers may be related to the perceived costs and benefits of direct intervention. Previous research has indicated that response may depend on the nature of the offense. For instance, campers have reported that they would directly intervene with a litterer but would report a vandal (Clark et al. 1971b). If the offense is innocuous, like littering, campers apparently prefer to intervene directly. Intervention may depend on the number, ages, and appearance of offenders, and other unidentified factors.

Efforts to educate the public to intervene or to report are not new. Reporting programs began in the early 1960's. Examples of current campaigns are: "Next time you see someone polluting, point it out" (Keep America Beautiful); "Report Vandalism" (Washington State Highway Department); and "Rat on a Rat" (Washington Bankers Association and Washington Savings League). Similar reporting programs relate to hunting and fishing violations.

Such reporting programs may control some current problems and prevent others. They have several benefits:

- They may deter a potential rule violator out of fear of being caught or being reported by a witness.
- They may reach people who do not recognize certain actions as being depreciative. Persons reported can be told by rangers what the campground problems are and asked for their cooperation. This strategy can help generate skills and behaviors needed in recreation settings. Research has demonstrated that contact with rangers is perceived by campers as positive.
- They can help control problems with individuals or groups who purposely commit violations, by identifying rule violators so authorities can remove them from the area.

- They inform managers of offenses previously unreported, giving a better assessment of the extent and nature of depreciative behavior.

- They reduce impacts on the natural environment on both public and private property, reduce the impact on fiscal resources, and increase users' satisfaction and enjoyment of areas.

A reporting program must be conducted with a positive attitude. Recreational visitors are willing to become involved; managers and researchers need to find appropriate ways to channel that involvement. Some general guidelines can be listed for managers considering an appeal-to-help program:

- Campground users must be informed why reporting is needed and the costs of rule violations in terms of damage to facilities and natural resources. If users fail to perceive the seriousness of carving initials in a table or throwing knives at trees, they are not likely to report such violations by others.

- Users must be told what kinds of information to report, such as the offender's campsite number or vehicle license number.

- Users must be told how to report by filling out a card at the campground fee box, by informing the ranger on patrol, or in a letter or telephone call to the appropriate authorities.

- Reporting must be convenient; rangers or report boxes in campgrounds must be accessible. In this study, reporting orally to the ranger was more convenient than filling out the report card and depositing it in the box. Boxes were from 25 feet to more than 1,000 yards from campsites. Parties that reported by card were camped from 143 to 350 yards from the boxes. Further tests are needed to determine whether campers will report on cards in the absence of a ranger.

- Protecting the identity of witnesses may be necessary to minimize fear of retaliation and potential risks.

Several steps are required to initiate a system for reporting by recreation users.

STEP 1. ASSESS THE PROBLEM and DECIDE ON A TARGET LOCATION

What is the problem? How serious is it? Where does it occur?

STEP 2. DETERMINE THE AUDIENCE

Is the program to be geared to individuals, groups, or both? People with special interests?

STEP 3. EDUCATE THE USERS

A. *Tell users why their help is needed.* How serious is the problem? What are its financial, resource, and social impacts? What other consequences might these violations have—closures, increased fees, more laws and restrictions?

B. *Tell users what to report.* Should they report any person or group behaving suspiciously? Should they watch for specific violations only? What details should the report include — campsite number, license number, trail number, description of the rule violator?

C. *Tell users how to report and to whom.* Reporting must be convenient. Some alternatives are by citizenband radio, report card, in person, telephone call, or letter.

Media for educating users include television, radio, signs, car stickers, brochures, newspapers, presentations at environmental programs, and personal appeals by rangers, fire-patrol persons, or other representatives.

Research Needs

No one program will control or prevent problem behavior. A systems approach, with empirical testing of the effectiveness of different programs, is needed. This study tested the effectiveness of one approach: appealing to witnesses to report violations. Many questions remain. Costs and incentives need to be identified. Literature on this subject is scant, but a recent study by Bickman and Helvig (1979) found that anonymity and monetary rewards had no effect on reporting. They found that subjects did not expect rewards for doing their duty. Researchers might identify the nature and extent of reporting for various types of violations and determine whether appeals need to be targeted or can be generalized. Additional testing is needed on media for appeals.

More research of this type is needed on other strategies with the potential for reducing and controlling depreciative behavior. What kinds of site designs deter vandalism? Why? Evaluative research is an effective tool for testing the strengths and weaknesses of different approaches to control and prevention.

iterature Cited

fano, S. S., and A. W. Magill, Eds.
1976. Vandalism and outdoor recreation: Symposium proceedings. USDA For. Serv. Gen. Tech. Rep. PSW-17, 72 p. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

ron, R. A., and D. Byrne.
1976. Social psychology, understanding human interaction. 2d ed. 588 p. Ellyn and Bacon, Inc., Boston.

rkowitz, L., Ed.
1972. Social norms, feelings, and other factors affecting helping and altruism. *In* Advances in social psychology 6, p. 63-108. Acad. Press, N.Y.

ckman, L.
1972. Social influence and diffusion of responsibility in an emergency. J. Exp. Soc. Psychol. 8:438-445.

ckman, L.
1976. Attitude toward an authority and the reporting of a crime. Sociometry 39(1):76-82.

ckman, L., and S. K. Green.
1977. Situational cues and crime reporting: Do signs make a difference? J. Appl. Soc. Psychol. 7(1):1-18.

ckman, L., and H. Helwig.
1979. Bystander reporting of a crime. Criminology 17(3):283-300.

kman, L., P. Lavrakas, S. Green, and thers. 1977. Citizen crime reporting projects (April). National Evaluation Program, Phase I Summary Report. U.S. Dep. Justice, Natl. Inst. of Law Enforcement and Crim. Justice, Law Enforcement Assist. Adm., Washington, D.C.

lock, H. M., Jr.
1972. Social statistics. 2d ed. 583 p. McGraw Hill, N. Y.

da, P. R., S. E. Bleda, D. Byrne, and L. A. Vhite. 1976. When a bystander becomes n accomplice: Situational determinants of eactions to dishonesty. J. Exp. Soc. sychol. 12:9-25.

B ton Parks and Recreation Commission.
978. Managing vandalism — a guide to educing damage in parks and recreation acilities. 58 p. Parkman Cent. Urban Aff., oston, Mass.

B verman, I. K., S. R. Vogel, D. M. roverman, and others. 1972. Sex-role tereotypes: A current appraisal. J. Soc. ssues 28(2):59-78.

Burgess, R. L., R. N. Clark, and J. C. Hendee. 1971. An experimental analysis of anti-litter procedures. J. Appl. Behav. Anal. 4(2):71-75.

Campbell, F. L., J. C. Hendee, and R. N. Clark. 1968. Law and order in public parks. Parks and Recreat. (December): 28-31, 51-55.

Chesney-Lind, M.
1973. Judicial enforcement of the female sex role. Issues in Crim. 8(1):51-69.

Chesney-Lind, M.
1974. Juvenile delinquency: The sexualization of female crime. Psychol. Today 8:43-46.

Christensen, H.
1978. Bystander reactions to illegal behavior in a forest recreation area. Ph.D. thesis, Univ. Wash., Seattle. 166 p.

Christensen, H. H., and R. N. Clark.
1978. Understanding and controlling vandalism and other rule violations in urban recreation areas. *In* Proceedings, Natl. Urban For. Conf., p. 63-84. November 13-16, 1978, Washington, D.C.

Clark, R. D. III, and L. E. Word.
1972. Why don't bystanders help? Because of ambiguity? J. Pers. and Soc. Psychol. 24(3):392-400.

Clark, R. D. III, and L. E. Word.
1974. Where is the apathetic bystander? Situational characteristics of the emergency. J. Pers. and Soc. Psychol. 29(3):279-287.

Clark, R. N.
1976a. Controlling vandalism in recreation areas — fact, fiction, or folklore? *In* Vandalism and outdoor recreation: Symposium proceedings, p. 62-72. S. S. Alfano and A. W. Magill, eds. USDA For. Serv. Gen. Tech. Rep. PSW-17. Pac. Southwest For. and Range Exp. Stn., Berkeley, Calif.

Clark, R. N.
1976b. How to control litter in recreation areas: The incentive system. USDA For. Serv., Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Clark, R. N., R. L. Burgess, and J. C. Hendee.
1972a. The development of anti-litter behavior in a forest campground. J. Appl. Behav. Anal. 5(1):1-5.

Clark, R. N., J. C. Hendee, and R. L. Burgess.
1972b. The experimental control of littering. J. Environ. Educ. 4(2):7 p.

Clark, R. N., J. C. Hendee, and F. L. Campbell. 1971a. Depreciative behavior in forest campgrounds; an exploratory study. USDA For. Serv. Res. Pap. PNW-161, 12 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Clark, R. N., J. C. Hendee, and F. L. Campbell. 1971b. Values, behavior, and conflict in modern camping culture. J. Leisure Res. 3(3):143-159.

Clinard, M. B.
1974. Sociology of deviant behavior. 4th ed. 685 p. Holt, Rinehart and Winston, N. Y.

Downing, K., and C. M. Moutsinas.
1978. Manager's views of dispersed recreation along forest roads. J. For. 76(9):583-585.

Driessen, J.
1978. Problems in managing forest recreation facilities: A survey of field personnel. USDA For. Serv., Equip. Dev. Cent., p. 106, Missoula, Mont.

Flickinger, T. B.
1976. Crime and law enforcement in Ohio's State Parks. Ph.D. thesis, Ohio State Univ., Columbus.

Heberlein, T. A.
1971. Moral norms, threatened sanctions, and littering behavior. Ph.D. thesis, Univ. Wis., Madison. 253 p.

Hendee, J. C., G. H. Stankey, and R. C. Lucas. 1978. Wilderness management. Misc. Publ. 1365, USDA For. Serv., Washington, D.C.

Keep America Beautiful.
1968. Who litters and why. Summary of survey findings concerning public awareness and concern about the problem of litter. Prepared by Public Opinion Surv., Inc., Princeton, N.J.

Latané, B., and J. M. Darley.
1968. Group inhibition of bystander intervention in emergencies. J. Pers. and Soc. Psychol. 10(3):215-221.

Latane, B., and J. M. Darley.
1970. The unresponsive bystander. Why doesn't he help? 131 p. Appleton-Century-Crofts, N. Y.

Latané, B., and J. Rodin.
1969. A lady in distress: Inhibiting effects of friends and strangers on bystander intervention. J. Exp. Soc. Psychol. 5:189-202

Maier, N. R.
1970. Male versus female discussion leaders. Personnel Psychol. 23(3):455-461.

Morgan, C. J.
1976. Bystander intervention: Experimental test of a formal model. Ph.D. thesis, Univ. Wash., Seattle. 89 p.

Morgan, C. J.
1978. Bystander intervention: Experimental test of a formal model. J. Pers. and Soc. Psychol. 36(1):43-55.

Moriarty, T.
1975. Crime, commitment, and the responsive bystander: Two field experiments. J. Pers. and Soc. Psychol. 31(2):370-376.

Muth, R. M., and R. N. Clark.
1978. Public participation in wilderness and backcountry litter control: A review of research and management. USDA For. Serv. Gen. Tech. Rep. PNW-75, 12 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Piliavin, J. A., and I. M. Piliavin.
1972. Effect of blood on reactions to a victim. J. Pers. and Soc. Psychol. 23(3):353-361.

Piliavin, I. M., J. Rodin, and J. A. Piliavin.
1969. Good samaritanism: An underground phenomenon? J. Pers. and Soc. Psychol. 13(4):289-299.

Shafer, E. L., Jr., and R. C. Lucas.
1978. Research needs and priorities for dispersed recreation management. J. Leisure Res. 10(4):311-320.

Shaffer, D. R., M. Rogel, and C. Hendrick.
1975. Intervention in the library: The effect of increased responsibility on bystanders' willingness to prevent a theft. J. Appl. Soc. Psych. 5(4):303-319.

U.S. Department of Agriculture, Forest Service. 1975. Recreation information management system. RIM Center, Washington, D.C.

U.S. Department of the Interior.
1977. National urban recreation study. Seattle, Everett, and Tacoma. 363 p. Heritage Conserv. and Recreat. Serv., and Natl. Park Serv., Seattle, Wash.

U.S. Department of the Interior.
1978. National urban recreation study. 184 p. Executive Rep., Heritage Conserv. and Recreat. Serv., Washington, D.C.

U.S. Department of the Interior.
1979. Memorandum — Servicewide crime statistics, 1978. 56 p. Natl. Park Serv., Washington, D.C.

ppendix

ble 1—Number of cases[1] for experimental conditions (N = 128)

peal deliverer	Without cards		With cards	
	Oral appeal	Printed appeal	Oral appeal	Printed appeal
nger	20	21	15	12
rest Service volunteer	5	10		
rest Service campground host	0	9		
ntrol	36			

case is a camping party at a campsite.

ble 2—Effect of an appeal to help on users' reaction to rule violation

action of mpers	Treatment (appeal to help)	Control	Total
	Percent		
action Direct or in-irect inter-ention)	82.6	61.1	76.6(98)[1]
reaction Noninterven-on)	17.4	38.9	23.4(30)
Total	100.0(92)	100.0(36)	100.0(128)[2]

mbers in parentheses indicate number of trials.

u_b = .23 significant at .005 level; gamma = .50, x^2 = 5.52(1) significant at .02 level. Several sures of association are used in this paper. Both gamma and tau coefficients will be reported some tables. Tau is considered a more reliable measure of association and does not tend to te a relationship, as gamma has a tendency to do. Gamma is preferred by many readers, how-, and both measures will be reported (Blalock 1972). Gamma and taus are measures of ciation that describe the strength of the relation between two variables; they describe the ee to which the values of one variable vary with the values of another variable. Both the es of one variable vary with the values of another variable. Both the tau and gamma vary from a positive relationship, to −1.0, a negative relationship. Zero defines situations in which ables are completely unrelated. Ordinal-level measurement is required for both variables pt in instances where dichotomous variables are tested, as was the case here.

Table 3—Bystander intervention process: Analogy between perspectives of subject and investigator

Stage[1]	Investigator	Subject
2	Describe problem	Become aware of problem
3	Appeal to decide to take personal responsibility	Consider taking and decide to take responsibility
4	Suggest a way to minimize or mitigate problem	Become aware of or be reminded of a way to mitigate problem
1	Simulate littering (delay until stages 2, 3, and 4 completed)	Observe littering
5	Observe intervention among those to whom it has been suggested	Intervene

[1] Stages are those described by Latané and Darley 1970, described on page 1 of this paper.

Table 4—Reactions and percent responses to different types of appeals

Type of reaction by campers	Type of appeal (N = 128)		
	Oral (N = 40)	Printed (N = 52)	Control (N = 36)
	Percent		
Antilittering[1] (N = 128)	72.5[2] (40)[3]	73.1 (52)	55.6 (36)
Direct intervention[4] (N = 128)	25.0 (40)	26.9 (52)	19.4 (36)
Reporting[5] (N = 128)	20.0 (40)	13.5 (52)	5.6 (36)

[1] Cramers V = .17, n.s. Cramers V is a measure of association describing the strength of a relationship between two variables. It assumes that both variables are measured at the nominal level and ranges from 0 to + 1.

[2] To obtain percent of trials in which subjects who received the oral message did not pick up the litter, subtract 72.5 from 100.0 percent.

[3] Numbers in parentheses indicate total number of trials with oral message.

[4] Cramers V = .07, n.s.

[5] Cramers V = .16, n.s.

able 5—Type of appeal deliverer and percentage of trials in which campers reacted to tering

ppeal deliverer	Treatment (N = 92)	Control (N = 36)
	Percent	
rest Service ranger[1] (N = 22)	89.5 (19)	66.7 (3)
esearcher in ranger uniform[2] (N = 74)	82.0 (50)[3]	66.7 (24)
lunteer[4] (N = 23)	85.7 (14)	44.4 (9)
rest Service campground host (N = 9)	66.7 (9)	

Eta = .23, n.s. Eta is a measure of association that describes the strength of a relation between o variables. Eta ranges from 0, no relationship, to + 1, a positive relationship. The dependent riables must be interval or ratio level and the independent variable must be nominal.

Eta = .17, n.s.

Numbers in parentheses indicate total number of trials.

Eta = .43, n.s.

ble 6—Relation of campers' reactions to the number of party members witnessing littering

	Number of party members witnessing the littering			
action of mpers	Camper alone	Two witnesses	Three or more witnesses	Total
	Percent			
reaction	18.7	21.2	27.3	24.3(28)
action	81.3	78.8	72.7	75.7(87)
Total	100.0(16)	100.0(33)	100.0(66)	100.0(115)[1]

au$_c$ = −.07, n.s.

amma = −.17, n.s.

Table 7—Relation of reporting behavior to size of camping party

Behavior	Size of camping party 0 - 2	 3 - 5	 6 or more	 Total
	Percent			
Did not report	69.6	87.3	95.2	86.7(111)
Reported	30.4	12.7	4.8	13.3(17)
Total	100.0(23)	100.0(63)	100.0(42)	100.0(128)[1]

[1] Tau$_c$ = $-$.17 significant at .003 level. Gamma = $-$.57, x^2 = 8.54(2) significant at .01 level.

Table 8—Relation between reaction and the number of other occupied sites in view

Reaction of subjects to staged littering	Number of other occupied sites in view None	 1	 2	 3 or more	 Total
	Percent				
No reaction	26.7	21.9	18.2	0.0	20.3(15)
Reaction	73.3	78.1	81.8	100.0	79.7(59)
Total	100.0(15)	100.0(32)	100.0(22)	100.0(5)	100.0(74)[1]

[1] Tau$_c$ = .11, n.s. Gamma = .26, n.s.

Table 9—Types of problems, how and when reported

Reporting	N	Percent
Problems reported		
Staged littering	17	13.3
Unstaged violations	9	7.0
Did not report	102	79.7
Number of trials	128	100.0
How and when problems are reported		
Unstaged violations reported orally during appeal	9	32.0
Staged littering reported orally during patrol	16	57.0
Staged littering reported in writing during the patrol or by card in box	3	11.0
Number of trials	28	100.0

able 10—Types of reporting systems and to whom campers reported

eporting system	N	Percent
Oral report to patrol		
Reported staged littering	8	20.0
Reported unstaged violations	1	2.5
Did not report	31	77.5
Number of trials	40	100.0
Card		
Reported staged littering	9	10.2
Reported unstaged violations	8	9.1
Did not report	71	80.7
Number of trials	88	100.0

o whom campers reported	N	Percent
Oral report		
To ranger	24	85.6
To campground host	1	3.6
Written report		
To ranger	1	3.6
To campground host	1	3.6
To fee box	1	3.6
Number of trials	28	100.0

Table 11—Characteristics of the reporters

Age group and sex	N	Percent
Male adult	7	30.4
Female adult	4	17.4
Male child	1	4.4
Female child	3	13.0
Male and female adults, together	6	26.1
Female adult and male child, together	2	8.7
Total number of trials reported orally	23	100.0

Table 12—Reports of violations that involved automobiles

Reports	N	Percent
Make of vehicle		
No	8	42.1
Yes	11	57.9
Color of vehicle		
No	6	31.6
Yes	13	68.4
License number		
No	16	84.2
Yes	3	15.8
Number of violations involving automobile	19	100.0

ble 13—Relation of reporting behavior to selected rule-violation variables

eporting	Variable			
	TIME OF OFFENSE			
	Morning	Afternoon	Evening	Total
d not report	81.1	88.6	93.5	86.7(111)
eported	18.9	11.4	6.5	13.3(17)
Total	100.0(53)	100.0(44)	100.0(31)	100.0(128)[1]
	TYPE OF CAN			
	Beer	Soda	Total	
d not report	83.3	91.1	86.7(111)	
eported	16.7	8.9	13.3(17)	
Total	100.0(72)	100.0(56)	100.0(128)[2]	
	SEX OF THE LITTERER			
	Male	Female	Total	
d not report	89.1	84.9	86.7(111)	
eported	10.9	15.1	13.3(17)	
Total	100.0(55)	100.0(73)	100.0(128)[3]	

$au_c = -.11$ significant at .05 level. Gamma $= -.37$, n.s.

$au_b = -.11$, n.s. Gamma $= -.34$, n.s.

$au_b = .06$, n.s. Gamma $= .18$, n.s.

Table 14—Nature and extent of intervention by male and female adults

Type of response	Men		Women	
	N	Percent	N	Percent
Physical gesture				
1 adult	3	96.9	2	1.6
2 adults	1	2.3	0	0
No reaction	124	.8	126	98.4
Number of trials	128	100.0	128	100.0
Spoken reaction				
1 adult	15	11.7	5	3.9
2 adults	3	2.3	0	0
No reaction	110	86.0	123	96.1
Number of trials	128	100.0	128	100.0
Followed offender				
1 adult	2	1.6	2	1.6
2 adults	2	1.6	1	.8
3 adults	1	.7	0	0
No reaction	123	96.1	125	97.6
Number of trials	128	100.0	128	100.0

le 15—Relation between direct intervention and selected rule-violation variables

rvention	Variable		
	TYPE OF CAN		
	Beer	Soda	Total
not intervene	66.7	87.5	75.8(97)
rvened	33.3	12.5	24.2(31)
Total	100.0(72)	100.0(56)	100.0(128)[1]
	SEX OF THE LITTERER		
	Male	Female	Total
not intervene	70.9	79.5	75.8(97)
rvened	29.1	20.5	24.2(31)
Total	100.0(55)	100.0(73)	100.0(128)[2]

ı$_b$ = −.24, significant at .003 level. Gamma = −.56, x^2 = 6.36(1) significant at .01 level.

ı$_b$ = −.08, n.s. Gamma = −.23, n.s.

le 16—Relations between direct intervention and selected situational variables

rvention	Variable		
	STYLE OF CAMPING		
	Single	Multiple[1]	Total
not intervene	78.6	61.1	76.0(92)
vened	21.4	38.9	24.0(29)
Total	100.0(103)	100.0(18)	100.0(121)[2]
	DESIGN OF CAMPSITE		
	Single	Double	Total
iot intervene	79.2	59.1	75.8(97)
vened	20.8	40.9	24.2(31)
Total	100.0(106)	100.0(22)	100.0(128)[3]

itiple" implies more than one type of equipment and may also imply larger groups.

ɛ$_b$ = .15 significant at .05 level. Gamma = .40, n.s.

ɛ$_b$ = .18 significant at .02 level. Gamma = .45, n.s.

Table 17—Relation of antilittering to sex of the offender

Behavior	Male	Female	Total
Did not pick up litter	40.0	26.0	32.0(41)
Picked up litter	60.0	74.0	68.0(87)
Total	100.0(55)	100.0(73)	100.0(128)[1]

[1] Tau_c = .15 significant at .05 level. Gamma = .31, n.s.

Table 18—Change in litter and nail counts at campsites

Change	N	Percent
Litter		
Increase	12	24.5
Decrease	21	42.8
Remained the same	16	32.7
Total	49	100.0
Nails in trees		
Increase	7	20.6
Decrease	1	2.9
Remained the same	26	76.5
Total	34	100.0

ble 19—Relation of reactions to campers' litter behavior

actions by campers	Change in campsite litter Pieces of litter increased	Pieces of litter decreased	No change	Total
ect intervention				
Did not intervene	75.0	61.9	93.7	75.5(37)
Directly intervened	25.0	38.1	6.3	24.5(12)
Total	100.0(12)	100.0(21)	100.0(16)	100.0(49)[1]
porting				
Did not report	91.7	71.4	93.7	83.7(41)
Reported	8.3	28.6	6.3	16.3(8)
Total	100.0(12)	100.0(21)	100.0(16)	100.0(49)[2]
ilittering				
Did not pick up staged litter	25.0	9.5	37.5	22.4(11)
Picked up staged litter	75.0	90.5	62.5	77.6(38)
Total	100.0(12)	100.0(21)	100.0(16)	100.0(49)[3]

$u_c = -.18$, n.s. Gamma $= -.37$, n.s.

$u_c = -.05$, n.s. Gamma $= -.13$, n.s.

$u_c = -.13$, n.s. Gamma $= -.27$, n.s.

Christensen, Harriet H.
1981. Bystander intervention and litter control: Evaluation of an appeal-to-help program. USDA For. Serv. Res. Pap. PNW-287, 25 p. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Managers of public recreation areas are concerned about increases in vandalism and disregard for regulations and the rights of others by some users. Other than the litter incentive program, none of the approaches for reducing violations have been evaluated or proved effective. The present study evaluated a program to increase involvement of campers in the management of depreciative behavior by reporting violations they witness. Results suggest that users who witness littering will help, by reporting infractions to authorities, dealing with the litterer, or picking up the litter.

Keywords: Appeal to help, public involvement, litter, recreation research, depreciative behavior, bystander intervention, recreation management, experimental analysis.

The **Forest Service** of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

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Acceptance by Black-Tailed Deer of Foliage Treated With Herbicides

Dan L. Campbell, James Evans, Gerald D. Lindsey
and William E. Dusenberry

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CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

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bstract

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illiam E. Acceptance by black-tailed
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ides. Res. Pap. PNW-290. Portland,
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orest Service, Pacific Northwest
orest and Range Experiment Station;
lympia, WA: U.S. Department of the
nterior, Fish and Wildlife Service,
orest-Animal Damage Control Research
roject; 1981. 31 p.

o test their acceptance of foliage
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lack-tailed deer were exposed to
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ests were made from November 1977
nrough February 1978. Deer readily
rowsed 2,4,5-T treatments and most
ormulations of 2,4-D in oil compared
ith oil alone, but showed rejection
 some phytotoxic glyphosate treat-
ents. Consumption of herbicide-
reated foliage did not cause notice-
ble health problems in test animals.

ywords: Herbicides, browse prefer-
ce, deer (black-tailed), *Odocoileus*
mionus columbianus, Douglas-fir,
eudotsuga menziesii, salal, *Gaul-*
eria shallon, atrazine, 2,4,5-T,
4-D.

Summary

Herbicides are an integral part of forest management in the Pacific Northwest. Effects of herbicides on forest vegetation are fairly well known, but their effects on wildlife are relatively unknown.

To test acceptance by black-tailed deer of foliage treated with herbicides, we treated dormant Douglas-fir seedlings and salal with standard herbicide formulations and exposed them to two groups of captive deer in large enclosures. The deer readily browsed most standard formulations regardless of herbicide, carrier, or plant material tested without obvious effects on their behavior or health. Formulations of 2,4,5-T from 1.12 to 5.60 kilograms active ingredient per hectare in 93.45 liters per hectare of water or diesel oil carrier had no significant effect on deer browsing. Significant interaction of 2,4-D and carriers occurred with 2,4-D in 100-percent diesel oil, resulting in increased acceptance of plant material compared with 100-percent diesel oil alone. Reduced acceptance of seedlings treated with glyphosate, which later proved phytotoxic, indicated possible deer sensitivity to either the herbicide or physiological change of Douglas-fir; we suspect the latter. Deer accepted Douglas-fir treated with atrazine, fosamine, and dalapon. Douglas-fir treated with atrazine formulations showed significantly better growth than controls.

Results suggest that further field study should be conducted on deer feeding preferences under operational spraying programs. Modification of formulations might reduce acceptance of treated browse plants by deer in the field.

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ntroduction

erbicides are commonly used to manage egetation on National Forests and ther lands to promote reforestation nd wildlife. In the Western United tates, foliage sprays are used to ontrol unwanted vegetation for conier release and site preparation or onversion of brush fields to producive forests (Dimock et al. 1976; ratkowski 1971, 1977, 1978; Newton 975; Stewart 1974). The sprays have lso been used to improve forage for ildlife (Krefting and Hansen 1969; ufeld 1977; Mueggler 1966). Some ave even promoted dominance of cerain forbs (Newton and Overton 1973) hat have been useful in reducing amage to Douglas-fir (*Pseudotsuga enziesii* (Mirb.) Franco) by blackailed deer (*Odocoileus hemionus olumbianus* Richardson) (Campbell and vans 1975, 1978).

ajor reforestation goals call for ehabilitation of several million cres of brush fields in the Pacific orthwest (Gratkowski et al. 1973). ntensive forest management also frequently requires regular treatment of oung plantations with herbicides to educe brush competition (Newton 970). These brushy areas are prime abitat for wildlife. Added to the eneral concern about safe use of erbicides in forests (Evans 1974; orris 1971; Plumb et al. 1977)is onsiderable concern about effects of erbicides on wildlife (Juntenen and orris 1972; Leng 1977; Meehan et al. 974; Mullison 1970; Thilenius and rown 1976). Effects on deer consuming reated foliage and the possible coneyance of herbicide residues to human eings are of particular concern (Dost 978; Newton and Snyder 1978).

Despite numerous evaluations of positive and negative effects of herbicides, limited study has been done on direct consumption of herbicide-treated plants by animals (Scifres 1977). Although numerous chemicals have been tested on black-tailed deer (Campbell and Bullard 1972; Campbell and Evans 1977; Gauditz 1977), only one recently registered forest herbicide--Roundup® (glyphosate)--has been evaluated on black-tailed deer (Sullivan and Sullivan 1979). We conducted tests to determine if black-tailed deer selectively browsed vegetation treated with glyphosate and five other registered herbicides. Label information on herbicides is given in Appendix A.

Methods

Tests were conducted from November 1977 through February 1978 at the Forestry Sciences Laboratory at Olympia, Washington. Two groups of captive black-tailed deer served as test animals. Douglas-fir and salal (Gaultheria shallon Pursh)--both typical deer browse plants--were sprayed with selected herbicide formulations, and the amount of browsing by deer was measured. The effects of the herbicides on Douglas-fir seedling growth and survival were also measured.

Figure 1.--Black-tailed deer acceptance of Douglas-fir seedlings treated with herbicides being tested in a U.S. Fish and Wildlife Service enclosure at Olympia, Washington.

Test Animals

In Douglas-fir tests, we used a group of four bucks (1 subadult and 3 adults) and four does (2 subadults and 2 adults). In salal tests, three adult deer (1 buck and 2 does) were used. The groups were tested in large, partially wooded enclosures (fig. 1). Each deer had free access to treated materials, natural forage, pelleted food, and water.

Plant Materials

The Douglas-fir seedlings tested, averaging 20-cm tall, were grown in containers by the Weyerhaeuser Company. The seedlings were washed five times with cold water by pressure spray and air dried overnight under an outdoor shelter. The seedlings were spaced in racks for uniform spray treatment(fig. 2).

Salal branches of uniform size with 10 leaves per branch were freshly cut from a nearby stand before each test. The salal branches were also washed and placed in racks for treating.

Figure 2.--Placement of container-grown Douglas-fir seedlings in racks to allow uniform coverage of herbicide spray.

Herbicides and Carriers

Six registered herbicides were formulated in tap water, 10-percent diesel oil in water, or 100-percent diesel oil. Chevron Diesel Fuel No. 2 was used in all oil formulations. Herbicides tested were:

Trade name	Common name	Chemical name
Esteron 245®	2,4,5-T	propylene glycol butyl ether ester of 2,4,5-trichlorophenoxyacetic acid.
Esteron 99 Concentrate®	2,4-D	propylene glycol butyl ether ester of 2,4-dichlorophenoxyacetic acid.
AAtrex 50W®	atrazine	2-chloro-4-ethylamino-6-isopropylamino-1,3,5-triazine.
Dowpon M®	dalapon	sodium salt of 2,2-dichloropropionic acid.
Krenite®	fosamine	ammonium ethyl carbamoylphosphonate
Roundup®	glyphosate	isopropylamine salt of N-(phosphonomethyl) glycine.

Formulation and Application

Herbicides were mixed in the laboratory according to label instructions and applied at a uniform rate of 93.45 liters per hectare. The amount of active ingredient applied was based on recommended rates for each herbicide, from 1.12 to 8.96 kilograms per hectare. Application to foliage was standardized by spraying droplets about 200 microns in diameter at a pressure of 0.91 kilograms per square centimeter from about 1 meter above the plants (fig. 3). Spray equipment was described by Duffy and Schneider (1974).

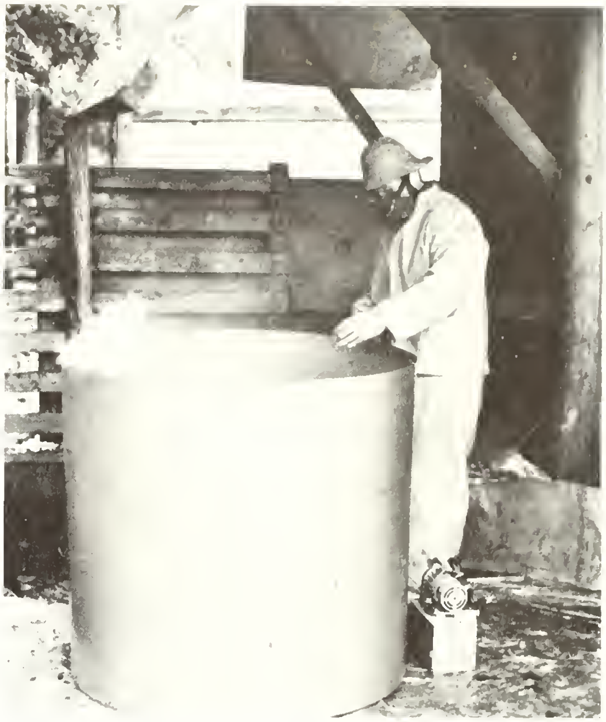

Figure 3.--Herbicide formulations being sprayed on vegetation for exposure in black-tailed deer acceptance tests.

Treatments

Six tests were conducted, four with Douglas-fir seedlings and two with salal branches. Herbicide treatment combinations with carriers are listed in table 1. All plant materials that served as controls were sprayed with water.

Table 1--Levels of herbicides and carriers used in the treatment combinations for Douglas-fir and salal tests

Plant	Test	Carrier (diesel oil in water)	Herbicide	Rate of application
		Percent		Kilograms per hectare
Douglas-fir	1A	0 (water), 10, 100	2,4,5-T	0, 1.12, 2.24, 3.36, 4.48, 5.60
	2A	0, 10, 100	2,4-D	0, 1.12, 2.24, 3.36, 4.48, 5.60
	3A	0, 10, 100	50% 2,4,5-T + 50% 2,4-D	0, 1.12, 2.24, 3.36, 4.48, 5.60
	4A	0 (water only)	control	0
			2,4-D	1.12
			fosamine	2.24, 3.36, 4.48, 5.60
			glyphosate	1.12, 2.24, 3.36, 4.48
			dalapon	2.24, 4.48, 6.72, 8.96
			atrazine	2.24, 3.36, 4.48, 5.60
Salal	1B	0, 10, 100	2,4,5-T	1.12, 5.60
			2,4-D	1.12, 5.60
	2B	0, 10, 100	50% 2,4,5-T + 50% 2,4-D	1.12, 2.24, 4.48, 5.60

Test Design and Analysis

Douglas-fir tests.--Treated seedlings were planted 1 meter apart in five blocks in a cultivated area inside a 1-hectare deer enclosure (fig. 4). In each block were 36 rows of 10 trees. Each row of 10 trees was an experimental unit to avoid the problems of dichotomous data that would result if individual trees were the experimental unit. Two rows of each treatment combination were in each block, and rows were randomly selected for application of treatment within each block. Each test compared 18 different treatments of 100 seedlings per treatment for a total of 180 rows. The actual measurement was the proportion of seedlings browsed in each row of 10 at a given time.

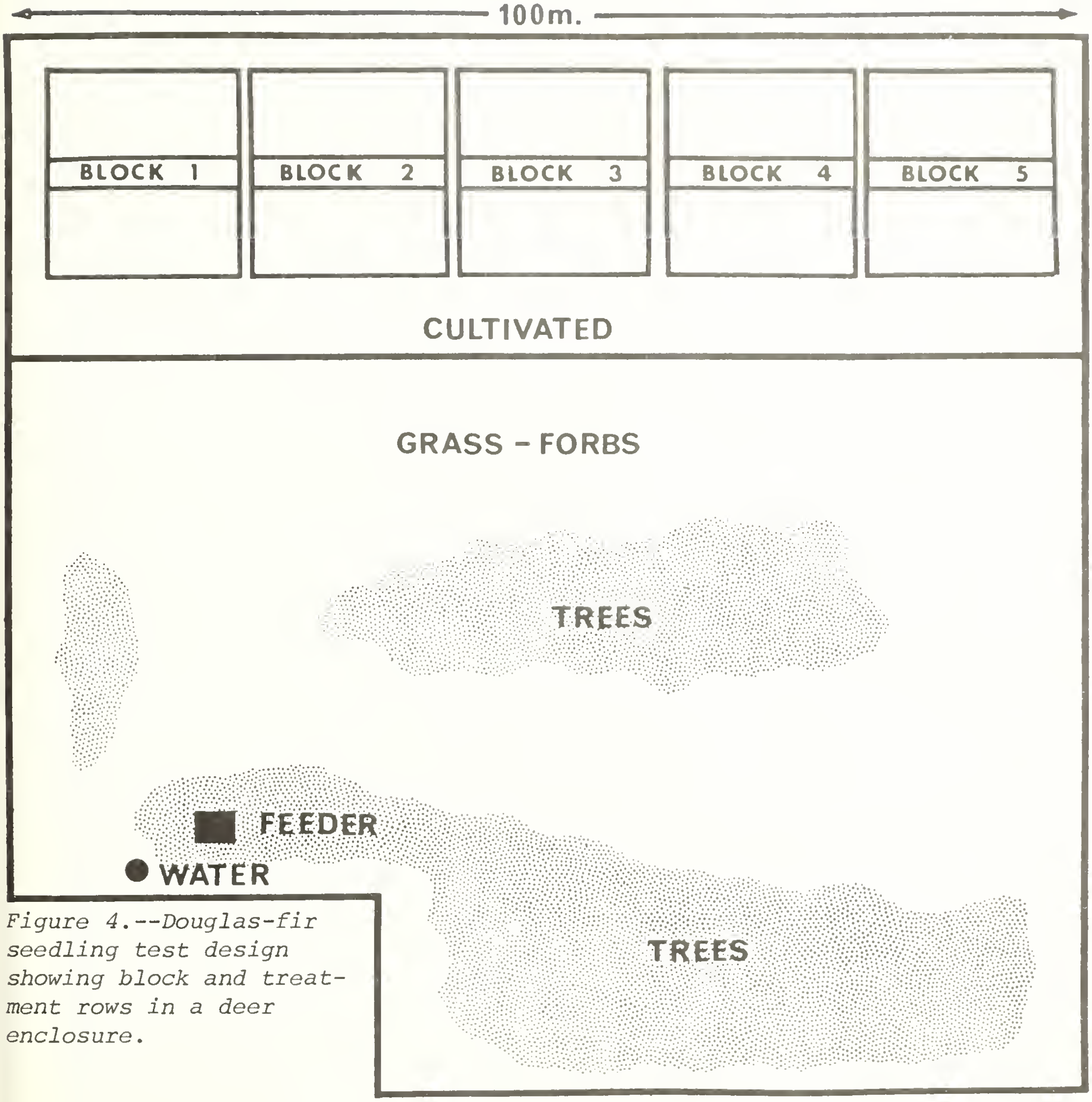

Figure 4.--Douglas-fir seedling test design showing block and treatment rows in a deer enclosure.

Measurements of browsing were started a few hours after planting and subsequent observations made several times each day. To complete a test, deer were required to browse the terminal of 60 percent of the water-sprayed control seedlings within 21 days. Measurements at observation times nearest the 60-percent requirement were selected for analysis of deer preference. Additional measurements were taken for several days for further analysis of preference. The proportion of seedlings browsed (p) was analyzed by the arc sin $\sqrt{p}$ transformation to normalize the proportion data before analysis of variance. Statistically significant main effects or interactions in the analysis of variance were further analyzed by Duncan's multiple-range test applied to the appropriate arc sin $\sqrt{p}$ transformed means.

Salal tests.--Untreated and treated salal branches were stapled to paired stakes (A and B in fig. 5) in each of five blocks spaced throughout a 0.15-hectare enclosure. Either an untreated or treated branch was assigned to stakes A and B at random. Twelve treatments were randomly located within each block. For each test, 120 pairs of treated and untreated salal branches were used.

Browsing was initially measured hourly for the first 6 hours until darkness and then periodically thereafter. A branch was considered browsed if one or more leaves were missing. The observation at the time nearest to when 60 percent of the control branches had been browsed was selected for the primary analysis for deer preference. The differences in numbers of leaves eaten between paired control and treated branches (control minus treated) were tested by analysis of variance to detect treatment effects, and Duncan's multiple-range test was used to separate the means in significant treatment effects.

Douglas-Fir Phytotoxicity

Immediately after Douglas-fir tests were installed, a group of 25 seedlings of each treatment was planted in a separate nursery. These seedlings were checked during the deer tests for any obvious phytotoxicity that might affect deer acceptance and checked again at budburst to determine if trees were alive. Seedlings were also measured 1.5 months after budburst to determine length of new growth in centimeters. The measurements of new growth were analyzed using analysis of variance. Statistically significant main effects of interactions in the analysis of variance were further analyzed using Duncan's multiple-range test applied to appropriate means. Seedling mortality rates were compared among various treatments using Chi-square tests for homogeneity.

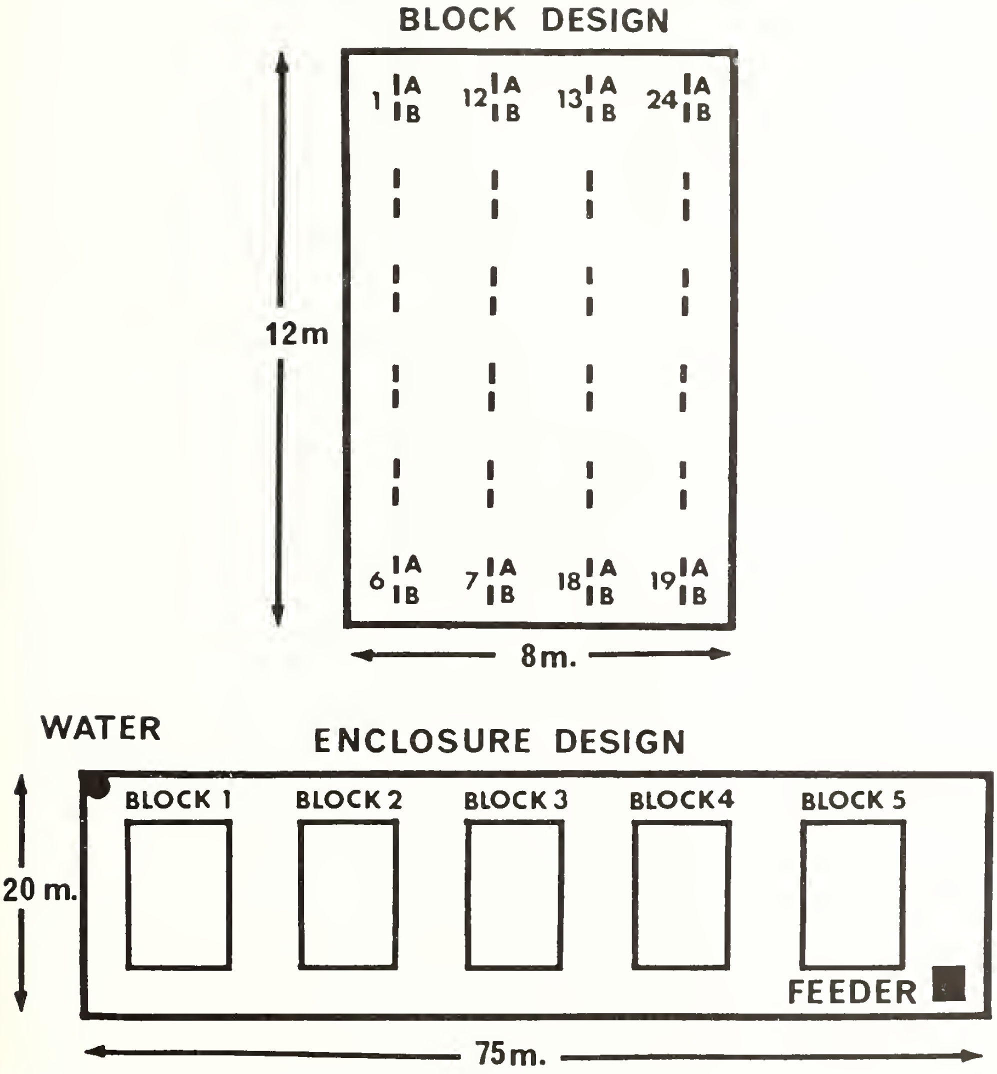

Figure 5.--Salal-test design showing treatment and block location in a deer enclosure.

Deer readily browsed Douglas-fir seedlings and salal cuttings during all tests. (See appendix B - tables 2 through 18 for specific test data.) Temperatures averaged 5°C and relative humidity about 100 percent during each test. Rainfall occurred only during the last Douglas-fir test. Deer behavior and health were not obviously affected by feeding on foliage treated with herbicides or diesel oil during the observation period.

Douglas-Fir Tests

The first Douglas-fir test required 3 days of exposure for the eight deer to browse 60 percent of the untreated control seedlings. The next three tests required an average of only 0.9-day exposure to obtain 60-percent acceptance. Each test was concluded in 4 to 10 days--nearly all seedlings in each test were browsed in this time.

2,4,5-T formulations (TEST 1A).--No significant difference in acceptance was found between controls and 2,4,5-T treatments of 1.12, 2.24, 3.36, 4.48, and 5.60 kilograms per hectare at either 3 days (table 2) or 5 days (table 3). After 5 days of exposure, over 90 percent of most seedling treatments were browsed. Initially, deer showed no significant preference for Douglas-fir treated with water or 10-percent oil (table 4), but they significantly preferred those treated with water or 10-percent diesel oil over 100-percent diesel oil after 5 days.

2,4-D formulations (TEST 2A).--After 0.8-day exposure, seedlings treated with 2,4-D at 1.12, 2.24, 3.36, 4.48, and 5.60 kilograms per hectare in water or in 10-percent diesel oil showed few significant differences in acceptance (table 5). Formulations containing 2.24 and 5.60 kilograms per hectare of 2,4-D in 100-percent diesel oil had significantly higher acceptance than 100-percent diesel oil alone. This significant difference was lost after 1.8 days' exposure (table 6). Deer generally preferred water and 10-percent diesel oil carriers over 100-percent diesel oil (table 7) during these exposure periods.

Mixed formulations of 2,4,5-T and 2,4-D (TEST 3A).--Few significant differences occurred in browsing among control and half-and-half mixtures of 2,4,5-T and 2,4-D. The formulations containing 5.60 kilograms per hectare of 2,4,5-T and 2,4-D were browsed less (but not significantly less) than the controls for the first day only (table 8). After 1.9 days, the 100-percent diesel oil-herbicide formulations at 0, 1.12, 3.36, and 5.60 kilograms active herbicide per hectare were browsed significantly less than the controls (water only, see table 9). Browsing was significantly lower for treatments of 100-percent diesel oil than for 10-percent oil or water treatments at 1.0 and 1.9 days of exposure (table 10).

Other herbicide formulations (TEST 4A).--Only a few of these herbicides, formulated only in water, were browsed significantly less than controls after 0.9-day exposure (table 11). We do not know the effect of light rainfall (0.51 centimeter) during this period. No significant difference was found between 1.12 kilograms per hectare of 2,4-D (standard) and water-treated controls. Most formulations of fosamine, dalapon, and atrazine were readily browsed by deer. Atrazine at 2.24 kilograms per hectare was browsed significantly less than controls and significantly less than atrazine at 3.36, 4.48, and 5.60 kilograms per hectare. Browsing was also significantly lower for formulations of glyphosate at 2.24, 3.36, and 4.48 kilograms per hectare than for controls, and it was significantly higher for 1.12 kilograms per hectare glyphosate than for 3.36 and 4.48 kilograms per hectare. After exposure for 1.9 days, nearly all seedlings of all formulations were browsed, although glyphosate treatments at 3.36 and 4.48 kilograms per hectare were still browsed least (at 88 percent and 89 percent, respectively).

Salal Tests

Formulations of 2,4,5-T and 2,4-D had little effect on consumption of salal. n each test, the three deer browsed 0 percent of the 120 untreated (con- rol) salal branches in less than 0.4 ay. Almost all of the 240 branches nd 2,400 leaves in each test were ompletely browsed by the 2d day.

2,4,5-T and 2,4-D formulations (TEST 1B).--Results of testing 2,4,5-T and 2,4-D separately on salal are summarized in table 12. After 0.4-day exposure, deer showed a significant preference for 2,4,5-T at 1.12 kilograms per hectare over 5.60 kilograms per hectare of 2,4,5-T and 1.12 kilograms per hectare of 2,4-D. Deer preferences among herbicide treatments disappeared after 1 day when nearly everything was uniformly browsed. Water(only)-treated salal was significantly preferred over all herbicide treatments except for 2,4,5-T at 1.12 kilograms per hectare after 0.4-day exposure. The herbicide carriers, including 100-percent diesel oil, had no significant effect on deer acceptance of salal.

Formulations with half-and-half mixtures of 2,4,5-T and 2,4-D (TEST 2B).--After 0.4-day exposure, deer browsing showed no significant difference for salal treated with any of the formulations with half-and-half mixtures of 2,4,5-T and 2,4-D applied at 1.12, 2.24, 4.48, and 5.60 kilograms active herbicide per hectare (table 13). After exposure for 1 day, however, deer showed significant preference for treatments of 4.48 and 5.60 kilograms per hectare over treatments of 2.24 kilograms per hectare. Diesel oil had no obvious effect on preferences in this test. Water(only)-treated salal was significantly preferred over all herbicide treatments after 0.4-day exposure, but this significant preference was only apparent at 1.12 and 2.24 kilograms active herbicide per hectare after exposure for 1 day.

Phytotoxicity and Seedling Growth

The early December applications of 5.60 kilograms per hectare of 2,4,5-T in water or 10-percent diesel oil exhibited no reduction in seedling growth (table 14). Most 100-percent diesel oil formulations were associated with reduced seedling growth and may have contributed to increased mortality of Douglas-fir seedlings.

Some formulations of 2,4-D in water or in 10-percent diesel oil applied in mid-December had a significant effect on Douglas-fir seedling growth (table 15). Formulations that resulted in significantly reduced growth were 3.36 kilograms per hectare in water and 5.60 kilograms per hectare in 10-percent diesel oil. Seedlings treated with 2.24,.3.36, 4.48, and 5.60 kilograms per hectare in 100-percent diesel oil exhibited significantly reduced growth in comparison to controls. Also, seedlings treated with 1.12 kilograms per hectare of 2,4-D in water in December grew significantly more than seedlings treated with the same formulation in February (table 16).

Eight of the nine formulations with half-and-half mixtures of 2,4,5-T and 2,4-D containing 3.36 or more kilograms per hectare active herbicide applied in mid-January, as well as 2.24 kilograms per hectare in 100-percent diesel oil, significantly reduced height growth of Douglas-fir seedlings (table 17). Again, lower rates of the mixed herbicides and oil-carrier treatments did not significantly affect growth.

Douglas-fir seedlings treated with 3.36 and 5.60 kilograms per hectare of atrazine showed a significant height increase over control seedlings (table 18). The mid-February applications of glyphosate, on the other hand, resulted in reduced growth, 28-percent mortality at 1.12 kilograms per hectare, and 88-percent total mortality for treatments at 2.24, 3.36, and 4.48 kilograms per hectare. Fosamine formulations did not affect growth at 2.24 and 5.60 kilograms per hectare, but seedlings treated at 3.36 and 4.48 kilograms per hectare showed significantly less growth than controls. Dalapon formulations at 4.48, 6.72, and 8.96 kilograms per hectare resulted in reduced seedling growth; 2.24 kilograms per hectare did not.

Discussion and Conclusions

None of the 61 forest herbicide treatments tested prevented browsing by these deer. Although plants treated with water or 10-percent diesel oil were initially preferred over those treated with 100-percent diesel oil, these differences became insignificant as browsing progressed and deer had fewer choices. The overall high acceptance of herbicide formulations and carriers is not surprising in view of the known acceptance of other chemicals that have shown high candidacy as deer repellents (Campbell and Bullard 1972).

Formulations of 2,4,5-T from 1.12 to 5.60 kilograms per hectare apparently had little or no effect on deer feeding preferences, 2,4-D in 100-percent diesel oil produced higher deer acceptance than pure diesel oil alone, and all formulations of fosamine and dalapon, and all formulations of atrazine except a 2.24 kilograms-per-hectare treatment, were readily browsed. The phytotoxic effects of glyphosate should be investigated further before field application to dormant Douglas-fir seedlings. The reduced acceptance of glyphosate-affected Douglas-fir seedlings should also be investigated.

Deer showed no obvious adverse effects from herbicides or herbicide formulations; however, only general observations were made on the health of the deer. Long-term effects of these herbicide formulations on deer are not known. If 2,4-D and 2,4,5-T herbicide formulations have no adverse effects on deer as reported by Norris (1971), their ingestion of treated foliage would cause no concern. If food preferences by ruminants are severely altered by herbicide ingestion (Sjöden and Söderberg 1978), the degree of acceptance of treated foliage could be important. More studies are warranted on seasonal variation in deer browsing related to herbicide use and on physiological and ecological effects of herbicides.

Apparent interactions of carriers and herbicides, timing of spray application on dormant Douglas-fir, and effects of some herbicides alone on growth of seedlings produced some noteworthy results. For example, diesel oil alone or at 10-percent in water had no significant effect on spring growth of treated seedlings; however, seedlings treated with several formulations of 2,4,5-T and 2,4-D alone or mixed together in 100-percent diesel oil showed less growth than controls. Using water instead of oil would not necessarily offset this problem. Some treatments of 2,4-D at 1.12 kilograms per hectare in water in December grew as well as control seedlings, but the same treatment applied in February produced a significant reduction in seedling growth. Proper timing could apparently reduce adverse effects of these herbicide formulations on Douglas-fir. Based on our tests and other results, proper timing and application of glyphosate seems to be a critical factor in minimizing its phytotoxic effects on Douglas-fir seedlings.

Our tests and others (Newton and Overton 1973) indicate a direct positive effect of atrazine on growth of Douglas-fir. Deer damage to this increased growth should be determined, because a problem with deer browse was attributed to increased crude protein with simazine (2-chloro-4,6-bis(ethylamino)-s-triazine) in young balsam firs (*Abies balsamea*) by Morgan and McCormack (1973). Some combined properties of herbicides and repellents might be used in developing methods to reduce deer browsing on treated plants, including Douglas-fir, to prevent deer from consuming specific herbicides and damaging trees.

Lastly, to compensate for differences in response of individual deer, we suggest using this herd approach in acceptance tests to simulate the group feeding behavior that occurs under field conditions. Phytotoxicity should be a strongly considered factor in evaluating deer acceptance of herbicide-treated plants. The generally high acceptance of herbicide-treated foliage found in these tests suggests that field evaluations should be done to determine long-term benefits and adverse effects of operationally applied herbicides on deer and deer habitat in the Pacific Northwest.

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Metric Equivalents

1 centimeter = 0.394 inch
1 meter = 3.28 feet
1 hectare = 2.47 acres

1.12 kilograms/hectare = 1 pound/acre
2.24 kilograms/hectare = 2 pounds/acre
3.36 kilograms/hectare = 3 pounds/acre
4.48 kilograms/hectare = 4 pounds/acre
5.60 kilograms/hectare = 5 pounds/acre
6.72 kilograms/hectare = 6 pounds/acre
8.96 kilograms/hectare = 8 pounds/acre

93.45 liters/hectare = 10 gallons/acre

0 degrees Celsius
= 32 degrees Fahrenheit

5 degrees Celsius
= 41 degrees Fahrenheit

Literature Cited

Campbell, D. L.; Bullard, R. W. A preference testing system for evaluating repellents for black-tailed deer. Proceedings, 5th Vertebr. Pest Conf., p. 56-63. Fresno, CA; 1972.

Campbell, D. L.; Evans, J. Improving wildlife habitat in young Douglas-fir plantations. In 40th North Am. Wildl. and Nat. Resour. Conf. Trans. Washington, DC: Wildl. Manage. Inst.; 1975:202-208.

Campbell, D. L.; Evans, J. Guidelines for field evaluation of repellents to control deer damage to reforestation. In Test methods for vertebrate pest control and management materials. Jackson, W. B.; **Marsh, R. E.**, eds. Am. Soc. Test. and Mat. Spec. Tech. Publ. 385:145-150; 1977.

Campbell, D. L.; Evans, J. Establishing native forbs to reduce black-tailed deer damage to Douglas-fir. **Proceedings, 8th Vertebr. Pest Conf., p. 145-151. Sacramento, CA; 1978.**

Dimock, E. J. II; Bell, E.; Randall, R. M. Converting brush and hardwoods to conifers on high sites in western Washington and Oregon--progress, policy, success, and costs. USDA For. Serv. Res. Pap. PNW-213. Portland, OR: Pac. Northwest For. and Range Exp. Stn.; 1976.

Dost, F. N. Toxicology of phenoxy herbicides and hazard assessment of their use in reforestation. USDA For. Serv. Calif. Reg. (R-5); 1978.

Duffy, S. L.; Schneider, B. A. A portable electric sprayer for small plots. Weed Sci. 22(6):568-570; 1974.

Evans, J. Pesticides and forest wildlife in the Pacific Northwest. In Symposium on wildlife and forest management in the Pacific Northwest. Corvallis, OR: Oreg. State Univ.; 1974:205-219.

Gauditz, I. Bioassay methods guiding the development of a big game repellent. In Test methods for vertebrate pest control and management materials. Jackson, W. B.; Marsh, R. E., eds. Am. Soc. Test. and Mat. Spec. Tech. Publ. 625:34-46; 1977.

Gratkowski, H. Midsummer foliage sprays on salmonberry and thimbleberry. USDA For. Serv. Res. Note PNW-171. Portland, OR: Pac. Northwest For. and Range Exp. Stn.; 1971.

Gratkowski, H. Site preparation and conifer release in Pacific Northwest forests. Proceedings 27th Annu. Weed Conf., p. 29-32. Yakima, WA; 1977.

Gratkowski, H. Herbicides for shrub and weed tree control in western Oregon. USDA For. Serv. Gen. Tech. Rep. PNW-77. Portland, OR: Pac. Northwest For. and Range Exp. Stn.; 1978.

Gratkowski, H.; Hopkins, D.; Lauterbach, L. The Pacific Coast and Northern Rocky Mountain Region. J. For. 71(3):138-139; 1973.

Juntenen, E. T.; Norris, L. A. Field application of herbicides--avoiding danger to fish. Agric. Exp. Stn. Spec. Rep. 354. Corvallis, OR: Oreg. State Univ.; 1972.

Krefting, L. W.; Hansen, H. L. Increasing browse for deer by aerial application of 2,4-D. J. Wildl. Manage. 33(4):784-790; 1969.

Kufeld, R. C. Improving Gambel oak ranges for elk and mule deer by spraying 2,4,5-TP. J. Range Manage. 30(1):53-57; 1977.

Leng, M. L. Comparative metabolism of phenoxy herbicides in animals. In Fate of pesticides in the large animal. New York, NY: Academic Press, Inc. 1977:53-76.

Meehan, W. R.; Norris, L. A.; Sears, H. S. Toxicity of various formulations of 2,4-D to salmonids in southeast Alaska. J. Fish. Res. Board Can. 31(4):480-485; 1974.

Morgan, R. H.; McCormack, M. L., Jr. Simazine enhances balsam fir growth but contributes to deer damage. Tree Plant. Notes 24(4):11-13; 1973.

Mueggler, W. F. Herbicide treatment of browse on big game winter range in northern Idaho. J. Wildl. Manage. 31(1):141-151; 1966.

Mullison, W. R. Effects of herbicides on water and its inhabitants. Weed Sci. 18(6):738-750; 1970.

Newton, M. Chemical silviculture. In Management of young growth Douglas-fir and western hemlock. Corvallis, OR: School For., Oreg. State Univ. 1970:21-29.

Newton, M. Constructive use of herbicides in forest resource management. J. For. 73(6):329-336; 1975.

Newton, M.; Overton, W. S. Direct and indirect effects of atrazine, 2,4-D, and dalapon mixtures on conifers. Weed Sci. 21(4):269-275; 1973.

Newton, M.; Snyder, S. P. Exposure of forest herbivores to 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) in areas sprayed with 2,4,5-T. Bull. Environ. Contam. Toxicol. 21:743-750; 1978.

Norris, L. A. Chemical brush control: assessing the hazard. J. For. 69(10):715-720; 1971.

Plumb, T. R.; Norris, L. A.; Montgomery, M. L. Persistence of 2,4-D and 2,4,5-T in chaparral soil and vegetation. Bull. Environ. Contam. Toxicol. 17(1):1-8; 1977.

Scifres, C. J. Herbicides and the range ecosystem: residues, research, and the role of rangemen. J. Range Manage. 30(2):86-91; 1977.

Sjöden, P. O.; Söderberg, U. Phenoxyacetic acids: sublethal effects. In Chlorinated phenoxy acids and their dioxins. Ramel, C., ed. Ecol. Bull. (Stockholm) 27:149-164; 1978.

Stewart, R. E. Foliage sprays for site preparation and release from six coastal brush species. USDA For. Serv. Res. Pap. PNW-172. Portland, OR: Pac. Northwest For. and Range Exp. Stn.; 1974.

Sullivan, T. P.; Sullivan, D. S. The effects of glyphosate herbicide on food preference and consumption in black-tailed deer. Can. J. Zool. 57(7):1407-1412; 1979.

Thilenius, J. F.; Brown, G. R. Effects of 2,4-D on digestibility and production of subalpine herbage. J. Range Manage. 29(1):63-65; 1976.

Appendix A

Labels of the Six Herbicides Tested for Acceptance by Black-Tailed Deer

DOW ESTERON 245 LOW VOLATILE BRUSH AND WEED KILLER

Acid Equivalent: 4 pounds per gallon
Active Ingredient:
  2,4,5-Trichlorophenoxyacetic Acid Propylene Glycol Butyl Ether Esters 67.7 percent
    2,4,5-Trichlorophenoxyacetic Acid Equivalent 44.1 percent
USDA Reg. No. 464-205

DOW ESTERON 99 CONCENTRATE LOW VOLATILE WEED KILLER

Acid Equivalent: 4 pounds per gallon
Active Ingredient:
  2,4-Dichlorophenoxyacetic Acid Propylene Glycol Butyl Ether Esters 72.8 percent
    2,4-Dichlorophenoxyacetic Acid
USDA Reg. No. 464-201

CIBA-GIEGY AATREX 80W HERBICIDE

Batch No. FL-751924
ARS No. 2351/75

DOW DOWPON M GRASS KILLER

Active Ingredients:
  Sodium salt of dalapon 72.5 percent
  Magnesium salt of dalapon 12.0 percent
  Total active ingredients equivalent to 74 percent dalapon (2,2-dichloropropionic acid)
EPA Reg. No. 464-402-2A

MONTSANTO ROUNDUP HERBICIDE

4 pounds of isopropylamine salt of N-(phosphonomethyl) glycine per U.S. Gallon
3 pounds of equivalent acid glyphosate per U.S. Gallon
Active Ingredient:
  Isopropylamine salt of Glyphosate 41.0 percent
EPA Reg. No. 524-308-AA

DUPONT KRENITE

4 pounds per gallon concentrate
Active Ingredient:
  Ammonium ethyl carbamoylphosphonate
EPA Reg. No. 352-376

Table 2--Deer browsing on Douglas-fir seedlings treated with standard 2,4,5-T herbicide formulations after 3 days of exposure (Test 1A)

Rate of application	Diesel oil carrier[1]	Detransformed means[2]
Kilograms per hectare	Percent	Percent
2.24	100	74.1
0	10	71.7
1.12	0	68.8
2.24	0	68.4
1.12	10	67.7
0	0	66.3
5.60	10	65.1
4.48	10	63.6
5.60	0	63.2
0	100	62.0
3.36	10	61.2
5.60	100	60.7
3.36	0	58.3
4.48	100	55.9
4.48	0	53.2
2.24	10	49.6
3.36	100	44.5
1.12	100	40.8

[1] 0 = water only; 10 = 10 percent diesel oil and 90 percent water.

[2] No significant differences were found in the treatment levels.

Table 3--Deer browsing on Douglas-fir seedlings treated with standard 2,4,5-T herbicide formulations after 5 days of exposure (Test 1A)

Rate of application	Diesel oil carrier[1]	Detransformed means[2]
Kilograms per hectare	Percent	Percent
0	0	98.8
1.12	0	98.2
4.48	10	96.6
0	10	96.5
1.12	10	96.0
3.36	0	95.3
2.24	0	95.2
5.60	0	95.1
2.24	10	95.1
0	100	95.0
4.48	100	94.2
4.48	0	94.0
5.60	10	93.5
2.24	100	93.2
3.36	10	91.6
5.60	100	87.0
3.36	100	85.2
1.12	100	77.8

[1] 0 = water only; 10 = 10 percent diesel oil and 90 percent water.

[2] No significant differences were found in the treatment levels.

Table 4--Deer browsing preferences for carriers used in formulations of 2,4,5-T herbicide on Douglas-fir seedlings after 3 days and 5 days of exposure (Test 1A)[1]

Diesel oil carrier[2]	Detransformed means[3]	
	3 days	5 days
	Percent	
0	63.1 a	96.3 a
10	63.3 a	94.9 a
100	56.5 a	89.4 b

[1] See tables 2 and 3 for specific herbicide/carrier interaction means.

[2] 0 = water only; 10 = 10 percent diesel oil and 90 percent water.

[3] Treatment levels with a common letter are not significantly different at the .05-level of significance using Duncan's multiple-range test.

Table 5--Deer browsing preferences for standard formulations of 2,4-D herbicide on Douglas-fir seedlings after 0.8 day exposure (Test 2A)

Rate of application	Diesel oil carrier[1]	Detransformed means[2]
Kilograms per hectare	Percent	Percent
3.36	10	85.7 a
0	0	81.8 a b
1.12	0	81.7 a b
0	10	76.6 a b c
4.48	0	75.8 a b c
2.24	0	75.7 a b c
2.24	10	74.7 a b c
2.24	100	73.0 a b c
5.60	0	72.7 a b c
5.60	100	71.7 a b c
1.12	10	70.9 a b c
4.48	10	69.1 a b c d
4.48	100	62.0 a b c d
3.36	0	61.3 a b c d
1.12	100	58.8 b c d
5.60	10	56.7 b c d
3.36	100	53.2 c d
0	100	42.6 d

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[1] 0 = water only; 10 = 10 percent diesel oil and 90 percent water.

[2] Treatment levels with a common letter are not significantly differenc at the .05-level of significance using Duncan's multiple-range test.

Table 6--Deer browsing preferences for standard formulations of 2,4-D herbicide on Douglas-fir seedlings after 1.8 days of exposure (Test 2A)

Rate of application	Diesel oil carrier[1]	Detransformed means[2]
Kilograms per hectare	Percent	Percent
5.60	0	99.6 a
2.24	10	99.4 a b
3.36	10	99.4 a b c
2.24	0	99.1 a b c
0	0	98.4 a b c
4.48	0	98.0 a b c
0	10	97.0 a b c
1.12	0	97.0 a b c
5.60	10	97.0 a b c
2.24	100	95.9 a b c
1.12	100	95.3 a b c
5.60	100	95.2 a b c
1.12	10	95.0 b c
4.48	100	94.1 b c
3.36	100	94.0 c
4.48	10	93.8 c
3.36	0	91.8 c
0	100	88.4 c

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[1] 0 = water only; 10 = 10 percent diesel oil and 90 percent water.

[2] Treatment levels with a common letter are not significantly different at the .05-level of significance using Duncan's multiple-range test.

Table 7--Deer browsing preferences for carriers used in formulations of 2,4-D herbicide on Douglas-fir seedlings after 0.8 day and 1.8 days of exposure (Test 2A)[1]

Diesel oil carrier[2]	Detransformed means[3] 0.8 days	Detransformed means[3] 1.8 days
- - - - - - - - - - - - -	Percent	- - - - - - - - - - - - -
0	75.1 a	97.8 a
10	72.7 a	97.3 a
100	60.4 b	94.0 b

[1] See tables 5 and 6 for specific herbicide/carrier interaction means.

[2] 0 = water only; 10 = 10 percent diesel oil and 90 percent water.

[3] Treatment levels with a common letter are not significantly different at the .05-level of significance using Duncan's multiple-range test.

Table 8--Deer browsing on Douglas-fir seedlings treated with formulations containing half-and-half mixtures of 2,4,5-T and 2,4-D herbicides after 1.0 day exposure (Test 3A)

Rate of application	Diesel oil carrier[1]	Detransformed means[2]
Kilograms per hectare	Percent	Percent
0	0	82.3
0	10	80.1
2.24	0	76.5
2.24	10	75.4
1.12	10	70.8
1.12	0	66.5
4.48	10	65.8
4.48	0	62.6
5.60	10	62.5
5.60	0	61.4
3.36	10	59.7
4.48	100	45.7
1.12	100	40.5
2.24	100	39.1
3.36	100	35.9
0	100	33.8
5.60	100	29.3

[1] 0 = water only; 10 = 10 percent diesel oil and 90 percent water.

[2] No significant differences were found in the treatment levels.

Table 9--Deer browsing preferences for formulations containing half-and-half mixtures of 2,4,5-T and 2,4-D herbicides after 1.9 days of exposure (Test 3A)

Rate of application of combined herbicides	Diesel oil carrier[1]	Detransformed means[2]
Kilograms per hectare	Percent	Percent
1.12	10	99.1 a
0	10	99.1 a
2.24	0	98.2 a b
3.36	0	98.0 a b
5.60	10	98.0 a b
0	0	97.6 a b c
4.48	10	96.2 a b c d
5.60	0	95.6 a b c d
1.12	0	94.2 a b c d
2.24	10	93.0 a b c d
4.48	0	91.4 a b c d e
3.36	10	90.1 b c d e
4.48	100	87.9 c d e f
2.24	100	87.9 c d e f
0	100	85.4 d e f
1.12	100	78.3 e f
5.60	100	74.3 f
3.36	100	73.1 f

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[1] 0 = water only; 10 = 10 percent diesel oil and 90 percent water.

[2] Treatment levels with a common letter are not significantly different at the .05-level of significance using Duncan's multiple-range test.

Table 10--Deer browsing preferences for carriers used in formulations containing half-and-half mixtures of 2,4,5-T and 2,4-D on Douglas-fir seedlings after 1 day and 1.9 days of exposure (Test 3A)[1]

Diesel oil carrier[2]	Detransformed means[3]	
	1.0 day	1.9 days
	Percent	
0	70.4 a	96.1 a
10	69.3 a	96.5 a
100	37.3 b	81.5 b

[1] See tables 8 and 9 for specific herbicide/carrier interaction means.

[2] 0 = water only; 10 = 10 percent diesel oil and 90 percent water.

[3] Treatment levels with a common letter are not significantly different at the .05-level of significance using Duncan's multiple-range test.

Table 11--Deer browsing preference after 0.9-day exposure for standard formulations of fosamine, dalapon, atrazine, glyphosate, and 2,4-D herbicides applied to Douglas-fir seedlings in water carrier (Test 4A)

Rate of application	Formulation	Detransformed means[1]
Kilograms per hectare		Percent
4.48	fosamine	89.6 a
0	water only	88.5 a b
8.96	dalapon	86.4 a b
4.48	atrazine	86.4 a b
5.60	atrazine	85.8 a b
3.36	atrazine	84.8 a b
2.24	dalapon	82.9 a b
2.24	fosamine	82.5 a b
3.36	fosamine	82.1 a b c
5.60	fosamine	80.2 a b c
4.48	dalapon	77.9 a b c
1.12	glyphosate	71.7 a b c d
1.12	2,4-D	70.6 a b c d
6.72	dalapon	68.3 b c d e
2.24	atrazine	59.6 c d e f
2.24	glyphosate	50.9 d e f
4.48	glyphosate	46.2 e f
3.36	glyphosate	39.6 f

[1] Treatment levels with a common letter are not significantly different at the .05-level of significance using Duncan's multiple-range test.

Table 12--Deer browsing preferences for water-treated salal and salal treated with 2,4,5-T and 2,4-D herbicide formulations after 0.4 day and 1.0 day of exposure (Test 1B)

Herbicide	Rate of application	Mean differences[1] 0.4 day	Mean differences[1] 1.0 day
	Kilograms per hectare	Percent	Percent
2,4,5-T	1.12	0.03 a	-0.17 a
2,4-D	5.60	1.33 a b	0.20 a
2,4,5-T	5.60	2.40 b	1.27 a
2,4-D	1.12	2.53 b	0.63 a

[1] A mean difference of 0.00 would show equal browsing of herbicide and water treatments. A negative number indicates preference for an herbicide treatment and a positive number indicates preference for a water treatment. Treatment levels with a common letter are not significantly different at the .05-level of significance using Duncan's multiple-range test.

Table 13--Deer browsing preferences for water-treated salal and salal treated with herbicide formulations containing a half-and-half mixture of 2,4,5-T and 2,4-D after 0.4 day and 1.0 day of exposure (Test 2B)

Rate of application	Mean differences[1] 0.4 day	Mean differences[1] 1.0 day
Kilograms per hectare	Percent	Percent
5.60	1.50 a	0.07 a
4.48	1.17 a	0.13 a
1.12	1.73 a	0.87 a b
2.24	1.43 a	1.50 b

[1] A mean difference of 0.00 would show equal browsing of herbicide and water treatments. A positive number indicates preference for a water treatment. Treatment levels with a common letter are not significantly different at the .05-level of significance using Duncan's multiple-range test.

Table 14--Effects of early December application of 2,4,5-T herbicide in water and diesel oil formulations on growth of Douglas-fir seedlings in early summer

Rate of application	Diesel oil carrier[1]	Living seedlings	Mean[2] height growth
Kilograms per hectare	Percent	Number	Centimeters
5.60	10	24	7.04 a
5.60	0	25	6.16 a b
3.36	0	25	6.12 a b
1.12	10	24	6.08 a b c
0	0	25	5.92 a b c d
4.48	10	23	5.48 b c d
4.48	0	25	5.44 b c d
0	10	23	5.39 b c d
2.24	0	23	5.17 b c d
0	100	23	5.00 b c d e
3.36	100	25	4.88 b c d e
3.36	10	23	4.87 b c d e
1.12	100	22	4.68 b c d e f
1.12	0	24	4.58 c d e f
2.24	10	25	4.52 d e f
2.24	100	20	3.50 e f
5.60	100	22	3.23 f
4.48	100	17	3.12 f

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[1] 0 = water only; 10 = 10 percent diesel oil and 90 percent water.

[2] Treatment levels with a common letter are not significantly different at the .05-level of significance using Duncan's multiple-range test.

Table 15--Effects of mid-December application of 2,4-D herbicide in water and diesel oil formulations on growth of Douglas-fir seedlings in early summer

Rate of application	Diesel oil carrier[1]	Living seedlings	Mean[2] height growth
Kilograms per hectare	Percent	Number	Centimeters
1.12	0	23	5.22 a
0	100	22	5.09 a
0	10	14	4.50 a b
4.48	10	20	4.25 a b c
0	0	25	4.24 a b
1.12	10	20	3.75 b c
2.24	0	25	3.72 b c
2.24	10	25	3.68 b c
3.36	10	25	3.52 b c
5.60	0	21	3.41 b c
1.12	100	21	3.33 b c
4.48	0	22	3.27 b c
2.24	100	23	3.09 c
3.36	0	25	2.00 d
3.36	100	25	1.64 d
5.60	100	20	1.43 d
4.48	100	20	1.05 d e
5.60	10	23	0.13 e

[1] 0 = water only; 10 = 10 percent diesel oil and 90 percent water.

[2] Treatment levels with a common letter are not significantly different at the .05-level of significance using Duncan's multiple-range test.

Table 16--Comparison of growth of Douglas-fir seedlings treated with 1.12 kilograms of 2,4-D in water carrier in December (Test 2A) and February (Test 4A)

Treatment date	Living seedlings	Mean[1] height growth
	Number	Centimeters
December 19, 1977	23	5.22 a
February 13, 1978	24	1.83 b

[1] Treatment dates are significantly different at the .05-level of significance.

Table 17--Effects of mid-January applications of formulations with half-and-half mixtures of 2,4,5-T and 2,4-D herbicides in water and diesel oil carriers on growth of Douglas-fir seedlings in early summer

Rate of application	Diesel oil carrier[1]	Living seedlings	Mean[2] height growth
Kilograms per hectare	Percent	Number	Centimeters
1.12	10	25	4.92 a
0	100	25	4.68 a b
0	10	22	4.09 a b c
1.12	0	19	3.79 a b c d
0	0	23	3.78 b c d
2.24	10	24	3.46 c d e
2.24	0	25	3.42 c d e
1.12	100	25	3.06 c d e
3.36	0	25	2.86 d e f
2.24	100	23	2.48 e f g
3.36	10	24	1.83 f g h
4.48	10	23	1.63 g h
4.48	0	22	1.61 g h
3.36	100	24	1.29 h i
5.60	0	24	1.23 h i
5.60	10	23	1.11 h i
4.48	100	24	0.71 h i
5.60	100	24	0.27 i

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[1] 0 = water only; 10 = 10 percent diesel oil and 90 percent water.

[2] Treatment levels with a common letter are not significantly different at the .05-level of significance using Duncan's multiple-range test.

Table 18--Effects of mid-February applications of fosamine, dalapon, atrazine, glyphosate, and 2,4-D herbicides in water carrier on growth of Douglas-fir seedlings in early summer

Rate of application	Formulation	Living seedlings	Mean[1] height growth
Kilograms per hectare		Number	Centimeters
5.60	atrazine	23	6.96 a
3.36	atrazine	23	6.30 a b
4.48	atrazine	20	5.85 b c
2.24	atrazine	22	5.55 b c d
0	water only	25	4.84 c d e
5.60	fosamine	25	4.52 d e f
2.24	fosamine	25	4.10 e f g
2.24	dalapon	24	3.92 e f g
4.48	dalapon	25	3.70 f g h
3.36	fosamine	23	3.33 g h i
8.96	dalapon	25	3.16 g h i
6.72	dalapon	24	2.77 h i j
1.12	glyphosate	18	2.72 h i j
4.48	fosamine	25	2.32 i j
1.12	2,4-D	24	1.83 j
4.48	glyphosate	1	1.00 e f g h i j k
2.24	glyphosate	2	0.50 i j k
3.36	glyphosate	6	0.00 k

[1] Treatment levels with a common letter are not significantly different at the .05-level of significance using Duncan's multiple-range test.

Campbell, Dan L.; Evans, James; Lindsey, Gerald D.; Dusenberry, William E. Acceptance by black-tailed deer of foliage treated with herbicides. Res. Pap. PNW-290. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; Olympia, WA: U.S. Department of the Interior, Fish and Wildlife Service, Forest-Animal Damage Control Research Project; 1981. 31 p.

To test their acceptance of foliage treated with herbicides, captive black-tailed deer were exposed to Douglas-fir seedlings and salal treated with standard formulations of 2,4,5-T, 2,4-D, atrazine, dalapon, fosamine, and glyphosate herbicides. Carriers were diesel oil and water. Tests were made from November 1977 through February 1978. Deer readily browsed 2,4,5-T treatments and most formulations of 2,4-D in oil compared with oil alone, but showed rejection of some phytotoxic glyphosate treatments. Consumption of herbicide-treated foliage did not cause noticeable health problems in test animals.

Keywords: Herbicides, browse preference, deer (black-tailed), *Odocoileus hemionus columbianus*, Douglas-fir, *Pseudotsuga menziesii*, salal, *Gaultheria shallon*, atrazine, 2,4,5-T, 2,4-D.

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PNW-291
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Precipitation and Streamwater Chemistry in an Undisturbed Watershed in Southeast Alaska

John D. Stednick

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Abstract

Stednick, John D. Precipitation and streamwater chemistry in an undisturbed watershed in southeast Alaska. Res. Pap. PNW-291. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1981. 8 p.

Water chemistry samples have been taken from streamflow since 1976 and precipitation since 1978 in Indian River, an undisturbed watershed on Chichagof Island in Southeast Alaska. Volume-weighted concentrations of total nitrogen, ammonium nitrogen, nitrate nitrogen, total phosphorus, orthophosphate, sulfate sulfur, chloride, bicarbonate, silica, calcium, magnesium, sodium, and potassium were used with precipitation and streamflow volumes to calculate annual input and output of elements. Total nitrogen accumulated at 1.0 kg/ha per year and ammonium-nitrogen at 3.3 kg/ha per year; other monitored elements showed a net loss or export from 0.1 kg/ha per year of total phosphorus to 256 kg/ha per year of calcium. Precipitation and weathering of soil and bedrock material account for these elemental losses in streamflow. The geochemistry of Indian River is compared to other studies done in mountainous forested watersheds.

Keywords: Water analysis, nutrient budget, precipitation, streamflow, southeast Alaska.

Introduction

Precipitation and streamflow measurements have been collected in Indian River since 1976 (fig. 1). Water chemistry samples have been collected from streamflow waters since 1976 and precipitation chemistry measured since 1978. The objective is to characterize the hydrology and elemental balances in the study area. The valley forests are being logged for the first time, and logging and associated impacts on water quantity and quality will be measured in later efforts.

Pretreatment results from a case-history study of precipitation and streamwater chemistry are presented. From these, a basis for evaluating timber harvest impacts in this watershed can be developed.

Nutrient budgets have not been developed for Southeast Alaska watersheds and we have little understanding of the biogeochemical processes that control streamflow chemistry. This investigation of bulk inputs and outputs did not attempt to differentiate elemental exports from pedogenic or bedrock weathering.

To understand the biogeochemical behavior of terrestrial ecosystems, a budgetary approach, which assesses inputs to and outputs from small watershed ecosystems, is often used. Investigations into the control of inputs and outputs of elements have been made through intensive measurements of single watersheds. Paired watersheds are often used to measure land-management impacts. Departures in water chemistry in the treatment watershed are attributed to the management activity. This approach has produced hypotheses for the understanding of specific situations.

Water-balance measurements of precipitation and streamflow were used in conjunction with volume-weighted concentrations. Climate may affect water quality by determining the absolute amount of water input as a diluting influence, as well as regulating losses to evapotranspiration as a concentrating effect. Streamflow volume for the Indian River basin is 81 percent of the precipitation volume.

Cation outputs in streamwater from a forested watershed in the Oregon Cascade Range were related to the amounts in excess of the annual requirements of the forest vegetation (Fredriksen 1972). The cation source was chemical weathering of the forest soil. Other studies, however, have indicated bedrock weathering rather than soil weathering was primarily responsible for chemical composition of streamwater. Active chemical weathering was found in the absence of biological and pedogenic processes (Reynolds and Johnson 1972).

The generation of mobile anions and concomitant cation leaching will also define the weathering rate and solute removal in some soils. Cations may be leached when the cation equivalence is greater than the available capacity for cation exchange in the soil.

Outputs are considered to originate from precipitation and pedogenic and bedrock weathering. Definition of these components will occur as nutrient budgets are better defined for ecosystems in Southeast Alaska.

Methodology

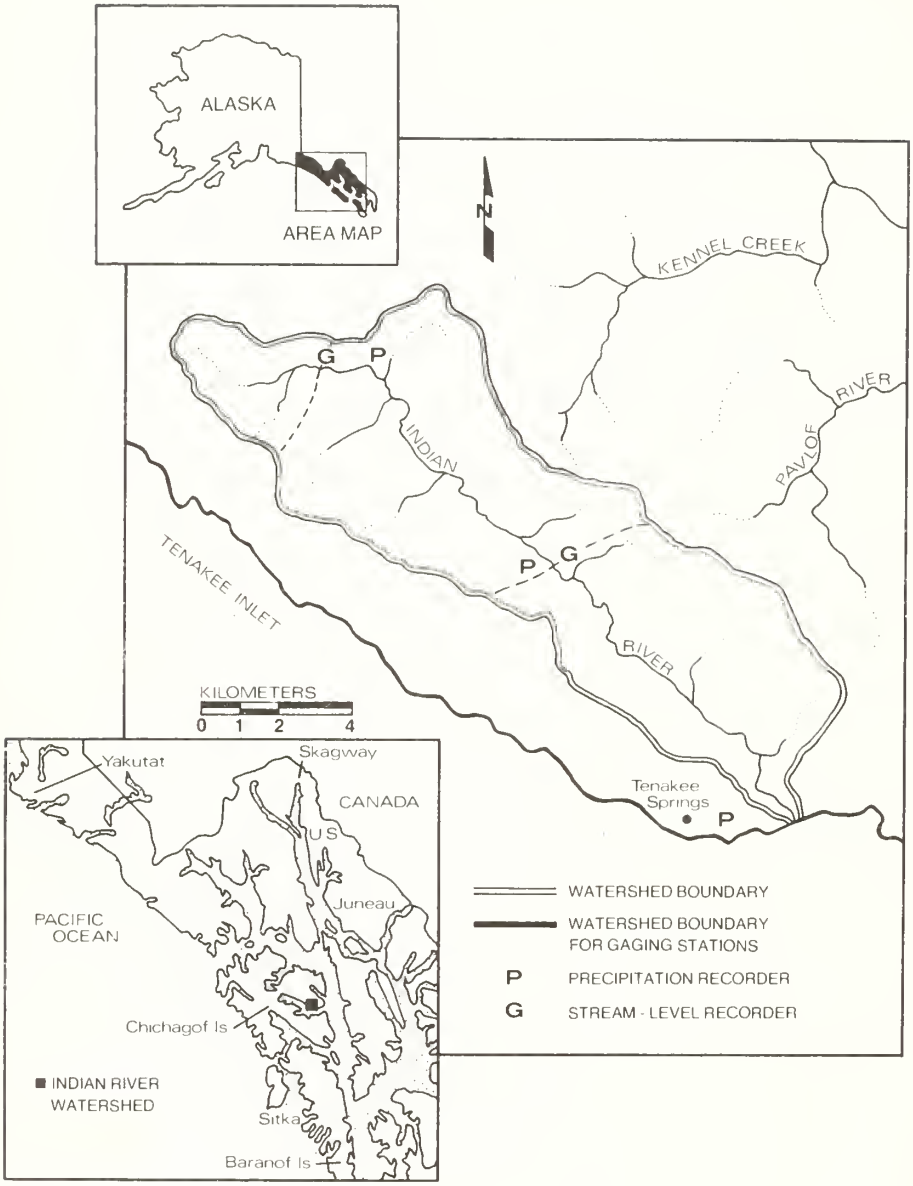

Figure 1.—Key and vicinity maps for Indian River.

Site Description

Indian River Valley is a broad U-shaped valley near Tenakee Springs on Chichagof Island in Southeast Alaska (fig. 1). The valley is approximately 50-percent forested with a mature coastal Sitka spruce (*Picea sitchenis* (Bong.) Carr.) -western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) forest. The nonforested alpine areas are generally above 770 m with mountain peaks up to 960 m. The watershed area is 72 km^2.

Geology

Freshwater Bay is northeast of Indian River and is the northeast fold of a syncline in sedimentary and volcanic rocks that range in age from Silurian to Mississippian (Loney et al. 1975). These are gently folded and are metamorphosed in the vicinity of granitic rock masses. The head of Indian River is a syncline in this material. The valley bottom is composed of unconsolidated alluvium, colluvium, and glacial sediments. Subsurface water may flow through these sediments and not be measured as streamflow. Deep percolation of groundwater is prevented, however, by a marine till that underlies the valley bottom. The valley follows the northwest-southeast strike of the Indian River Fault, with a linear outcrop of Kennel Creek limestone on the east side. Upper elevation rocks are intrusive igneous composed of hornblende, adamellite, biotite alaskite, and biotite-hornblende meladiorite. The western valley wall (of lower elevation) is composed of intensely folded, interlayered hornfels, schist, and amphibolite (Loney et al. 1975).

Soil

Alpine areas are characteristically steep with shallow soils and frequent bedrock outcrops and talus slopes including alpine and subalpine meadows, brush slopes, and muskegs. The alpine soils are largely organic, poorly drained, and acidic. Soils on the brushy slopes are mineral and acidic but well drained. These soils have characteristically thick, rapidly decomposing layers of surface litter over 15-30 cm of dark and friable, gravelly silt loam. The alpine and brush soils may occupy slopes greater than 100 percent.

Muskeg soils (Histosols) have a water table at or close to the surface year-round and may support Alaska-cedar (*Chamaecyparis nootkatensis* (D.Don) Spach) and lodgepole pine (*Pinus contorta* Dougl. ex Loud.) in areas where the water table is below the surface. The forested mineral soils lower in the valley are composed of alluvial and colluvial materials. These soils have thick surface organic horizons and are typically well drained.

Vegetation

The valley forest is primarily western hemlock and Sitka spruce with occasional clusters of Alaska-cedar. A variety of lodgepole pine is found on poorly drained sites. Dwarf mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.) is often associated with muskegs and alpine areas. Alder (*Alnus rubra* Bong. and *A. sinuata* (Regel) Rydb.) line some streams and dominate landslides or other exposed mineral soil areas. The lodgepole and alder species are noncommercial.

The understory vegetation is characteristically blueberry (*Vaccinium ovalifolium* Sm.), huckleberry (*V. parvifolium* Sm.), rusty menziesia (*Menziesia ferruginea* Sm.), and devilsclub (*Oplopanax horridus* (Sm.) Miq.). Muskeg areas are dominated by sphagnum mosses, sedges, rushes, and ericaceous shrubs. Alpine areas are largely composed of heaths, grasses, and deer cabbage (*Fauria crista-galli* (Menzies) Makino).

Streamflow

Indian River annual streamflow ranges from 1800 to 2400 mm and averages 2200 mm distributed in a bimodal pattern (fig. 2). Tenakee Springs (at sea level) has a long-term annual precipitation average of 1700 mm; short-term measurements in the valley indicate about 2700 mm. Precipitation and streamflow measurements in the valley indicate orographic effects and storm-front funneling. Precipitation events may produce small cyclonic cells that result in localized precipitation. About 40 percent of the annual precipitation occurs as rainfall in September and October. Most precipitation occurs as snow in March or April. Fall peakflows are reduced as snow accumulates. Winter low flows occur until May or June when rain, snow melt, or both often create peakflows. Decreasing rainfall through summer results in a generally receding hydrograph. Fogs and mists contribute an additional but undetermined quantity of water.

A continuous stream-level recorder was installed at midvalley in 1976 at an elevation of 100 m and drainage area of 34.2 km^2. The gaging cross section was located in a gravelly bottomed stream reach and was resurveyed for the stage-discharge calibration annually. Streamflow measurements over the 4-year period for weekly flows were accurate to ± 10 percent. The results reported here are from this midvalley gaging station.

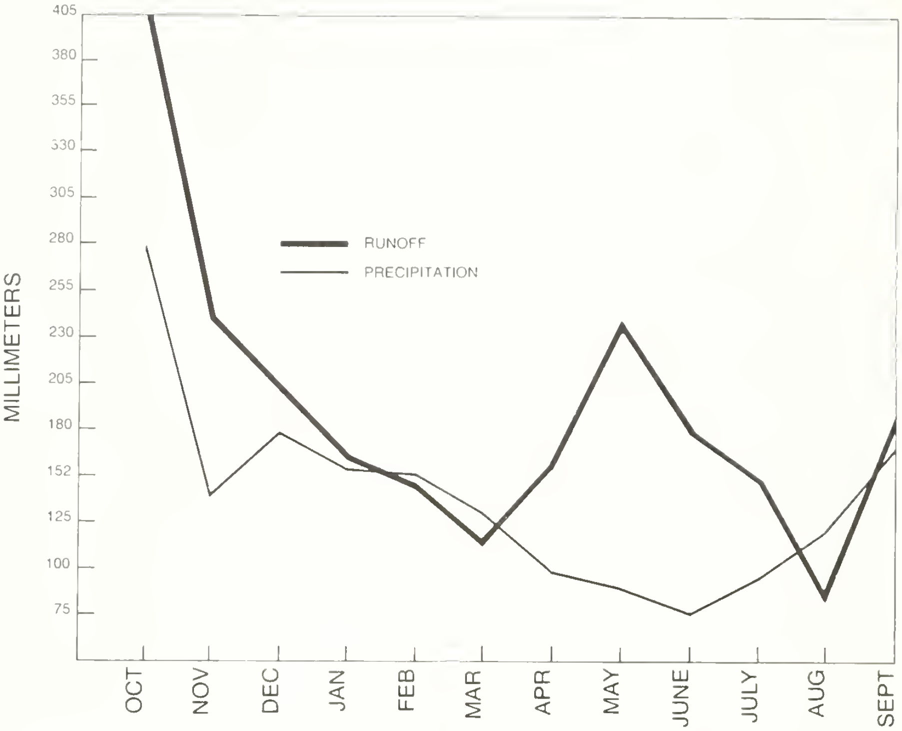

Figure 2.—Average monthly Indian River streamflow at gaging station (4 yr) and Tenakee Springs precipitation (10-yr average).

Water Sampling and Analysis

Surface grab-samples of Indian River water were collected during instrumentation servicing trips, about every 2 weeks during the summer and every 3-4 weeks in winter, depending on access. Precipitation samples were taken as an aliquot of precipitation collected in weighing recorders near the stream-level recorder and at the valley mouth. Spun fiberglass kept detritus and other debris out of the collected precipitation water. Snow samples were taken by collecting surface snow in wide-mouth sampling bottles.

All samples were frozen, unfiltered and unpreserved, and shipped to the USDA Forest Service Forestry Sciences Laboratory in Corvallis, Oregon, for analysis. Samples were analyzed for total nitrogen, ammonium nitrogen, nitrate nitrogen, total phosphorus, orthophosphate, sulfate sulfur, chloride, bicarbonate, silica, calcium, magnesium, sodium, and potassium.

A pH meter with an automatic titrator measured alkalinity as bicarbonate (HCO_3–C) and pH (American Public Health Association 1975). A Varian 1200 Atomic Absorption Emission Spectrophotometer was used to measure dissolved cations of calcium, magnesium, sodium, and potassium. A Technicon II Autoanalyzer was used to measure nitrogen and phosphorus forms. A copper-cadmium reductor column reduced nitrate to nitrite for measurement (Wood et al. 1967). Total nitrogen and total phosphorus were analyzed after macro-Kjeldahl and perchloric acid digestions (American Public Health Association 1975) and measured by the Berthelot reaction and molybdenum blue method, respectively (Technicon Industrial Systems 1971, Murphy and Riley 1962, Gales et al. 1966). Sulfate-sulfur was measured by the methylthymol blue technique (Gales et al. 1968). The molybdate-stannous chloride procedure was used to measure silica (Golterman 1969). Chloride was measured by using the ferricyanide method (O'Brien 1962).

Inputs and outputs were calculated on an annual basis, given that year's precipitation or streamflow and chemical data. The variance of the annual values was used to calculate a standard error and subsequently the 95-percent confidence interval. The net change was calculated as the mathematical difference between input and output. The confidence interval was calculated from a weighted average variance and standard error for the difference (Steele and Torrie 1960).

Results

Precipitation Chemistry

Indian River precipitation is slightly acidic (pH = 6.5) and chemically dilute; however, the large precipitation influx (2300 to 2900 mm per year) results in substantial deposition of elements. Precipitation originates over saltwater and is reflected in the deposition of chloride, calcium, magnesium, sodium, and potassium (Pritchett 1979, Patterson 1976). The total nitrogen (ammonium, nitrate, nitrite, Kjeldahl, and organic) input of 5.5 kg/ha per year must be assumed to originate from soil and ocean surfaces (Wollum and Davey 1975), because anthropogenic sources are not evident (table 1). No explanation is offered as to the ammonium-nitrogen source. The ammonium-nitrogen concentration average in precipitation was high and considered to be a valid measurement. Because samples were collected every 2-4 weeks, interconversion among nitrogen species may occur; however, the total nitrogen content would not change.

Amount of precipitation did not appear to be related to element concentration. Separating element concentrations for separate storms was impossible because of logistics and access to study sites. A study in the North Cascades of Washington State indicated no consistent chemical differences in precipitation samples collected at a range of elevations and subsequently volumes (Dethier 1979). Preliminary investigations did not indicate element concentration enrichment by dry deposition on surface snow layers.

Element inputs to Indian River were calculated by precipitation amounts and volume-weighted concentrations and averaged for the 1979 and 1980 water years. Streamflow outputs were determined for water years 1977-80. Elemental transfers in Indian River are comparable to geochemical studies of other watersheds. (table 2).

Runoff Chemistry

Water chemistry samples from Indian River have been collected since 1976. Volume (discharge)-weighted concentrations and streamflow data were used to calculate annual streamflow losses for water years 1977-80. Water chemistry samples often contained suspended sediment; however, the transport of elements associated with sediment was not measured. Sediment movement occurred during the higher peakflows on the rising limb of the hydrograph and was composed of 5- to 25-percent organic materials. The organic material could act as exchange sites. Therefore, element outputs in streamflow do not indicate total watershed output.

The alkalinity of runoff waters averaged 10.47 mg/1, and the near neutral pH (7.2) was not apparently related to discharge or season. Alkalinity increased from precipitation inputs because of interactions with the biological and pedological components. Changes in pH and alkalinity may be influenced by the presence of organic acids as evidenced by solution color.

Dissolved cation outputs are about 400 kg/ha per year with an anion output of 300 kg/ha per year. Additional ion transport may result from organic acids or association with suspended sediments. The output:input ratio of the cations calcium, magnesium, sodium, and potassium is 4.8—comparable to the 3.3 of Jamieson Creek (Zeman 1975), and 4.8 of the Olympics (Larson 1979), but less than the 12.0 of the H.J. Andrews Experimental Forest in Oregon (Henderson et al. 1978).

Nutrient conservation occurred for total nitrogen (+1.0 kg/ha per year) and ammonium nitrogen (+3.3), but all other element transfers exhibited a net loss. Losses ranged from 0.1 kg/ha per year of total phosphorus to 256 kg/ha per year of calcium. The average net change (element gain or loss) was calculated as the mathematical difference between input and output (table 1).

able 1—Summary of average precipitation input (1979-80), streamflow output 977-80), and average net change all with 95-percent confidence intervals

ement	Input	Output	Net change
	Kilograms/hectare per year		
otal N	5.5 ± 3.4	4.5 ± 0.8	+ 1.0 ± 1.2
H_4N	4.7 ± 2.8	1.4 ± 0.3	+ 3.3 ± 0.5
O_3N	0.5 ± 0.3	2.2 ± 0.4	− 1.7 ± 0.5
otal P	0.7 ± 0.4	0.8 ± 0.2	− 0.1 ± 0.3
O_4P	0.5 ± 0.8	0.4 ± 0.6	+ 0.1 ± 0.1
O_4S	9.6 ± 5.8	22.8 ± 4.2	− 13.2 ± 5.6
l	20.3 ± 12.2	90.1 ± 16.7	− 69.8 ± 21.8
CO_3	23.4 ± 14.1	183.5 ± 33.7	−160.1 ± 44.3
	1.7 ± 0.9	34.1 ± 6.3	− 32.4 ± 8.2
a	18.8 ± 11.3	275.0 ± 50.6	−256.2 ± 66.2
g	12.3 ± 7.4	24.0 ± 4.4	− 11.7 ± 5.9
a	38.4 ± 23.1	39.6 ± 7.3	− 1.2 ± 9.6
	4.0 ± 2.4	10.3 ± 1.9	− 6.3 ± 2.5

ble 2—Summary of precipitation inputs and streamflow outputs for Indian River, Jamieson Creek (British Columbia), estern Olympic Peninsula (Washington State), and Watershed West (New Hampshire)

	Indian River (2-yr input) (4-yr output)		Jamieson Creek[1] (1 yr)		Olympic Peninsula[2] (2-yr average)		Watershed West[3] (1 yr)	
ement	Input	Output	Input	Output	Input	Output	Input	Output
	Kilograms/hectare per year							
tal N	5.5	4.5	—	—	3.8	2.2	—	—
${}_4N$	4.7	1.4	0.5	0.4	—	—	2.8	0.4
${}_3N$	0.5	2.2	1.1	0.8	0.7	1.3	6.0	6.6
tal P	0.7	0.8	—	—	1.1	1.0	—	—
${}_4P$	0.5	0.4	0.1	0.2	1.2	0.8	—	—
${}_4S$	9.6	22.8	2.1	3.0	10.8	83.0	17.3	22.9
	20.3	90.1	23.1	38.1	—	—	—	—
O_3	23.4	183.5	7.6	37.2	90.5	1220.0	0	41.9
	1.7	34.1	0.4	48.9	0	102.0	—	—
	18.8	275.0	7.3	41.7	10.5	320.0	3.1	26.4
	12.3	24.0	2.2	8.8	6.0	44.5	0.7	3.8
	38.4	39.6	13.2	25.6	82.0	112.5	1.3	13.1
	4.0	10.3	0.9	2.6	3.8	12.0	2.4	7.0

eman, 1975.
rson, 1979.
artin, 1979.

Discussion

Chemical composition of streamflow water can come either from tropospheric fallout—including elements originally derived from the ocean, terrestrial sources, or biological fixation. The tropospheric contributions of each element can be expressed as a percentage of streamflow output (table 3). Sulphate sulfur, chloride, bicarbonate, silica, calcium, magnesium, and potassium are largely derived from terrestrial sources.

Table 3—Percent contribution of chemistry from tropospheric sources for streamflow water from Indian River, Jamieson Creek (British Columbia), and Western Olympic Peninsula (Washington State)

Constituent	Indian River	Jamieson Creek	Olympics
Total N	122	—	173
NH_4N	336	106	—
NO_3N	23	138	54
Total P	88	—	110
PO_4P	125	55	150
SO_4S	42	74	13
C1	23	61	—
HCO_3	13	20	7
Si	5	1	0
Ca	7	17	3
Mg	51	25	13
Na	97	51	73
K	39	34	32

The conservation of nitrogen in the system may be attributed to utilization of ammonium or nitrate nitrogen by forest flora, actual storage of the nitrogen in the soil, or both. The input of nitrogen as ammonia was greater than the nitrate nitrogen input, a similar observation but of greater magnitude than that in the H. J. Andrews Experimental Forest (Henderson et al. 1978). The majority of streamwater nitrogen output from undisturbed watersheds occurs in organic forms (Fredriksen 1972). Nitrogen budgets are assessed through hydrologic processes and do not reflect transfers through gaseous forms, nitrogen fixation, or denitrification. Denitrification is probably not appreciable in the forest soils, because they are acid, well drained, and aerated. Denitrification and volatilization, however, may be occurring in muskegs, where precipitation collectors were located, and account for the ammonium nitrogen input.

The total loss of phosphorus of 0.1 kg/ha per year results from weathering of the apatite series, which consists of orthophosphate (Hem 1970). Phosphorus concentrations in naturally occurring surface waters are usually small because of its utilization by aquatic vegetation (Hem 1970). Fixation of phosphate in soils containing appreciable amounts of hydrated iron and aluminum oxides—typical of podzolized soils—restricts phosphate movement (Zeman 1975). The mechanisms of organic phosphorus retention by soils have not been fully established. Although organic phosphorus is reported to leach from soils, a large proportion of the organic phosphorus appears to be removed as particulate matter rather than as dissolved phosphorus (Fredriksen 1972).

Chloride is present in certain of the minerals of the igneous rocks, such as chlorapatite or as apatite in limestone (Mason and Berry 1968), but these minerals have a limited distribution in Indian River Valley (Loney et al. 1975). Not all of the chloride output is believed to come from weathering of this parent material. During dry periods, forest canopies are effective interceptors of chloride from sea salt in the dry state. Rains in late summer and fall wash out salts accumulated on the foliage (Eriksson 1955).

The net loss of sulfur (−13.2 kg/ha per year) may be the result of weathering of sulphur-bearing minerals within the watershed. Pyrite occurrences are not uncommon (Loney et al. 1975). Decomposition of organic matter is another possible source of vadose sulphur compounds (Zeman 1975). This may be important in organic soil (muskeg) areas. The net outflow of sulfur is attributed to dissolution of sedimentary rocks and from organic material containing sulphur (Rainwater and Thatcher 1960). A hot-water spring, containing sulfur, exists in the community of Tenakee Springs. The extent of this spring or other hot springs in Indian River Valley is not known.

The principal source of magnesium in natural waters is ferromagnesian minerals in igneous rocks and magnesium carbonate in carbonate rocks (Hem 1970). The potassium content in natural waters is usually small. Potassium occurs in rocks in a form not easily brought into solution, although several geochemical processes tend to remove potassium selectively and return it to the solid phase (Hem 1970).

odium is very soluble and readily ·ached from soil, mineral, or bedrock. nce in solution, sodium tends to remain ere. Calcium is dissolved from ractically all rocks, but is usually found greater quantities in waters leaching mestone, dolomite, or gypsum deposits Hem 1970).

he precipitation input of calcium (18.8 g/ha per year) as well as potassium, odium, and magnesium largely riginates as an aerosol over saltwater Pritchett 1979). The net calcium loss of 56 kg/ha per year is from dissolution and eathering of a linear outcrop of Kennel reek limestone. Similarly, the losses of agnesium, sodium, and potassium at 1.7, 1.2, and 6.3 kg/ha per year, espectively, may be dissolution and eathering of limestone, as well as otassium and sodium feldspars and the vailable hornfels, schists, and mphiboles.

he elemental balances from Indian River re comparable to similar studies in rested watersheds. Indian River had an verage annual precipitation of 2700 mm, amieson Creek in British Columbia had 540 mm for the 1970-71 water year Zeman 1975), and the Olympic eninsula averaged 4230 mm (Larson 979). No precipitation or streamflow data ere presented for Watershed West Martin 1979).

hough precipitation was less than in the ther studies, element inputs or outputs re comparable to them because of gher concentrations of elements. The rge input of total nitrogen to Indian River not observed in the other cited studies; owever, nitrogen conservation still ccurs.

uring the early stages of succession hen production and biomass accumu- tion are rapid, nutrients essential to ant growth may be retained in the omass with a reduction in concentra- on of streamwater. As the forest matures nd net production declines, uptake of essential nutrients will be reduced and these nutrients will be leached out of the system in streamwater (Vitousek 1977, Vitousek and Reiners 1975). Nitrogen and phosphorus accumulate while the other essential plant nutrients have a net loss in Indian River. The nutrient budgets of nonessential ions—chloride, bicarbonate, and sodium—should be unaffected by successional stage. The biogeochemistry of cations seems to be strongly controlled by precipitation, soil water movement, chemical weathering of bedrock materials, and movement of suspended sediment, rather than forest succession.

Geochemical influences on streamwater chemistry are evident in this forested watershed. Water quality is influenced by the mineral composition and solubility of underlying rocks. Water percolating through soil and substrata en route to the stream may be enriched with dissolved solids. A correlation between the mineral composition of water and that of the geologic formation with which the water has been in contact seems reasonable. The major constituents of sodium, calcium, magnesium, bicarbonate, sulphate, chloride, and silica may be readily influenced by bedrock weathering, depending on the bedrock with secondary constituents of iron, potassium, carbonate, nitrate, fluoride, and boron influenced less (Davis and DeWiest 1966). Note that the weathered elements coming from geologic formations can be overshadowed by other effects. Differences in climate or other influences on the weathering process can produce very different types of water from essentially similar rock sources (Hem 1970). A satisfactory system of classifying water based entirely on composition of source rocks is unlikely.

Conclusions

Indian River receives about 140 kg/ha per year of dissolved solids in 2700 mm of precipitation. Average annual losses in streamflow are 700 kg/ha per year of dissolved solids and do not include elemental losses associated with sediment transport or gaseous transfers. Total nitrogen accumulated in the watershed at a rate of 1.0 kg/ha per year. Other monitored elements had greater streamflow losses than precipitation inputs. Precipitation (tropospheric) inputs accounted for 5-336 percent of the elemental losses in streamflow.

Individual storm volumes and element concentrations were not investigated because of limited access to the study area during the rainy fall months. The relation of streamflow to element concentrations was not apparent; however, volume-weighted concentrations were used to portray elemental gains and losses more accurately.

The terrestrial sources of elements are from soil (pedogenic) and bedrock weathering. The presence of a linear outcrop of Kennel Creek limestone and associated minerals can account for the bulk of element addition to the streamwater. Calcium as well as sodium, potassium, and magnesium losses were largely from limestone. Potassium and sodium were also derived from available hornfels, schists, and amphiboles. Phosphorus and sulfur were derived largely from apatite and pyrite, respectively. No effort was made to separate elements weathered from the soil and those from bedrock.

The elemental losses from Indian River are comparable to similar studies in mountainous and forested watersheds. The nitrogen budget distinguishes Indian River from other watersheds studied, however.

Acknowledgment

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Literature Cited

American Public Health Association. Standard methods for the examination of water and wastewater. 14th ed. Washington, DC: American Public Health Association; 1975. 1193 p.

Davis, S. N.; DeWiest, R. J. M. Hydrogeology. New York: John Wiley and Sons; 1966. 463 p.

Dethier, D. P. Atmospheric contributions to streamwater chemistry in the North Cascade Range, Washington. Water Resour. Res. 15(4): 787-794; 1979.

Eriksson, E. Airborne salts and the chemical composition of river waters. Tellus (7): 243-250; 1955.

Fredriksen, R. L. Nutrient budget of a Douglas-fir forest on an experimental watershed in western Oregon. In: Franklin, J. F.; Dempster, L. J.; Waring, R. H., eds. Research on coniferous forest ecosystems. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1972: 115-131.

Gales, M. E.; Julian, E.; Kroner, R. Methods for quantitative determination of total phosphorus in water. J. Am. Waterworks Assoc. 58 (10): 1363; 1966.

Gales, M. E.; Kaylor, W. H.; Longbottom, J. E. Determination of sulphate by automatic colorimetric analysis. Analyst 93:97; 1968.

Golterman, H. T. Methods for chemical analysis of fresh waters. IBP. Handbk. 8. Oxford: Blackwell Scientific Publications; 1969. 166 p.

Hem, J. D. Study and interpretation of the chemical characteristics of natural water. Water Supply Paper 1473. Washington, DC: U.S. Department of the Interior; Geological Survey; 1970. 363 p.

Henderson, G. S.; Swank, W. T.; Waide, J. B.; Grier, C. C. Nutrient budgets of Appalachian and Cascade Region watersheds: a comparison. For. Sci. 24(3):385-397; 1978.

Larson, A. G. Origin of the chemical composition of undisturbed forested streams. Western Olympic Peninsula, Washington State. Seattle: University of Washington; 1979. 216 p. Ph. D. dissertation.

Loney, R. A.; Brew, D. A.; Muffler, T. J. P.; Pomeroy, J. S. Reconnaissance geology of Chichagof, Baranof and Kruzof Islands, Southeastern Alaska. Paper 792. Washington, DC: U.S. Department of the Interior, Geological Survey; 1975. 105 p.

Martin, D. W. Precipitation and streamwater chemistry in an undisturbed forested watershed in New Hampshire. Ecology 60(1):36-42;1979.

Mason, B.; Berry, L. G. Elements of mineralogy. San Francisco: W. H. Freeman and Co.; 1968. 500 p.

Murphy, J.; Riley, J. A modified single solution for the determination of phosphate in natural waters. Anal. Chim. Acta (24):27-31;1962.

O'Brien, J. E. Automatic analysis of chlorides in sewage. Waste Eng. 33: 670-672; 1962.

Patterson, M. P. Is air chemistry monitoring worth its salt? In: Environmental biogeochemistry, Vol. 2. Ann Arbor, MI; Ann Arbor Science; 1976:77-78.

Pritchett, W. L. Properties and management of forest soils. New York: John Wiley and Sons; 1979. 500 p.

Rainwater, F. H.; Thatcher, L. L. Methods for collection and analysis of water samples. Water Supply Paper 1454. Washington, DC: U.S. Department of the Interior, Geological Survey; 1960. 301 p.

Reynolds, R. C.; Johnson, N. M. Chemical weathering in the temperate glacial environment of the northern Cascade Mountains. Geochim. Cosmochim. Acta 36: 537-554; 1972.

Steele, R. G. D.; Torrie, J. H. Principles and procedures for statistics. New York: McGraw Hill, Inc.; 1960. 481 p.

Technicon Industrial Systems. Low-level ammonia in fresh and estuarine water. Industrial Method AAII, 108-71W. Tarrytown, NY: 1971. 2 p.

Vitousek, P. M. The regulation of element concentrations in mountain streams in the northeastern United States. Ecol. Monogr. 47:65-87; 1977.

Vitousek, P. M.; Reiners, W. A. Ecosystem succession and nutrient retention: a hypothesis. Bioscience 25:376-381; 1975.

Wollum, A. G. II; Davey, C. B. Nitrogen accumulation, transformation and transport in forest soils. In: Bernier, B.; Winget, C. H., eds. Forest soils and forest land management. Quebec City, PQ: Les Presses de L'Université Laval; 1975: 67-107.

Wood, E. D.; Armstrong, F. A. J.; Richards, F. A. Determination of nitrate in sea water by cadmium-copper reduction to nitrite. J. Mar. Biol. Assoc. U. K.; 1967: 23-31.

Zeman, T. J. Hydrochemical balance of a British Columbia mountainous watershed. Catena 2:81-93; 1975.

Stednick, John D. Precipitation and streamwater chemistry in an undisturbed watershed in southeast Alaska. Res. Pap. PNW-291. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1981. 8 p.

Water chemistry samples have been taken from streamflow since 1976 and precipitation since 1978 in Indian River, an undisturbed watershed on Chichagof Island in Southeast Alaska. Volume-weighted concentrations of total nitrogen, ammonium nitrogen, nitrate nitrogen, total phosphorus, orthophosphate, sulfate sulfur, chloride, bicarbonate, silica, calcium, magnesium, sodium, and potassium were used with precipitation and streamflow volumes to calculate annual input and output of elements. Total nitrogen accumulated at 1.0 kg/ha per year and ammonium-nitrogen at 3.3 kg/ha per year; other monitored elements showed a net loss or export from 0.1 kg/ha per year of total phosphorus to 256 kg/ha per year of calcium. Precipitation and weathering of soil and bedrock material account for these elemental losses in streamflow. The geochemistry of Indian River is compared to other studies done in mountainous forested watersheds.

Keywords: Water analysis, nutrient budget, precipitation, streamflow, southeast Alaska.

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Herbicide and Conifer Options for Reforesting Upper Slopes in the Cascade Range

Edward J. Dimock II

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bstract

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ine herbicides were compared for aiding stablishment of four conifer species on pper-slope forest sites dominated by edge and beargrass. Both glyphosate nd a mixture of atrazine + dalapon roduced substantial and consistent ains in survival of all four conifers after years.

eywords: Herbicides (-regeneration, site reparation (-regeneration, herbicide rmulations, regeneration (stands), estern white pine, Engelmann spruce, oble fir, Shasta red fir.

Summary

Nine herbicides (asulam, atrazine, bromacil, cyanazine, dalapon, glyphosate, hexazinone, pronamide, and terbacil) were evaluated for control of sedge (*Carex* spp.) and beargrass (*Xerophyllum tenax* [Pursh] Nutt.) to aid establishment of newly planted seedlings of western white pine (*Pinus monticola* Dougl. ex D. Don), noble fir (*Abies procera* Rehd.), Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), and Shasta red fir (*Abies magnifica* Murr. var. *shastensis* Lemm.). All trials were conducted on upper-slope sites ranging from 3300 to 4600 ft (1000 to 1400 m) in the Cascade Range. Various rates and mixtures of herbicide were compared as both preplanting and postplanting sprays in three independent studies.

After 3 years, greatest gains in conifer survival were associated with glyphosate sprays. In three widely separated localities, survival of white pine associated with best glyphosate treatments was 80, 77, and 30 percent compared to 40, 34, and 4 percent for untreated checks, respectively. Among other conifers, corresponding contrasts in survival between glyphosate treatment and untreated checks were: 56 versus 12 percent for noble fir, 30 versus 14 percent for Engelmann spruce, and 14 versus 0 percent for Shasta red fir.

Similar survival increases were also consistently achieved with atrazine + dalapon mixtures. Most successful applications of mixture produced 3-year survival of 62, 77, and 14 percent for white pine at the same three localities above. Survival of other conifers resulting from best atrazine + dalapon treatments was: 33 percent for noble fir, 46 percent for Engelmann spruce, and 14 percent for Shasta red fir.

Preplanting sprays of glyphosate and atrazine + dalapon proved generally, but not always, superior to postplanting sprays for enhancing survival of conifers.

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ntroduction

pper-slope coniferous forests occupy an regular belt paralleling the crest of the ascade Range. These subalpine forests osely conform to the cool, moist ansition zone separating lower-evation temperate forests to the west nd more arid forest types eastward Franklin and Dyrness 1973). Reforesting oper slopes concurrent with orderly mber harvest presents new challenges, nd silvicultural practices adapted to ouglas-fir (*Pseudotsuga menziesii* Mirb.] Franco) at lower elevations apply nly generally. A wider array of ianagement options and species hoices is needed for upper slopes.

s elevations increase in subalpine ands, Douglas-fir is replaced by other onifers. Typically, dominant species clude Pacific silver fir (*Abies amabilis* ougl. ex Forbes), western hemlock *Tsuga heterophylla* [Raf.] Sarg.), noble (*Abies procera* Rehd.), and Shasta red (*A. magnifica* Murr. var. *shastensis* emm.). When harvested, such stands ay regenerate unsatisfactorily despite tensive reforestation efforts. To survive, ewly planted conifers must withstand xtremes of temperature and also oisture stress, which is exacerbated by stablished plant competitors. Sites upporting dense cover of sedge (*Carex* pp.)— particularly long stolon sedge *C. pensylvanica* Lam.)— and beargrass *Xerophyllum tenax* [Pursh] Nutt.) appear specially prone to unacceptable eedling mortality and plantation failure.

erbicides have proved useful for reparing conifer reforestation sites in erbaceous cover. Most studies, owever, have concerned conifer crop pecies either unadapted or only arginally adapted to upper-slope forests f the Cascade Range (Crouch 1979; imock and Collard 1981; Eckert 1979; ratkowski et al. 1979; Heidmann 1969, 970; Newton 1974; and Stewart and eebe 1974). Moreover, weed species rgeted for control in other studies have een chiefly grasses (Gramineae) and road-leaved forbs. Little is known about ontrol of either sedges (Cyperaceae) or eargrass (Liliaceae) in forestry pplications.

describe three studies aimed at valuating the potential of nine herbicides r use in planting-site preparation with ur conifer species. All studies were egun in 1977 and monitored for 3 years.

Study Areas

A separate study was conducted on each of three ranger districts: Mount Adams (Gifford Pinchot National Forest), McKenzie (Willamette National Forest), and Prospect (Rogue River National Forest). The northernmost and intermediate locations (Mount Adams and McKenzie) fall within the *Abies amabilis* zone as described by Franklin and Dyrness (1973); the southernmost location (Prospect) falls within the *Abies magnifica shastensis* zone. Most prevalent soils at Mount Adams range from gravelly sandy loams to silt loams derived from varying combinations of pumice, basalt, and andesite. To the southward occur increasing deposits of pyroclastic rocks (tuffs, breccias, and agglomerates) that weather to silty clay and silty clay loams mixed with stonier and coarser soils derived from basaltic and andesitic bedrock. Topography on all districts is bench-like or mountainous with level to steeply sloping ground. Mean annual precipitation near the study areas is: 100 in (254 cm) at Mount Adams, 70 in (179 cm) at McKenzie, and 42 in (107 cm) at Prospect. Mean precipitation during June through August for the same locations is: 4.7 in (11.9 cm) at Mount Adams, 4.2 in (10.6 cm) at McKenzie, and 2.5 in (6.4 cm) at Prospect.

Site elevations of individual study blocks (three per district) averaged about 4000 ft (1220 m), but ranged from as low as 3300 ft (1000 m) at Mount Adams to as high as 4600 ft (1400 m) at Prospect (fig. 1). History of forest disturbance differed somewhat both within and between district locations. At McKenzie, all three blocks were sited within ½ mile (0.8 km) of one another. Slash on each had been burned broadcast after clear-cutting about 8 years before study initiation. Failing to regenerate naturally, each site supported a heavy cover of beargrass interspersed with sedge (fig. 2). Up to 12 miles (19.2 km) separated different block sites at Mount Adams and Prospect. Slash had been burned broadcast after recent clear-cutting on only one site at Mount Adams, and had been piled and burned on all sites at Prospect. Sedge was well represented at all district locations, but beargrass was sparse at Mount Adams and totally absent at Prospect. Only scattered advance regeneration of conifers had occurred at any location (fig. 3). Dominant species before harvest had been primarily noble fir at McKenzie, Pacific silver and noble fir at Mount Adams, and Shasta red fir at Prospect.

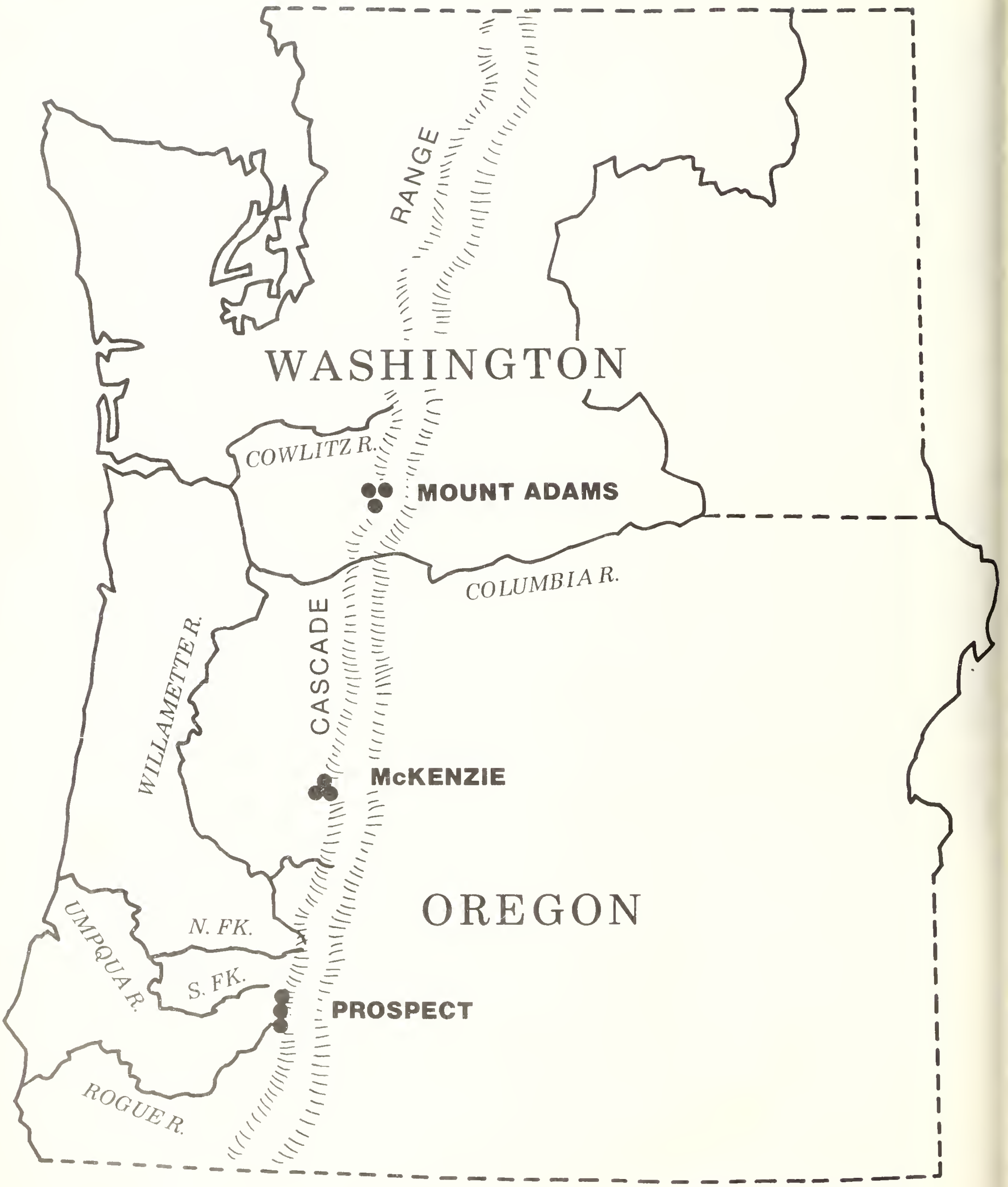
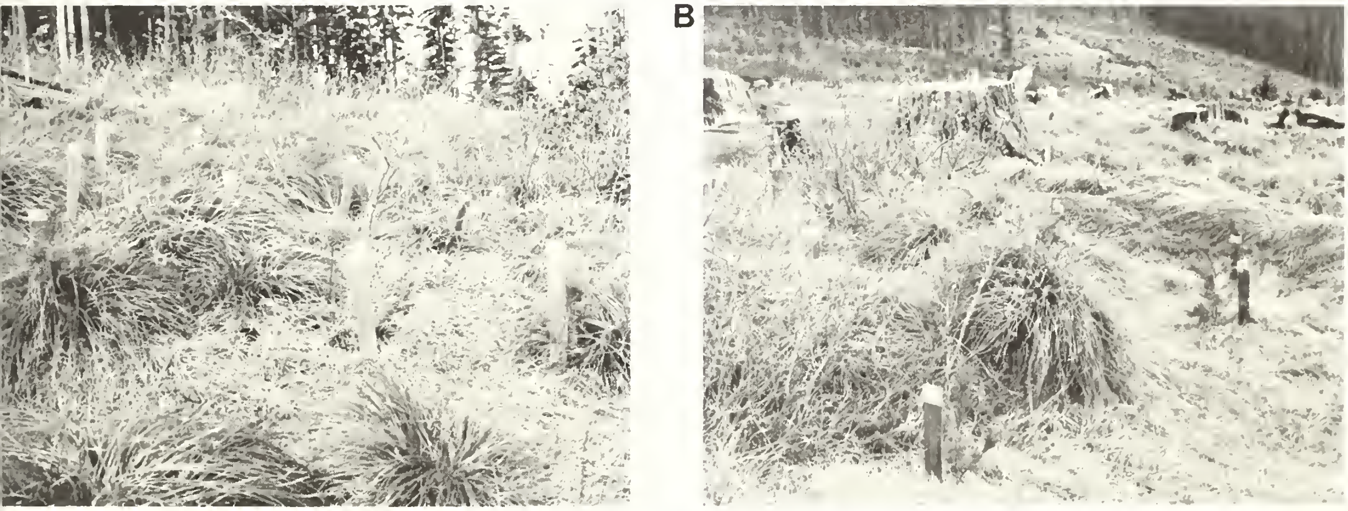


Figure 1.—The nine study blocks.

gure 2.—(**A**) Canopy coverage of beargrass ranged up to 90 percent at McKenzie. (**B**) Gaps between beargrass clumps were dominated by continuous mat of sedge, as shown in foreground.



gure 3.—(**A**) The predominant sedge-beargrass community at McKenzie proliferated from plants established under the preharvest forest verstory. Only scattered shrubs and (**B**) occasional naturally regenerated conifers were present.

Materials and Methods

Experimental design was identical on every district, and two conifer species were tested per study. Western white pine (*Pinus monticola* Dougl. ex D. Don) was common to all three tests, but a different second species was used in each: noble fir at McKenzie; Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) at Mount Adams; and Shasta red fir at Prospect. Hence, every district supported an intact split-plot (two species as subplots), randomized complete-block experiment replicated in 3 blocks. Each block contained 20 treatments (herbicides and rates) and 2 application times (preplanting and postplanting) randomly allocated to each of 40 square 1/100-acre (1/250-ha) main plots. Fifteen pine and 15 fir or spruce seedlings were planted on each plot in 6 rows of alternating species with 5 seedlings per row. Untreated buffers 10 ft (3 m) wide separated individual plots.

The USDA Forest Service nursery at Dorena, Oregon, provided all western white pine planting stock from a single source with general resistance to white pine blister rust (*Cronartium ribicola* Fisch.). The USDA Forest Service nursery at Wind River, Washington, provided all other stock grown from sources local to each study area. Class of planting stock was 2-0 for pine and Shasta red fir; 3-0 for noble fir and Engelmann spruce. Stock was lifted in late winter or early spring, stored at 2°C, and planted in late May. Where possible, the same worker planted all seedlings of one species in each experimental block.

Nine herbicides were used in each study (table 1). Both toxicity to herbaceous plants and tolerance by conifers were considered in selecting candidate herbicides, rates, and mixtures. Preplanting applications were made in mid-May and postplanting applications in early June—about 10 days, respectively, before and after tree planting. All herbicides were sprayed broadcast by backpack equipment at specified rates of active ingredient (ai) in water carriers at volumes of 200 gal/acre (1870 liter/ha). No attempt was made to protect tree seedlings from postplanting herbicide sprays.

Control of sedge (all locations) and beargrass (McKenzie) was rated in midsummer; survival of conifers in early fall. Changes in species cover, visually estimated to the nearest 10 percent between plots and adjacent buffers, were used to calculate percentage control. Analysis of variance was used to test treatment response in separate years, and multiple comparisons were made by the FLSD method as recommended by Carmer and Swanson (1971). Primary analysis dealt with each study separately; secondary analysis combined all studies. Results of all studies were monitored for 3 years, but one block of treatments was lost in the 3d year (1979) at both Mount Adams and Prospect when some plots were inadvertently included in machine-scarification projects.

Table 1—Herbicides applied to sedge and beargrass

Common name	Chemical name	Formulation
Asulam	methyl sulfanilylcarbamate	Liquid, 3.34 lb ai/gal as sodium salt
Atrazine	2-chloro-4-(ethylamino)-6-(isopropylamino)-*s*-triazine	80% wettable powder
Bromacil	5-bromo-3-*sec*-butyl-6-methyluracil	Liquid, 2 lb ai/gal as lithium salt
Cyanazine	2-[[4-chloro-6-(ethylamino)-*s*-triazin-2-yl] amino]-2-methylpropionitrile	80% wettable powder
Dalapon	2,2-dichloropropionic acid	84.5% soluble powder as sodium and magnesium salts
Glyphosate	*N*-(phosphonomethyl) glycine	Liquid, 4 lb ai/gal as isopropylamine salt
Hexazinone	3-cyclohexyl-6-(dimethylamino)-1 methyl-1,3,5-triazine-2,4(1*H*, 3*H*)-dione	90% soluble powder
Pronamide	3,5-dichloro (*N*-1, 1-dimethyl-2-propynyl) benzamide	50% wettable powder
Terbacil	3-*tert*-butyl-5-chloro-6-methyluracil	80% wettable powder

esults

able 2—Control of sedge and beargrass at McKenzie after preplanting and postplanting herbicide sprays

Treatment	(Rate in lb ai/acre)[1]	1977				1978				1979			
		Sedge		Beargrass		Sedge		Beargrass		Sedge		Beargrass	
		Pre-plant	Post-plant	Pre-plant	Post-plant	Pre-plant	Post-plant	Pre-plant	Post-plant	Pre-plant	Post-plant	Pre-plant	Post-plant
		Percent[2]											
ntreated check	(–)	0	0	0	0	0	0	0	0	0	0	0	0
sulam	(5)	0	0	0	0	0	0	0	0	0	0	0	0
trazine	(4)	23	50	17	30	0	3	13	27	0	0	0	3
trazine + dalapon	(3 + 6)	87	83	23	27	25	23	30	27	7	10	0	7
trazine + dalapon	(4 + 8)	85	83	30	30	35	33	33	40	20	10	10	3
trazine + dalapon	(5 + 10)	90	97	30	43	47	45	43	40	27	17	27	7
romacil	(5)	73	73	53	47	3	3	53	40	7	13	40	33
yanazine + atrazine	(4 + 2)	30	43	27	33	0	3	37	23	3	0	0	0
alapon	(8)	77	77	30	20	10	23	27	27	3	7	7	0
lyphosate	(2)	100	100	7	17	53	30	20	20	10	37	0	0
lyphosate	(4)	100	97	30	23	90	63	50	37	63	37	23	17
exazinone	(1)	47	57	33	23	0	0	30	27	0	0	0	0
exazinone	(2)	70	77	50	40	0	10	37	40	0	7	0	7
exazinone	(3)	77	87	50	43	25	17	50	40	10	17	23	27
exazinone	(4)	87	87	53	40	20	47	47	47	13	27	13	17
ronamide	(2)	0	0	0	0	0	0	0	0	0	3	0	0
ronamide	(4)	3	0	0	0	0	0	0	0	0	0	0	0
erbacil	(2)	47	37	30	27	0	0	20	33	0	0	0	3
erbacil	(4)	60	53	47	47	20	10	37	40	0	3	0	0
erbacil	(6)	83	70	47	53	17	7	47	40	20	13	13	3
LSD (P = 0.05)		20	20	16	16	23	23	15	15	17	17	15	15
LSD (P = 0.01)		26	26	22	22	31	31	20	20	23	23	20	20

1 lb/acre = 1.12 kg/ha.

Values are means based on three replicates.

cKenzie

edge control.—With exception of sulam and pronamide, all herbicides gnificantly reduced sedge the 1st year able 2). Glyphosate was clearly most fective, providing almost total initial ontrol. Moreover, control with this erbicide persisted longer than that with ny other. The preplanting application of yphosate at 4 lb/acre[1] was still providing 3-percent sedge control through the 3d ear. Atrazine + dalapon mixtures also ave good to excellent initial results at all tes used, but visible persistence of effect averaged less than with glyphosate. Atrazine used alone affected sedge only slightly, but dalapon alone gave moderately good control the 1st year. Dalapon probably contributed most to effectiveness of the atrazine + dalapon mixtures. A combination of cyanazine and atrazine performed similarly to atrazine alone, and resulted in light to moderate control with no effect persisting past the 1st year. Bromacil, hexazinone, and terbacil controlled sedge well initially at all except the lowest rates, but control with bromacil did not persist. Duration of control was short with terbacil, and only moderate with one high rate of hexazinone.

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lb/acre = 1.12 kg/ha.

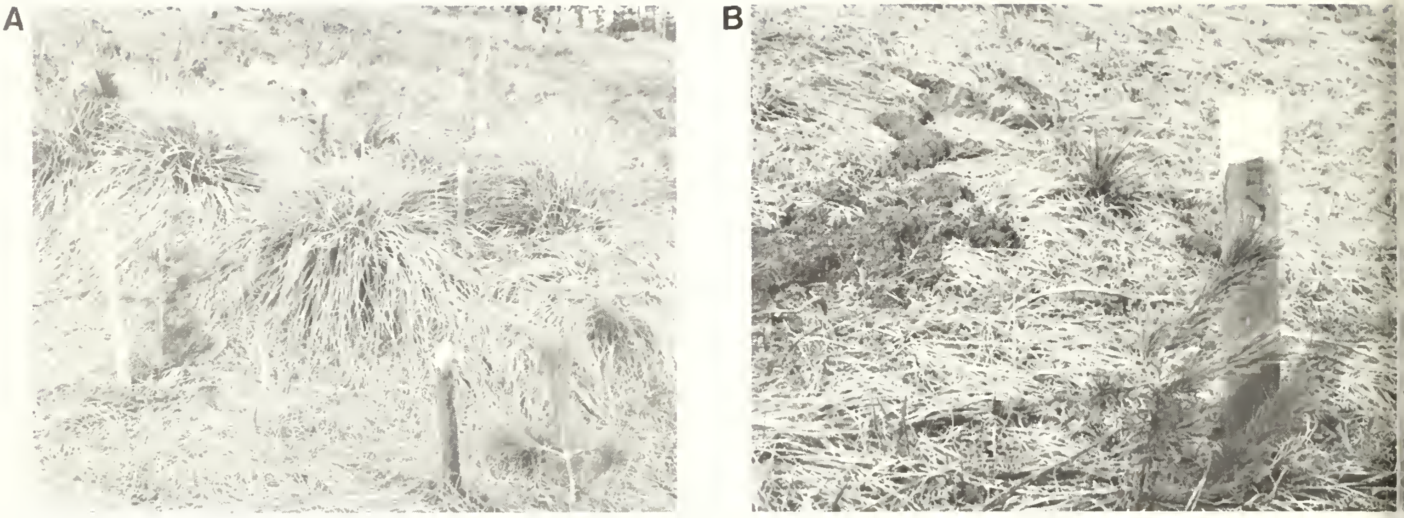

Figure 4.—(**A**) Most surviving western white pine commenced vigorous growth after the third growing season, but some additional mortality seems likely. (**B**) Damage by pocket gophers (*Thomomys monticola mazama* Merriam) was often associated with conifer losses at McKenzie, and will probably continue.

Beargrass control.—First-year control of beargrass did not exceed 53 percent for any herbicide, and reached that level only with bromacil, hexazinone, and terbacil (table 2). Moderate control persisted for 3 years with bromacil, and for 2 years with hexazinone and terbacil. Glyphosate had almost no effect on beargrass the 1st year at a rate of 2 lb/acre and only a slight effect at 4 lb/acre. Interestingly, at the higher rate, control increased from light the 1st year to moderate the 2d. Light 1st-year control was also attained with atrazine, cyanazine + atrazine, and dalapon, and persisted undiminished through the 2d year. Control of beargrass with combined atrazine and dalapon consistently bordered between light and moderate in both 1st and 2d years at all rates applied. Asulam and pronamide appeared totally ineffective on beargrass.

Conifer survival.—Seventy-four percent of untreated western white pine seedlings survived the first growing season, but only 40 percent were alive by the end of the third (fig. 4). Untreated noble fir survived less well, and declined from 44 percent alive the 1st year to 18 percent the 3d.

During 1977, no herbicide produced a significant gain in white pine survival, and only glyphosate benefited noble fir (table 3). The gain for noble fir, however, was substantial. Both low and high preplanting rates of glyphosate produced 71-percent survival versus 37 percent for the untreated check. This 34-percent margin widened to a mean for both rates of 40 percent (52 versus 12 percent) by the 3d year. Though benefits of glyphosate were not significant for white pine in 1977, they became so in 1978, and were associated with both preplanting and postplanting applications in 1979. Th greatest survival gain accrued from post-planting treatment at 2 lb/acre that significantly doubled pine survival after 3 years—i.e., 80 percent for glyphosate treatment versus 40 percent for the untreated check.

Table 3—Survival of western white pine and noble fir at McKenzie after preplanting and postplanting herbicide sprays

Treatment	(Rate in lb ai/acre)[1]	1977				1978				1979			
		White pine		Noble fir		White pine		Noble fir		White pine		Noble fir	
		Pre-plant	Post-plant	Pre-plant	Post-plant	Pre-plant	Post-plant	Pre-plant	Post-plant	Pre-plant	Post-plant	Pre-plant	Post-plant
		Percent [2]											
Untreated check	(–)	78	71	37	51	58	49	20	29	40	40	12	24
Asulam	(5)	54†	62	27	22†	34†	56	18	15	34	51	11	15
Atrazine	(4)	62	69	24	40	55	65	12	23	44	57	7	20
Atrazine + dalapon	(3 + 6)	69	76	44	49	56	62	30	38	54	58	28	32
Atrazine + dalapon	(4 + 8)	68	76	47	42	56	58	33	36	49	58	27	33
Atrazine + dalapon	(5 + 10)	80	49	50	22†	67	40	21	16	62*	35	14	9
Bromacil	(5)	33††	47†	20	18††	27††	20††	7	11	16†	20†	4	7
Cyanazine + atrazine	(4 + 2)	78	49	44	27†	55	44	22	18	49	42	18	16
Dalapon	(8)	74	71	40	47	66	57	33	18	60*	52	33*	13
Glyphosate	(2)	74	93	71**	72	67	80**	58**	42	64*	80**	56**	33
Glyphosate	(4)	59	78	71**	64	59	71*	53**	49	56	71**	47**	40
Hexazinone	(1)	47††	58	31	27†	35†	42	13	16	29	40	11	9
Hexazinone	(2)	49†	50	27	27†	40	35	22	9	31	34	22	9
Hexazinone	(3)	41††	28††	30	18††	33†	14††	18	11	21	9††	11	9
Hexazinone	(4)	38††	33††	13†	27†	31†	14††	11	13	29	9††	7	9
Pronamide	(2)	82	55	40	29	70	47	22	16	64*	38	22	9
Pronamide	(4)	82	51	44	27†	64	44	35	20	53	34	24	13
Terbacil	(2)	58	53	13†	31	48	42	0	18	44	29	0	16
Terbacil	(4)	49†	43†	7††	15††	42	23†	2	2†	38	21	2	0†
Terbacil	(6)	29††	38††	5††	13††	11††	32	0	4†	9††	29	0	4†
LSD (P = 0.05)		23	23	23	23	21	21	21	21	20	20	20	20
LSD (P = 0.01)		30	30	30	30	28	28	28	28	27	27	27	27

[1] 1 lb/acre = 1.12 kg/ha.

[2] Values are means based on 3 replicates of 15 trees each. Means followed by * or ** exceed untreated checks by P<0.05 and P<0.01, respectively; means followed by † or †† fall below untreated checks by P<0.05 and P<0.01, respectively.

Three other preplanting treatments roduced significant survival gains for hite pine by 1979: atrazine + dalapon 5 + 10 lb/acre), dalapon (8 lb/acre), and ronamide (2 lb/acre). Preplanting pplication of dalapon also benefited oble fir. Except for the highest post-lanting rate (5 + 10 lb/acre), atrazine + alapon mixtures at other rates and pplication times consistently tended to mprove white pine survival — but not ignificantly. The two lower rates (3 + 6 nd 4 + 8 lb/acre) were probably also eneficial for noble fir. Dalapon alone at lb/acre appeared possibly harmful only as a postplanting spray to noble fir. The significant benefit of pronamide at 2 lb/acre for white pine was surprising in view of its lack of visible effect on sedge and beargrass. Postplanting applications of this herbicide appeared damaging to both pine and fir in 1977, but this effect became less evident by 1979.

Asulam significantly reduced 1st-year survival of both white pine and noble fir after preplanting and postplanting applications, respectively. By the end of the third season, however, effects were mostly neutral. Both atrazine and cyanazine + atrazine had a similarly neutral effect on conifer survival over time, though postplanting use of the combination tended to depress survival of both species the 1st year. Bromacil clearly reduced pine and fir survival throughout the 3-year period, and preplanting application was no less toxic than postplanting. With minor exceptions, conifers treated with hexazinone and terbacil, regardless of application time, survived less well than untreated checks —and mortality generally increased with increasing dosage rate.

Table 4—Control of sedge at Mount Adams after preplanting and postplanting herbicide sprays

Treatment (Rate in lb ai/acre)[1]		1977		1978		1979	
		Pre-plant	Post-plant	Pre-plant	Post-plant	Pre-plant	Post-plant
		Percent[2]					
Untreated check	(−)	0	0	0	0	0	0
Asulam	(5)	0	0	0	0	0	0
Atrazine	(4)	0	10	0	0	0	0
Atrazine + dalapon	(3+6)	83	70	57	33	55	40
Atrazine + dalapon	(4+8)	100	90	75	75	60	55
Atrazine + dalapon	(5+10)	100	73	93	83	60	70
Bromacil	(5)	73	50	55	20	95	50
Cyanazine + atrazine	(4+2)	10	27	5	0	15	0
Dalapon	(8)	47	50	37	33	40	35
Glyphosate	(2)	83	100	50	47	60	60
Glyphosate	(4)	100	100	63	75	85	70
Hexazinone	(1)	27	5	10	0	5	0
Hexazinone	(2)	60	37	40	10	40	15
Hexazinone	(3)	73	30	47	40	65	40
Hexazinone	(4)	83	43	77	40	60	50
Pronamide	(2)	0	0	0	0	0	0
Pronamide	(4)	0	3	0	0	0	0
Terbacil	(2)	30	7	7	3	10	0
Terbacil	(4)	57	20	60	20	60	25
Terbacil	(6)	60	25	60	43	60	50
LSD (P = 0.05)		37	37	40	40	47	47
LSD (P = 0.01)		49	49	53	53	64	64

[1] 1 lb/acre = 1.12 kg/ha.

[2] Values in 1977 and 1978 are means based on 3 replicates; values in 1979 on 2 replicates.

Mount Adams

Sedge control.—Glyphosate provided total initial control of sedge for all applications except preplanting spray at 2 lb/acre (table 4). Significant control persisted through the 3d year at levels of 60 to 85 percent. During the 1st year, applications of atrazine + dalapon also produced 100-percent control at preplanting rates of 4 + 8 and 5 + 10 lb/acre, and gave good to excellent control at the preplanting rate of 3 + 6 lb/acre, as well as at all postplanting rates. Significant sedge reductions likewise persisted through the 3d year, when control ranged from 40 to 70 percent. Dalapon alone at 8 lb/acre controlled sedge moderately in all years, but significantly in only the 1st. Atrazine at 4 lb/acre was almost totally ineffective—as also were asulam and pronamide. Despite some visible, but not significant, 1st-year control, cyanazine + atrazine failed to reduce sedge. Control with bromacil was both effective and extremely persistent, though the 95-percent 3d-year control with preplanting application reflects loss of the replicate in which bromacil controlled sedge least. Higher rates of hexazinone and terbacil also significantly controlled sedge for 3 years, especially in preplanting applications.

All preplanting treatments combined produced significantly greater sedge control each year than all postplanting treatments. Because of nearly 5 weeks between spraying times in this test, activity of most preplanting sprays was likely enhanced by higher precipitation shortly after application.

Table 5—Survival of western white pine and Engelmann spruce at Mount Adams after preplanting and postplanting erbicide sprays

Treatment	(Rate in lb ai/acre)[1]	1977				1978				1979			
		White pine		Engelmann spruce		White pine		Engelmann spruce		White pine		Engelmann spruce	
		Pre-plant	Post-plant	Pre-plant	Post-plant	Pre-plant	Post-plant	Pre-plant	Post-plant	Pre-plant	Post-plant	Pre-plant	Post-plant
		Percent [2]											
ntreated check	(−)	73	80	25	35	53	69	16	29	34	43	14	14
sulam	(5)	71	75	27	22	55	51	20	16	43	40	16	10
trazine	(4)	79	73	33	25	67	64	24	23	54	54	16	27
trazine + dalapon	(3 + 6)	89	79	40	47	82*	74	32	38	76**	57	40	46*
trazine + dalapon	(4 + 8)	82	84	31	33	78*	73	31	20	77**	46	30	16
trazine + dalapon	(5 + 10)	82	62	44	27	62	53	31	27	50	37	37	26
romacil	(5)	18††	42††	14	2††	9††	25††	9	0†	4†	14†	0	0
yanazine + atrazine	(4 + 2)	78	89	27	47	62	66	20	42	50	60	27	33
alapon	(8)	63	76	36	27	49	55	24	9	23	36	24	6
lyphosate	(2)	89	25††	36	22	84*	25††	24	20	77**	37	20	26
lyphosate	(4)	91	11††	53*	27	87**	11††	38	22	76**	14†	30	24
exazinone	(1)	80	67	36	47	71	58	31	38	64*	47	27	30
exazinone	(2)	47†	47††	27	38	45	38†	20	33	47	36	20	30
exazinone	(3)	31††	36††	38	29	22†	27††	29	20	14	20	30	20
exazinone	(4)	33††	36††	20	22	27†	22††	13	18	14	14†	14	20
ronamide	(2)	55	87	15	42	45	58	13	27	44	36	16	10
ronamide	(4)	62	84	25	33	47	62	18	18	26	34	20	14
erbacil	(2)	49†	73	18	9†	31	44†	13	0†	13	37	10	0
erbacil	(4)	40††	45††	11	24	29†	27††	4	4†	20	16	4	0
erbacil	(6)	13††	31††	11	7†	2††	7††	2	2†	4†	4††	0	0
LSD (P = 0.05)		22	22	22	22	24	24	24	24	29	29	29	29
LSD (P = 0.01)		30	30	30	30	32	32	32	32	39	39	39	39

1 lb/acre = 1.12 kg/ha.

Values in 1977 and 1978 are means based on 3 replicates of 15 trees each; values in 1979 on 2 replicates. Means followed by * or ** exceed untreated hecks by P<0.05 and P<0.01, respectively; means followed by † or †† fall below untreated checks by P< 0.05 and P< 0.01, respectively.

onifer survival.—White pine survival n untreated plots at Mount Adams, much ke that at McKenzie, dropped from 76 ercent the first season to 38 percent the nird. Engelmann spruce survived oorly—only 30 percent the 1st year, eclining to 14 percent by the 3d. 'replanting sprays of glyphosate at both and 4 lb/acre significantly increased hite pine survival over untreated checks y the 2d and 3d years (table 5). Postlanting sprays of the same herbicide, owever, proved decidedly harmful—ontradictory to results at McKenzie. ngelmann spruce strongly benefited in ne 1st year from preplanting application of glyphosate at 4 lb/acre, but the significant gain was ephemeral. For pine, patterns of gain with preplanting sprays of atrazine + dalapon at 3 + 6 and 4 + 8 lb/acre were nearly identical to those attained with glyphosate. Postplanting atrazine + dalapon spray at the lightest rate also significantly increased survival of Engelmann spruce. Preplanting spray of hexazinone at 1 lb/acre initially suggested some possible benefit for pine, and ultimately became significantly beneficial after 3 years. Other applications of hexazinone resulted in seedling survival generally equal to or less than untreated checks.

Among remaining herbicides, cyanazine + atrazine proved the most promising for enhancing conifer survival. Though the combination produced no significant gains, both preplanting and postplanting sprays may have improved survival of white pine and Engelmann spruce after three seasons. Atrazine by itself also produced no conclusive gains, but survival of white pine at 3 years may have benefited moderately. Asulam, dalapon, and pronamide neither increased nor reduced survival of pine and spruce in any consistent way. Bromacil and terbacil produced consistently negative responses with both species.

Table 6—Control of sedge at Prospect after preplanting and postplanting herbicide sprays

Treatment (Rate in lb ai/acre)[1]		1977		1978		1979	
		Pre-plant	Post-plant	Pre-plant	Post-plant	Pre-plant	Post-plant
		Percent[2]					
Untreated check	(−)	0	0	5	0	0	0
Asulam	(5)	3	0	0	9	0	0
Atrazine	(4)	40	53	4	13	6	8
Atrazine + dalapon	(3+6)	77	87	52	54	25	40
Atrazine + dalapon	(4+8)	83	90	77	66	68	60
Atrazine + dalapon	(5+10)	97	93	76	80	69	64
Bromacil	(5)	60	67	53	63	85	71
Cyanazine + atrazine	(4+2)	47	63	0	12	0	0
Dalapon	(8)	93	60	53	54	40	40
Glyphosate	(2)	90	90	65	61	72	28
Glyphosate	(4)	97	97	85	92	46	70
Hexazinone	(1)	53	47	20	4	34	0
Hexazinone	(2)	70	63	37	26	42	14
Hexazinone	(3)	77	83	83	34	59	41
Hexazinone	(4)	83	90	71	55	63	40
Pronamide	(2)	0	3	0	4	0	6
Pronamide	(4)	3	0	0	4	0	6
Terbacil	(2)	43	50	5	4	8	0
Terbacil	(4)	60	67	46	25	39	28
Terbacil	(6)	87	77	47	23	52	29
LSD ($P = 0.05$)		24	24	29	29	42	42
LSD ($P = 0.01$)		32	32	38	38	57	57

[1] 1 lb/acre = 1.12 kg/ha.

[2] Values in 1977 and 1978 are means based on 3 replicates; values in 1979 on 2 replicates.

Prospect

Sedge control.—As at McKenzie and Mount Adams, only asulam and pronamide failed to control sedge (table 6). Excellent to nearly total control was attained with glyphosate at rates of both 2 and 4 lb/acre, and significant control persisted through the 3d year for all but the lightest postplanting application rate. All rates of atrazine + dalapon gave good to excellent control initially, and only the lightest application of the mixture (3 + 6 lb/acre) did not control sedge significantly through the 3d year. Atrazine alone at 4 lb/acre reduced sedge moderately in 1977, but control did not persist. Dalapo alone at 8 lb/acre, however, provided appreciably better and far more lasting control. As at other study locations, sedg control with cyanazine + atrazine was similar to that attained with atrazine use alone. Highly persistent activity was evident with bromacil, which produced moderate control of sedge in 1st and 2d years, and even greater control in the 3 This persistence agrees with a like resul at Mount Adams, but contradicts the short-term control of sedge attained wit bromacil at McKenzie. All rates of hexazinone and terbacil produced moderate to good sedge control the 1st year, and significant control carried over to the 3d year with higher rates of both herbicides.

Table 7—Survival of western white pine and Shasta red fir at Prospect after preplanting and postplanting herbicide sprays

Treatment	(Rate in lb ai/acre)[1]	1977				1978				1979			
		White pine		Shasta fir		White pine		Shasta fir		White pine		Shasta fir	
		Preplant	Postplant	Preplant	Postplant	Preplant	Postplant	Preplant	Postplant	Preplant	Postplant	Preplant	Postplant
		Percent[2]											
Untreated check	(−)	27	33	5	18	9	9	2	0	10	4	0	0
Asulam	(5)	24	49	2	22	11	11	2	9	10	10	0	4
Atrazine	(4)	40	55	5	28	5	14	5	11	7	10	0	0
Atrazine + dalapon	(3 + 6)	60**	45	29*	11	13	9	20**	2	10	4	0	0
Atrazine + dalapon	(4 + 8)	49	57*	36*	44*	25**	13	18**	9	10	14	4	0
Atrazine + dalapon	(5 + 10)	29	49	27	24	13	7	16*	9	0	4	14**	6
Bromacil	(5)	2†	35	0	5	0	9	0	2	0	10	0	4
Cyanazine + atrazine	(4 + 2)	58*	44	23	23	18	14	7	15*	10	6	6	20**
Dalapon	(8)	44	38	27	9	11	15	5	2	6	13	0	0
Glyphosate	(2)	64**	55	49**	42*	27**	25**	24**	20**	24**	30**	4	14**
Glyphosate	(4)	60**	24	40**	34	29**	7	24**	13*	10	4	14**	6
Hexazinone	(1)	11	21	2	13	0	2	0	0	0	4	0	0
Hexazinone	(2)	12	18	5	11	2	7	0	4	4	0	0	0
Hexazinone	(3)	2†	27	11	18	2	9	2	11	4	10	0	7
Hexazinone	(4)	4	11	7	7	0	2	2	0	0	4	4	0
Pronamide	(2)	42	47	27	9	18	15	15*	2	14	16*	6	0
Pronamide	(4)	38	34	16	18	11	5	9	2	6	0	6	0
Terbacil	(2)	20	36	9	5	0	5	0	0	0	4	0	0
Terbacil	(4)	2†	40	0	0	2	5	0	0	0	0	0	0
Terbacil	(6)	4	18	2	0	0	2	0	0	0	0	0	0
LSD ($P = 0.05$)		24	24	24	24	12	12	12	12	11	11	11	11
LSD ($P = 0.01$)		32	32	32	32	16	16	16	16	14	14	14	14

[1] lb/acre = 1.12 kg/ha.

[2] Values in 1977 and 1978 are means based on 3 replicates of 15 trees each; values in 1979 on 2 replicates. Means followed by * or ** exceed untreated checks by $P<0.05$ and $P<0.01$, respectively; means followed by † fall below untreated checks by $P<0.05$.

Conifer survival.—Subfreezing temperatures occurred at Prospect during the 1st week of July in 1977, and planted conifers survived their 1st year poorly in consequence. Adverse effects were even more evident by the 2d year. Mean survival of untreated seedlings dropped from 30 to 9 percent for white pine and from 12 to 1 percent for Shasta fir by the end of 1978. Despite these heavy losses, some increases in survival were associated with herbicide treatment table 7). Glyphosate proved most consistently beneficial for both pine and fir over the 3-year period. Substantial gains for both species during 1977 and 1978 were chiefly associated with preplanting sprays at rates of either 2 or 4 lb/acre. Postplanting sprays at the lower rate were also nearly as effective. By the end of 1979, either preplanting or postplanting applications at the rate of 2 lb/acre were still providing small but significant gains for pine. Several preplanting and postplanting applications of atrazine + dalapon similarly improved pine and fir survival in 1977, but significant gains in 1978 and 1979 stemmed only from preplanting sprays. A substantial 1st-year benefit to white pine from preplanting spray of cyanazine + atrazine proved only temporary, but postplanting spray of the same herbicide aided Shasta fir in the 2d and 3d years. Pronamide at 2 lb/acre also produced small gains for fir during the 2d year and pine during the 3d.

Among other treatments, atrazine at 4 lb/acre and dalapon at 8 lb/acre came closest to providing significant gains in 1977 with postplanting application to pine and preplanting application to fir, respectively. Though survival was 22 percent higher than untreated checks in each case, the advantages did not persist. Asulam appeared neither to increase nor reduce survival of either species in any year. With exception of a few generally neutral responses, bromacil, hexazinone, and terbacil consistently depressed survival of both conifer species below that of untreated checks.

Discussion

Study locations varied considerably in soil, climate, and vegetation. Trends common to all three studies, therefore, are useful for evaluating the consistency of results and broadening the base for inference. Pine was common as a crop species to all tests, but another conifer was unique to each. As survival and treatment response were similar for fir and spruce, all three studies were combined for gross comparison of treatments. This grouping provided nine survival replicates per treatment for pine, and a like number for fir and spruce combined. The number of replicates in each group declined to seven in 1979.

Greatest and most obvious survival gains were consistently associated with preplanting sprays of glyphosate (table 8). Among pine, differences between glyphosate treatments and untreated checks were significant each year for all but one preplanting comparison. Among fir and spruce, all corresponding comparisons, without exception, revealed significant gains. Though 2 lb/acre of glyphosate proved somewhat more effective with pine than 4 lb/acre, the opposite was true with fir + spruce. Partly because of poorer survival of fir + spruce compared to pine, gains for fir + spruce were proportionally greater than those for pine. Absolute percentage gains, however, were similar for both species groups. A significant survival benefit at 3 years for pine sprayed after planting with 2 lb/acre of glyphosate reflects a cumulative superiority of this treatment at McKenzie and Prospect (tables 3 and 7). Postplanting glyphosate sprays, nevertheless, were clearly toxic to pine at Mount Adams (table 5).

Applied before planting, combination sprays of atrazine and dalapon also significantly increased survival of both pine and fir + spruce (table 8). Gains were correspondingly less than those attained with glyphosate, but still highly practical. The rate of 3 + 6 lb/acre provided greatest success by the 3d year for both species groups. The two higher rates (4 + 8 and 5 + 10 lb/acre) generally tended to decline in effectiveness as dosages increased. Postplanting spray at the highest rate consistently reduced survival below that of untreated checks, but losses were not significant.

The significant increase in survival for white pine associated with preplanting application of pronamide at 2 lb/acre may or may not indicate a general benefit of treatment (table 8). This gain depends strongly on results attained with pronamide at McKenzie (table 3). Mode of action by pronamide, and also asulam, is through disruption of mitosis in meristematic plant tissue (Weed Science Society of America 1979). As neither herbicide visibly affected sedge or beargrass, the apparent benefit to pine from a preplanting pronamide spray is not readily explained. Possible impact upon soil organisms or upon allelopathic activity of target plants may be involved, and further research is warranted.

Except for asulam and pronamide, all herbicides controlled target species at least minimally. Two *s*-triazine compounds, atrazine and cyanazine, were associated with light initial control, short persistence of effect, and little or no toxicity to conifers. A third *s*-triazine, hexazinone, resulted in moderate to good initial control, moderate to long persistence of effect, but unacceptable toxicity to conifers at all but the lightest rate (1 lb/acre) of application. The two substituted uracils, terbacil and bromacil, provided control of target species, persistence of effect, and mortality of conifers similar to results attained with hexazinone. Triazines and uracils act in plants chiefly as inhibitors of photosynthesis; dalapon and glyphosate interfere with protein metabolism (Hoagland and Duke 1981, Whitesides 1981). Interestingly, the latter two herbicides were the ones in these tests most commonly associated with effective control of target vegetation coupled with enhancement of conifer survival.

Though control of beargrass was rated only at McKenzie, herbicides with the most visible impact—i.e., bromacil, hexazinone, and terbacil—were not the ones yielding greatest survival benefits for conifers. Rather, herbicides combinin maximal activity on the sedge componer of the sedge-beargrass community with minimal toxicity to conifers proved ultimately best. Even if attainable, a high degree of beargrass control may well be unnecessary if substantially improved survival of conifers is possible without it. Sedge is more shallowly rooted than beargrass, and, where the two species coexist, competes more directly in the rooting zone of newly planted seedlings. Measures that effectively mitigate effect of below-ground competition at shallowe depths are more likely to forestall much conifer mortality that occurs soon after planting.

Both success of plantation establishmer and subsequent stand development nee be considered in species selection for upper slopes. Conifers in these studies are well adapted to the locations where tested. Western white pine on various sites consistently survived 2 to 3 times better than noble fir, Engelmann spruce, or Shasta red fir. Without treatment, however, survival of all species was ultimately disappointing after 3 years. Certain herbicides used for site preparation succeeded in substantially raising survival of all four species. Moreover, th gains achieved were of sufficient proportion or magnitude to bridge the gap between success and failure of conifer plantations in typical management situations.

Table 8—Survival of western white pine, noble fir, Engelmann spruce, and Shasta red fir at McKenzie, Mount Adams, and Prospect combined, after preplanting and postplanting herbicide sprays

Treatment	(Rate in lb ai/acre)[1]	1977				1978				1979			
		White pine		Fir + spruce		White pine		Fir + spruce		White pine		Fir + spruce	
		Pre-plant	Post-plant	Pre-plant	Post-plant	Pre-plant	Post-plant	Pre-plant	Post-plant	Pre-plant	Post-plant	Pre-plant	Post-plant
		Percent[2]											
Untreated check	(−)	59	61	22	35	40	42	13	19	30	31	9	14
Asulam	(5)	50	62	19	22	33	39	13	13	30	34	9	9
Atrazine	(4)	60	66	21	31	42	48	14	19	36	43	8	16
Atrazine + dalapon	(3+6)	73*	67	38*	36	50	48	27*	26	48*	42	23*	27
Atrazine + dalapon	(4+8)	66	72	38*	40	53	48	27*	22	46*	42	21	19
Atrazine + dalapon	(5+10)	64	53	40**	24	47	33	23	17	41	27	21	13
Bromacil	(5)	18††	41††	11	8††	12††	18††	5	4†	8††	15†	2	3
Cyanazine + atrazine	(4+2)	71	61	31	32	45	41	16	25	38	37	17	22
Dalapon	(8)	60	62	32	28	42	42	22	10	34	36	21	7
Glyphosate	(2)	76*	58	52**	42	59**	43	35**	27	56**	53**	31**	26
Glyphosate	(4)	70	38††	55**	42	58*	30	38**	28	49**	36	33**	26
Hexazinone	(1)	46	49	23	29	35	34	15	18	31	32	12	12
Hexazinone	(2)	36††	38††	20	25	29	27†	14	15	28	25	15	12
Hexazinone	(3)	25††	30††	26	22	19††	17††	16	14	14†	12††	13	12
Hexazinone	(4)	25††	27††	13	19†	19††	13††	9	10	16†	9††	8	10
Pronamide	(2)	60	63	27	27	44	40	17	15	44*	31	16	7
Pronamide	(4)	61	56	28	26	41	37	21	13	32	24	18	10
Terbacil	(2)	42†	54	13	15††	26†	30	4	6	23	24	3	7
Terbacil	(4)	30††	43††	6†	13††	24†	18††	2	2†	22	14†	2	0†
Terbacil	(6)	15††	29††	6†	7††	4††	14††	1	2†	5††	14†	0	2
LSD (P = 0.05)		14	14	14	14	14	14	14	14	14	14	14	14
LSD (P = 0.01)		18	18	18	18	19	19	19	19	19	19	19	19

[1] 1 lb/acre = 1.12 kg/ha.

[2] Values in 1977 and 1978 are means based on 9 replicates of 15 trees each; values in 1979 on 7 replicates. Means followed by * or ** exceed untreated checks by $P<0.05$ and $P<0.01$, respectively; means followed by † or †† fall below untreated checks by $P<0.05$ and $P<0.01$, respectively.

Research Application

Recent progress toward improving resistance of western white pine to blister rust demands reconsideration of this conifer for reforesting upper slopes. Moreover, its inherent capacity to tolerate freezing temperatures and moisture stress (Minore 1979) applies well to the normally frost-prone environments of sedge and beargrass communities. Relative resistance of Engelmann spruce to both frost and drought (Minore 1979) would likewise appear promising for exploitation. Plantations of noble fir and Shasta red fir, conifers frequently predominating in upper-slope stands, could also benefit by planting them mixed with hardier species. Mixed plantings would provide potential for more rapid and certain site occupancy, greater initial stand growth, and more efficient use of growing space.

Sprays of glyphosate or atrazine + dalapon mixtures can be used effectively for site preparation in plantations of western white pine, noble fir, Engelmann spruce, and Shasta red fir. The lowest rates tested—i.e., 2 lb ai/acre of glyphosate, or 3 + 6 lb ai/acre of atrazine + dalapon—provided gains in conifer survival similar to those achieved with higher rates. These herbicides and rates appear adequate for general use with the above species in aiding reforestation of upper-slope sites dominated by sedge and beargrass. Preplanting sprays averaged consistently more successful than postplanting sprays, but the latter produced equivalent and sometimes superior results in specific situations. In practice, performance of postplanting sprays could probably be enhanced by shielding conifers or directing spray applications to minimize contact with conifer foliage. High volume of water carrier used in herbicide treatments was aimed at enhancing thoroughness and uniformity of herbicide distribution. Lower volumes, normally used in practice, should differ little in effectiveness.

Literature Cited

Carmer, S. G.; Swanson, M. R. Detection of differences between means: a Monte Carlo study of five pairwise multiple comparison procedures. Agron. J. 63:940-945; 1971.

Crouch, G. L. Atrazine improves survival and growth of ponderosa pine threatened by vegetative competition and pocket gophers. For. Sci. 25(1):99-111; 1979.

Dimock, E. J. II; Collard, E. B. Postplanting sprays of dalapon and atrazine to aid conifer establishment. USDA For. Serv. Res. Pap. PNW-280. Portland, OR: Pac. Northwest For. and Range Exp. Stn.; 1981.

Eckert, R. E., Jr. Establishment of pine (*Pinus* spp.) transplants in perennial grass stands with atrazine. Weed Sci. 27(3):253-257; 1979.

Franklin, J. F.; Dyrness, C. T. Natural vegetation of Oregon and Washington. USDA For. Serv. Gen. Tech. Rep. PNW-8. Portland, OR: Pac. Northwest For. and Range Exp. Stn.; 1973.

Gratkowski, H.; Jaszkowski, R.; Armstrong, L. Survival of Douglas-fir seedlings sprayed with atrazine, terbacil, and 2,4-D. USDA For. Serv. Res. Pap. PNW-256. Portland, OR: Pac. Northwest For. and Range Exp. Stn.; 1979.

Heidmann, L. J. Use of herbicides for plantin site preparations in the Southwest. J. For 67:506-509; 1969.

Heidmann, L. J. Preemergent herbicides for preparing ponderosa pine planting sites i the Southwest. USDA For. Serv. Res. No RM-164. Fort Collins, CO: Rocky Mt. For. and Range Exp. Stn.; 1970.

Hoagland, R. E.; Duke, S. O. Glyphosate: a unique herbicide. Weeds Today 12(2): 21-23; 1981.

Minore, D. Comparative autecological characteristics of northwestern tree species — a literature review. USDA For. Serv. Gen. Tech. Rep. PNW-87. Portland OR: Pac. Northwest For. and Range Exp. Stn.; 1979.

Newton, M. Mixing herbicides for optimum weed control in Pacific Northwest conifer Ind. Veg. Manage. 6(3):15-18; 1974.

Stewart, R. E.; Beebe, T. Survival of ponderosa pine seedlings following contr of competing grasses. Proc. West. Soc. Weed Sci. 27:55-58; 1974.

Weed Science Society of America. Herbicide handbook. 4th ed. Champaign, IL: Weed Sci. Soc. Am.; 1979.

Whitesides, R. E., compiler. Oregon weed control handbook. Corvallis, OR: Oreg. State Univ. Ext. Serv.; 1981.

Dimock, Edward J. II. Herbicide and conifer options for reforesting upper slopes in the Cascade Range. Res. Pap. PNW-292. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1981. 14 p.

Nine herbicides were compared for aiding establishment of four conifer species on upper-slope forest sites dominated by sedge and beargrass. Both glyphosate and a mixture of atrazine + dalapon produced substantial and consistent gains in survival of all four conifers after 3 years.

Keywords: Herbicides (-regeneration, site preparation (-regeneration, herbicide formulations, regeneration (stands), western white pine, Engelmann spruce, noble fir, Shasta red fir.

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Interactions Between Domestic and Export Markets for Softwood Lumber and Plywood: Tests of Six Hypotheses

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Abstract

Darr, David R. Interactions between domestic and export markets for softwood lumber and plywood: tests of six hypotheses. Res. Pap. PNW-293. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1981. 22 p.

Price formation in export markets and available data on export and domestic markets are discussed. The results of tests of several hypotheses about interactions between domestic and export markets are presented and interpreted from the standpoints of trade promotion and trade policy.

Keywords: Markets (external), markets (internal), market prices, trade policy, import/export (forest products), softwoods, plywood.

Summary

The objective of this report was to identify patterns of interactions between domestic and export markets in terms of volume and price. A conceptual model of trade in terms of excess supply and excess demand served as a basis for the analysis. The model was applied to analysis of the interaction of domestic production and prices and the volume and price of exports for softwood lumber and softwood plywood using quarterly data for the period, 1965-79. The focus of the analysis was to interpret these interactions from the standpoint of promotion of exports and trade policy that has the intent of making exports responsive to domestic market conditions.

Exports of softwood lumber were classified according to rough and dressed southern pine and by all other species in an attempt to account for possible differences in the characteristics of interactions of markets.

Results of the analysis suggest that prices in the export market have a positive, significant relationship to prices in the domestic market: The same set of variables that influence prices in one market influence prices in the other market or different sets of variables influence the two markets and are themselves related.

The results of tests of hypotheses about the behavior of prices and volumes in the two markets suggests that shifts in excess supply through shifts in the product mix of exports have had a major influence on the movements of the prices and volumes of exports of dressed softwood lumber and softwood plywood. For rough softwood lumber, results of the analysis suggest that shifts in excess demand have been especially important in determining the volume and price of exports.

Efforts to promote the export of U.S. softwood lumber and plywood to date have generally concentrated on attempts to shift excess demand for lumber and plywood to the sizes and grades consumed in the United States. If promotion efforts are successful over time, shifts in excess supply may increase in importance as sources of movements in the price and quantity of total exports.

If one accepts the view that manipulation of domestic demand for the purposes of promoting exports is generally unacceptable in the United States, then excess supply can be affected only through shifts in domestic supply.

Efforts to make the volume and price of exports responsive to domestic market conditions generally have the intent of relieving the pressure of exports on domestic prices when these prices are high. If the manipulation of domestic demand is dismissed as a viable option, efforts to relieve the pressure of exports on domestic prices are limited to increases (shifts) in domestic supply and/or decreases (shifts) in excess demand.

The results of the study suggest that shifts in supply and/or demand in one market are reflected quickly in the other market. From the standpoint of promotion of exports, this responsiveness to markets may contribute to the impression of U.S. producers being in and out of the export market, depending on domestic market conditions. The linkages of domestic and export markets also suggest that trade policy, to be effective in making exports responsive to domestic market conditions, must anticipate rather than respond to market interactions.

Introduction

The behavior of prices and volumes in export markets in relation to domestic markets is of interest for:

1. Formulation of trade policy particularly in developing a policy to reduce exports during times of high domestic prices and increase exports during times of low domestic prices.

2. Development and promotion of export sales. Over the past several years, there has been renewed interest in expansion of U.S. export of timber products.

The objective of this report is to identify patterns of interactions between domestic and export markets in terms of volume and price.

The pattern and causes of movements in prices and volumes in U.S. domestic markets for timber products have been the subject of numerous studies. A review of the literature is available in Adams and Haynes (1980). Analysis of the behavior of prices and volumes in U.S. export markets for timber products has been limited. Identification of patterns of market interactions between domestic and export markets is a first step in evaluating alternative trade and promotion policies. Much of the interest in export sales from the standpoint of trade policy and export promotion has been shown for softwood construction materials. The analyses in this report are limited to softwood lumber and softwood plywood.

The Hypotheses

The analyses in this report test the following hypotheses:

1. There is a positive relationship between price in the export market and price in the domestic market.

2. There is a positive relationship between price in the export market and the volume of exports.

3. There is a positive relationship between the volume of exports and the ratio of export to domestic prices.

4. There is a positive relationship between the volume of exports and the volume of domestic production.

5. There is a positive relationship between production in the United States and price in the export market.

6. There is a positive relationship between price in the domestic market and the volume of exports.

Patterns of market interactions indicated by tests of these hypotheses are interpreted for their implications for trade policy and promotion of exports after presentation of results and conclusions.

A Model of Trade

Markets cannot be modeled in total detail: Many variables are interacting at the same time and the influence of any one variable may be masked by the influence of other variables. Traditionally, analysts have attempted to abstract from some of the complexity of interactions in markets. The purpose has been to identify principles that underlie the behavior of markets under specified assumptions. The theory of price formation in export markets is presented in most texts on trade theory, for example, Kreinin (1971). This theory provides the conceptual framework for interpretating the tests of the hypotheses examined in this study. Key concepts in the theory are excess supply and excess demand.

Excess supply refers to the volume of product that producers in an exporting country are willing to sell in foreign markets at various prices. Excess demand refers to the volume of product that an importing country is willing to purchase from foreign producers at various prices.

Excess supply is determined by total supply and domestic demand in exporting countries. Excess demand is determined by total domestic supply and total demand in importing countries. The concept of excess supply and excess demand determining prices in the export market is illustrated in figure 1.

At prices above P_{1E} in the exporting country, supply exceeds demand. At prices below P_{1I} in the importing country, demand exceeds supply. The prices P_{1E} and P_{1I} would be the prices that would exist in the exporting and importing country, respectively, in the absence of trade. For trade to take place in the

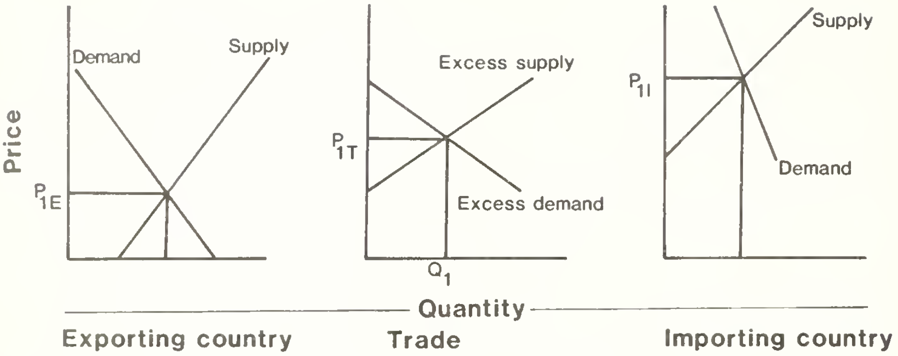

Figure 1.—Conceptual model of trade between two countries.

situation depicted in figure 1, P_{1I} must be greater than P_{1E}. If supply is subtracted from demand at prices lower than P_{1I} in the importing country, the demand for imports results. The "excess demand schedule" is equal to zero at price, P_{1I}. If demand is subtracted from supply at prices greater than P_{1E} in the exporting country, the export supply results. This "excess supply schedule" is equal to zero at price P_{1E}. The volume of exports is determined by the intersection of the excess supply and excess demand schedules. In figure 1, the volume of exports is equal to Q_1, at price P_{1T}. After trade occurs, the price of the commodity is equal to P_{1T} in both the exporting country and the importing country. Trade has the effect of raising prices in the exporting country and lowering prices in the importing country.

Changes in prices in the export market are caused by shifts in excess supply or shifts in excess demand, or by shifts in both at the same time. Shifts in excess supply schedule are caused by shifts in supply or demand in the exporting country. Variables that would cause demand to shift in the exporting country include population, income, housing starts, and consumer preferences. For example, an increase in housing starts would cause demand in the exporting country in figure 1 to shift upward and to the right. This would cause the excess supply schedule to shift upward and to the left. Price would increase in the exporting country. Through trade, price would also increase in the importing country.

Variables that would cause supply to shift in the exporting country include the cost of land and timber, the cost of labor, the cost of capital, and the type of processing equipment used. For example, an increase in the cost of timber would cause supply in the exporting country in figure 1 to shift upward and to the left. This would cause the excess supply schedule to shift upward and to the left. Price would increase in both the exporting and importing countries. Total production would decline in the exporting country and the volume exported would decline.

Shifts in the excess demand schedule are caused by shifts in supply or demand in the importing country. For example, an increase in housing starts in the importing country in figure 1 would cause demand to shift upward and to the right. This would cause the excess demand schedule to shift upward and to the right. Price would increase in both the importing and exporting countries and the volume of trade would increase. An increase in the cost of timber in the importing country would cause the supply schedule in the importing country to shift upward and to the left. The excess demand schedule would shift upward and to the right. The price of the commodity would increase as would the volume of imports.

Shifts in the price and volume of exports over time are determined by the interaction of shifts in supply and demand in the importing and exporting countries. The price and quantity of exports thus show the end result of these interactions. If the price and quantity of exports are the only data available over time, it is not possible to determine what caused prices and exports to change over time. For example, in figure 2A, the price and quantity data could indicate that the excess supply schedule has remained stable over time and that all changes in price and export volume are attributable to shifts in the excess demand schedule. Alternatively, however, both the excess supply and excess demand schedules may have shifted over time, resulting in the pattern of prices and exports shown in figure 2A. Similarly in figure 2B, changes in prices and exports may be caused only by shifts in the excess supply schedule; or they may be caused by shifts in both the excess demand and excess supply schedules. In figure 2C, there is no apparent pattern to shifts in either the excess supply or excess demand schedule.

Trade policies that have the objective of making exports responsive to domestic market conditions generally must operate through tariffs and quotas that influence the excess supply schedule. Alternatively, the exporting country may try to implement policies that would increase domestic supplies during times of high prices, thereby making more of the commodity available to both domestic and export markets. Finally, the exporting country may somehow convince the importing country to implement policies designed to make their demands for imports responsive to market conditions in the exporting country.

Figure 2. — Examples of patterns of price and volume in an export market. **A.** Possible shifts in excess demand; **B.** Possible shifts in excess supply; **C.** No apparent pattern in shifts in excess supply and excess demand.

Efforts to promote exports must work through shifts in the excess supply schedule or shifts in the excess demand schedule. These efforts may take the form of subsidies or other incentives for exports and programs designed to point out market opportunities to producers in the exporting country. Attempts may be made to increase domestic supply so as to make more of the commodity available to both the domestic and export markets. Alternatively, the exporting country may shift domestic demand through taxes and other disincentives to consumption, thereby making more output available for the export market. Finally, the exporting country may somehow shift the excess demand schedule for the commodity in the importing country through promotion of the products of the exporting country and through reductions in tariff and nontariff trade barriers.

In this report, the United States is considered to be the exporting country as in figure 1. Exports from the United States are not analyzed by country of destination. The rest of the world is treated as the importing country. Product categories considered in the analyses are assumed to be homogeneous. For example, exported plywood is assumed to be identical in size and grade to plywood that is consumed domestically. Descriptions of models of trade that consider more than two countries, more than one product, and nonhomogeneous products are available in other sources such as Kreinin (1971).

Methods

Data

Specifications and tests of the hypotheses were determined in part by available data. The data sources for U.S. exports of all commodities originate with individual exporters who submit Export Declaration Forms to the U.S. Treasury Department. These forms provide information on the type of commodity exported and its volume, price, and country of destination. The U.S. Department of Treasury provides this information to the U.S. Department of Commerce which compiles and publishes the data.

The various categories of softwood lumber and softwood plywood as compiled in reports by the Department of Commerce are discussed in appendix A. The data provide a breakdown of exports by species for softwood lumber and less detail by species for softwood plywood. The detail on softwood lumber extends to categorization by rough and dressed or worked. The detail provided by these categories is in general not sufficient to relate export volumes and prices to specific end uses in the importing countries. For example, a 2″ x 4″ by 8′ piece of lumber is a different type of product than a 12″ by 12″ by 30′ timber. Nor do the available data on exports have any detail on the quality or grade of exports of either softwood lumber or softwood plywood.

Exports from Alaska have only an indirect effect on the volume and price of exports from the lower 48 States. As a result, exports from Alaska have not been given much weight in programs to expand U.S. exports of timber products nor have they received much weight in the formulation of policies to link export sales to conditions in domestic markets. In 1979, Alaska exported a total of 228 million board feet of lumber, almost all to Japan. This volume amounted to about 16 percent of total U.S. foreign sales of softwood lumber.

The data base for tests of the hypotheses consisted of quarterly data for the period, 1965-79. Especially during the 1970's, major movements in prices, production, and consumption of timber products have occurred within the period of a year. Annual data would tend to mask these types of changes.

For exports of softwood lumber and softwood plywood, U.S. Department of Commerce data for volume and value were aggregated into the following categories:

1. Rough lumber, except rough southern pine

2. Rough southern pine lumber

3. Dressed lumber, except dressed southern pine

4. Dressed southern pine lumber

5. Softwood plywood.

The distinction between rough and dressed lumber was made on the rationale that rough lumber probably consists of large timbers and other specialty items. These items may bear a different relationship between domestic and export markets than is the case for dressed lumber which is likely to consist of dimension lumber of the sizes and grades consumed in the U.S. domestic market.

Southern pine was differentiated from other softwood lumber primarily because export markets differ between the two categories. Southern pine export volume is concentrated in shipments to Central America and Western Europe. Except for shipments from Alaska, most of the softwood lumber exports other than southern pine originate in the West, primarily Washington and Oregon. Lumber of western species is shipped worldwide.

No data are available to differentiate end uses of the various categories of softwood plywood in the export market. All categories of softwood plywood were combined for the purposes of this analysis.

The volume and value data for the categories of exports used in the analysis are shown in table 1. In recent years, rough lumber except southern pine accounted for about 64 percent of total exports; rough southern pine, 8 percent; dressed lumber except southern pine, 25 percent; and dressed southern pine the remaining 3 percent. Exports from Alaska amount to almost 16 percent of total shipments. The generally higher prices for rough compared with dressed lumber indicate that the rough lumber category probably includes specialty items such as clear timbers that command premium prices. The average value of each category of exports has generally been increasing over time, especially in the 1970's.

All data were tested for seasonality, and there were no significant seasonal patterns in any of the data series (see appendix B for details).

Data for domestic production and prices used in the analysis are shown in table 2. The data series were tested for seasonality and adjusted where significant seasonal patterns were found (see appendix B for details). Significant seasonal patterns were found for all data series for production of softwood lumber. The original and seasonally adjusted data series are shown in table 2. The seasonally adjusted data series were used in the analyses that follow.

In recent years, the southern pine region has accounted for about 27 percent of U.S. production of softwood lumber and the Douglas-fir region, 28 percent. The States of Washington and Oregon together account for 49 percent of total U.S. exports of softwood lumber.

Total U.S. softwood plywood production increased rapidly during the 1960's and early 70's but has shown no growth trend in recent years. In the late 1970's, the States of Washington and Oregon accounted for 82 percent of U.S. exports of softwood plywood.

Procedure for Testing Hypotheses

In the analyses that follow, hypotheses of relationships between variables are tested using the linear relationship, $Y = A + Bx$, where Y is the dependent variable, A is a constant, B is the slope or regression coefficient, and x is the independent variable.

No attempt is made to identify causality in the relationships. The emphasis is on whether change in one variable is related to change in another. For example, in the case of the relationship between prices in the export and domestic markets, previous discussion has pointed out that prices in these markets are determined by the interactions of variables affecting supplies and demands in both markets. Without additional information on supply and demand conditions in the two markets, one cannot infer that prices in one market are determined by prices in the other: Prices are determined simultaneously.

In the analyses that follow, the standard F test was used to determine if the slope coefficient was significantly different from zero. This test of the slope coefficient is a test of the stated hypotheses.

In accepting or rejecting a hypothesis, the 5-percent level of significance is used. This means that the probability of obtaining a significant value of F when the two variables actually are completely uncorrelated is 5 percent.

All relationships were quantified using a data base for the 1965-79 period. These relationships were tested for autocorrelation according to the Durbin-Watson statistic. When autocorrelation was indicated, the relationship was respecified and estimated in terms of residuals.

Implications of the analysis for trade promotion programs and trade policies are discussed after presentation of the results of tests of the hypotheses.

Table 1—Volume and average value of U.S. exports of softwood lumber and softwood plywood and volume of softwood lumber exports from Alaska, 1965-79

Year and quarter	Softwood lumber										Softwood plywood		Softwood lumber, Alaska[1]
	Rough except southern pine		Rough southern pine		Dressed except southern pine		Dressed southern pine		Total				
	Volume[1]	Average value[2]	Volume[1]	Average value[2]	Volume[1]	Average value[2]	Volume[1]	Average value[2]	Volume[1]	Average value[2]	Volume[3]	Average value[4]	
1965:													
1st	138.8	114.56	13.0	149.81	17.9	100.53	6.4	129.69	176.1	280.78	6.8	135.16	34.2
2d	136.6	121.13	21.7	153.30	24.9	107.40	10.8	134.77	194	266.30	6.5	128.35	51.3
3d	168.1	121.03	16.2	153.23	33.3	110.34	7.8	125.12	225.4	226.11	9.3	123.04	51.3
4th	148.6	121.85	18.1	152.97	86.7	39.66	10.2	132.27	263.6	169.54	10.5	117.75	34.2
1966:													
1st	133.8	117.12	19.5	147.38	24.4	108.66	9.8	112.97	187.5	259.26	9.7	113.59	40.8
2d	188.7	119.64	17.8	153.14	39.7	108.54	8.2	123.52	254.4	198.48	10.6	123.86	61.2
3d	147.8	115.47	15.4	152.21	48.8	102.36	8.7	135.92	220.7	229.23	11.6	124.39	61.2
4th	141.9	118.96	12.5	161.76	48.2	104.12	9.0	134.14	211.6	245.23	15.8	106.41	40.8
1967:													
1st	140.7	113.51	14.4	154.89	32.4	110.06	7.5	131.14	195	261.33	20.6	101.60	18.8
2d	205.4	106.77	14.3	161.35	38.8	104.07	7.6	134.31	266.1	190.37	20.5	106.69	60.4
3d	187.7	102.31	10.3	159.22	47.5	110.95	8.6	134.38	254.1	199.43	22.0	106.14	62.9
4th	180.3	106.36	15.7	153.96	42.6	103.87	9.2	145.86	247.8	205.83	21.8	105.15	61.8
1968:													
1st	213.6	108.61	13.4	159.34	47.7	112.15	9.7	110.66	284.4	172.59	15.8	116.28	74.1
2d	197.2	124.45	14.5	162.75	44.2	118.12	8.4	154.15	264.3	211.70	16.5	142.46	54.4
3d	192.6	124.52	13.9	160.16	39.5	129.56	9.6	158.24	255.6	223.99	16.9	131.55	59.6
4th	189.2	131.84	15.0	124.94	38.6	124.72	11.2	175.96	254	219.46	14.7	137.43	57.6
1969:													
1st	149.4	137.99	7.1	158.60	34.2	146.21	4.4	183.33	195.1	320.90	13.5	162.95	45.7
2d	209.0	138.80	15.3	170.64	49.4	153.15	8.3	180.06	282	227.88	55.5	121.37	81.2
3d	195.1	160.25	11.9	166.63	48.8	128.76	7.8	177.71	263.6	240.26	80.0	111.37	76.9
4th	216.9	152.40	13.5	173.13	51.0	109.49	6.9	149.01	288.3	202.60	50.3	115.12	82.0
1970:													
1st	187.2	161.19	11.7	177.54	46.4	119.77	7.6	157.87	252.9	243.75	28.4	112.24	60.5
2d	270.5	137.25	19.6	182.60	39.8	127.31	5.3	166.44	335.2	183.03	31.4	102.64	86.2
3d	249.8	112.25	12.5	182.03	54.3	114.59	5.3	153.52	321.9	174.68	23.3	123.82	105.5
4th	155.7	176.86	13.0	181.23	61.1	113.68	5.0	153.53	234.8	266.30	30.7	129.55	63.4
1971:													
1st	167.6	153.35	10.9	193.14	45.1	125.94	5.0	164.77	228.6	278.72	26.5	119.62	43.9
2d	169.3	158.80	11.0	188.92	49.7	147.32	7.2	198.59	237.2	292.41	29.8	135.20	50.3
3d	145.8	124.85	13.2	146.78	42.9	152.01	7.7	218.02	209.6	306.09	7.8	142.72	73.7
4th	173.8	136.36	4.9	175.89	40.5	152.16	5.6	219.04	224.8	304.04	35.0	138.11	79.5
1972:													
1st	200.4	147.60	7.5	175.75	57.3	138.02	7.0	280.57	272.2	272.63	34.3	119.19	91.0
2d	215.5	178.53	9.8	185.11	61.6	180.86	6.8	274.50	293.7	278.82	56.2	145.25	69.4
3d	226.8	175.80	9.9	210.43	70.7	148.75	5.3	298.98	312.7	266.69	82.7	140.94	99.3
4th	205.3	181.85	15.4	251.98	59.2	176.41	3.6	366.15	283.5	344.41	50.3	162.82	80.5

1973:													
1st	374.0	191.88	12.4	233.47	84.0	172.50	3.7	328.93	474.1	195.47	76.9	149.83	93.9
2d	300.4	269.35	24.2	232.65	89.7	174.19	4.2	165.83	418.5	225.12	77.8	165.82	101.6
3d	379.2	269.23	24.6	219.87	82.1	180.26	4.3	269.57	490.2	191.52	97.0	164.16	121.4
4th	277.6	316.80	17.2	261.99	84.7	179.54	4.3	303.30	383.8	276.61	210.7	103.14	88.0
1974:													
1st	350.9	284.43	14.2	299.63	91.4	214.22	4.7	319.99	461.2	242.48	202.6	151.52	105.7
2d	372.5	259.65	15.1	271.73	87.0	222.62	8.8	310.91	483.4	220.29	146.2	163.42	108.3
3d	236.1	271.46	13.1	268.49	61.1	240.79	6.5	275.51	316.8	333.43	111.5	154.24	64.2
4th	210.3	225.36	11.6	243.40	63.7	210.00	6.0	281.83	291.6	329.43	89.2	141.07	84.2
1975:													
1st	218.8	236.17	5.7	254.0	69.6	206.88	5.1	246.79	299.2	315.50	83.1	144.03	80.4
2d	230.3	249.50	11.2	314.2	81.4	212.51	6.8	274.13	329.7	318.61	151.3	165.55	74.9
3d	308.7	266.22	11.6	316.66	86.7	224.59	7.2	270.26	414.2	260.17	276.9	163.35	101.9
4th	233.9	273.82	12.8	324.20	95.3	232.62	9.7	269.46	351.7	312.76	285.0	153.57	56.2
1976:													
1st	224.7	278.37	22.8	310.22	97.8	244.89	11.4	299.69	346.7	326.81	161.0	174.33	59.0
2d	277.1	310.02	25.4	362.79	93.7	259.70	9.4	339.55	405.5	313.70	271.1	175.55	69.2
3d	296.2	300.13	30.7	332.46	92.7	229.12	8.4	306.74	428.0	273.01	139.8	176.77	97.2
4th	275.6	324.72	28.1	343.88	87.5	285.60	15.8	323.90	407.0	314.04	154.4	197.20	64.7
1977:													
1st	275.2	300.59	29.7	359.65	86.3	295.65	9.5	349.73	400.7	325.85	103.9	186.95	59.4
2d	261.6	325.83	37.7	369.56	88.2	297.76	13.3	330.03	400.8	330.12	80.2	192.58	67.8
3d	217.3	304.34	31.6	392.28	74.8	286.11	14.6	379.21	338.3	402.63	53.4	212.90	64.0
4th	181.3	327.50	31.5	362.67	88.9	251.64	13.6	384.30	315.3	420.58	57.0	225.16	58.8
1978:													
1st	205.5	315.81	22.6	400.94	77.9	256.95	8.2	335.73	314.2	416.72	72.3	211.49	53.7
2d	245.2	336.58	28.7	421.92	106.9	264.02	8.2	309.93	389.0	342.53	103.1	204.86	61.0
3d	184.5	353.92	24.0	457.74	107.3	252.57	6.1	336.79	321.9	435.24	52.3	230.80	56.1
4th	213.6	386.73	31.0	452.72	99.4	317.59	11.4	397.42	355.4	437.37	69.9	240.69	67.0
1979:													
1st	268.4	418.46	42.3	347.77	86.4	335.79	9.0	384.76	406.1	366.09	108.6	232.23	80.7
2d	292.1	489.81	30.5	510.31	114.3	339.41	10.1	457.03	447.0	401.91	114.7	240.48	75.8
3d	283.3	506.30	31.4	573.88	116.3	341.39	12.4	465.10	443.4	425.48	96.2	260.53	64.2
4th	264.6	522.38	36.0	584.39	108.0	356.27	24.0	445.93	432.6	441.26	82.3	253.94	57.8

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[1] In million board feet.
[2] In dollars per thousand board feet.
[3] In million square feet, 3/8-inch basis.
[4] In dollars per thousand square feet.

Source: Ruderman (1981) and U.S. Bureau of the Census (monthly).

Table 2—Wholesale price indexes (1967 = 100) for Douglas-fir lumber, southern pine lumber, all softwood lumber, and softwood plywood; production of softwood lumber in the southern pine region; U.S. production of softwood lumber other than in the southern pine region, and production of softwood plywood, 1965-79

Year and quarter	Wholesale price indexes				Production of softwood lumber (Million board feet)								Production of softwood plywood[1]
					Southern pine region		Douglas-fir region		Total except southern pine region		Total		
	Douglas-fir lumber	Southern pine lumber	All softwood lumber	Softwood plywood	Actual	Seasonally adjusted	Actual	Seasonally adjusted	Actual	Seasonally adjusted	Actual	Seasonally adjusted	
1965:													
1st	94.3	89.7	95.3	95.3	1,594	1,633	2,148	2,108	5,167	5,317	6,761	6,947	2,861
2d	92.0	89.9	96.2	96.2	1,650	1,595	2,256	2,159	5,662	5,384	7,312	6,981	3,072
3d	92.3	91.7	96.9	96.9	1,719	1,701	2,250	2,292	6,075	5,903	7,794	7,608	3,011
4th	91.0	94.0	97.6	97.6	1,665	1,700	2,259	2,367	5,627	5,939	7,292	7,636	3,239
1966:													
1st	93.7	96.2	99.0	99.0	1,633	1,673	2,304	2,261	5,643	5,806	7,276	7,477	3,317
2d	102.2	101.6	99.4	99.4	1,753	1,695	2,317	2,218	6,070	5,772	7,823	7,469	3,442
3d	97.5	102.5	100.5	100.5	1,655	1,637	2,004	2,041	5,631	5,472	7,286	7,112	3,137
4th	93.6	100.6	94.9	99.8	1,568	1,601	1,811	1,897	4,894	5,166	6,462	6,767	2,914
1967:													
1st	96.3	98.5	95.7	99.8	1,548	1,586	2,043	2,005	5,190	5,340	6,738	6,924	3,057
2d	98.2	98.9	98.2	99.6	1,613	1,560	2,120	2,029	5,543	5,271	7,156	6,832	3,147
3d	102.3	100.5	101.8	100.1	1,603	1,586	1,942	1,978	5,498	5,342	7,101	6,931	3,202
4th	103.5	102.4	103.8	100.2	1,651	1,686	1,941	2,033	5,228	5,518	6,879	7,204	3,299
1968:													
1st	110.7	106.8	110.1	101.5	1,652	1,693	2,203	2,162	5,492	5,651	7,144	7,341	3,476
2d	116.7	112.1	117.8	102.2	1,760	1,702	2,339	2,239	6,098	5,799	7,858	7,502	3,669
3d	124.6	115.7	123.4	102.6	1,774	1,755	2,152	2,192	5,993	5,823	7,767	7,581	3,702
4th	129.1	120.7	130.9	103.1	1,868	1,908	2,087	2,186	5,586	5,896	7,454	7,806	3,842
1969:													
1st	142.5	128.7	151.0	104.3	1,985	2,034	2,129	2,089	5,486	5,645	7,471	7,677	3,754
2d	144.4	136.8	147.7	106.0	2,018	1,951	2,181	2,088	5,729	5,448	7,747	7,396	3,775
3d	117.3	119.5	121.1	106.8	1,843	1,823	1,918	1,953	5,405	5,252	7,248	7,075	3,240
4th	116.5	115.8	117.7	107.9	1,799	1,837	1,990	2,085	5,216	5,505	7,015	7,346	3,499
1970:													
1st	110.2	115.0	113.6	109.5	1,672	1,913	1,712	1,877	5,023	5,169	6,695	6,880	3,359
2d	109.6	113.5	113.4	110.0	1,789	1,730	1,934	1,851	5,319	5,058	7,107	6,785	3,664
3d	108.9	114.1	113.6	110.7	1,765	1,746	1,862	1,896	5,288	5,138	7,053	6,884	3,826
4th	106.9	116.0	112.9	110.9	1,837	1,876	1,767	1,851	4,717	4,979	6,555	6,864	3,724
1971:													
1st	121.9	122.3	123.4	122.8	1,802	1,847	1,998	1,961	5,152	5,301	6,954	7,146	4,008
2d	136.9	130.8	138.0	121.6	1,995	1,929	2,112	2,022	5,619	5,343	7,614	7,269	4,200
3d	149.3	140.5	152.9	132.6	1,976	1,955	2,098	2,137	5,775	5,611	7,751	7,566	4,229
4th	142.5	141.6	149.4	131.9	1,961	2,003	2,075	2,174	5,464	5,767	7,425	7,775	4,276
1972:													
1st	151.1	145.5	157.6	145.7	2,029	2,070	2,275	2,233	5,713	5,879	7,733	7,946	4,632
2d	158.7	151.4	165.1	155.6	2,154	2,083	2,263	2,166	6,031	5,735	8,185	7,815	4,732
3d	166.5	153.3	172.1	160.8	2,124	2,101	2,297	2,339	5,934	5,766	8,078	7,885	4,595
4th	168.1	155.8	176.1	157.4	2,039	2,082	2,057	2,155	5,538	5,845	7,577	7,935	4,563

1973:													
1st	188.8	164.3	192.6	197.4	2,042	2,093	2,346	2,302	5,898	6,069	7,940	8,159	4,872
2d	217.0	187.6	225.2	228.1	2,010	1,943	2,363	2,262	6,256	5,949	8,266	7,892	4,900
3d	217.5	197.9	220.8	159.0	1,973	1,952	2,208	2,249	5,974	5,805	7,947	7,757	4,518
4th	215.1	201.8	218.6	191.6	1,870	1,910	2,157	2,260	5,627	5,939	7,497	7,851	4,486
1974:													
1st	217.5	196.5	220.6	191.4	1,910	1,957	2,094	2,055	5,518	5,678	7,428	7,633	4,247
2d	231.9	194.7	234.0	214.0	2,054	1,986	2,202	2,108	6,034	5,738	8,088	7,722	4,561
3d	217.6	178.8	210.9	178.2	1,730	1,712	1,894	1,929	5,334	5,183	7,064	6,895	4,212
4th	187.8	168.0	180.1	163.4	1,427	1,457	1,590	1,666	4,034	4,258	5,461	5,719	3,488
1975:													
1st	194.3	164.5	184.0	188.1	1,473	1,509	1,645	1,614	3,978	4,093	5,451	5,601	3,699
2d	220.8	181.9	206.3	212.7	1,759	1,701	1,883	1,802	5,130	4,878	6,889	6,577	4,139
3d	219.2	217.8	206.6	200.6	1,772	1,753	1,870	1,905	5,296	5,146	7,068	6,899	4,406
4th	213.7	176.7	205.5	200.9	1,786	1,824	1,736	1,819	4,844	5,113	6,630	6,943	4,384
1976:													
1st	239.7	203.1	234.6	240.2	1,842	1,888	2,073	2,035	5,380	5,536	7,222	7,421	4,764
2d	239.1	215.8	243.2	236.6	1,896	1,833	1,996	1,911	5,575	5,302	7,471	7,133	4,802
3d	256.6	222.5	251.2	245.9	2,169	2,146	1,998	2,035	5,722	5,560	7,891	7,702	4,816
4th	267.8	227.7	263.5	266.8	2,080	2,124	2,062	2,160	5,682	5,997	7,762	8,128	4,555
1977:													
1st	276.9	236.3	281.6	283.3	2,025	2,075	2,241	2,199	5,609	5,772	7,634	7,844	4,954
2d	278.2	245.4	285.5	276.2	2,115	2,045	2,229	2,134	5,747	5,465	7,862	7,506	4,978
3d	306.0	280.5	310.8	314.3	2,090	2,068	2,140	2,180	5,806	5,642	7,896	7,707	4,917
4th	297.6	286.7	312.1	308.2	1,968	2,010	2,186	2,290	5,536	5,872	7,531	7,886	4,828
1978:													
1st	312.9	295.9	331.6	323.1	1,958	2,007	2,370	2,326	5,646	5,810	7,604	7,814	5,030
2d	326.7	302.8	341.4	314.2	2,193	2,120	2,285	2,187	5,720	5,439	7,913	7,555	5,126
3d	353.3	305.9	348.4	328.5	2,090	2,068	2,023	2,060	5,535	5,378	7,625	7,443	4,803
4th	367.4	310.5	361.4	339.3	2,046	2,089	2,167	2,270	5,488	5,793	7,534	7,890	4,977
1979:													
1st	362.8	309.0	364.9	342.9	2,038	2,088	2,156	2,060	5,306	5,382	7,344	7,468	5,016
2d	380.6	316.4	380.4	316.4	2,007	2,941	2,185	2,035	5,641	5,286	7,648	7,224	5,146
3d	406.5	332.7	393.4	323.6	2,034	2,012	2,048	2,030	5,612	5,438	7,646	7,449	4,882
4th	383.9	337.9	380.5	307.3	1,859	1,899	2,038	2,077	5,247	5,521	7,106	7,425	4,690

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[1] In million square feet, 3/8-inch basis.

Source: Unadjusted data from National Forest Products Association (1981). Seasonal adjustments discussed in Appendix B.

Results

Hypothesis 1: There is a positive relationship between the price in the export market and price in the domestic market.

The hypothesis was tested for the data series shown in table 3. All relationships were respecified and estimated in terms of a lag of one quarter; and for each index, 1967 = 100. The price indexes were not deflated by the U.S. wholesale price index for all commodities.

All relationships were significant and positive (table 3). Values of R^2 for all unlagged relationships exceeded .5; and for lagged relationships, they exceeded .43. According to the conceptual framework discussed previously, a positive relationship between the prices in the export and domestic markets could occur under any of the following conditions:

1. Domestic supply and excess demand assumed not to shift. An increase (shift) in demand in the domestic market would decrease (shift) excess supply in the export market. The increase in domestic demand would cause prices to increase in both markets.

2. Domestic demand and excess demand assumed not to shift. A decrease (shift) in domestic supply would have the effect of raising prices in the domestic market. The decrease in domestic supply also would decrease (shift) excess supply in the export market, leading to higher prices.

3. Domestic demand and supply assumed not to shift. An increase (shift) in excess demand in the export market would lead to higher prices in both markets.

Table 3—Results of tests of hypothesis 1, by price series

Price series	Components of equation				Durbin-Watson statistic
	A	B	R^2	F	
1. Price of rough southern pine lumber in the export market and price of southern pine lumber in the domestic market:					
Domestic price not lagged	-1.528	0.951	0.8	227.8[1]	1.94
Domestic price lagged	7.23	.898	.753	174[1]	1.64
2. Price of dressed southern pine lumber in the export market and price of southern pine lumber in the domestic market:					
Domestic price not lagged	11.939	.813	.51	59.26[1]	1.91
Domestic price lagged	25.32	.696	.431	43.10[1]	1.75
3. Price of rough softwood lumber except rough southern pine in the export market and price of Douglas-fir lumber in the domestic market:					
Domestic price not lagged	0.969	6.795	.805	235.5[1]	2.1
Domestic price lagged	7.136	1.058	.825	269[1]	1.69
4. Price of dressed softwood lumber except dressed southern pine in the export market and price of Douglas-fir lumber in the domestic market:					
Domestic price not lagged	17.19	.754	.843	305.7[1]	2.08
Domestic price lagged	23.781	.735	.821	262[1]	1.68
5. Price of all softwood lumber in the export market and price of softwood lumber in the domestic market:					
Domestic price not lagged	12.052	.921	.787	211[1]	1.64
Domestic price lagged	3.249	.9669	.741	163.2[1]	2.1
6. Price of softwood plywood in the export and domestic markets:					
Domestic price not lagged	51.418	.443	.741	163.3[1]	1.57
Domestic price lagged	57.578	.484	.894	480.9[1]	1.59

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[1] Significant at 5-percent level.

4. A combination of shifts in domestic demand and supply and excess demand that leads to a pattern of a positive relationship in prices in the two markets.

A positive relationship between price changes in the two markets is not surprising in view of the conceptual framework for price formation discussed previously. If prices were not equal, domestic consumers would purchase products offered in the export market and foreign consumers would purchase products offered in the domestic market. Price series in the two markets were placed on an index basis with 1967 = 100. This has the effect of equalizing prices in the two markets. For example, the price in the two markets equals 100 for 1967 despite the existence of an actual price difference in that year. Since the price series are on an index basis, the regression coefficient, B, in each equation should be close to 1 if all of the assumptions of the conceptual model of price formation actually hold for the two markets.

The regression coefficient was significantly different from 1 at the 5-percent level[1] for category 2 in table 3 with the domestic price lagged one quarter and for categories 4 and 6 with domestic price unlagged or lagged. The regression coefficient for category 2 with domestic price unlagged was significantly different from 1 at the 10-percent level. There are no data available to document why prices in the two markets do not tend to equalize for the two categories of dressed lumber (categories 2 and 4 in table 3) and softwood plywood (category 6). A possible explanation is that the product mix for dressed lumber and softwood plywood in the export market changes when price changes in the domestic market. For example, U. S. producers may be less willing to produce specialty items for the export market when domestic markets are going through an up phase of the cycle in prices. When domestic markets turn down, U. S. producers may be more willing to produce items specifically for the export market. The product mix for rough softwood lumber may not tend to vary in the export market according to domestic market conditions. This explanation of the observed behavior of prices would support the idea that shifts in excess supply may be especially important in determining prices and volumes in export markets for dressed lumber and softwood plywood. The pattern of behavior of prices for rough softwood lumber does not offer insight into underlying shifts in excess supply and excess demand.

For all of the categories in table 3, correlation coefficients with domestic price unlagged were not significantly different from correlation coefficients with domestic price lagged[2]. This suggests that information on price movements in the two markets may be generally available: Exporters can follow domestic markets well and mills in the domestic market can follow export markets well.

Hypotheses 2: There is a positive relationship between price in the export market and the volume of exports.

The hypotheses was tested for the data series shown in table 4. All prices in the export market were converted to indexes (1967 = 100) and deflated by the U.S. wholesale price index for all commodities (1967 = 100) in order to reduce an upward trend in prices attributable in part to inflation. For each series of quantities and prices, the hypothesized relationship was respecified and quantified with a lag of one quarter in the price variable. This was done to see if exports respond to price changes with a lag of one quarter. A lag may exist because of characteristics of markets such as long-term contracts that would have volume and price specified for a quarter or more into the future.

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[1] A T-test was applied to test the hypothesis that the regression coefficient was equal to 1 as per Snedecor and Cochran (1967).

[2] The hypothesis that the two correlation coefficients were drawn from the same population was tested by transforming the regression coefficients to Z′ values and testing the significance of differences in the Z′ values as per Snedecor and Cochran (1967) at the 5-percent level.

Table 4—Results of tests of hypothesis 2, by product category and price series

Product category and price series	Components of equation A	B	R^2	F	Durbin-Watson statistic
1. Quantity and price of dressed southern pine lumber:					
Price not lagged	1.351	3.511	0.041	2.46	1.796
Price lagged	3.489	-3.359	-.04	2.40	1.724
2. Quantity and price of dressed lumber except southern pine:					
Price not lagged	17.082	-31.477	-.177	12.27[1]	2.139
Price lagged	12.142	28.345	.12	7.73[1]	2.084
3. Quantity and price of rough southern pine:					
Price not lagged	.472	16.067	.109	6.96[1]	1.551
Price lagged	4.366	7.249	.035	2.09	1.72
4. Quantity and price of rough lumber except southern pine:					
Price not lagged	33.534	137.045	.401	38.23[1]	1.596
Price lagged	53.576	125.607	.447	46.07[1]	1.221
5. Quantity of rough lumber, except exports from Alaska and southern pine and price of rough lumber except southern pine:					
Price not lagged	-5.274	114.673	.452	46.99[1]	1.697
Price lagged	23.485	89.09	.309	25.44[1]	1.856
6. Quantity of rough lumber, except exports from Alaska and price of rough lumber:					
Price not lagged	-91.42	259.118	.634	98.6[1]	1.741
Price lagged	30.214	157.15	.33	28.02[1]	1.709
7. Quantity and price of all softwood lumber:					
Price not lagged	-60.881	289.169	.605	87.42[1]	1.882
Price lagged	55.568	184.57	.344	29.92[1]	1.704
8. Quantity and price of softwood plywood:					
Price not lagged	59.249	-80.749	-.098	6.21[1]	1.73
Price lagged	26.777	-8.911	-.001	.082	1.86

[1] Significant at 5-percent level.

For rough lumber, there was a significant, positive relationship between the quantity exported and the price of lumber in the export market (categories 3, 4, 5, and 6 in table 4). With the exception of rough southern pine lumber, the relationships remained significant when price was lagged by one quarter with an effect generally to lessen the size of the correlation coefficient.

According to the model of trade discussed previously, a positive relationship between quantity and price in the export market could occur under any of the following conditions:

1. Domestic demand assumed not to shift. A decrease (shift) in domestic supply would increase price in the export market. Volume could increase only if excess demand increased (shifted).

2. Domestic supply assumed not to shift. An increase (shift) in domestic demand would increase price in the export market. Volume could increase only if excess demand increased (shifted).

3. Excess supply assumed not to shift. An increase (shift) in excess demand would increase price and volume in the export market.

4. A combination of shifts in excess supply and excess demand.

There was a significant, negative relationship between the price and quantity of dressed lumber except southern pine, indicating that shifts in excess supply are probably important in determining the volume of exports. When the price of this commodity was lagged one quarter, the relationship was still significant, but positive rather than negative.

There was no significant relationship between the quantity and price of dressed southern pine lumber in the export market.

There was a significant, negative relationship between the volume of exports of softwood plywood and the unlagged price of these exports. This suggests that shifts in excess supply have been important in determining the volume and price of these exports.

The findings of negative correlation between export volume and price for dressed lumber except southern pine and softwood plywood supports the findings in the test of hypothesis 1 in that shifts in excess supply have probably been important in determining prices in export markets for these products.

Correlation coefficients with price not lagged and with price lagged were significantly different for both categories 6 and 7 in table 4. An effect of lagging price by one quarter was to reduce correlation between price and volume. This suggests that a spot market with prices determined by current market conditions may be an important means of price formation of rough lumber.

Hypothesis 3: There is a positive relationship between the volume of exports and the ratio of export to domestic prices.

The hypothesis was tested for the relationships shown in table 5. For each series of quantities and price ratios, the hypothesized relationship was respecified and quantified with a lag of one quarter in the price ratio variable. Prices in the two markets were converted to indexes (1967 = 100).

The results of analysis of hypothesis 1 suggest that the ratio of export to domestic prices would not vary much with the exceptions of dressed lumber and softwood plywood. Except for these two categories, price changes in one market are reflected in similar price changes in the other market. The results of the test of hypothesis 3 are consistent with the results of the test of hypothesis 1. Significant relationships were found only for exports of dressed softwood lumber except southern pine and exports of softwood plywood with the ratio of prices lagged one quarter (table 5). In both cases, the relationships were negative, suggesting that shifts in excess supply were probably important contributors to determination of prices for these two product categories.

Table 5—Results of tests of hypothesis 3, by product category and price series

Product category and price series	Components of equation		R^2	F	Durbin-Watson statistic
	A	B			
1. Quantity of exports of dressed southern pine lumber and the ratio of the price of these exports to the price of southern pine lumber in the U.S. domestic market:					
Price ratio not lagged	2.333	2.761	0.02	1.14	1.62
Price ratio lagged	1.694	3.642	.04	2.13	1.73
2. Quantity of exports of rough southern pine lumber and the ratio of the price of these exports to the price of southern pine lumber in the U.S. domestic market:					
Price ratio not lagged	3.441	4.302	.014	0.82	2.23
Price ratio lagged	2.624	4.638	.018	1.018	2.36
3. Quantity of exports of dressed softwood lumber except southern pine and the ratio of the price of these exports to the price of Douglas-fir lumber in the U.S. domestic market:					
Price ratio not lagged	24.601	-38.245	-.232	17.26[1]	1.97
Price ratio lagged	24.501	-38.193	-.232	17.23[1]	1.97
4. Quantity of exports of rough softwood lumber except southern pine and the ratio of the price of these exports to the price of Douglas-fir lumber in the U.S. domestic market:					
Price ratio not lagged	97.814	-22.515	-.007	.39	2.11
Price ratio lagged	97.296	29.529	.012	.69	1.86
5. Quantity of exports of rough softwood lumber except southern pine and exports from Alaska and the ratio of the price of exports of rough softwood lumber except southern pine to an index of the price of Douglas-fir in the U.S. domestic market:					
Price ratio not lagged	66.964	-8.112	-.001	.08	2.07
Price ratio lagged	58.985	-6.882	-.001	.06	2.19
6. Quantity of exports of softwood lumber except exports from Alaska and the ratio of the price of all exports of softwood lumber to the price of softwood lumber in the U.S. domestic market:					
Price ratio not lagged	47.185	29.616	.011	.63	2.31
Price ratio lagged	43.548	31.322	.013	.72	2.34
7. Quantity of exports of softwood lumber and the ratio of the price of these exports to an index of the price of softwood lumber in the U.S. domestic market:					
Price ratio not lagged	74.076	22.558	.004	.24	2.32
Price ratio lagged	67.787	25.485	.005	.31	2.36
8. Quantity of exports of softwood plywood and the ratio of the price of these exports to the price of softwood plywood in the U.S. domestic market:					
Price ratio not lagged	59.249	-80.749	-.098	6.21[1]	1.73
Price ratio lagged	26.777	-8.911	-.001	.08	1.86

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[1] Significant at 5-percent level.

The lack of positive correlation between export volumes and relative prices may be due to the importance of other variables that determine export volumes, or it may be that a time period of one quarter is too long to identify association between the two data series. This would especially be the case if spot markets tended to determine prices. In spot markets, relative prices could change rapidly within a time period of one quarter.

Hypothesis 4: There is a positive relationship between the volume of exports and the volume of domestic production.

The hypothesis was tested for the relationships shown in table 6. All relationships were respecified and estimated with a lag of one quarter. There were significant, positive relationships for the export categories of dressed southern pine lumber, rough southern pine lumber, and total exports of softwood lumber except exports from Alaska (table 6). According to the conceptual framework discussed previously, a positive relationship between the volume of exports and the volume of domestic production would be consistent with any of the following conditions.

1. Domestic supply assumed not to shift. An increase (shift) in domestic demand would lead to increased domestic production. Excess supply would decrease (shift) and excess demand would have to increase (shift) in order for the volume of exports to increase.

Table 6—Results of tests of hypothesis 4, by product category

Product category	Components of equation A	Components of equation B	R^2	F	Durbin-Watson statistic
1. Quantity of exports of dressed southern pine lumber and production of softwood lumber in the southern pine region:					
Production not lagged	-0.255	0.0053	0.091	5.68[1]	1.91
Production lagged	3.494	-.0019	-.014	0.82	1.79
2. Quantity of exports of rough southern pine lumber and production of softwood lumber in the southern pine region:					
Production not lagged	-1.312	.0135	.198	14.06[1]	2.22
Production lagged	-1.555	.0137	.195	13.78[1]	2.16
3. Quantity of exports of dressed softwood lumber except southern pine and production of softwood lumber except production in the southern pine region and Alaska:					
Production not lagged	11.554	.0024	.011	.63	2.54
Production lagged	7.978	.0029	.011	.61	2.56
4. Quantity of exports of rough softwood lumber except southern pine and exports from Alaska and production of softwood lumber except production in the southern pine region and Alaska:					
Production not lagged	31.031	.0126	.033	1.93	2.27
Production lagged	31.792	.0125	.031	1.87	2.25
5. Quantity of exports of softwood lumber except exports from Alaska and production of softwood lumber except production in Alaska:					
Production not lagged	24.466	.0189	.108	6.89[1]	2.38
Production lagged	6.088	.006	.189	13.26[1]	2.65
6. Quantity of exports of softwood plywood and production of softwood plywood:					
Production not lagged	5.567	.1402	.0152	.88	1.84
Production lagged	3.102	.0156	.0235	1.37	1.97

[1] Significant at 5-percent level.

2. Domestic demand and excess demand assumed not to shift. An increase (shift) in domestic supply would lead to increased domestic production. Excess supply would increase (shift), leading to increased volume of exports.

3. Products that are exported and consumed domestically are not homogeneous. An increase (shift) in domestic demand would lead to an increase in domestic production that would result in an increase in the volume of specialty items produced for the export market. The resulting increase (shift) in excess supply of specialty items would lead to an increase in the volume of exports.

4. A combination of shifts in domestic supply and demand and excess demand as well as differing product mixes for the two markets that would lead to a positive relationship between the volume of exports and the volume of domestic production.

Without further information about the behavior of shifters of domestic supply and demand and excess demand, it is not possible to attribute movements in production and exports to either the domestic or export market. If, as might be expected, the economies of countries of the Caribbean area and Central America tend to have economic cycles that closely follow those in the United States, shifts in excess demand may explain at least part of the association of exports of southern pine lumber and production of softwood lumber in the southern pine region.

The lack of significant association between exports of dressed lumber except southern pine and domestic production is consistent with the results of tests of hypothesis 1. Shifts in product mix in the export market during times of upturns in domestic markets may account for the lack of correlation between domestic production and the volume of exports. A similar rationale could be developed for the weak correlation between the quantity of exports of softwood plywood and domestic production of softwood plywood.

The results of analysis for hypothesis 2 suggested that shifts in excess demand were probably important in determining the price and volume of exports of rough lumber (category 4 in table 6). The lack of significant correlation between domestic production and export volume suggests that shifts in excess supply are also important determinants of price and volume or that shifts in excess demand are not highly correlated with shifts in domestic demand and/or supply.

For category 5 in table 6, there was no significant difference in the correlation coefficients with production lagged or unlagged. This is consistent with the view that information on price changes in the two markets is generally available and that producers respond quickly to developments in the two markets.

Hypothesis 5: There is a positive relationship between production in the United States and price in the export market.

The hypothesis was tested for the data series shown in table 7. All relationships were respecified and estimated with a lag of one quarter. All price series were converted to indexes (1967 = 100), and all price indexes were deflated by the U.S. wholesale price index for all commodities.

In the unlagged form, there was a significant, positive relationship between production in the United States and price in the export market with one exception: An index of prices in the export market for dressed softwood lumber except southern pine and production of softwood lumber except production in the southern pine region and Alaska (table 7). According to the conceptual framework discussed previously, a positive relationship between production in the United States and price in the export market would be consistent with any of the following conditions:

1. Domestic supply and excess demand assumed not to shift. An increase (shift) in domestic demand would decrease (shift) excess supply, leading to higher domestic production and higher prices in the export market.

Table 7—Results of tests of hypothesis 5, by product category and price series

Product category and price series	Components of equation				Durbin-Watson statistic
	A	B	R^2	F	
1. Price of rough southern pine lumber in the export market and production of softwood lumber in the southern pine region:					
Production not lagged	0.1197	0.00044	0.236	17.6[1]	2.03
Production lagged	.559	-.000166	-.048	2.88	1.51
2. Price of dressed southern pine lumber in the export market and production of softwood lumber in the southern pine region:					
Production not lagged	.0567	.0005839	.287	22.9[1]	1.89
Production lagged	.5508	-.0001245	-.017	0.992	1.34
3. Price of rough softwood lumber except southern pine in the export market and production of softwood lumber except production in the southern pine region and Alaska:					
Production not lagged	.0649	.0001821	.369	33.38[1]	2.5
Production lagged	.2384	-.0000247	-.007	.40	1.76
4. Price of dressed softwood lumber except southern pine in the export market and production of softwood lumber except production in the southern pine region and Alaska:					
Production not lagged	.6887	-.000063	-.049	2.9	2.22
Production lagged	.6951	-.0000619	-.047	2.81	2.20
5. Price of rough softwood lumber except southern pine in the export market and production of softwood lumber in the Douglas-fir region:					
Production not lagged	.0821	.0004288	.339	29.28[1]	2.54
Production lagged	.2285	-.0000379	-.003	.155	1.79
6. Price of dressed softwood lumber except southern pine in the export market and production of softwood lumber in the Douglas-fir region:					
Production not lagged	.2937	.0002508	.092	5.80[1]	2.32
Production lagged	.6452	-.0001266	-.033	1.92	2.22
7. Price of softwood lumber in the export market and production of softwood lumber except production in Alaska:					
Production not lagged	.0471	.0001435	.487	54.12[1]	2.48
Production lagged	.2685	-.0000278	-.019	1.09	1.58
8. Price of softwood plywood in the export market and production of softwood plywood:					
Production not lagged	.2341	.000123	.087	5.41[1]	1.52
Production lagged	.6806	-.0001131	-.108	6.89[1]	1.53

[1] Significant at 5-percent level.

2. Domestic demand and supply assumed not to shift. An increase (shift) in excess demand would increase domestic production and increase prices in the export market.

3. A combination of shifts in domestic supply and demand and excess demand that would result in a positive relationship between domestic production and price in the export market.

A positive relationship between the price of exports and domestic production of rough lumber is not inconsistent with the view that shifts in excess demand have been important in determining the price and volume of exports of these products. Shifts in excess supply may also be important, however. The positive relationship between the price of dressed southern pine lumber in the export market and production of softwood lumber in the southern pine region is consistent with a view that shifts in excess demand as well as shifts in excess supply are important determinants of price and volume in the export market.

There was a negative, though not significant, relationship between the price of dressed softwood lumber except southern pine and domestic production (category 4 in table 7). This is not inconsistent with the previously discussed view that shifts in product mix in the export market that occur during cycles in domestic markets may be important determinants of the price and volume of exports.

When production was lagged one quarter there was a significant, negative relationship between the price of softwood plywood in the export market and domestic production (category 8 in table 7), but the relationship was positive and significant with production unlagged. A shift in product mix in the export market as domestic markets go through cycles would be consistent with a negative relationship between price and production. The results of the analysis of hypothesis 5 suggest that if this does occur for softwood plywood, it occurs with a lag.

Hypothesis 6: There is a positive relationship between the volume of exports and price in the domestic market.

The hypothesis was tested for the data series shown in table 8. All relationships were respecified and estimated with a lag of one quarter in the domestic price index (1967 = 100). All price indexes were deflated by the U. S. wholesale price index for all commodities.

In the unlagged form, there were significant, positive relationships for all categories of exports except softwood plywood (table 8). According to the conceptual framework discussed previously, a positive relationship between the volume of exports and price in the domestic market would be consistent with any of the following conditions:

1. Domestic supply assumed not to shift. An increase (shift) in domestic demand would increase price in the domestic market and decrease (shift) excess supply. Excess demand would have to increase (shift) for volume to increase in the export market.

2. Domestic demand assumed not to shift. A decrease (shift) in domestic supply would increase price in the domestic market and decrease (shift) excess supply. Excess demand would have to increase (shift) in order for the volume of exports to increase.

3. A combination of shifts in domestic supply and demand and excess demand that resulted in a positive relationship between price in the domestic market and volume in the export market.

For the significant relationships, the value of R^2 ranged from a low of .074 for the volume of exports of all softwood lumber except exports from Alaska and an index of prices for all softwood lumber in the U.S. domestic market to a high of .256 for the volume of exports of dressed softwood lumber except southern pine and an index of prices for Douglas-fir lumber in the U.S. domestic market. The general effect of lagging price in the domestic market by one quarter was to lower the value of R^2 and to lessen the degree of significance of the relationship.

Table 8—Results of tests of hypothesis 6, by product category and price series

Product category and price series	Components of equation		R^2	F	Durbin-Watson statistic
	A	B			
1. Quantity of exports of rough southern pine lumber and the price of southern pine lumber in the domestic market:					
Price not lagged	-2.51	23.661	0.222	16.25[1]	2.25
Price lagged	7.805	-6.982	-.022	1.29	1.82
2. Quantity of exports of dressed southern pine lumber and the price of southern pine lumber in the domestic market:					
Price not lagged	-0.55	9.075	.108	6.9[1]	1.87
Price lagged	4.402	-4.577	-.033	1.93	1.68
3. Quantity of exports of rough softwood lumber except southern pine and exports from Alaska and the price of Douglas-fir lumber in the domestic market:					
Price not lagged	16.646	92.339	.111	7.14[1]	2.26
Price lagged	40.467	66.675	.097	6.11[1]	1.93
4. Quantity of exports of dressed softwood lumber except southern pine and the price of Douglas-fir lumber in the domestic market:					
Price not lagged	-4.903	59.758	.256	19.58[1]	1.94
Price lagged	3.750	48.407	.244	18.34[1]	2.01
5. Quantity of exports of softwood lumber from Alaska and the price of softwood lumber in the domestic market:					
Price not lagged	28.424	138.494	.150	10.07[1]	2.12
Price lagged	62.463	84.644	.074	4.58[1]	1.88
6. Quantity of exports of softwood plywood and the price of softwood plywood in the domestic market:					
Price not lagged	24.219	-23.525	-.014	0.80	2.09
Price lagged	15.987	4.443	.001	.03	2.10

[1] Significant at 5-percent level.

The significant, positive relationship between quantities of exports and prices in the domestic market shown in table 8 suggest that shifts in excess demand have been important determinants of prices and volumes in the export market.

The positive relationships between exports of dressed southern pine lumber (category 2), other dressed lumber (category 4), and corresponding domestic prices are not inconsistent with previous speculation that shifts in the product mix of exports may occur. For example, U.S. exporters may ship larger quantities of lower valued products in response to shifts in excess demand and be less willing to produce specialty items that are higher priced. By contrast, there may be less opportunity to shift product mixes for the categories of rough lumber. These categories are likely to contain certain products such as large timbers that are relatively more homogeneous than categories of dressed lumber.

The lack of a significant, positive relationship between exports of softwood plywood and domestic price is not inconsistent with the view that shifts in both product mix and excess supply may be important in determining the price and volume of exports of this commodity.

Conclusions

The tests of the 6 hypotheses indicate that shifts in both excess supply and excess demand have influenced the pattern of interactions between U.S. domestic and export markets in terms of volume and price. Shifts in excess supply have been important in determining the volumes and prices of dressed softwood lumber and softwood plywood. The volumes of exports of these commodities tended to decline when prices in export markets increased (hypothesis 2). Export volumes also declined when the price in the export market tended to increase relative to price in the domestic market (hypothesis 3). The volumes of exports tended to increase when price in the domestic market increased (hypothesis 6). Results of the test of hypothesis 1 are consistent with the view that changes in product mixes of exports of dressed lumber and plywood occur according to conditions in domestic markets. Results of tests of hypotheses 4 and 5 generally neither supported nor refuted shifts in excess supply as being factors in explaining changes in the price and volume of exports of dressed lumber and plywood.

Shifts in excess demand also influence the volume of exports of dressed lumber (hypotheses 5 and 6).

Shifts in excess demand have been important in determining prices and volumes for exports of rough softwood lumber. The quantity exported tended to increase when the export price increased (hypothesis 2), and the volume of exports tended to increase when the domestic price increased (hypothesis 6). Results of tests of hypotheses 1, 3, and 5 neither supported nor refuted excess demand as a determinant of shifts in price and volume in the export market. Shifts in excess supply may also influence prices and volumes in the export market for rough lumber (hypothesis 4).

Price changes in one market are reflected quickly in the other market, especially for rough lumber (hypothesis 1). The possible changes in product mixes in the export markets for dressed lumber and softwood plywood may tend to mask any association of price changes in the two markets for these products.

Implications for Foreign Trade

Trade Policy

This analysis has shown that shifts in both excess supply and excess demand have caused shifts in the volume and value of exports of softwood lumber and softwood plywood. Changes in supply and demand in the domestic market are probably reflected rapidly in the export market and vice versa.

Policies to make U.S. exports responsive to domestic market conditions would probably have to be confined to those affecting domestic supply and excess demand. Manipulation of U.S. domestic demand to make exports responsive to domestic market conditions probably would be unacceptable in the United States except for reasons of national security.

Policies to make domestic supply responsive to short-run market conditions would be difficult to implement. The possibility of restricting exports of softwood lumber during times of peak domestic demand have been discussed in the past, but general restrictions on the export of softwood lumber and plywood have never been implemented. Taxes on exports are illegal in the United States. The United States does have restrictions on the export of roundwood logs from various public lands in the West (Lindell 1978). These restrictions, however, are not designed to make exports responsive to domestic market conditions. The possibility of increasing total domestic supply so as to increase volumes in both domestic and export markets has been discussed in hearings (U.S. Senate Committee on Banking, Housing, and Urban Affairs 1973). This option becomes limited by the availability of processing capacity for both lumber and plywood.

Efforts to make excess demand responsive to U.S. domestic market conditions have been limited mainly to negotiations between Japan and the United States. The concern has been stability of markets or softwood logs and softwood lumber. These markets are discussed at meetings of the U.S./Japan Forest Products Committee. The Committee meets periodically to discuss supply and demand conditions for forest products as well as other matters affecting trade. There have been no formal agreements, however, to make U.S. exports responsive o supply and demand conditions in either of the two countries.

The lack of detail in available data would be especially important in trying to anticipate the effects of restrictions if exported products differed from products consumed domestically or if the product mix in the export market was not constant over time. For example, the available data do not provide the base needed o identify what types of products may be nvolved in the shifts in excess supplies of dressed lumber. Nor is information available to determine if products classed as rough lumber could meet the needs of domestic markets. For example, if exports were restricted, how much difference would it make for the prices of various ypes of timber products in the domestic market?

Supply and demand conditions in both domestic and export markets would have o be monitored for the purposes of trade policy formulation. For example, an ncrease in price in the export market may be caused by either a shift in excess supply, reflecting domestic market conditions, or a shift in excess demand, eflecting primarily market conditions in other countries. Further research to dentify linkages of shifts in excess supply and excess demand to specific variables would facilitate formulation of alternative policies.

Export Promotion

Results of this analysis suggest that interactions between export and domestic markets differ for rough softwood lumber compared with dressed softwood lumber and plywood. For dressed lumber and plywood, shifts in excess supply probably underlie major movements in price and quantity in the export market. Shifts in excess demand are more important determinants or price and quantity of exported rough lumber.

Promotion of exports must work through an increase (shift) in excess demand and through an increase (shift) in excess supply. Constraints on domestic demand as a means to increase excess supply in the export market are generally not used in the United States. An increase (shift) in domestic supply would be necessary to increase (shift) excess supply.

Efforts to promote the export of softwood lumber and softwood plywood from the United States have consisted primarily of attempting to increase (shift) excess demand. These efforts have focused mainly on the promotion of the sale of dimension lumber and plywood of the grades and sizes used in the United States. Examples include the promotion of the "platform frame" construction technique in Japan and western Europe and efforts to reduce tariff and nontariff trade barriers to imports of lumber and plywood from the United States. These efforts have met with limited success.

Recently, representatives of Japanese and U.S. industry have entered into discussions as to how U.S. producers might produce and market lumber of the sizes and grades consumed in Japan. If successful, these efforts would have the effect of shifting U.S. excess supplies of these products to the Japanese market.

Fluctuations in excess supply due to shifts in domestic demand give rise to the charge of importing countries that U.S. producers are "in and out" of the export market depending on domestic market conditions. Being "in and out" of the export market, however, is consistent with the conceptual model of trade discussed previously. Traditional approaches to alleviate shifts in excess supply as well as shifts in excess demand include long-term contracts and variations on joint-venture operations which assure the price and/or volume of exports despite market conditions in both the importing and exporting countries. Results of this analysis suggest that spot markets rather than long-term contracts better characterize price formation in the export market.

Efforts to influence excess supply for the purpose of promoting exports have generally been limited to educating U.S. producers about export opportunities, especially when U.S. domestic markets are slow. The U.S. industry also favors the concept of export trading companies which would influence excess supply through making help available for financing and other aspects of maintaining a viable, sustained presence in export markets.

Fluctuations in excess supply and excess demand work against stable, long-term trade relationships of the type that seem necessary for U.S. producers to maintain export sales. Whether or not promotion programs should be directed at excess supply or excess demand depends on the effectiveness of alternatives. Further research is needed to provide a basis for judging the effectiveness of alternative promotion programs. Research is needed to identify the linkages among excess supply, excess demand, and specific variables that shift these relationships. For example, estimates of the elasticity of excess demand with respect to price and with respect to variables that shift excess demand would enable U.S. producers to anticipate cycles in markets. These estimates also would help producers judge the effectiveness of alternative programs that have the intent of increasing (shifting) excess demand.

Further Research

Admittedly, this study has been exploratory and should be considered as just the first step in analysis of the linkages of export and domestic markets. The lack of homogeneity of products and lack of data to delineate specific products, especially for softwood lumber, will probably always be a problem in trying to understand the behavior of the two markets. There is little reason to expect that the detail of available data will improve on the sizes and qualities of lumber that is exported or produced domestically. Additional research could be attempted in the area of linking variables that shift supply and demand in the domestic market to shifts in excess supply; linking shifts in variables that influence supplies and demands in major markets for U.S. products to shifts in excess demand; estimation of the elasticity of price and quantity of exports with respect to these shifters; and estimation of the elasticity of quantity with respect to price for excess supply and excess demand. Estimates of elasticity with respect to variables that shift excess supply and excess demand would better enable the anticipation of movements in markets that influence the success of promotion programs and trade policies. These estimates plus estimates of the elasticity of supply and demand with respect to price would also allow analysis of the potential effectiveness of alternative programs and policies that influence the volume and value of exports.

Literature Cited

Adams, Darius M.; Haynes, Richard M. The 1980 softwood timber assessment market model: Structure, projections, and policy simulations. For. Sci. Monogr. 22. Supplement to For. Sci. Vol. 26, No. 3; 1980.

Bureau of Economic Analysis. Business Conditions Digest. Washington, D.C.: U.S. Gov. Print. Off.; Monthly.

Kreinin, Mordechai E. International economics: A policy approach. 379 p. New York: Harcourt Bruce Jovanovich, Inc.; 1971.

Lindell, Gary R. Log export restrictions of the western states and British Columbia. USDA For. Serv., Gen. Tech. Rep. PNW-63. Portland, OR: Pac. Northwest For. and Range Exp. Stn.; 1978.

National Forest Products Association. Fingertip facts and figures. Published monthly; Washington, D.C.: 1981.

Ruderman, F. K. Production, prices, employment, and trade in Northwest forest industries. Published quarterly. USDA For. Serv. Portland, OR: Pac. Northwest For. and Range Exp. Stn.; 1980.

Snedecor, George W.; Cochran, William G. Statistical methods. Sixth edition. Ames, Iowa: The Iowa State University Press; 1967.

U.S. Bureau of the Census. U.S. exports: Schedule E Commodity by country. Rep. FT 410. Washington, D.C.: U.S. Gov. Print. Off., (Monthly).

U.S. Bureau of the Census. Schedule B., Statistical classification of domestic and foreign commodities exported from the United States. January 1, 1978 edition. Washington, D.C.: U.S. Gov. Print. Off.; 1977.

United States Senate Committee on Banking, Housing and Urban Affairs, United States Senate. Log export restrictions. Hearing before subcommittee on international finance, April 11 in Portland, Oregon, and April 13 in San Francisco, California. 93rd Congress, First Session; 1973.

Appendix A

The Data base for Volumes and Prices of Exports of Softwood Lumber and Plywood

Data for the volume and value of exports of softwood lumber and plywood originate with Export Declaration Forms. These forms may be filled out by anyone associated with the sales transaction. The completed form contains information on the type of commodity and its volume, value, and destination. Commodities are classed according to "Schedule E codes." The Schedule E codes for categories of softwood lumber and plywood used in this study are shown in Table 9. All categories of rough lumber except Schedule E 2482115 were combined for the purposes of this analysis. Rough lumber is defined as lumber just as it comes from the saw whether in the original sawed size or edged, resawn, crosscut, or trimmed to smaller sizes (U.S. Bureau of the Census 1977). All categories of dressed or worked lumber except Schedule E 2482215 were combined. Dressed lumber is defined as lumber which has been dressed or surfaced by planing on at least one edge or face. Worked lumber is defined as lumber which has been matched (provided with a tongue-and-grooved joint at the edges or ends), shiplapped (provided with a rabbeted or lapped joint at the edges), or patterned (shaped at the edges or on the faces to a patterned or molded form) on a matching machine, sticher, or molder (U.S. Bureau of the Census 1977). The three categories of softwood plywood were combined. Softwood plywood has been classified by species only since 1978.

Table 9—Schedule E codes for softwood lumber and plywood used in the analysis and volume shipped in 1979

Schedule E code	Description	Volume
		million board feet
Lumber:		
2482105	Spruce lumber, rough.	125.9
2482110	Pine lumber, eastern white and red, rough.	30.8
2482115	Pine lumber, southern yellow, longleaf, etc., rough.	140.1
2482120	Ponderosa pine lumber, rough.	29.7
2482125	Pine, NSPF,[1] rough.	32.5
2482130	Douglas-fir lumber, rough, under 2 in.	32.1
2482135	Douglas-fir lumber, rough, 2 in. to not over 5 in.	212.7
2482140	Douglas-fir lumber, rough, 5 in. and over.	156.3
2482145	Fir lumber, NSPF,[1] rough.	38.2
2482150	Hemlock lumber, rough.	378.7
2482155	Larch lumber, rough.	1.4
2482160	Western redcedar lumber, rough.	21.3
2482165	Cedar lumber, NSPF,[1] rough.	12.7
2482170	Redwood lumber, rough.	21.2
2482175	Softwood lumber, NSPF,[1] rough.	14.9
2482205	Spruce lumber, dressed or worked.	25.2
2482210	Pine lumber, eastern white and red, dressed or worked.	5.4
2482215	Pine lumber, southern yellow, longleaf, pitch, etc., dressed or worked.	55.5
2482220	Ponderosa pine lumber, dressed or worked.	71.9
2482225	Pine, NSPF,[1] dressed or worked.	66.1
2482230	Douglas-fir lumber, dressed or worked.	104.4
2482235	Fir lumber, NSPF,[1] dressed or worked.	19.3
2482240	Hemlock lumber, dressed or worked.	85
2482245	Larch lumber, dressed or worked.	1.2
2482250	Western redcedar lumber, dressed or worked.	11.5
2482255	Cedar lumber, NSPF,[1] dressed or worked.	10.5
2482260	Redwood lumber, dressed or worked.	8.9
2482265	Softwood lumber, NSPF, dressed or worked.	5.9
		million square feet, 3/8-inch basis
Plywood:		
6345040	Plywood, with a face ply of Douglas-fir.	337.7
6345050	Plywood, with a face ply of southern yellow pine, short leaf pine, slash pine, etc.	32.1
6345060	Plywood, with a face ply of softwood, NSPF.[1]	32

[1] NSPF = not specifically provided for.

Source: U.S. Bureau of the Census, 1980. U.S. exports: Schedule E commodity by country. Rep. FT410, Dec. 1979. U.S. Gov. Print. Off., Washington, D.C.

Appendix B

As a base for use in analyzing interactions of domestic and export markets, the data have shortcomings. For example, lumber of different sizes and grades of the same species may be different products as far as end uses are concerned. The data are reported as of the date of receipt by the Department of Commerce rather than the date of actual shipment. In some cases, this may introduce a lag of several months between the actual date of shipment and the date reported by the Department of Commerce. For example, a portion of the volume actually shipped in January of a year may not be reported as being shipped until March or April of the year. Errors in reporting data may go undetected. For example, the person filling out the Export Declaration Form may inadvertently use an incorrect Schedule E code. Despite these problems, however, the data will likely continue to be the primary source for analysis of interactions between domestic and export markets.

Test for Seasonality

The problem of seasonality in data series has not received much attention in the forestry literature, in part because most analyses have used annual data, e.g., Adams and Haynes (1980). Seasonality in data series can be a problem for analyses in that a pattern of variation in data may be attributable to seasonal factors rather than factors proposed as explaining the variation in the data. For example, lumber production may decline every winter, along with the number of housing starts, because of seasonal factors. If the two data series are not corrected for seasonality, correlation of the series may give the impression of a relationship that is different from the one attributable to underlying supply and demand conditions.

There are no regularly published series of seasonally adjusted data for the major variables that describe conditions such as production and prices in the timber industries. The U.S. Department of Commerce publishes seasonally adjusted data series for many other variables in Business Conditions Digest (Bureau of Economic Analysis monthly). Perhaps the most widely used of these series in the timber industries is data on seasonally adjusted housing starts.

Adjustment of data for seasonality may be subjective or it may involve quantitative analysis. The method to be used depends on the end use of the data and the analytical skills available. In this study, seasonal adjustment factors were calculated for each quarter by the use of moving averages. For each data series, a four-quarter, centered moving average of the original series was calculated. The original data series was then divided by this adjusted data series to obtain ratios to the moving averages for each quarter of the period, 1965-1978. For each quarter, the ratios were averaged to obtain a seasonal adjustment factor.

Most data series would have a pattern that the average of quarterly ratios to a moving average would not be equal, indicating the possibility of a seasonal factor in the data. The observed pattern in the data may indeed be due to seasonal factors or it may be due to chance. A two tailed F test was used to determine whether the observed differences in ratios of actual to seasonally adjusted data were significant or not. The value of F in each case was calculated as the ratio of the variation in the ratio between quarters to the variation in the ratio within quarters. The value of F was evaluated at the 5-percent level.

Significant seasonal patterns were found only for data series on lumber production. For these series, seasonal adjustment factors were used to adjust the original data series in an attempt to account for seasonality prior to analysis of interactions between the export and domestic markets.

Darr, David R. Interactions between domestic and export markets for softwood lumber and plywood: tests of six hypotheses. Res. Pap. PNW-293. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1981. 22 p.

Price formation in export markets and available data on export and domestic markets are discussed. The results of tests of several hypotheses about interactions between domestic and export markets are presented and interpreted from the standpoints of trade promotion and trade policy.

Keywords: Markets (external), markets (internal), market prices, trade policy, import/export (forest products), softwoods, plywood.

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Mount St. Helens Ash and Mud:

Chemical Properties and Effects on Germination and Establishment of Trees and Wildlife Browse Plants

M.A. Radwan and Dan L. Campbell

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Abstract

Radwan, M. A.; Campbell, Dan L. Mount St. Helens ash and mud: Chemical properties and effects on germination and establishment of trees and browse plants. Res. Pap.PNW-294. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1981. 8 p.

Chemical properties of ash and mud from the 1980 volcanic eruption of Mount St. Helens and their effect on germination and seedling production of selected plants were studied. The volcanic materials were low in some important nutrients and cation exchange capacity, and they adversely affected seedling production. Catsear, a preferred wildlife browse, and lodgepole pine appear promising for revegetation of some of the areas affected by the volcano; but frequent application of fertilizer will also be required.

Keywords: Volcano effects, chemical properties, volcanic ash soil, nutrient analyses, seedling production, germination –) environment, Washington (Mount St. Helens).

Summary

Samples of ash and mud from the 1980 volcanic eruption of Mount St. Helens were collected in western Washington soon after the May 18 eruption. For comparison, one soil sample was also collected near Toutle, 32 kilometers west of the volcano. Chemical properties of the volcanic deposit and effects on seed germination and seedling establishment of five important tree species and four different browse plants were studied. In general, the ash and mud were slightly acidic. Compared to the soil studied, the ash and mud were higher in available P, and Cu, extractable K, total S, and sulfate S; the volcanic materials were also much lower than the soil in cation exchange capacity, total N, extractable Mg, and available Fe. The ash slightly delayed seed germination, but final germination was not affected. For most species, the ash and mud adversely affected seedling production and establishment. Species' performance in volcanic mud was generally much better than in ash. Among the browse plants and tree species tested, performance in both the ash and mud was best with catsear and lodgepole pine and worst with redstem fireweed and red alder. Seedling growth in the ash and mud was generally less than that in soil. Fertilization increased seedling growth of all species in the mud and ash. Revegetation of the area devastated by the volcano will be difficult. Fertilization, especially with nitrogen, will be essential to success of any rehabilitation effort; and frequent application of fertilizer will also be necessary because of the extremely low cation exchange capacity of the volcanic deposits.

Introduction

In 1980, major volcanic eruptions occurred from Mount St. Helens in southwest Washington. These eruptions resulted in deposition of volcanic ash over much forested area in Washington and neighboring States. In addition, the eruptive events caused mud flows, especially along the Toutle River. The deposited ash ranged from light dustings on vegetation and soils, as in Olympia, to very thick layers, closer to the volcano. Similarly, mud varied in depth over the affected areas.

In addition to burying and destroying trees and forbs, the ash and mud will certainly affect natural and artificial regeneration and wildlife and may also influence plant growth by physical means or through chemical component(s). The purpose of this study was to chemically characterize the ash and mud, and to assess potential effects on plants which could be used to rehabilitate the area affected by the volcano for wildlife and timber production.

Materials and Methods

Collection and processing of ash, mud, and soil samples.—All materials were obtained from western Washington locations. Ash samples from three locations were collected: in Olympia, Capitol State Forest which is 16 kilometers west of Olympia, and near Toutle which is 32 kilometers west of the volcano. Olympia ash was from the May 25 eruption; it was collected on plastic sheets the day of the eruption and before any rain had fallen. The Capitol Forest sample was obtained by shaking the ashfall off plant leaves into a glass container. Toutle ash was collected on June 4 in plastic buckets by skimming the top layer from ground deposits. Mud was dug along the Toutle River, near Toutle; and soil was sampled to a depth of 20 cm (excluding any ash present on the surface) from a forest clearcut near Toutle.

Soil was passed through a 2-mm sieve, and ash and mud were screened to remove visible contaminants. Individual samples were thoroughly mixed and air dried at room temperature. Subsamples for chemical analysis were dried to constant weight at 65°C.

Chemical analysis.—The chemical determinations and analytical methods used were as follows: Ca, Mg, and K—extracted with neutral 1N ammonium acetate — and available Fe, Mn, Zn, and Cu—extracted with DTPA (diethylenetriaminepentaacetic acid) (Lindsey and Norvell 1978)—by atomic absorption spectrophotometric techniques (Perkin-Elmer 1976); total S and sulfate S—extracted with $Ca(H_2PO_4)_2$ solution (Fox et al. 1964)—by turbidimetric method (Butters and Chenery 1959); total N by micro-Kjeldahl procedure (Bremner 1965a); ammonium N and nitrate N—extracted with 2N KC1—by steam-distillation methods (Bremner 1965b); available P—extracted with Bray and Kurtz solution 2 (Bray and Kurtz 1945)—by the molybdenum blue technique (Chapman and Pratt 1961); pH—on a 1:1 paste with water—by glass electrode; and cation exchange capacity by the ammonium acetate method (Chapman 1965).

Test plants.—The following tree and browse species were used in the germination and seedling production tests: Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), western redcedar (*Thuja plicata* Donn ex D. Don), lodgepole pine (*Pinus contorta* Dougl. ex Loud.), red alder (*Alnus rubra* Bong.), catsear (*Hypochaeris radicata* L.), redstem fireweed (*Epilobium watsonii* Barbey), dwarf English trefoil (*Lotus corniculatus arvensis* L.), and orchard grass (*Dactylis glomerata* L.). All seeds were from local, low-elevation sources.

Germination.—Before germination tests, seeds of conifers were stratified at 2° to 5°C for 3 weeks; seeds of the other species were tested without stratification treatment. Four replicates of 100 seeds each were used (Association of Official Seed Analysts 1965). The seeds were germinated on moist germination paper or on moist Toutle ash in petri dishes. The dishes were randomly placed in an incubator programed for alternating diurnal temperatures of 30°C for 10 hours and 20°C for 14 hours, with fluorescent light available during the higher temperature. Emergence of radicle was the criterion for germination, and germinants were counted every week for 4 weeks.

Seedling production.—Production and establishment of seedlings were studied in 3-liter plastic pots filled with Toutle ash, ash on top of soil, mud, or soil. The ash-soil combination was obtained by filling the bottom one-half of the pot with soil and the upper half with ash; it was designed to simulate field conditions where ashfall covers the mineral soil.

On July 9, 1980, seeds were sown at a maximum depth of 3 mm. There were two replicates of 100 seeds each per species, and the pots were randomly placed on a bench in a covered lathhouse. Pots were watered as required, and emerged seedlings were counted at weekly intervals until harvest in November.

Fertilization and harvest of seedlings.—Starting on August 15 and continuing until harvest in November 1980, 0.5-strength nutrient solution (Hoagland and Arnon 1950) was used instead of water to irrigate one pot of each species in each of the four planting media. At the end of the experiment in November, seedlings were removed from the pots and roots were washed and examined. Dry weights of seedlings from selected fertilized and unfertilized treatments were determined by drying to constant weight at 65°C.

Results and Discussion

Chemical properties of ash and mud.—Comparative chemical characteristics of the ash and mud are shown in table 1. The data show that the three ash samples appreciably differed in most properties. For example, Olympia ash had the highest content of available Mn, Zn, Cu, total N, and ammonium N. The fact that this sample was collected without any leaching by rain may explain this result. Toutle ash also exceeded the other ash samples in content ot Ca, K, total S, sulfate S, and available P. This was probably the result of the closer proximity of the volcano to Toutle, where this sample was collected, compared with the other collection areas.

Volcanic mud was higher in Mg and appreciably lower in Ca than the ash. Other chemical properties of the mud were mostly within the range of values found in the ash samples.

In general, the ash and mud were very slightly acidic and soil much lower in pH. Compared to Toutle soil, the ash and mud were higher in available P and Cu, total S, sulfate S, and extractable K. The volcanic materials were much lower than the soil in total N, extractable Mg, available Fe, and cation exchange capacity. Despite these differences, characteristics of the ash and mud are still within ranges generally found in soils; and soil chemistry would be little affected by moderate amounts of these materials.

Effects of ash on seed germination.—Germination of all seed was somewhat delayed by the ash. Emergence of the radicle was slightly slower on ash than on germination paper. Also, the elongating radicles tended to grow horizontally without penetrating the compact ash (fig. 1), instead of growing vertically into the support medium as they did on the paper. Germination, otherwise, proceeded normally on ash as on the paper.

Table 1—Comparative chemical properties of Mount St. Helens ash and mud[1]

Property	Unit of measure	Ash sample 1	2	3	Mud	Soil
Extractable Ca	ppm	1130	540	1270	75	985
Extractable Mg	ppm	78	40	76	112	538
Extractable K	ppm	260	150	340	270	140
Available Fe	ppm	33	28	25	28	66
Available Mn	ppm	11	5	3	10	4
Available Zn	ppm	28	1	3	2	4
Available Cu	ppm	6	2	3	3	1
Total S	ppm	630	280	770	340	<10
Sulfate S	ppm	53	5	180	33	3
Total N	ppm	497	43	65	82	700
Ammonium N	ppm	7	1	2	2	[2]—
Nitrate N	ppm	3	1	2	1	[2]—
Available P	ppm	178	186	246	149	3
pH	pH	6.8	7.0	6.7	6.8	5.0
Cation exchange capacity	meqts./ 100 g	2	1	1	2	22

[1] Ash samples 1 and 2 were collected in Olympia and in Capitol Forest, which is west of Olympia, respectively. Ash sample 3, mud, and soil were obtained near Toutle, 32 kilometers west of Mount St. Helens.

[2] Not determined.

Figure 1.—Germination of lodgepole pine on compacted ash. (Note horizontal growth of radicles.)

Table 2—Effect of Mount St. Helens ash on cumulative germination percents of different plant species[1]

Plant Species	Germination medium	
	Germination paper	Ash
Douglas-fir	89	88
Western hemlock	70	69
Western redcedar	74	81
Lodgepole pine	97	97
Red alder	57	62
Catsear	90	90
Redstem fireweed	82	75
Dwarf English trefoil	70	64
Orchard grass	96	92

[1] Percents are averages of four 100-seed replicates.

Table 3—Established seedlings as percentages of seeds sown in different media [1]

Plant species	Growth medium			
	Ash	Ash on soil	Mud	Soil
Douglas-fir, sample 'a'	13	1	33	39
Douglas-fir, sample 'b'	26	10	43	79
Western hemlock	14	1	48	51
Western redcedar	19	0	49	56
Lodgepole pine	54	66	85	89
Red alder, sample 'a'	0	0	1	17
Red alder, sample 'b'	4	3	8	54
Catsear	94	62	82	81
Redstem fireweed	15	1	17	31
Dwarf English trefoil	48	67	50	46
Orchard grass	88	47	79	93

[1] Percents are averages of two 100-seed replicate pots.

Cumulative germination of the different species ranged from 57 percent with red alder to 97 percent with lodgepole pine on filter paper, and from 62 percent to 97 percent with the same species on ash (table 2). For individual species, germination was about the same on ash as on filter paper; the difference between germination on the two different media did not exceed 7 percent. Germination capacity of all species tested, therefore, was not impaired by the ash.

Seedling production and establishment in ash and mud.—Seeds of all species germinated in adequate numbers in all media at the beginning of the pot experiment. In the soil, most germinants grew into established seedlings and seedling production for the majority of species was higher than in ash or mud (table 3). On the other hand, many young germinants of most species were unable to get established in the ash. Upon watering after the seed had been sown, the ash became densely compacted like cement (fig. 2). Compaction limited aeration and resulted in a physical barrier to the radicles, restricting their ability to penetrate and grow into the ash. Many germinants, therefore, remained on top of the ash with their radicles and newly elongating aerial parts exposed (fig. 3) until they withered and died. At the end of the experiment, the number of established seedlings in the ash varied widely among the species. Among the browse plant and tree species tested, production of established seedlings was best with catsear and lodgepole pine and worst with fireweed and red alder.

Seedling production in the ash-soil combination was less than that on ash for most species. Causes for this are unknown.

Figure 2.—Mount St. Helens ash, before (right) and after (left) watering.

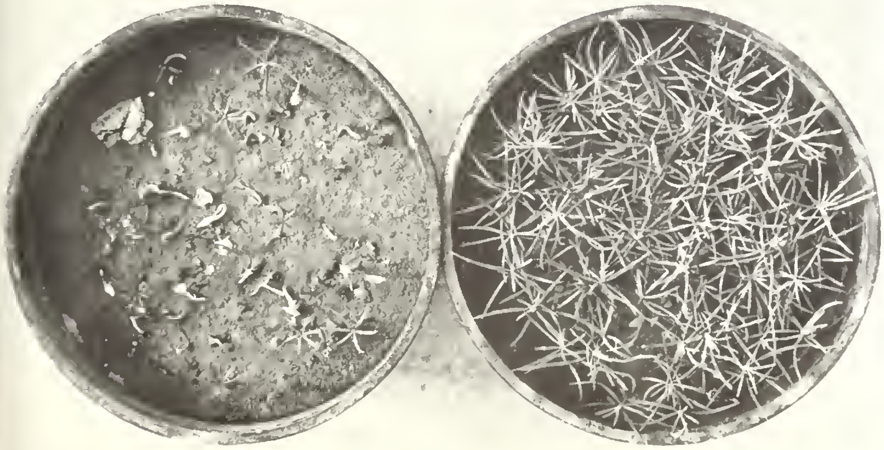

Figure 3.—Growth of Douglas-fir in Mount St. Helens ash (left) and in Toutle soil (right).

Figure 4.—Volcanic ash (left) and mud (right) (x 2) used in the study. (Note larger particles of mud.)

Figure 5.—Catsear growing in Mount St. Helens ash, without (left) and with (right) added nutrient solution.

Species' performance in volcanic mud was generally much better than in the ash The mud contained much large-particled sand (fig. 4) making it a much better medium than ash for seedling growth and establishment. Again, as with the ash, performance in mud was best with catsear and lodgepole pine, and worst with fireweed and red alder. Apparently, the red alder germinants were more sensitive to the ash and mud environment than those of other species. This was surprising because red alder, a nitrogen-fixing plant, had been considered a good candidate for rehabilitation of some areas affected by Mount St. Helens' eruption. Fortunately, dwarf English trefoil, an herbaceous nitrogen-fixing plant browsed by wildlife can be used instead of red alder; the species gave a good performance in ash and mud.

Effects of fertilization on biomass production.—Seedling growth in ash and mud was generally less than that in soil. This was expected because of limited nutrients, especially nitrogen, in the volcanic materials (table 1). Irrigating the plants with a "complete" nutrient solution, therefore, increased seedling growth (fig. 5) and dry weight of all species in both the ash and mud (table 4).

Table 4—Effect of fertilization on growth of different plant species in Mount St. Helens ash and mud

Plant species	Fertilization treatment	Dry Weight (g)	
		Growth medium	
		Ash	Mud
Western hemlock	Unfertilized	0.1	0.7
	Fertilized	.2	.8
Western redcedar	Unfertilized	.1	.6
	Fertilized	.5	1.1
Douglas-fir	Unfertilized	[1]—	2.8
	Fertilized	[1]—	3.2
Lodgepole pine	Unfertilized	1.3	1.9
	Fertilized	1.7	4.4
Dwarf English trefoil	Unfertilized	1.5	1.6
	Fertilized	5.7	3.5
Catsear	Unfertilized	5.0	.5
	Fertilized	9.8	7.1

[1] Seedlings destroyed by small rodents before harvest.

The dry-weight data (table 4) also show that: (1) with and without fertilizer, most species produced more biomass in mud than in ash; (2) regardless of fertilizer treatment, catsear was the leader in biomass production in ash; and (3) in mud, maximum biomass was produced by fertilized catsear, followed by fertilized lodgepole pine. These results confirm earlier observations that mud was more suitable for plant growth than ash, and that catsear and lodgepole pine were good candidates for revegetation of some of the areas affected by the eruption.

Conclusions

In moderate amounts, the volcanic deposits of Mount St. Helens investigated here would not have much effect on soil chemistry or growth of established plants. Revegetation of the area devastated by the volcano, so it can once again become useful for both timber production and wildlife, will be difficult, however. Ash becomes densely compacted upon wetting, it forms a physical barrier to successful establishment of young germinants, and adversely affects regeneration by seeding. Planting success may also be limited unless seedlings are planted in the soil beneath the ash. Fertilization, especially with nitrogen, will be essential to success of any rehabilitation effort; and frequent application of fertilizer will also be necessary because of the extremely low cation exchange capacity of the volcanic deposits. Species which appear promising for rehabilitation work include catsear, a preferred wildlife browse, and lodgepole pine.

Results of this study do not apply to areas around the volcano where deposits of materials such as pumice are different from those studied here.

Acknowledgments

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Literature Cited

Association of Official Seed Analysts. Rules for testing seeds. In: Assoc. Off. Seed Anal. Proc. 54. Lake Mills, Iowa: 1965: 112 p.

Bray, R. H.; Kurtz, L. T. Determination of total, organic, and available forms of phosphorus in soils. Soil Sci. 59:39-45; 1945.

Bremner, J. M. Total nitrogen. In: Methods of soil analysis, Part 2. C. A. Black, ed. Agronomy. 9:1149-1178; 1965a.

Bremner, J. M. Inorganic forms of nitrogen. In: Methods of soil analysis, Part 2. C. A. Black, ed. Madison, Wisconsin. Agronomy. 9:1179-1237; 1965b.

Butters, B.; Chenery, E. M. A rapid method for the determination of total sulfur in soils and plants. Analyst. 84:239-245; 1959.

Chapman, H. D. Cation exchange capacity. In: Methods of soil analysis, Part 2. C. A. Black, ed. Agronomy. 9:891-901; 1965.

Chapman, H. D.; Pratt, P. F. Methods of analysis for soils, plants, and waters. Berkeley, CA: University of California; 1961. 309 p.

Fox, R. L.; Olson, R. A.; Rhodes, H. F. Evaluating sulfur status of soils by plant and soil tests. Soil Sci. Soc. Proc. 1964: 243-246; 1964.

Hoagland, D. R.; Arnon, D. I. The water-culture method of growing plants without soil. Circ. 347. Berkeley, CA: University of California; 1950. 32 p.

Lindsay, W. L.; Norvell, W. A. Development of a DTPA soil test for zinc, iron, manganese, and copper. Soil Sci. Soc. Am. J. 42: 421-428; 1978.

Perkin-Elmer Corporation. Analytical methods for atomic absorption spectrophotometry. Norwalk, CO: Perkin-Elmer Corp.; 1976.

Radwan, M. A.; Campbell, Dan L. Mount St. Helens ash and mud: Chemical properties and effects on germination and establishment of trees and browse plants. Res. Pap.PNW-294. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1981. 8 p.

Chemical properties of ash and mud from the 1980 volcanic eruption of Mount St. Helens and their effect on germination and seedling production of selected plants were studied. The volcanic materials were low in some important nutrients and cation exchange capacity, and they adversely affected seedling production. Catsear, a preferred wildlife browse, and lodgepole pine appear promising for revegetation of some of the areas affected by the volcano; but frequent application of fertilizer will also be required.

Keywords: Volcano effects, chemical properties, volcanic ash soil, nutrient analyses, seedling production, germination –) environment, Washington (Mount St. Helens).

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Applicability of Four Regional Volume Tables for Estimating Growth Response to Thinning in Douglas Fir

CLEMSON UNIVERSITY
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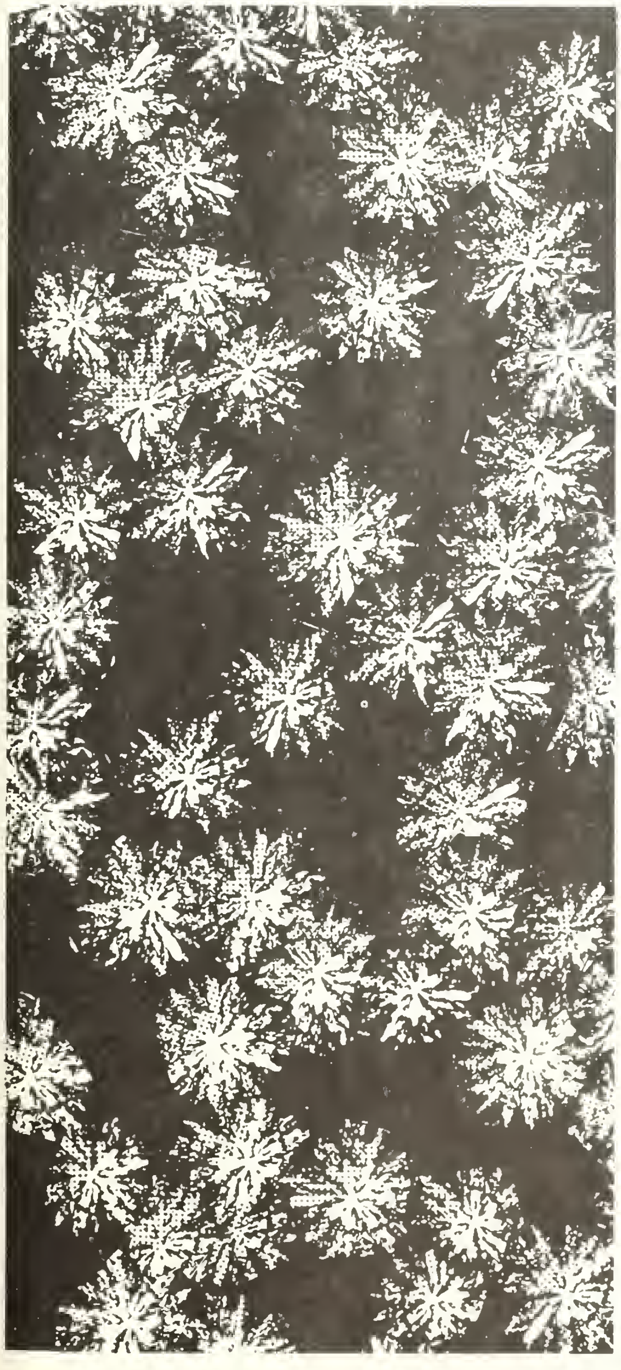
Richard L. Williamson



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Abstract

Williamson, Richard L. Applicability of four regional volume tables for estimating growth response to thinning in Douglas-fir. Res. Pap. PNW-295. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1982, 10 p.

Similar estimates of tree and stand growth 19 years after thinning a 110-year-old stand of Douglas-fir were derived from stem analysis and standard volume-table, plot-compilation procedures.

Keywords: Volume tables, thinnings (-stand volume, stem analysis, Douglas-fir, *Pseudotsuga menziesii*.

Summary

Regional, two-entry (d.b.h. and height) volume tables are routinely used to estimate the volume and volume growth of trees and stands, because alternatives—such as stem analysis or complete stem measurement—are prohibitively expensive or in conflict with study objectives. Thinning could conceivably affect the difference between actual volume and volume growth and estimates of volume and volume growth derived from volume tables. Such an effect could cause misleading inferences about results of thinning experiments.

The size and direction of such differences were tested 19 years after a 110-year-old stand of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) was thinned. Sections of stems were taken from 72 trees—sampling control, light, and heavy thinnings and dominant, codominant, intermediate, and suppressed crown classes—to analyze volume growth for 19 years before and 19 years after thinning. Estimates of volume growth for the same stands were also made from four volume equations (tables) and the results compared.

Thinning had no significant effect on the differences. Estimates of stand growth from volume tables agree with the stem analysis within about 10 percent, with standard errors of means ($p \leq 0.10$) 5 percent or less.

Introduction

Forest researchers commonly use regional volume equations (tables) to estimate volume of trees or stands and to compare growth response to various cultural treatments. Typically, these equations require only tree d.b.h. and total height. Four such regional volume equations are used in the Pacific Northwest for coastal Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*).

To determine whether silvicultural treatments influence local differences[1] between actual volumes and volume-table estimates, we measured by stem analysis the volume and volume growth of individual trees in two, long-term growth studies and compared the results with the corresponding estimates from each of the four standard volume equations. Because the results were from, and should be applied to, older stands or young stands thinned lightly, results should not be extrapolated too far, especially to younger stands with wide ranges of stocking level control.

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[1] The term difference or discrepancy is used because calculated values in this study include both bias and random variations.

Methods

The Study Area

Boundary Creek.—The primary stand studied was at Boundary Creek, in the Wind River Experimental Forest, near Carson, Washington. The stand was first thinned in 1952 at age 110 years, when an experiment consisting of three replications each of heavy thinning, light thinning, and control was established. The free-thinning method used has been described by Braathe (1957). Heavy thinning reduced cubic volume to an average of 62 percent of normal (McArdle et al. 1961) by removing 26 percent of initial volume. Light thinning reduced cubic volume to an average 78 percent of normal by removing 19 percent of initial volume. Stocking before thinning averaged 87 percent of normal cubic volume (Williamson 1966). A second thinning was made in 1971.

Snow Creek.—Supplementary data were available from three plots in the Snow Creek plantation, established in 1926 at an initial spacing of 8 x 8 feet, in Olympic National Forest near Quilcene, Washington. Two half-acre plots were first thinned at age 26, and were rethinned at ages 31, 36, 42, and 48. One half-acre plot was an unthinned control (Worthington 1961).

The first two thinnings were light, removing about 12 and 17 percent of initial volume. Later thinnings removed from 16 to 32 percent of volume.

Data Collection

Stem analyses were made from felled trees at the most recent thinnings on both areas. Trees were selected to sample the range of available diameters, prethinning competition, and release.

At Boundary Creek, two trees were selected on each plot from each of the dominant, codominant, intermediate, and suppressed crown classes, for a total of 72 trees over the nine plots.

The sample at Snow Creek was much smaller, including only 10 trees from the thinned plots and six trees from the unthinned area adjacent to the control plot, all unsegregated by crown class.

Discs were cut from each tree at stump height, breast height, base of live crown, and at 10, 30, 50, 70, and 90 percent of total 1952 height—a technique similar to Altherr's (1960).

Diameter (D) of each disc (inside bark) was calculated as twice the quadratic mean of eight regularly spaced radii (r), with initial radius randomly oriented. That is:

$$D = 2\,\{\Sigma r_i^2/8\}^{1/2}$$

Tree volume was calculated as the sum of the volumes of truncated right circular cones for sections above the stump, plus stump volume calculated as a cylinder.

Table 1 presents average values by crown classes and thinning treatments for Boundary Creek, at the time of first thinning (age 110), of d.b.h., total height, and cubic volume calculated from stem analyses.

For the limited Snow Creek data, at time of first thinning (age 26), sampled trees ranged from 6.7 to 8.8 inches in d.b.h. and from 5.2 to 10.2 cubic feet in volume. By age 48, the range was 10.1 to 15.5 inches in d.b.h., and 20.5 to 57.6 cubic feet in volume.

For Boundary Creek, tree dimensions and volumes were estimated as of 19 years before thinning (age 91); time of thinning (age 110); and 19 years after thinning (age 129).

For Snow Creek, tree dimensions and volumes were estimated as of age 26 (first thinning); age 36 (third thinning); and age 48 (fifth thinning).

The tree diameters and heights determined by stem analyses at each of these stand ages were then used to calculate estimated cubic foot volumes by the volume equations given by Browne (1962), Bruce and DeMars (1974), Curtis (1966), and Turnbull and King.[2]

Analysis

My primary interest was in possible treatment-related differences between measured and estimated volumes, and in their consistency or possible trends over time. Any regional volume equation can be expected to show volume discrepancies for any one stand. But such discrepancies would lead to misinterpretation of results of experimental treatments and to serious errors in growth estimates only if they are associated with the treatment and change substantially over the period of observation.

I first tested volume discrepancies (transformed by multiplying by the rec rocal of equation estimates to equalize variances); that is,

$$\frac{\text{(stem-analysis volume) - (equation estimate)}}{\text{(equation estimate)}},$$

to see if significant differences existed among thinning treatments, crown classes (Boundary Creek only), and years.

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[2] Turnbull, K.J., and J.E. King. Weyerhaeuser Company, Forestry Research Laboratory, Centralia, Washington. $\log V = 3.21809 + 0.04948 (\log H) (\log D) - 0.15664 (\log D)^2 + 2.02132 (\log D) + 1.63408 (\log H) - 0.16185 (\log H)^2$.

Table 1—Average dimensions of the six trees in each thinning treatment and crown class at the first thinning (age 110), Boundary Creek

Crown class	Control			Light			Heavy		
	Diameter	Height	Volume	Diameter	Height	Volume	Diameter	Height	Volume
	Inches	*Feet*	*Cubic feet*	*Inches*	*Feet*	*Cubic feet*	*Inches*	*Feet*	*Cubic feet*
Dominant	24.5	144	172	25.7	152	169	20.8	125	104
Codominant	18.5	130	92.7	22.8	138	114	17.6	121	77.9
Intermediate	17.0	131	84.7	17.3	122	74.9	15.3	107	55.2
Suppressed	12.4	106	34.7	14.4	108	42.9	12.3	93	30.0

At Boundary Creek, data for the two trees in a plot/crown-class cell were averaged, and the averages entered as observations in analyses of variance. Analyses followed a split-plot design using the original randomized-block design of the Boundary Creek thinning experiment, with years as subplots.

The Snow Creek analysis was treated as a simple split-plot design with individual trees as sources of observation.

A separate analysis was done for each area and for each volume equation. For Boundary Creek, the analysis of variance table is as follows:

Source of Variation	**Degrees of freedom**
Replications	2
Thinning treatment (T)	2
Error for testing major plot treatments	4
Crown class (CC)	3
TXCC	6
Error for testing intermediate plot classes	18
Year (Y)	2
TXY	4
CCXY	6
TXCCXY	12
Error for testing minor plot classes	48
Total	107

I then made a similar split-plot analysis of relative differences in volume growth, expressed as

$$\frac{(\Delta \text{ stem analysis volume}) - (\Delta \text{ equation estimate})}{(\Delta \text{ equation estimate})}$$

where Δ indicates the difference between volume at start and volume at end of the measurement period. In all statistical tests, differences between treatments or classes were deemed significant if $p \leq .10$.

Results

Boundary Creek

Volume discrepancies.—Averages of volume differences for the six trees in each thinning-treatment/crown-class cell, in cubic feet and in percent, are presented in tables 2a and 2b by equation, thinning treatment, year, and crown class.

Significant differences are indicated among years for the Turnbull-King and Curtis equations (table 3). The thinning x year interaction was significant for all equations. No effect of thinning alone was discernible when volume discrepancies were averaged over crown classes and years.

Percentage deviations differed significantly by crown class for three of the four equations, with the discrepancies generally tending from positive to negative for dominant through suppressed crown classes. The largest discrepancies are for codominant trees in lightly thinned plots; they are associated with four of the six trees in the cell, which had above average taper in the lower 1/10 of the bole, evidently not accounted for by the double-entry volume equations used.

Table 2A—Average volume discrepancy for the six trees in each thinning treatment and crown class, by year and by volume equation, with volume by stem analysis illustrated, Boundary Creek

				Discrepancy											
	Tree Volume			Bruce-DeMars			Turnbull-King			Curtis			Browne		
Crown Class	Control	Light	Heavy	Control	Light	Heavy	Control	Light	Heavy	Control	Light	Heavy	Control	Light	Heavy
							Cubic feet								
							1933								
Dominant	131.41	131.46	83.71	-2.71	-.60	-1.62	-1.49	1.99	-.72	5.54	6.94	1.60	.96	4.77	2.78
Codominant	74.98	90.73	61.77	-1.79	-10.54	1.47	-.71	-9.08	2.01	1.28	-5.95	3.00	1.85	-5.77	4.78
Intermediate	63.21	62.77	44.80	-.48	-1.07	-.80	.44	-.16	-.71	1.81	.93	-.10	2.70	2.23	1.75
Suppressed	29.94	36.47	25.39	-1.52	-1.92	-.82	-1.62	-1.92	-.99	-1.13	-1.40	-.94	-.04	.14	.52
24-tree average	74.89	80.36	53.92	-1.62	-3.53	-.44	-.84	-2.29	-.10	1.87	.13	.89	1.37	.34	2.46
							1952								
Dominant	172.21	169.09	103.67	.51	-.30	-2.51	2.55	3.75	-.79	11.60	9.92	2.47	3.16	4.70	2.38
Codominant	92.76	113.71	77.92	-2.42	-11.59	.50	-.51	-9.10	1.75	2.04	-5.15	3.27	2.14	-6.46	4.50
Intermediate	84.44	74.88	55.16	-.31	.61	-.59	1.62	2.00	-.13	3.14	3.11	.91	3.58	4.31	2.43
Suppressed	34.66	42.90	30.29	-2.72	-2.39	-1.10	-2.69	-2.19	-1.20	-1.89	-1.34	-.95	-.98	-.02	.52
24-tree average	96.02	100.14	66.76	-1.24	-3.42	-.93	.24	-1.39	-.09	3.72	1.63	1.42	1.98	.63	2.46
							1971								
Dominant	204.67	206.57	123.61	2.35	4.89	-2.79	4.45	9.80	-.31	15.20	16.89	3.74	3.02	8.71	2.37
Codominant	109.24	135.58	95.04	-3.35	-10.18	-1.11	-.62	-7.20	1.03	2.28	-2.15	2.67	1.61	-5.14	3.47
Intermediate	103.33	84.96	64.82	-1.38	1.19	-.70	1.56	3.01	.07	2.95	4.21	1.43	3.00	5.26	2.79
Suppressed	37.86	48.77	36.11	-3.26	-4.31	-1.32	-3.12	-2.88	-1.33	-2.32	-1.85	-.94	-1.34	-.59	.67

Table 2B—Average volume-equation discrepancy for the six trees in each thinning treatment and crown class, with volume by stem analysis illustrated, Boundary Creek (each discrepancy is a percentage of its respective equation estimate)

				Discrepancy										
	Tree Volume			Bruce-DeMars			Turnbull-King			Curtis			Browne	
Crown Class	Control	Light	Heavy	Control	Light	Heavy	Control	Light	Heavy	Control	Light	Heavy	Control	Light	Heavy
	Cubic feet			Percent											
						1933									
Dominant	131.41	131.46	83.71	-2.02	- .45	-1.90	-1.12	1.54	- .85	4.40	5.58	1.94	.73	3.76	3.44
Codominant	74.98	90.73	61.77	-2.33	-10.41	2.44	- .93	-9.09	3.36	1.74	-6.16	5.11	2.53	-5.98	8.39
Intermediate	63.21	62.77	44.80	- .75	- 1.67	-1.75	.71	- .25	-1.55	2.94	1.50	- .22	4.46	3.68	4.06
Suppressed	29.94	36.47	25.39	-4.82	- 4.99	-3 12	-5.12	-5.01	-3.77	- 3.63	-3.70	-3.58	- 12	.37	2.09
24-tree average	74.89	80.36	53.92	-2.48	- 4.38	-1.08	-1.97	-3.20	- .70	1.36	.70	.81	1.90	46	4.50
						1952									
Dominant	172.21	169.09	103.67	29	- .17	-2.37	1.50	2.26	- .76	7.22	6.23	2.44	1.87	2.86	2.35
Codominant	92.76	113.71	77.92	-2.55	- 9.25	.64	- .55	-7.41	2.30	2.25	-4.33	4.38	2.36	-5.38	6.13
Intermediate	84.44	74.88	55.16	- .37	.82	-1.05	1.96	2.74	- .24	3.86	4.33	1.67	4.43	6.10	4.61
Suppressed	34.66	42.90	30.29	-7 29	- 5.27	-3.49	-7.19	-4.85	-3.82	- 5.18	-3.03	-3.05	-2.74	- .05	1.75
24-tree average	96.02	100.14	66.76	-2.48	-3 46	-1.57	-1.07	-1.82	- .63	2.04	.80	1.36	1.48	.88	3.71
						1971									
Dominant	204.67	206.57	123.61	1.16	2.43	-2.20	2.22	4.98	- .25	8.02	8.90	3.12	1.50	4.40	1.95
Codominant	109.24	135.58	95.04	-2.97	- 6.98	-1.16	- .56	-5.04	1.10	2.13	-1.56	2.89	1.49	-3.65	3.79
Intermediate	103.33	84.96	64 82	-1.31	1.42	-1.06	1.53	3.67	.10	2.94	5.22	2.25	2.99	6.60	4.50
Suppressed	37.86	48.77	36.11	-7.92	- 8.11	-3.53	-7.61	-5.57	-3.55	- 5.77	-3.66	-2.53	-3.43	-1.20	1.88
24-tree average	113.77	118.97	79.89	-2.76	- 2.81	-1.99	-1.10	- .49	- .65	1.83	2.22	1.43	.64	1.54	3.03

Table 3—Significance levels of the F tests in the analyses of variance of relative differences in volume obtained by stem analysis and equation estimates

Factor	Equation			
	Bruce-DeMars	Turnbull-King	Curtis	Browne
Thinning (T)	0.760	0.891	0.858	0.747
Crown class (CC)	.049	.019	.005	.137
TXCC	.375	.426	.598	.381
Year (Y)	.938	.040	.004	.123
YXT	.052	.017	.101	.020
YXCC	.015	.028	.227	.267
YXTXCC	.092	.300	.346	.177

Most of the average deviations of volumes estimated by equation from those derived by stem analysis (tables 2a and 2b), whether by crown class or thinning treatment, are small. Even those differences that are statistically significant could easily have arisen from the techniques of stem analysis or volume computation rather than from the effects of thinning or inadequacy of the volume equations. They probably are of no practical magnitude.

Most of the discrepancies for the Bruce-DeMars and Turnbull-King equations are negative; most for the Curtis and Browne equations are positive. Mean deviations by year and thinning treatment (24 trees), however, do not exceed 5 percent for any of the equations.

Volume-growth discrepancies.—For all volume equations, thinning treatment had no significant effect on volume-growth discrepancies, nor was the thinning x period interaction significant, despite the significant year x thinning interaction found for volume estimates. The pattern of these nonsignificant differences among treatments is quite similar for the periods before and after thinning (fig. 1). This suggests that if the differences are real, they probably are not a result of thinning. This result is consistent with the generally small deviations of volume estimates from stem-analysis volumes (table 2).

Volume-growth discrepancies for the treatment averages of 24 trees—which correspond roughly to what one would expect from stand summaries—are all less than 10 percent (fig. 1 and table 4), and standard errors of the means ($p \leq 0.10$) are all 5 percent or less.

Figure 1.—Discrepancy of volume growth (24-tree averages) as percent of growth estimated by table—(measured - estimated) /estimated—by period, volume equation, thinning treatment, and d.b.h. class, Boundary Creek.

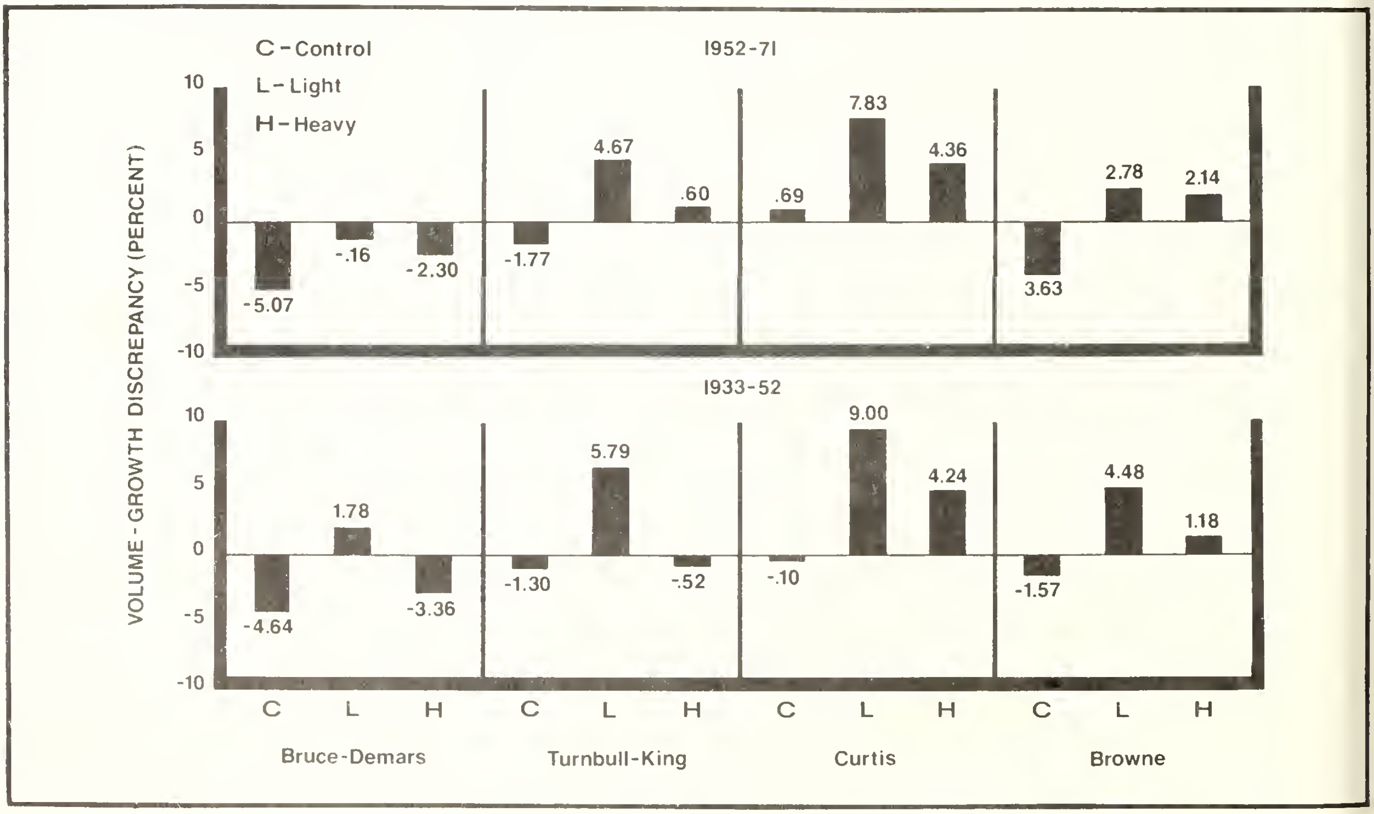

Table 4A—Average volume-growth discrepancy for the six trees in each thinning treatment and crown class, by period and by volume equation, Boundary Creek

				Discrepancy											
	Volume growth by stem analysis			Bruce-DeMars			Turnbull-King			Curtis			Browne		
Crown Class	Control	Light	Heavy	Control	Light	Heavy	Control	Light	Heavy	Control	Light	Heavy	Control	Light	Heavy
							Cubic feet								
							1933-52								
Dominant	40.80	37.63	19.96	3.21	.30	- .90	4.04	1.76	- .08	6.07	2.98	.87	2.20	- .06	- .40
Codominant	17.78	22.97	16.15	- .64	-1.05	- .98	.19	- .03	- .26	.76	.80	.27	.29	- .69	- .28
Intermediate	21.23	12.11	10.36	.17	1.68	.21	1.18	2.16	.58	1.33	2.18	1.01	.89	2.08	.68
Suppressed	4.72	6.43	4.91	-1.21	- .47	- .28	-1.07	- .26	- .21	- .77	.06	- .01	- .94	- .16	.00
24-tree average	21.13	19.79	12.84	.38	.11	- .48	1.08	.91	.01	1.85	1.51	.53	.61	.29	.00
							1953-71								
Dominant	32.46	37.47	19.94	1.85	5.19	- .27	1.90	6.06	.48	3.59	6.97	1.28	- .14	4.01	- .02
Codominant	16.47	21.88	17.12	- .92	1.42	-1.61	- .11	1.91	- .72	24	3.00	- .60	- .54	1.32	-1.03
Intermediate	18.89	10.09	9.66	-1.07	.58	- .11	- .06	1.01	.20	- .19	1.11	.52	.58	.95	.36
Suppressed	3.21	5.87	5.82	- .53	-1.92	- .23	- .43	- .69	- .13	- .43	- .51	.02	- .37	- .57	.15
24-tree average	17.76	18.83	13.13	- .17	1.32	- .55	.33	2.07	- .04	.81	2.64	.30	- .41	1.43	- .13

Table 4B—Average volume-growth discrepancy as a percent of the tabular estimate for the six trees in each thinning treatment and crown class relative to growth estimated by volume equations, by period and volume equations, Boundary Creek

Crown Class	Volume growth by stem analysis			Discrepancy											
				Bruce-DeMars			Turnbull-King			Curtis			Browne		
	Control	Light	Heavy	Control	Light	Heavy	Control	Light	Heavy	Control	Light	Heavy	Control	Light	Heavy
	Cubic feet			Percent											
	1933-52														
Dominant	40.80	37.63	19.96	6.69	.90	-1.12	9.48	5.35	2.34	15.87	8.45	8.34	5.26	.57	2.07
Codominant	17.78	22.97	16.15	- 3.86	- 2.47	-7.00	.51	1.69	-3.34	4.17	5.54	.52	1.99	- 1.14	-2.66
Intermediate	21.23	12.11	10.36	- 1.56	12.14	2.35	2.83	16.83	5.51	4.22	17.65	10.46	2.49	17.14	7.83
Suppressed	4.72	6.43	4.91	-19.84	- 3.47	-7.68	-18.00	- .72	-6.58	-13.23	4.35	- 2.36	-16.03	1.35	-2.51
24-tree average	21.13	19.79	12.84	- 4.64	1.78	-3.36	- 1.30	5.79	- .52	2.76	9.00	4.24	- 1.57	4.48	1.18
	1953-71														
Dominant	32.45	37.47	19.94	7.92	13.29	- .24	9.18	16.81	3.25	15.88	20.31	8.91	4.47	10.25	1.86
Codominant	16.47	21.88	17.12	- 3.51	4.86	-5.22	1.31	8.23	-1.43	3.20	13.13	1.59	- 1.00	4.92	-1.21
Intermediate	18.89	10.09	9.66	- 9.80	1.72	.96	- 5.29	5.91	3.84	- 5.50	7.63	7.61	- 6.95	6.18	6.41
Suppressed	3.21	5.87	5.82	-14.88	-20.49	-4.69	-12.26	-12.27	-3.27	-10.83	- 9.74	- .66	-11.04	-10.24	1.51
24-tree average	17.76	18.83	13.13	- 5.07	- .16	-2.30	- 1.77	4.67	.60	.69	7.83	4.36	- 3.63	2.78	2.14

Table 5—Significance levels of the F tests in the analyses of variance of relative differences between volume growth by stem analysis and estimates by equation of volume growth and of differences in form factor for Boundary Creek

Factor	Bruce-DeMars	Turnbull-King	Curtis	Browne	Form factor
Thinning (T)	0.123	0.127	0.154	0.293	0.644
Crown class (CC)	.004	.005	.010	.046	.100
TXCC	.425	.672	.694	.574	.256
Years (Y)	.805	.923	.564	.580	.001
YXT	.780	.843	.880	.724	.025
YXCC	.091	.091	.101	.169	.422
YXTXCC	.101	.165	.238	.198	.347

Table 6—Average volume-equation discrepancy of growth, as percent of growth by volume equation by period, equation, and thinning treatment, Snow Creek[1]

Period	Volume growth by stem analysis[2]		Bruce-DeMars		Turnbull-King		Curtis		Browne	
	Thinned	Unthinned	Thinned	Unthinned	Thinned	Unthinned	Thinned	Unthinned	Thinned	Unthinned
	Cubic feet		Percent							
1951-60	9.27 (2.64)	9.34 (2.17)	-2.33 (6.10)	-4.32 (6.87)	-1.52 (5.82)	-2.87 (7.42)	-3.23 (5.87)	-4.67 (7.36)	-8.18 (5.59)	-9.28 (6.81)
1961-72	16.65 (4.99)	13.91 (3.96)	2.98 (12.46)	.41 (6.16)	1.72 (12.30)	-.31 (5.60)	-1.83 (11.15)	-5.73 (5.56)	-3.61 (11.98)	-4.77 (5.79)

[1] Standard deviations are in parentheses.

[2] Sample size: thinned, 10; unthinned, 6.

Crown class did have a significant effect on volume-growth discrepancies, but interactions of year x crown class and year x thinning x crown class were of marginal significance (table 5).

Average discrepancies were positive and considerably larger in the second than in the first period for dominant and codominant sample trees in lightly thinned plots (table 4). Average discrepancies were more nearly equal among periods for such sample trees in the control and heavily thinned plots. Because the interaction of period x thinning x crown class for volume-growth discrepancies is nonsignificant (table 5), this apparent difference could be merely a chance event in sampling.

Snow Creek

The limited data from Snow Creek show no significant difference for percentage deviations of volume growth of thinned plots compared with control. Average deviations in growth estimates by volume equations from those made by stem analysis for each treatment were less than 10 percent for all four volume equations (table 6).

Discussion

No comparison made at only two locations can prove a general lack of material error for any volume equation if applied over a range of stand conditions. For the Boundary Creek and Snow Creek areas, however, no serious discrepancies were found with any of the four volume equations examined. This assumes that growth estimates accurate to within about 10 percent are acceptable, providing that differences in errors between thinning treatments are not significant at the 0.10 level. For the two stands studied, standard volume equations provided satisfactory estimates of volume response to thinning.

Estimating volume and volume growth of individual trees is not the same as estimating these values for entire stands. Differences in stand estimates will be influenced by stand structure and the distribution of differences among size classes or crown classes. At Boundary Creek, the relative numbers of trees by crown classes were not significantly different among plots. Apparently for these data (table 4), averages of the three upper crown classes—which contribute most of the growth—will still be near or below 10 percent. Thus, these results can reasonably be extended to per-acre values at Boundary Creek.

The stem analysis work at Boundary Creek was originally undertaken in connection with analysis of a thinning study. Thinning is commonly expected to accelerate diameter growth of residual trees, accompanied by a redistribution of increment along the bole with consequent increased stem taper. I suspected that application of a standard volume equation during the response period might result in an overestimate of the volume response to thinning, but this study found no clear evidence of that. To the contrary, all four volume equations show substantial underestimation for dominant and codominant trees in the lightly thinned stands.

Practically, insufficient or biased sampling of trees measured for height and volume is probably a more serious source of error than any one of the volume equations in these mature young-growth stands.

Literature Cited

Altherr, E. Die Genauigkeit verscheidner Verfahren der Sektionierung in absoluten und relation Schaftlänger. [The accuracy of different methods of sectioning by absolute and relative bole lengths.] Allg. Forst, u. Jagdztg. 131(10): 226-237; 1960.

Braathe, Peder. Thinnings in even-aged stands. A summary of European literature. Fredericton, NB: Faculty of Forestry, University of New Brunswick; 1957. 92 p.

Browne, J.E. Standard cubic-foot volume tables for the commercial tree species of British Columbia, 1962. Vancouver, BC: British Columbia Forest Service; 1962. 107 p.

Bruce, David; DeMars, Donald J. Volume equations for second-growth Douglas-fir. Res. Note PNW-239. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 5 p.

Curtis, Robert O. A formula for the Douglas-fir total cubic-foot volume table from Bulletin 201. Res. Note PNW-41. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1966. 8 p.

McArdle, Richard E.; Meyer, Walter H.; Bruce, Donald. The yield of Douglas-fir in the Pacific Northwest. Tech. Bull. 201. Washington, DC: U.S. Department of Agriculture; 1961: 50-55.

Williamson, Richard L. Thinning response in 110-year-old Douglas-fir. Res. Note PNW-36. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1966. 7 p.

Worthington, Norman P. Some observations on yield and early thinning in a Douglas-fir plantation. J. For. 59(5): 331-334; 1961.

Williamson, Richard L. Applicability of four regional volume tables for estimating growth response to thinning in Douglas-fir. Res. Pap. PNW-295. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1982, 10 p.

Similar estimates of tree and stand growth 19 years after thinning a 110-year-old stand of Douglas-fir were derived from stem analysis and standard volume-table, plot-compilation procedures.

Keywords: Volume tables, thinnings (-stand volume, stem analysis, Douglas-fir, *Pseudotsuga menziesii*.

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Response to Commercial Thinning in a 110-year-old Douglas-Fir Stand

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Abstract

Williamson, Richard L. Response to commercial thinning in a 110-year-old Douglas-fir stand. Res. Pap. PNW-296. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1982. 16 p.

During a 19-year period after a 110-year-old Douglas-fir stand was thinned, both standard plot compilations and stem analysis showed that growth of heavily and lightly thinned stands equaled growth of stands in control plots.

KEYWORDS: Thinning, Douglas-fir, volume increment of stands.

Summary

In 1952, the Pacific Northwest Forest and Range Experiment Station established a thinning study in a 110-year-old stand of Douglas-fir in southwest Washington. Density of lightly thinned stands was adjusted to about 75 percent of normal basal area, and heavily thinned stands to about 50 percent. Nominal treatments were confounded by initial differences among plots and treatments in site index, stocking, and density. After accounting for these confounding factors, gross growth of all plots—except a lightly thinned one—was about equal to normal gross growth during a 19-year period after thinning. The reason for poor growth on the lightly thinned plot is unknown.

Good growth response of individual trees, in line with that to be expected by stand response, was illustrated by results of stem analyses.

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Introduction

Foresters in the Pacific Northwest sometimes debate the merits of commercially thinning stands of mature young-growth Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). Yerkes (1960), writing about thinning in a 110-year-old stand at Boundary Creek, implied that growth response of residual trees was minimal, with little transfer of growth to residual trees, and that thinnings should remove only expected mortality.

My results from the same area were more positive, partly because of the longer period of observation (11, rather than 6 years), but mostly because the variation in site index among treatments was taken into account (Williamson 1966). When gross growth for the several treatments was compared with normal growth for their respective site indexes, only slight and nonsignificant differences were observed. This implied a substantial redistribution of growth from cut trees to residual trees, as did increased radial growth observed on increment cores.

All these results were based on stand volumes calculated from a regional d.b.h.—height volume table (McArdle et al. 1961, table 12), which could conceivably be biased as a result of thinning.[1]

A remeasurement and second thinning 19 years after the first provided a longer period to observe and compare effects of thinning. Trees cut during that second thinning at the end of this 19-year period provided information through stem analyses on individual-tree and stand response and reliability of standard techniques for compiling plot volume growth. This report describes results for the 19 years after the first thinning.

The Study Area

Location

The Boundary Creek thinning-study area is in the Panther Creek subdivision of the Wind River Experimental Forest near Carson, Washington, on the Wind River District of the Gifford Pinchot National Forest. The study area encompasses about 70 acres a an elevation of about 2500 feet. It occupies a slump basin with uneven topography. Slopes are generally less than 30 percent.

Study Design

The experiment tested heavy and light thinning against unthinned controls in a stand 110 years old in 1952 (table 1). Thinnings were "free,"[2] removing some trees in every crown class, but usually leaving the most vigorous dominants and codominants. Som dead and high-risk trees were also removed from the control plots and from the surrounding area in a sanitation-salvage cut made at the same time. Each treatment was replicated three times in a randomized block design. Each plot was rectangular, 1 by 10 chains (fig. 1), and surrounded by areas 1 to 3 chains wide that were sanitation-salvaged at time of initial thinning.

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[1] This hypothesis will be evaluated in a companion paper, in process.

[2] As described in Braathe (1957).

Table 1—Stand characteristics before and after thinning at Boundary Creek

Treatment	Site-index height at age 100	Normal[1] volume at age 110	Initial volume, 1952	Initial as percent of normal	Cut volume, 1952	Percent cut	d/D[2]	Residual, 1952	Residual as percent of normal
	Feet	-Cubic feet per acre-		Percent	Cubic feet per acre	Percent		Cubic feet per acre	Percent
Control									
Plot 1	152	15,532	15,171	97.7	[3]636	4.2	--	14,535	9.63
6	145	14,645	12,411	84.7	[3]902	7.3	--	11,509	78.6
7	143	14,387	8,892	61.8	0	0	--	8,892	61.8
Average	147	14,903	12,158	81.6	--	--	--	11,645	78.1
Light thinning									
Plot 3	150	15,290	14,403	94.2	3,078	21.4	0.83	11,325	74.1
4	151	15,411	13,557	88.0	2,431	17.9	.88	11,126	72.2
8	134	13,166	14,423	109.5	2,625	18.2	.85	11,798	89.6
Average	145	14,645	14,128	96.5	2,711	19.2	--	11,416	77.9
Heavy thinning									
Plot 2	121	11,233	9,535	84.9	3,208	33.6	.84	6,327	56.3
5	143	14,387	10,230	71.1	1,605	15.7	.75	8,625	59.9
9	114	10,132	10,224	100.9	2,989	29.2	.95	7,235	71.4
Average	126	11,917	9,784	82.1	2,426	24.8	--	7,395	62.0

[1] From McArdle et al. (1961).

[2] d = quadratic mean diameter of cut trees; D = quadratic mean diameter of all trees before cutting.

[3] Salvaged mortality.

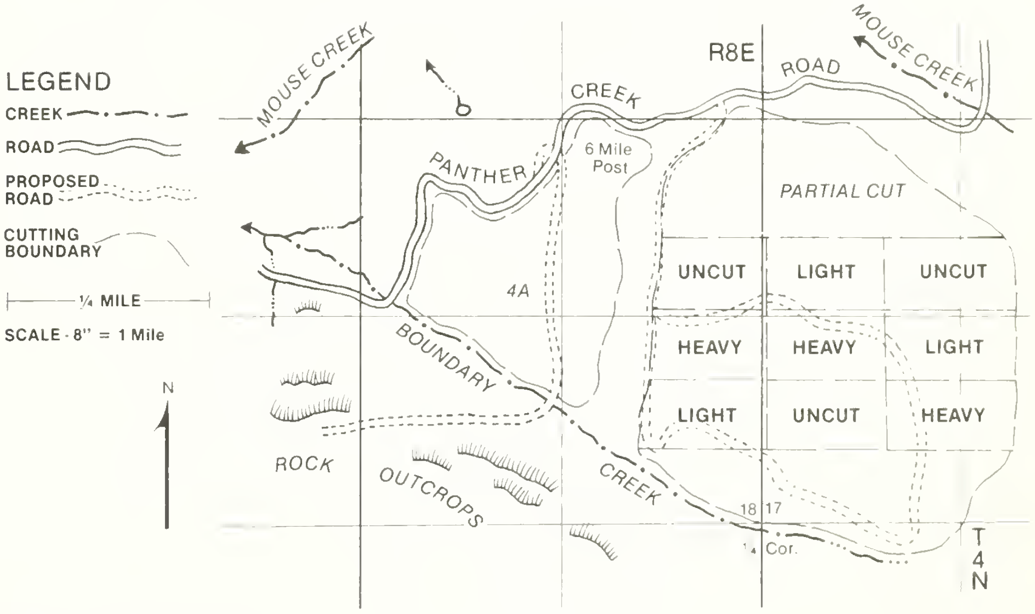

Figure 1.—Boundary Creek thinning study, Wind River Experimental Forest near Carson, Washington.

Stand Variability

Site index.—Total heights and ages were obtained for sufficient numbers of trees on each plot to give a standard error of site index for each plot of 6 feet or less. Site index (McArdle et al. 1961) ranged from 114 to 152, with six of the nine plots between 140 and 150 (table 1). The two plots of lowest site index were in the heavily thinned group.

Mortality.—Bark beetles (*Dendroctonus pseudotsugae* Hopkins) and root rot (*Phellinus weirii* (Murr.) Gilb.) were causing mortality when the study began in 1952. The second thinning, which made trees available for stem analysis, was instigated by mortality from these agents 16-18 years later. Mortality in 1968 was much more severe than in 1952 (fig. 2). The range in initial stocking is probably wide because similar mortality occurred in the area before the experiment began.

Density or stocking.—Plot 5 ("heavy thinning") was of low density (71 percent of normal) at study establishment, but without obvious unstocked[3] openings in the stand.

Mortality from bark beetles and root rot caused unstocked openings in plot 7—a control plot—accounting for its low initial volume. The unstocked openings in the area are mostly in control plots or otherwise simply sanitation-salvage areas. One other control plot (plot 6) was only 79 percent of normal after removal of mortality in 1952.

These differences in initial stocking or density, and the "cut" values in table 1, suggest that low- and medium-density are better descriptors than "light" and "heavy" thinning, but I will use these terms to be consistent with previous reports.

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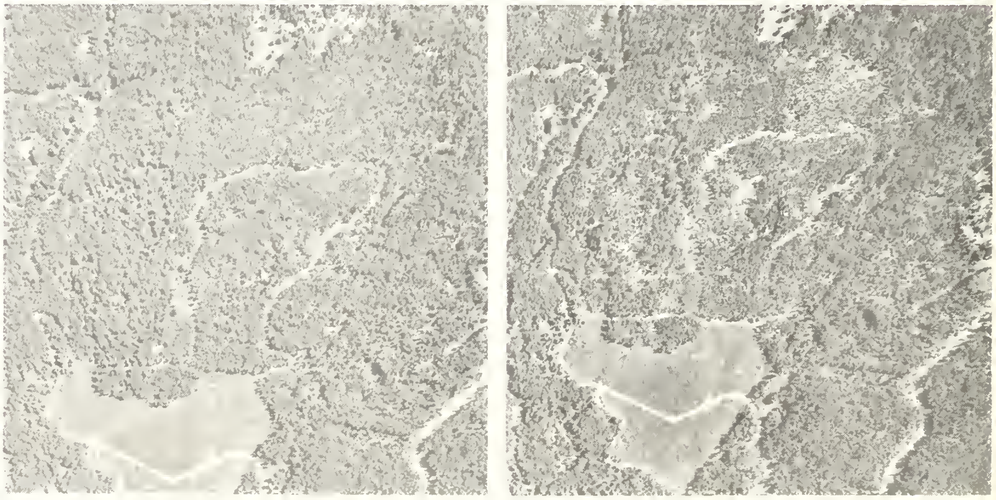
[3] An unstocked area is here defined as one where resources are not being fully utilized by neighboring trees.



1968

1973

Figure 2.—The Boundary Creek study area, 1967 (left) and 1973 (right) illustrating much poorer stocking after the 1968-70 mortality than before.

Study Objectives

My objectives were to compare response to thinning among treatments, as expressed by conventional plot totals of volume and volume growth, for the 19 years after initial thinning; to compare response to thinning of residual trees, as determined by stem analyses, for the same period; and to compare the estimates of response to thinning calculated for the stand with those obtained from stem analyses of residual trees.

Stand Comparisons

Standard plot computations.—On each 1-acre plot, diameter breast high (d.b.h.) was measured on all trees. Total height of 12 sample trees was measured on each plot, about 8 having diameters above the plot quadratic mean. Volumes of sample trees were determined from the volume table by Bruce and DeMars (1974). Regressions of sample-tree volume on d.b.h. were used to estimate individual tree volumes, and these estimates were summed for total plot volumes. Gross growth is the difference in volumes of the live stand at beginning and end of the growth period, plus volume in mortality.

Expression of thinning response.—Because of the wide range in site index among plots and because of potential problems with stocking differences on the control plots, thinning results were tested by comparing ratios of gross volume growth to normal gross growth for the same site index (Staebler 1955). Therefore, the variable

$$\frac{\Delta V}{\Delta V_{normal}} \qquad (1)$$

was used as the dependent variable in the analysis of variance.

Response can also be expressed as a ratio of growth of thinned stands to that of controls. Average gross growth relative to the average of controls, adjusted for differences in normal growth because of site-index differences, can be expressed as the ratio:

$$\frac{(\Delta V/\Delta V_{normal})\text{ thinned}}{(\Delta V/\Delta V_{normal})\text{ control}} \qquad (2)$$

where, again, normal gross-growth values are from Staebler (1955), using the treatment average, site-index value.

Similarly, volume relative to control, adjusted for differences related to site index in normal net volume (McArdle et al. 1961) can be expressed by the ratio:

$$\frac{(V/V_{normal})\text{ thinned.}}{(V/V_{normal})\text{ control}} \qquad (3)$$

Dividing (2) by (3) gives

$$\frac{(\Delta V/\Delta V_{normal})/(V/V_{normal})\text{ thinned.}}{(\Delta V/\Delta V_{normal})/(V/V_{normal})\text{ control}} = \text{“response.”} \qquad (4)$$

For treated and control plots with the same site index, the two values of ΔV_{normal} are identical, as are those of V_{normal}. Expression (4) then reduces to:

$$\frac{(\Delta V/V)\text{ thinned}}{(\Delta V/V)\text{ control}}$$

which is simply the ratio of volume-growth percent of treated to volume-growth percent of control.

The response ratio (4) can thus be regarded as a ratio of volume-growth percentages of treated plots relative to control, adjusted for differences in site index and stocking. A response value greater than 1.0 indicates an increase in increment per unit of growing stock relative to control. Such an increase could result from either the removal of slow-growing trees in thinning or an actual increase in growth rate of the remaining trees (or, usually, both).

Analysis.—The study was designed as a randomized block experiment with three replications. The analysis of variance for the ratio of plot gross-volume growth to normal growth for the plot site index is illustrated in table 2.

Table 2—Analysis of variance on gross growth as a percentage of normal gross growth

Source of variation	Degrees of freedom	Mean square	F
Thinning	2	22.484	0.139
Blocks	2	19.631	.120
Error	4	161.311	--

[1] Differences were considered significant if $p \leq 0.10$.

Individual-Tree Comparisons

Selection of sample trees.—I examined 72 trees, two in each of the four major crown classes, as of 1971, on each plot. All stem-analysis trees were alive at time of felling, had vigor commensurate with their crown class, and release typical of the thinning treatment.

Volume computations.—Volume of each tree was estimated at time of thinning and for 19 years before and after thinning.

Sections were cut from each stem at stump height, breast height, base of live crown, and at 0.1, 0.3, 0.5, 0.7, and 0.9 of total height.[4] Radius of each section was calculated as the quadratic mean of eight regularly spaced radii, with the initial radius randomly oriented. Volume of stem sections was calculated as that of a frustrum of a cone. As Grosenbaugh (1954) has demonstrated, the particular conic shape assumed for stem segments makes little practical difference as long as small diameters are at least 70 percent of the larger.

Periodic growth was calculated as the difference between volumes so determined at the beginning and end of each 19-year growth period.

Expression of individual-tree response.—Volume growth for the 19 years after thinning can be expected to reflect the known differences in plot site indexes, and it is not a suitable variable for comparison of thinning effects. The periodic-growth ratio,

$$\frac{\Delta V \text{ for 19 years after thinning}}{\Delta V \text{ for 19 years before thinning}}$$

was therefore used as the variable for testing thinning response.

The quotient obtained by dividing the value of this ratio for a specified class of trees in thinned plots by the corresponding value for control plots will be described as "relative response."

Analysis.—Analysis of variance of these periodic-growth ratios obtained by stem analysis followed the randomized block design of the main experiment. Each major plot, however, was split into the four crown classes, giving a split-plot randomized block analysis (table 3)

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[4] This procedure is similar to that given in Altherr (1960).

Table 3—Analysis of variance on periodic-growth ratios of individual trees

Source of variation	Degrees of freedom	Mean square	F
Thinning	2	3,846	5.193
Blocks	2	2,768	3.738
Major plot error	4	740	--
Crown class	3	227	.757
Thinning x crown class	6	797	2.659
Minor plot error	18	300	--

Results

Stand Comparisons

Gross growth.—The most recent (19-year period) estimates of volume growth for the stand at Boundary Creek (table 4) indicated good response to thinning, similar to that reported previously (Williamson 1966), after differences in site index and stocking were taken into account. Gross growth of plots, relative to normal growth, did not differ significantly among treatments (table 2).

The "response" variable (equation 4, table 5) suggests that gross growth of heavily thinned plots was 27 percent better than that expected if growth were directly proportional to growing stock. The lightly thinned plots showed no improvement, which probably reflects the fact that residual growing stock on the lightly thinned plots was nearly the same as that on controls (table 1).

Some apparent exceptions were found to the statement that gross growth was about normal, for these individual plots:

Plot 1 (control):—78 percent. This plot contained a large unstocked opening because of mortality during 1964-71.
Plot 3 (light thinning):—84.5 percent. The reason for poor growth on this plot is not known.
Plot 5 (heavy thinning):—84.8 percent. This plot had quite uniform low density (71 percent of normal) before thinning, for unknown reasons, as though stand density had always been open. Only 15.7 percent of volume was removed in thinning. A slow return to normal density (Briegleb 1942) is probably all that could be expected in a stand under these conditions.
Plot 7 (control):—85.3 percent. An unstocked opening existed in the east half at time of study establishment. The west half was widely spaced.

The block F (table 2) was nonsignificant. Clearly, the blocks, which were established on the basis of slope position, had little relation to the actual pattern of site index in the area and were ineffective in accounting for the considerable differences in site index there.

Mortality.—As reported previously (Williamson and Price 1971), thinning sharply reduced all types of mortality in mature young-growth stands. The latest measurements at Boundary Creek support this conclusion. Average mortality on control plots was five times the mortality on heavily thinned plots and about three times that on lightly thinned plots. Mortality on control plots has averaged 100 cubic feet per acre per year, but on lightly and heavily thinned stands was only 33 and 20, respectively.

The principal causes of nonsuppression mortality are thought to have been drought in combination with *Phellinus weirii* root rot and Douglas-fir bark beetle. Mortality in the general area has typically been in patches, killing trees of all crown classes.

Mortality in the control plots was 86 percent of gross growth and was patchy, resulting in unstocked openings. Mortality in lightly and heavily thinned stands was only 30 and 23 percent of gross growth, respectively, and generally widely scattered.

Net growth.—The relation of stand density to mortality also implies a corresponding and inverse relation to stand net growth (table 4). Although lightly thinned stands averaged 119 percent of normal net growth and heavily thinned stands averaged 136 percent, unthinned stands averaged much less than normal.

Table 4—Periodic, annual gross growth per acre by treatment, plot, and period at Boundary Creek

Treatment	Site-index height at age 100	Gross growth, annual, 1952-63	Normal[1] growth	Gross growth 1952-63 relative to normal	Gross growth, annual, 1964-71	Normal[1] growth	Gross growth 1964-71 relative to normal	Gross growth, annual, 1952-71	Normal[1] growth	Gross growth 1952-71 relative to normal	Normal gross growth relative to control	Net growth, annual, 1952-71	Normal[2] growth	Net growth relative to normal
	Feet	- - Cubic feet - -		Percent	- - Cubic feet - -		Percent	- - Cubic feet - -		- - Percent - -		- - Cubic feet - -		Percent
Control														
Plot 1	152	135	134	100.7	98	126	78.0	119	130	91.5	--	-148	65	-228
6	145	127	123	103.2	115	115	100.0	122	119	102.8	—	59	60	98
7	143	107	120	89.2	88	112	78.6	99	116	85.3	--	-84	59	-142
Average	147	123	126	97.6	100	118	85.0	113	122	93.2	100	-58	61	-91
Light thinning														
Plot 3	150	102	130	78.5	104	123	84.5	103	127	81.1	--	85	64	133
4	151	128	132	97.0	129	124	104.0	129	128	100.8	--	123	64	192
8	134	92	106	86.8	95	99	96.0	93	103	90.3	--	17	54	32
Average	145	107	123	87.0	109	115	94.8	108	119	90.7	98	75	61	119
Heavy thinning														
Plot 2	121	79	88	89.8	88	81	108.6	83	84	98.8	—	79	47	168
5	143	95	120	79.2	95	112	84.8	95	116	82.2	--	72	59	122
9	114	83	79	105.1	78	72	108.3	81	75	107.6	--	49	42	117
Average	126	86	94	91.5	87	88	98.9	86	92	96.2	100	67	49	136

[1] Staebler (1955).

[2] McArdle et al. (1961).

Table 5—Calculation of stand response to light and heavy thinning

	Control	Light thinning	Heavy thinning	Light thinning response		Heavy thinning response	
	1	2	3	4 (2÷1)	5 (4a÷4b)	6 (3÷1)	7 (6a÷6b)
a. Percent of normal[1] gross growth	93.1	90.7	93.5	0.9742	0.98	1.0043	1.27
b. Percent of normal[2] net growing stock	78.1	77.9	62.0	.9974	--	.7938	--

[1] Staebler (1955).

[2] McArdle et al. (1961).

Among individual plots, note: relatively poor net growth by thinned plot 8, which had an initial density above normal and residual density 90 percent of normal, with mortality in a portion of the plot that received little thinning; relatively good net growth by control plot 6, which had an initial density of only 85 percent of normal with fairly uniform stem distribution; and negative net growth for plot 7, where the east half with heavy mortality was about twice as dense (145 trees/acre) as the west half (78 trees/acre), which had little mortality.

Individual-Tree Comparisons

Average thinning effects.—Ratios of gross volume growth for 19 years after thinning to that for the 19 years before thinning differed significantly among treatments (table 3). Average relative response of all 24 sectioned trees in the heavily thinned stands was 30 percent greater than that of controls, but that of lightly thinned stands was 8 percent greater (table 6). Evidently, the response found in the stand comparisons was not solely or primarily the result of removal of slow-growing tres, but a real response by the residual trees.

Table 6—Comparison of response[1] and relative response[2] in volume growth treatment (arithmetic mean for 24 trees each in control, lightly thinned, and heavily thinned plots, based on stem analysis)

Treatment	Response	Relative response
Control	0.82	100
Light thinning	.89	108
Heavy thinning	1.07	130

[1] Response = volume growth 19 years after thinning relative to that 19 years before.
[2] Relative response = response of trees in thinned plots relative to that in controls.

Response by different crown classes.—Thinning had a significantly different effect on periodic growth ratios of different crown classes, as shown by the significant T x CC interaction (table 3). Particularly impressive is the relative response of suppressed trees in heavily thinned stands, almost double the control (table 7). Though suppressed trees should be expected to grow more slowly than superior crown class trees—and these did (table 8)—growth percent (periodic growth divided by initial volume) suggests that all crown classes in the heavily thinned stands contributed about as much to plot growth as they did to plot growing stock (table 9). Volume growth of these trees is low compared to that of trees in the other two treatments because of the lower site index in these plots. Good response by suppressed trees is not too surprising because they were under the most competition initially and should benefit more from release than would a dominant tree. Diameters of these suppressed trees averaged 60 percent of the dominant tree diameters, and live-crown ratios averaged 27 percent.

Table 7—Comparison of average response[1] and relative response[2] in volume growth for the 6 trees in each thinning treatment, crown-class category at Boundary Creek, based on stem analysis

		Light thinning		Heavy thinning	
Crown class	Control	Response	Relative response	Response	Relative response
Dominant	0.80	0.95	118	1.04	130
Codominant	.93	.91	98	1.05	112
Intermediate	.89	.79	90	.96	108
Suppressed	.68	.91	135	1.23	182

[1] Response = volume growth 19 years after thinning relative to that 19 years before.

[2] Relative response = response of trees in thinned plots relative to that in controls.

Table 8—Periodic growth, 1952-71, by thinning treatment and crown class, stem-analysis trees only

Treatment	Crown class			
	Dominant	Codominant	Intermediate	Suppressed
		Cubic feet		
Control	40.8	17.8	21.2	4.7
Light thinning	37.6	23.0	12.1	6.4
Heavy thinning	20.0	17.1	9.7	5.8

Table 9—Periodic growth percent, 1952-71, by thinning treatment and crown class, stem-analysis trees only

Treatment	Crown class			
	Dominant	Codominant	Intermediate	Suppressed
		Cubic feet		
Control	19.3	17.9	22.0	10.1
Light thinning	21.1	19.6	12.8	12.8
Heavy thinning	19.9	21.4	17.9	19.8

Codominant and intermediate trees had the lowest relative responses, 112 and 108 percent, respectively. Dominant trees responded less than suppressed trees, but better than intermediate and codominant trees with a gain of 30 percent, slightly above the overall average weighted response.

On the control plots, response for codominant trees generally was higher than for trees in the other crown classes. Response for suppressed trees invariably was the poorest.

Naturally, a lot of variation occurred in the growth ratios between trees within a given crown class on the thinned plots. This variation could result from differing amounts of competition before and after release by thinning. Some consistencies are apparent, however, among all thinned plots.

Although response of suppressed trees was invariably poorest in the control plots, it was better than all other crown classes on five of the six thinned plots. Codominant and intermediate trees had the lowest response on five of the six thinned plots. On the one plot (5) where codominant or intermediate trees were not the poorest responders, the dominant trees were. This plot is the heavily thinned one where the initial stand density was considerably below average for that treatment, and where little stand response was expected.

Comparison of Estimates of Stand and Individual-Tree Responses

To convert the stem-analysis estimates of individual-tree response to per-acre estimates of stand response, responses by crown class (table 7) were weighted by volume of trees in these classes on the plots. After thinning in 1952, growing stock of heavily thinned plots was only 79.4 percent of that of controls (both relative to normal). Therefore, if growth after thinning were equal to that of control plots, an average tree in a heavily thinned plot would have a relative response of 126 percent (1/.794). In fact, the stem analyses give a weighted average relative response of 120 percent, in good agreement.

This result also indicates (as did average thinning effects) that the observed stand response is not solely or primarily because of removal of slow-growing trees, but also includes a substantial real response by the residual stand.

Basal-Area Growth as an Estimator of Volume Growth

Stand-volume growth is a function of basal-area growth, form change, and height growth (Evert 1964). In young stands, where height and form are changing rapidly, basal-area growth can be a poor predictor of volume growth. In older (70- to 150-year-old) stands, where height growth is much reduced and form changes slowly, basal-area growth should be a much better predictor of volume growth (Williamson and Price 1971).

Williamson and Price (1971) expressed periodic, annual, gross basal-area increment as a percent of prethinning basal-area growing stock (technique 1), and assumed that such a percent for volume growth should be about the same. This provides a sort of self-calibration. Alternatively, standard growth percents (periodic annual growth divided by postthinning growing stock—technique 2) could be used. Both techniques tend to eliminate confounding influences of site and stocking. Technique 2 is useful primarily for deciding if thinning has caused any growth response, technique 1 for deciding if growth of thinned stands equals that of controls.

Volume growth ($\Delta\Sigma V$) may be expressed as a function of average form factor ($\bar{F}$), plot basal area and its increase ($\Sigma\beta$ and $\Delta\Sigma\beta$, respectively), and Lorey's height[5] and its increase ($\bar{H}$ and $\Delta\bar{H}$, respectively), as follows:

$$\Delta\Sigma V = \bar{F}(\Sigma\beta \bullet \Delta\bar{H} + \bar{H} \bullet \Delta\Sigma\beta + \Delta\Sigma\beta \bullet \Delta\bar{H}),$$

neglecting terms that involve change in form factor (Evert 1964). Volume may be expressed as $\Sigma V = \bar{F} \bullet \Sigma\beta \bullet \bar{H}$. Dividing the volume increment expression by that for volume, yields:

$$\frac{\Delta\Sigma V}{\Sigma V} = \frac{\Delta\bar{H}}{\bar{H}} + \frac{\Delta\Sigma\beta}{\Sigma\beta} + \frac{\Delta\Sigma\beta \bullet \Delta\bar{H}}{\Sigma\beta \bullet \bar{H}}$$

Therefore, volume-growth percent must always be greater than basal-area growth percent.

If $\Delta\bar{H}$ is small enough so that its effects can be ignored, then volume-growth percent should be very close to basal-area growth percent, neglecting changes in form factor.

These data illustrate that incorrect inferences can be derived from basal-area data whichever technique is used (table 10). Agreement between basal-area and volume percents is within 10 percent for control and lightly thinned stands. For heavily thinned stands, however, differences go up to 22 percent, with most over 10 percent. Basal-area growth grossly underestimates volume growth. Changes in form factor of the stem-analyzed trees were significant. Very likely, Williamson and Price (1971) underestimated volume growth of their more heavily thinned stands.

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[5] Lorey's height is the height of the tree of mean volume.

Table 10—Comparisons of periodic, annual-growth percent derived from stand basal area or cubic volume

Item	Control				Light thinning				Heavy thinning			
	1	6	7	Mean		4	8	Mean	2	5	9	Mean
						Percent						
						TECHNIQUE 1 (Pretreatment)						
Basal area	0.830	0.886	1.080	0.909	0.713	0.972	0.610	0.763	0.677	0.860	0.647	0.722
Volume growth	.784	.983	1.113	.929	.715	.952	.645	.764	.870	.990	.792	.879
$\frac{(BA-V)}{V}$ 1/ X 100	5.87	-9.87	-2.96	-2.15	-.28	2.10	-5.43	-.13	-22.18	-13.13	-18.31	-17.86
						TECHNIQUE 2 (Posttreatment)						
Basal area	.865	.954	1.080	.969	.912	1.187	.719	.934	1.053	1.080	1.004	1.057
Volume growth	.819	1.060	1.113	.970	.909	1.159	.788	.946	1.312	1.115	1.119	1.163
$\frac{(BA-V)}{V}$ 1/ X 100	5.62	-10.00	-2.96	-.10	.33	2.42	8.76	-1.27	-19.74	-3.14	-10.28	-9.11

1/The percentage difference between estimates of the basal-area and cubic-volume growth percents.

Discussion

Whether growth is measured for stands or individual trees, thinned plots at Boundary Creek have responded well to thinning, exhibiting very nearly normal gross growth in the latest period (1964-71) and with growth for the total 19 years just slightly reduced. This result—better than previously reported (Williamson 1966, Yerkes 1960)—is because of the longer period of observation and the better recognition and use of differences among the plots and treatments in site index and in stocking and density levels.

Beneficial effects of thinning were illustrated here, although plots were only 1 chain wide and 10 chains long, and entirely surrounded by areas that were only sanitation-salvaged in 1952. Perimeter is 74 percent greater than that of a square plot and 96 percent greater than that of a round one. Any adverse effects of unbuffered surroundings should be proportional to perimeter length. Very likely, the beneficial effects of thinning have been underestimated somewhat at this study area.

This long-term record and long-term records at five other study areas (Williamson and Price 1971) suggest that reductions in gross growth from thinning in these older stands are usually minor.

In contrast, Reukema (1972) and Reukema and Bruce (1977) estimated 15- to 20-percent reduction in gross growth for commercial thinning in younger stands over 20-year periods. Worthington (1966) found a 25-percent reduction in gross growth for 30 years after thinning that removed about 50 percent of initial volume in a 60-year-old, site IV stand.

The apparent discrepancies in results may be partly because of differences in initial stand density, kind of cutting, growing-stock levels, and the semantic ambiguities in terms such as "heavy thinning" and "light thinning."

Lower average initial density at Boundary Creek (compared to Worthington's (1966) study area, in which heavily thinned plots were reduced to 50 percent of normal by removal of half the growing stock) was probably associated with larger crowns and greater capacity to respond. The lower average initial density, of course, called for correspondingly lighter removals.

A similar comparison is appropriate to Reukema's (1972) study area, where initial density of thinned plots averaged about 117 percent of normal volume. In addition, periodic thinnings allowed only about 10 percent of gross increment to accrue to growing stock, resulting in final densities about 60 percent of normal. These various data suggest that best results of initial thinnings in mature young-growth stands will be obtained when stand density is between about 80 and 100 percent of normal (McArdle et al. 1961) density. If stands already exceed normal density, with accompanying crown restriction, initial thinnings should be light—about 30 percent or less by basal area—to minimize windthrow and mortality from snow-or-ice load.

This study illustrates vividly the advantages of thinning stands that are this old, rather than simply sanitizing them and salvaging mortality. The control stands were sanitation-salvaged in 1952 at the start of the experiment when mortality from bark beetle and root rot were occurring. Only dead or morbid trees were removed; no additional thinning was done. Natural mortality has been much greater on control plots than on thinned plots. The most unfortunate aspect of this mortality in unthinned stands is that it has occurred primarily in clumps of ever-increasing size. This has resulted in unstocked openings that were quickly taken over by brush.

Thinning, in contrast, forestalled much mortality and resulted in fairly uniform spacing with little loss of stocking, while maintaining about normal gross growth.

Metric Equivalents

1 foot = 0.3048 m
1 chain = 20.12 m
1 square foot per acre = 0.2295 m^2/ha
1 cubic foot per acre = 0.0700 m^3/ha
1 acre = 0.4047 ha

Literature Cited

Altherr, E. Die Genauigkeit verscheidner Verfahren der Sektionierung in absoluten und relativen Schaftlangen. Allg. Forst. u. Jagdztg 131(10):226-237; 1960.

Braathe, Peder. Thinnings in even-aged stands: a summary of European literature. Fredericton, NB: Faculty of Forestry, University of New Brunswick; 1957. 92 p.

Briegleb, P.A. Progress in estimating trend of normality percentage in second-growth Douglas-fir. J. For. 40(10):785-793; 1942.

Bruce, David; DeMars, Donald J. Volume equations for second-growth Douglas-fir. Res. Note-239. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1974. 5 p.

Evert F. Components of stand volume and its increment. J. For. 62:810-813; 1964.

Grosenbaugh, L.R. New tree-measurement concepts: height accumulation, giant tree, taper and shape. Occas. Pap. 134. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; 1954. 32 p.

McArdle, Richard E.; Meyer, Walter H.; Bruce, Donald. The yield of Douglas-fir in the Pacific Northwest. Tech. Bull. 201. Washington, DC: U.S. Department of Agriculture, Forest Service, U.S. Government Printing Office; 1961. 74 p.

Reukema, Donald L. Twenty-one year development of Douglas-fir stands repeatedly thinned at varying intervals. Res. Pap. PNW-141. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1972. 23 p.

Reukema, Donald L.; Bruce, David. Effects of thinning on yield of Douglas-fir: concepts and some estimates obtained by simulation. Gen. Tech. Rep. PNW-58. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1977. 36 p.

Staebler, George R. Gross yield and mortality tables for fully stocked stands of Douglas-fir. Res. Pap. 14. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1955. 20 p.

Williamson, Richard L. Thinning response in 110-year-old Douglas-fir. Res. Note PNW-36. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1966. 7 p.

Williamson, Richard L.; Price, Frank E. Initial thinning effects in 70- to 150-year-old Douglas-fir—western Oregon and Washington. Res. Pap. PNW-117. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1971. 15 p.

Worthington, Norman P. Response to thinning 60-year-old Douglas-fir. Res. Note PNW-35. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1966. 5 p.

Yerkes, Vern P. Growth after thinning in 110-year-old Douglas-fir. Res. Note 189. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1960. 3 p.

Williamson, Richard L. Response to commercial thinning in a 110-year-old Douglas-fir stand. Res. Pap. PNW-296. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1982. 16 p.

During a 19-year period after a 110-year-old Douglas-fir stand was thinned, both standard plot compilations and stem analysis showed that growth of heavily and lightly thinned stands equaled growth of stands in control plots.

KEYWORDS: Thinning, Douglas-fir, volume increment of stands.

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Lumber Recovery From Ponderosa Pine in Western Montana

Marlin E. Plank

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Abstract

Plank, Marlin E. Lumber recovery from ponderosa pine in western Montana. Res. Pap. PNW-297. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1982. 24 p.

Lumber grade yields and recovery ratios are shown for a sample of ponderosa pine (Pinus ponderosa Dougl. ex Laws.) in western Montana. About 9 percent of the lumber produced was in Select grades, 48 percent in Shop grades, and 43 percent in Common grades. Information on log scale and yield is presented in tables by log grade and diameter class.

KEYWORDS: Lumber recovery, lumber yield, ponderosa pine, Pinus ponderosa, Montana.

Summary

Ponderosa pine (Pinus ponderosa Dougl. ex Laws.) is a desirable species for boards and millwork; some products made from ponderosa pine cost over $1,200 per thousand board feet. Yields of Moulding and Shop grades of lumber have been reduced because the production of dimension lumber items has increased because of changes in the size of trees and the demand for these items.

This report presents yield data for a sample of 262 ponderosa pine trees taken from six areas on the Lolo National Forest in western Montana. It provides current information on lumber recovery which can be used by timber and land managers and by the forest products industry.

For the 236 live trees in the sample, 1,033 logs were sawn, yielding 165,226 board feet of surfaced-dry lumber. About 9 percent of this lumber was in Select grades, 48 percent in Shop grades, and the remaining 43 percent in Common grades. Tables and figures show log scale and yield information by log grade and diameter class, based on board-foot and cubic-foot volumes.

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Introduction

Ponderosa pine (Pinus ponderosa Dougl. ex Laws.) is a major softwood species in the Western United States. A USDA Forest Service (1980) report states that the 1977 inventory volume in the northern Rocky Mountain Region alone is an estimated 35 billion board feet (International 1/4-inch rule). Of the 4.4 billion board feet harvested in the Western United States in 1979, 703 million was from the Rocky Mountain Region. Most of this volume is on lands administered by the National Forest System.

Ponderosa pine is a desirable species for boards and millwork; some products reach market prices of more than $1,200 per thousand board feet. Production of dimension lumber items instead of more traditional 1-inch boards has caused reductions in yields of Moulding and Shop grades of lumber. These changes in product mix are associated with changes in the size and quality of timber available for harvest and with the industry processing technology. The occurrence of these changes has created a demand by land managers for information necessary to make reliable predictions of timber value.

The research reported here is the result of a study conducted on lumber recovery from ponderosa pine in western Montana in July 1976. The major objective of the study was to obtain information on lumber volume and grade yields by log size for the current log grading system (Gaines 1962).

The research provides the manager of both public and private timberland with a basis for estimating lumber volume and grade recovery from logs of similar size and grade. The information can be used for making log allocations and for improving mill design and processing.

Study Procedures

Timber Sample

The Lolo National Forest was selected as the sampling area because it contained stands with trees representing the full range of ponderosa pine sawtimber found in the Northern Region (Region 1). Regional Office personnel, industry representatives, and I selected the specific sample areas and study trees.

Six areas that contained a full range of log grades and sizes of sawtimber were selected. The range of tree diameters was divided into 5-inch classes, and trees were selected to obtain about the same number of trees in each class. Trees with grade 1 or 2 logs were specifically selected whenever possible because of the scarcity of these log grades. A total of 262 trees were selected in the six areas, including 26 older dead trees that yielded 95 logs. Each tree was numbered, and the logs sawn from the tree were identified by that number.

Table 1 shows some characteristics of the sample trees.

Table 1--Characteristics of trees by sample area

Sample area	Number of trees	D.b.h.		Height		Defect		Age	
		Range	Average	Range	Average	Range	Average	Range	Average
		- - -Inches- - -		- - -Feet- - -		- -Percent- -		- - -Years- - -	
1	34	8.9-36.5	25.9	44-136	102	0-38	11	265-413	343
2	34	7.9-37.2	17.9	65-165	108	0-36	7	90-312	181
3	44	12.0-36.7	25.0	52-153	111	0-86	9	110-370	220
4	44	7.4-37.2	20.5	54-139	97	0-17	5	85-345	192
5	47	7.8-16.5	12.0	54-104	76	0-11	3	56-115	75
6	33	8.5-33.8	20.2	30-130	79	0-40	12	104-465	251
Dead trees	26	8.4-34.4	20.4	54-144	98	0-83	44	103-370	183

Falling and Log Identification

Trees were selected and cruised, then felled and bucked. The normal industry practice of bucking logs to maximize 32-foot lengths (woods-length logs) was followed. Total length and diameter of each tree and length of each bucked log were recorded. The end of each log was identified by tree number and log within the tree. The log number was used to identify lumber items by the log of origin.

Scaling

After all the logs were delivered to the millyard, they were rolled out and scaled according to Forest Service Scaling Handbook rules (USDA Forest Service 1973). In addition, measurements were taken that provided information for the application of several methods of determining cubic volume (USDA Forest Service 1978). Scribner log scale was used during the sawing phase when logs were scaled on the log deck.

Lumber Manufacturing

Each log was sawn to recover its optimum value through manufacture of the mill's usual lumber items. Production equipment included two single-cut bandsaws mounted with vertical edgers, a sash gangsaw, and bank of trim saws. Log size determined which side of the mill was used for initial breakdown.

Research methodology on product yield has been developed for application at near-production conditions in most mills. These study techniques use a numerical sequence and color codes to maintain identity of each product throughout the sawing and planing phases. A quality inspector from Western Wood Products Association supervised the grading of the surfaced-dry lumber. A series of data records--hand tallies, cassette tape, black and white film, or television tapes--were used to ensure accuracy of the recorded information. Final point of tally was surfaced-dry lumber ready for shipment.

Table 2 shows surfaced-dry lumber tally volume for the items cut in the study.

Table 2--Lumber item and surfaced-dry volume for all live logs

Size	Volume
Inches	Board feet
Shops:	
5/4	75,671
4/4	9,560
Boards:	
1x4	10,513
1x6	25,302
1x8	11,207
1x10	7,737
1x12	25,236
	165,226

Cubic Calculations

The gross cubic volume of logs was computed by Bruce's (1970) butt-log equation for butt logs and Smalian's formula for all other logs:

Smalian's formula: $0.002727\ (D_S^2 + D_L^2)\ L.$

Butt-log equation: $$\text{Volume} = 0.005454\ (0.3677\ D_S^2)$$

$$+\ 0.6688\ (D_S \times D_L)$$

$$-\ 0.000148\ (D_S \times D_L)L;$$

where: D_S is the log scaling diameter (inches) of the small end,

D_L is the log scaling diameter (inches) of the large end, and

L is the log scaling length (feet).

The cubic-foot volumes of lumber were based on measurements of surfaced-dry lumber. The cubic-foot volumes of sawdust were calculated from the average saw-kerf thickness and the rough-green surface area of the lumber from each log. Shrinkage and planer shavings were determined by subtracting the volume of surfaced-dry lumber from the volume of rough-green lumber. The residue volume was the gross log volume minus volumes of lumber, sawdust, shrinkage, and planer shavings. Thus, the residue volume includes a small amount of sawdust from the production of slabs, edgings, and trim ends.

Model Selection

Five regression models were compared for volume and value relationships. The models were different combinations of the independent variables D, 1/D, $1/D^2$. The final model was selected based on the statistics of the regression ($s_{y.x}$, the standard deviation about regression; and R^2, the coefficient of determination), each coefficient being significant ($P \leq 0.05$), and experience from fitting these models in previous studies.

Results

Lumber yields presented in tables 6 through 11 in the appendix are in board feet of surfaced-dry lumber (shipping tally volume). The cubic-foot volume of the logs, lumber, sawdust, and residues calculated for each log grade by 1-inch diameter classes is also shown.

Cubic Recovery

Cubic recovery percent (CR%) over diameter for all live logs is shown in figure 1.[1] Cubic recovery percent rises slowly in the lower diameters and tends to flatten in the upper limits. This is characteristic and is a result of cutting rectangular lumber from round logs. There was no significant relationship between cubic recovery and diameter for the dead logs. Increasing defect for increasing diameters in dead logs seems to account for the lower recovery in the upper diameters compared with live logs. This in turn balances the lower recoveries in the smaller diameters resulting in no significant relationship between percent recovery and diameter; therefore, an average recovery of 38 percent is appropriate.

Figure 2 presents the relationship between lumber recovery factor (LRF) and diameter.[2] The shape of the curve is similar to the curve for cubic recovery percent. The LRF weighted average recovery for the live logs is 7.13 and for the dead logs, 6.55.

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[1] Cubic recovery percent = surfaced-dry cubic-foot lumber volume divided by gross cubic-foot log volume times 100.

[2] LRF = board feet of lumber tally per cubic foot of gross log volume.

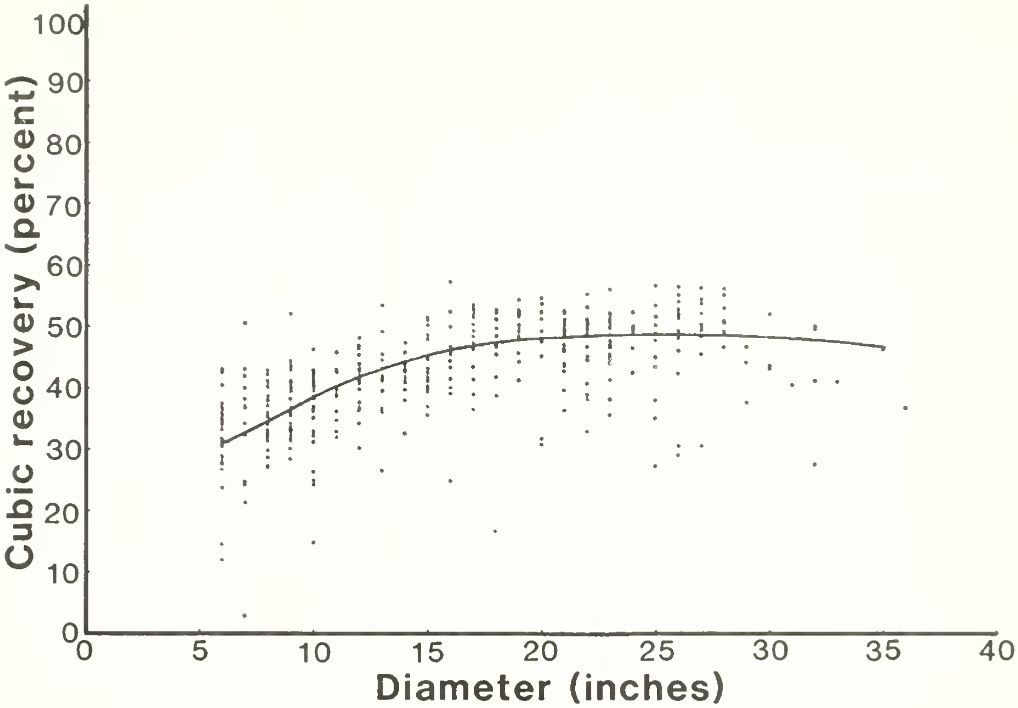

Figure 1.--Percent of cubic log volume produced as surfaced-dry lumber by log diameter, live ponderosa pine. (Cubic recovery percent = 87.4195 - 0.7119(D) - 576.9119 (1/D) + 1595.0388 $(1/D^2)$. Coefficient of determination = 0.491. Standard deviation from regression = 6.62.)

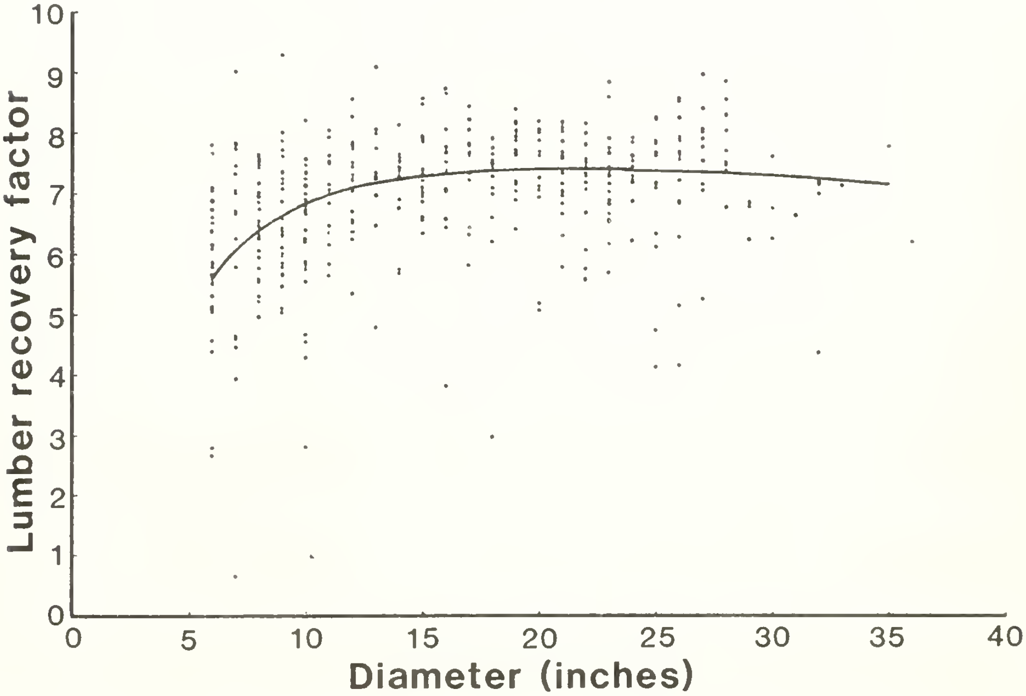

Figure 2.--Lumber recovery factor: Board feet of lumber tally per cubic foot of log by diameter, live ponderosa pine. (Lumber recovery factor = 9.4079 - 0.04658(D) - 21.1536(1/D). Coefficient of determination = 0.253. Standard deviation from regression = 1.067.)

Recovery Ratio

Recovery ratio (overrun) based on net log scale is shown in figure 3 for all live logs.[3] This ratio decreases as diameter increases.

The relationship between recovery ratio and diameter for the dead logs was not statistically significant. The weighted average recovery was 160 percent for dead logs. Only the dead logs scaled as merchantable were included in this group, and they had a weighted average defect of 39 percent.

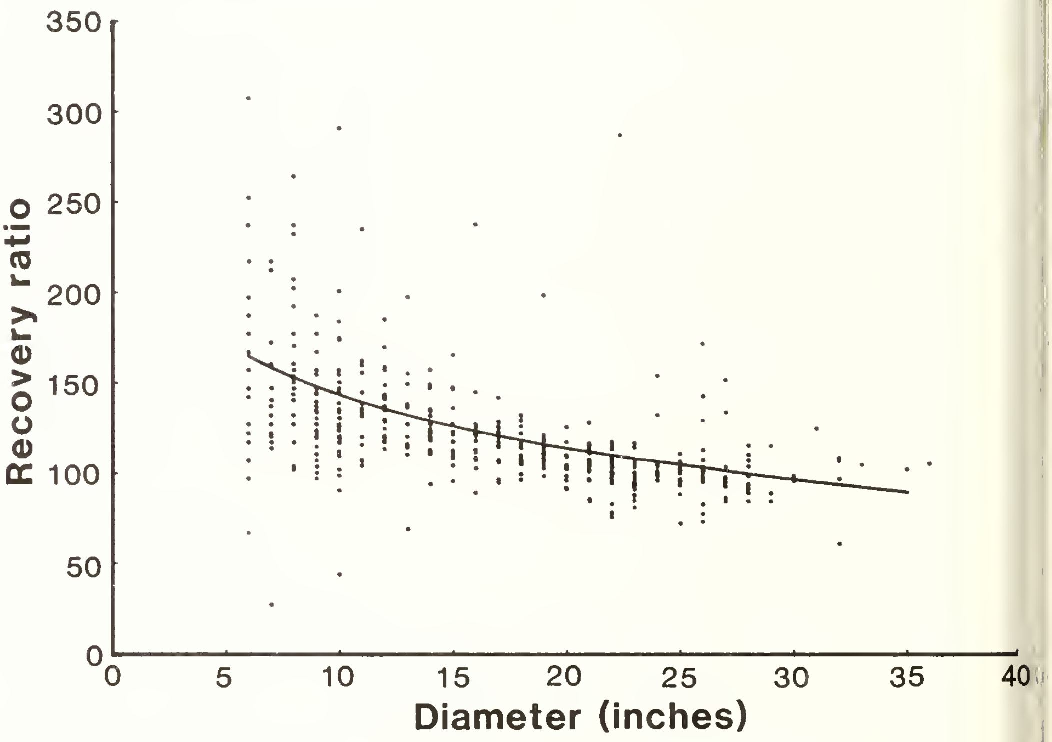

Figure 3.--Recovery ratio curve for all live ponderosa pine logs. (Recovery ratio = 106.7545 - 0.9471(D) + 568.3461(1/D) - 1116.9745($1/D^2$). Coefficient of determination = 0.2533. Standard deviation from regression = 35.35.)

Grade Yields

Tables 12-17 in the appendix show percent of recovery for each lumber grade by 1-inch diameter classes by log grade and by all log grades combined. Dead logs are shown in table 16 but are not included in table 17 for all log grades.

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[3] Recovery ratio = lumber tally volume divided by net log scale volume times 100.

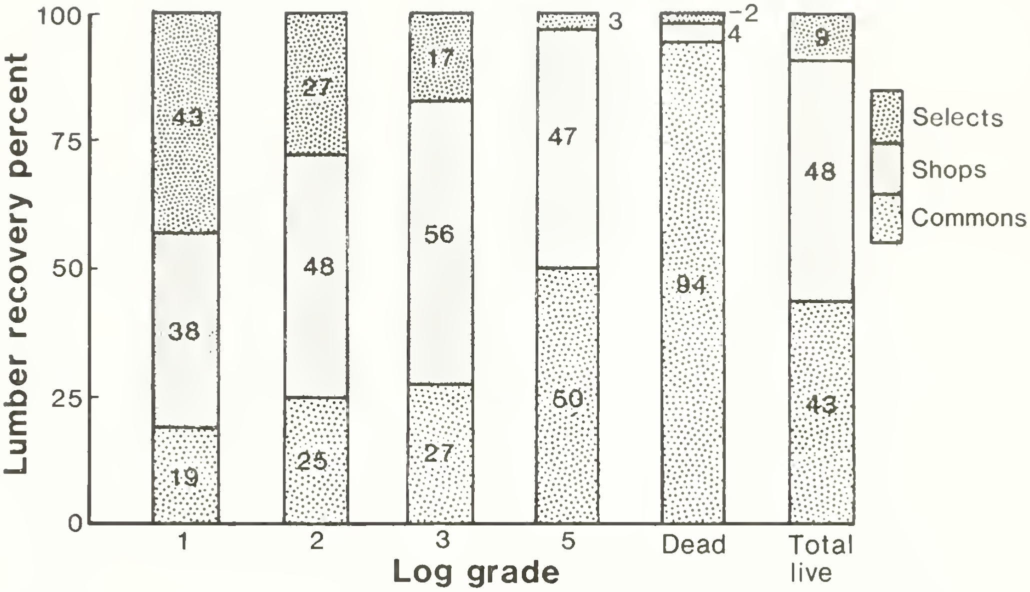

Figure 4.--Lumber grade yield as a percent of total lumber tally volume by log grade.

About 9 percent of the lumber produced from the logs in this study was in Select grades, 48 percent in Shop grades, and 43 percent in Common grades. Figure 4 presents recovery of Select, Shop, and Common lumber for the various log grades.

Value ($/MLT)

Figure 5 shows the relationship of dollars per thousand board feet of lumber tally ($/MLT) to diameter. These relationships are based on 1976 lumber prices (table 3), furnished by Region 1 of the USDA Forest Service. There was no statistically significant relationship between diameter and $/MLT for grades 1, 2, and 3; however, there is a significant difference between the arithmetic means of those grades. Grade 5 logs show an increase in unit value with increasing diameter, whereas the reverse is true for the dead logs.

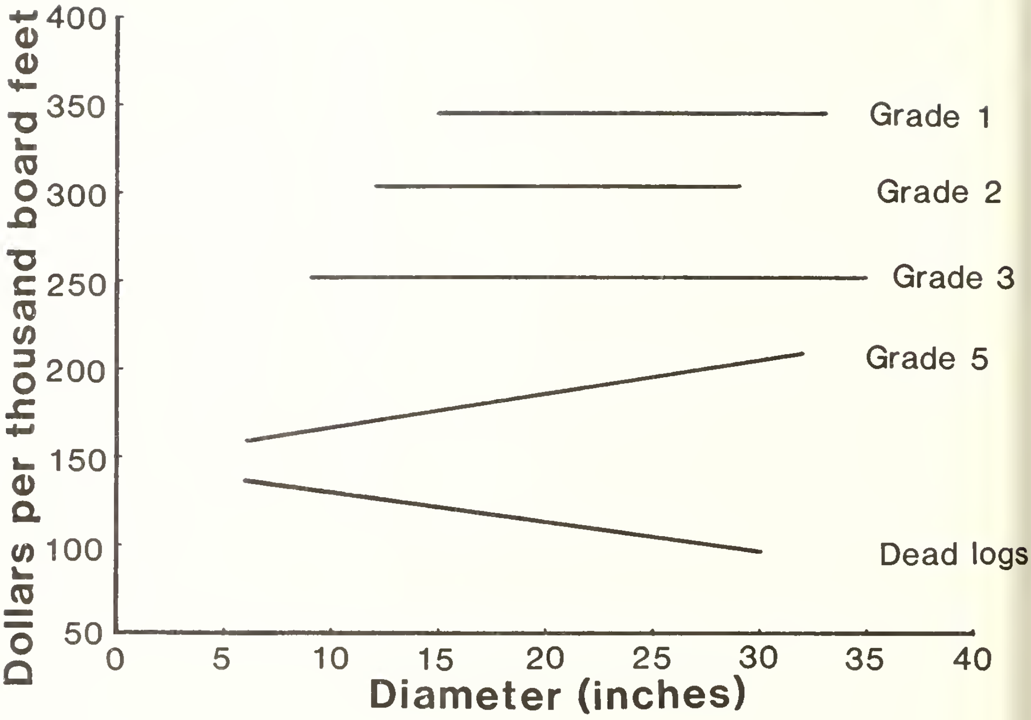

Figure 5.--Relationship of dollars per thousand board feet of lumber tally to diameter for each log grade, ponderosa pine.

Statistical information:

y (grade 1) = 345.90.
Standard error of the mean = 16.17.
y (grade 2) = 302.35.
Standard error of the mean = 9.32.
y (grade 3) = 251.91.
Standard error of the mean = 6.78.
y (grade 5) = 147.508 + 9038 (D).
Coefficient of determination = 0.070.
Standard deviation from regression = 40.48.
y (dead) = 146.8879 - 1.6896(D).
Coefficient of determination = 0.094.
Standard deviation from regression = 31.96.

Table 3--1975 lumber grade prices

	Thickness (inches)	
Lumber grade	4/4	5/4
	- - - -Dollars- - -	
B & Better Select	609.58	584.97
C Select	609.58	584.97
D Select	424.07	411.24
Moulding	224.68	431.40
3 Clear	236.47	237.70
1 Shop	148.56	260.83
2 Shop	148.56	195.08
3 Shop	--	146.25
Shop Out	--	146.25
2 & Better Common	235.83	--
3 Common	119.63	--
4 Common	79.50	--
5 Common	40.53	--
Pitch Select	411.24	411.24

Value ($/CCF)

Figure 6 shows the relationship of dollars per hundred cubic feet of gross log volume ($/CCF) to diameter for each log grade. There was no statistically significant relationship between diameter and $/CCF for grades 2 and 3, nor for the dead logs; however, there is a significant difference between the means of those grades.

Application

Many of the relationships in this report can be used in various ways. Data presented can also be used to develop other relationships; for example, board feet of lumber divided by cubic feet of lumber can be a useful tool in rating a mill's efficiency (Fahey and Woodfin 1976). Table 4 illustrates the relationship for three different widths of 1-inch boards.

This relationship also varies by size of rough-green lumber; a mill cutting to closer tolerances will attain the higher ratios, as shown in table 5.

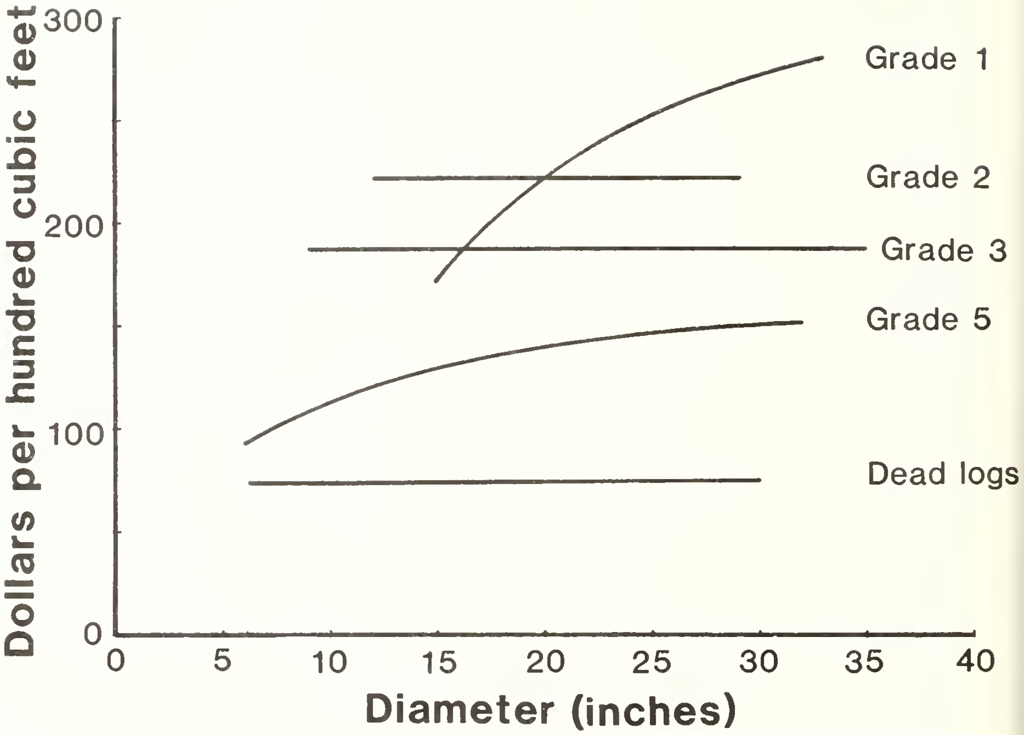

Figure 6.--Relationship of dollars per hundred cubic feet of log volume to diameter for each log grade, ponderosa pine.

Statistical information:

y (grade 1) = 370.606 - 2987.01(1/D).
Coefficient of determination = 0.247.
Standard deviation from regression = 57.77.
y (grade 2) = 223.14.
Standard error of the mean = 8.88.
y (grade 3) = 186.58.
Standard error of the mean = 5.56.
y (grade 5) = 147.825 - 808.1106(1/D) + 1893.1839($1/D^2$).
Coefficient of determination = 0.204.
Standard deviation from regression = 34.24.
y (dead) = 79.19.
Standard error of the mean = 2.83.

The board-foot-per-cubic-foot (BF/CF) ratio calculated from table 11 for the live logs on a basis of surfaced-dry lumber was 15.67. By adding the cubic volume of shrinkage and planer shavings to the surfaced-dry cubic volume of lumber, the ratio can be computed on the basis of rough-green lumber--in this case, 11.08. This ratio and the data obtained from similar publications and reports will allow comparisons of mill efficiency. Multiplying BF/CF ratio of 15.67 by the cubic recovery percent (46) will equal the recovery factor for surfaced-dry lumber.

Table 4--Board-foot:cubic-foot ratios for various sizes of surfaced-dry lumber

Item, nominal size	Surfaced-dry size	Board feet per linear foot		Cubic feet per linear foot		Board feet per cubic foot
1 x 4	0.75 x 3.5	0.333	÷	0.018	=	18.5
1 x 6	.75 x 5.5	.50	÷	.029	=	17.2
1 x 12	.75 x 11.25	1.0	÷	.059	=	16.9
5/4 x 12	1.16 x 12.0	1.25	÷	.097	=	12.9

Table 5--Board foot:cubic foot ratios for various sizes of rough-green lumber

Item, nominal size	Rough-green size	Board feet per linear foot		Cubic feet per linear foot		Board feet per cubic foot
1 x 4	0.969 x 4.125	0.333	÷	0.028	=	11.9
Closer tolerance	.906 x 3.875	.333	÷	.024	=	13.9
1 x 6	.969 x 6.125	.50	÷	.041	=	12.2
Closer tolerance	.906 x 5.875	.50	÷	.037	=	13.5
1 x 12	.969 x 12.0	1.0	÷	.081	=	12.3
Closer tolerance	.906 x 11.75	1.0	÷	.074	=	13.5
5/4 x 12	1.5 x 12.25	1.25	÷	.128	=	9.8
Closer tolerance	1.375 x 12.0	1.25	÷	.115	=	10.9

To adapt information published about a mill to a mill that is similarly cutting logs:

1. Carefully measure a sample of the various lumber items to determine a BF/CF ratio. For instance, use a ratio of 9.91 and a green cubic recovery percent of 65.

2. LRF = (BF/CF)(CR%).
   LRF = (9.91)(0.65).
   LRF = 6.44.

Point 2 illustrates that an improvement in the LRF could be obtained by cutting to closer tolerances. If a mill cuts items in a different relationship than those in published reports, compute the BF/CF ratios for individual items, calculate an average BF/CF weighted by dimension, and then proceed with the LRF calculation.

Metric Equivalents

1 inch = 2.540 centimeters
1 foot = 0.305 meter
1 cubic foot = 0.028 cubic meter

Literature Cited

Bruce, David. Estimating volume of Douglas-fir butt logs. Res. Note PNW-117. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1970. 5 p.

Fahey, Thomas D.; Woodfin, Richard O. The cubics are coming: predicting product recovery from cubic volume. J. For. 74(11): 739-743; 1976.

Gaines, Edward M. Improved system for grading ponderosa pine and sugar pine saw logs in trees. Res. Pap. PSW-75. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1962. 22 p.

U.S. Department of Agriculture, Forest Service. National Forest log scaling handbook. FSH 2409.11. Amend. 4. Washington, DC: U.S. Department of Agriculture, Forest Service; Sept. 1973.

U.S. Department of Agriculture, Forest Service. Cubic scaling handbook. (A review draft.) Washington, DC: U.S. Department of Agriculture, Forest Service; Aug. 1978.

U.S. Department of Agriculture, Forest Service. An analysis of the timber situation in the United States 1952-2030. (A review draft.) Washington, DC: U.S. Department of Agriculture, Forest Service; 1980.

Table 6--Log scale, lumber tally, and cubic volumes by scaling diameter, log grade 1, mill-length, ponderosa pine logs

		Scribner log scale		Lumber tally		Volume3/					
Log scaling diameter1/	Number of logs	Gross	Net	Volume	Recovery ratio2/	Log	Surfaced-dry lumber	Lumber recovery ratio4/	Sawdust	Shrinkage and planer shavings	Residue
Inches		- - - -Board feet- - - -			Percent	- - -Cubic feet- - -		Percent	- - - - - -Cubic feet- - - - - -		
15	1	140	110	165	150	20.73	10.14	49	2.64	4.37	3.58
16	1	160	100	92	92	23.53	6.05	26	1.44	2.63	13.41
17	--	--	--	--	--	--	--	--	--	--	--
18	--	--	--	--	--	--	--	--	--	--	--
19	1	240	210	231	110	32.98	14.92	45	3.59	6.24	8.23
20	--	--	--	--	--	--	--	--	--	--	--
21	1	300	280	330	118	41.34	19.45	47	5.45	7.93	8.51
22	--	--	--	--	--	--	--	--	--	--	--
23	1	380	280	286	102	49.34	18.04	37	4.54	7.46	19.30
24	1	400	400	435	109	54.63	27.47	50	6.93	11.36	8.87
25	2	920	830	861	104	114.70	51.99	45	13.99	20.85	27.87
26	3	1,370	1,280	1,278	100	170.06	77.94	46	20.94	32.25	38.93
27	1	550	230	354	154	65.95	20.81	32	5.98	8.75	30.41
28	2	1,160	1,110	1,245	112	143.32	77.68	54	19.82	31.24	14.58
29	1	610	410	482	118	75.96	29.41	39	7.83	11.90	26.82
30	--	--	--	--	--	--	--	--	--	--	--
31	--	--	--	--	--	--	--	--	--	--	--
32	1	740	590	655	111	92.31	39.09	42	10.64	15.50	27.08
33	1	780	660	716	108	98.11	41.72	43	12.09	17.34	26.96
Total or average	17	7,750	6,490	7,130	110	982.96	434.71	44	115.88	177.82	254.55

1/In accordance with National Forest Log Scaling Handbook rules.
2/Equals lumber tally volume divided by net log scale times 100.
3/Lumber volume based on surfaced-dry dimensions. Chippable volume based on rough-green dimensions. Residue equals gross log volume minus lumber, sawdust, and shrinkage and planer shavings volume.
4/Equals cubic lumber volume divided by cubic log volume times 100.

Table 7--Log scale, lumber tally, and cubic volumes by scaling diameter, log grade 2, mill-length, ponderosa pine logs

		Scribner log scale		Lumber tally		Volume[3]					
Log scaling diameter[1]	Number of logs	Gross	Net	Volume	Recovery ratio[2]	Log	Surfaced-dry lumber	Lumber recovery ratio[4]	Sawdust	Shrinkage and planer shavings	Residue
Inches		- - - -Board feet- - -			Percent	- - -Cubic feet- - -		Percent	- - - - - -Cubic feet- - - - - -		
12	1	80	60	73	122	13.40	4.16	31	1.30	1.85	6.09
--	--	--	--	--	--	--	--	--	--	--	--
14	2	220	220	273	124	36.74	16.08	44	4.62	7.00	9.04
15	2	280	270	305	113	41.72	18.10	43	5.25	7.93	10.44
16	--	--	--	--	--	--	--	--	--	--	--
17	2	360	360	422	117	53.25	25.76	48	6.81	10.52	10.16
18	2	420	380	453	119	59.54	29.92	50	7.00	12.44	10.18
19	2	480	480	525	109	69.04	33.49	49	8.29	14.01	13.25
20	1	280	180	189	105	36.48	11.60	32	3.06	4.84	16.98
21	4	1,200	1,140	1,249	110	162.22	80.31	50	19.40	32.73	29.78
22	5	1,650	1,550	1,639	106	222.51	107.09	48	25.10	43.24	47.08
23	5	1,900	1,860	1,858	100	245.13	116.69	48	29.56	47.62	51.26
24	1	400	400	396	99	52.40	26.52	51	5.96	10.91	9.01
25	4	1,670	1,290	1,216	94	207.19	76.10	37	19.50	31.42	80.17
26	5	2,500	1,970	2,249	114	308.63	147.82	48	34.35	59.82	66.64
27	2	1,100	1,090	1,115	102	134.94	68.22	51	17.97	27.65	21.10
28	3	1,740	1,690	1,591	94	211.06	106.70	51	23.80	42.92	37.64
29	1	610	590	540	92	77.60	35.11	45	8.29	14.24	19.96
30	--	--	--	--	--	--	--	--	--	--	--
31	--	--	--	--	--	--	--	--	--	--	--
32	--	--	--	--	--	--	--	--	--	--	--
33	--	--	--	--	--	--	--	--	--	--	--
34	--	--	--	--	--	--	--	--	--	--	--
35	--	--	--	--	--	--	--	--	--	--	--
36	1	920	680	735	108	116.57	44.17	38	11.93	17.49	42.98
Total or average	43	15,810	14,210	14,828	104	2,048.42	947.84	46	232.19	386.63	481.76

[1] In accordance with National Forest Log Scaling Handbook rules.

[2] Equals lumber tally volume divided by net log scale times 100.

[3] Lumber volume based on surfaced-dry dimensions. Chippable volume based on rough-green dimensions. Residue equals gross log volume minus lumber, sawdust, and shrinkage and planer shavings volume.

[4] Equals cubic lumber volume divided by cubic log volume times 100.

Log scaling diameter1/	Number of logs	Scribner log scale Gross	Scribner log scale Net	Lumber tally Volume	Lumber tally Recovery ratio2/	Volume3/ Log	Volume3/ Surfaced-dry lumber	Volume3/ Lumber recovery ratio4/	Volume3/ Sawdust	Volume3/ Shrinkage and planer shavings	Volume3/ Residue
Inches		- - - -Board feet- - - -			Percent	- - -Cubic feet- - -		Percent	- - - - - - -Cubic feet- - - - - -		
9	2	70	60	73	122	13.00	4.04	31	1.33	1.92	5.71
10	2	100	100	128	128	17.84	7.21	40	2.29	3.25	5.09
11	2	140	130	179	138	23.86	10.17	43	3.23	4.60	5.86
12	2	160	150	229	153	28.24	12.96	46	4.07	5.96	5.42
13	1	100	100	117	117	15.93	7.24	45	1.94	3.22	3.53
14	3	320	320	356	111	53.07	20.82	39	6.18	9.21	16.86
15	2	280	230	324	141	43.16	19.09	44	5.50	8.29	10.28
16	4	640	610	781	128	93.22	47.82	51	12.85	20.40	12.15
17	1	180	160	205	128	26.50	11.76	44	3.44	4.81	6.49
18	2	420	240	313	130	60.31	19.54	32	5.02	8.21	27.54
19	6	1,440	1,440	1,600	111	204.35	107.59	53	23.80	44.21	28.84
20	4	1,120	1,030	1,050	102	151.23	69.62	46	15.94	28.40	37.27
21	8	2,400	2,280	2,460	108	333.86	161.92	48	37.20	65.25	69.49
22	6	1,900	1,880	1,871	100	256.56	124.03	48	28.36	50.86	53.31
23	8	3,040	2,910	2,837	101	395.17	191.93	49	45.03	77.33	80.88
24	5	2,000	1,720	2,025	118	267.86	131.88	49	31.35	54.22	50.41
25	7	3,160	2,960	2,976	101	393.89	195.68	50	45.50	80.21	72.50
26	5	2,500	2,210	2,332	106	311.55	160.32	51	34.16	65.15	51.92
27	5	2,750	2,640	2,686	102	335.48	180.49	54	40.09	73.00	41.90
28	2	1,160	1,140	1,175	103	144.35	72.55	50	18.73	28.98	24.09
29	1	610	600	523	87	75.96	36.30	48	7.52	14.44	17.70
30	2	1,320	1,090	1,096	100	165.84	73.93	45	16.20	30.01	45.70
31	1	710	460	585	127	86.61	36.04	42	9.41	14.78	26.38
32	2	1,480	1,300	1,356	104	186.31	95.16	51	19.39	38.41	33.35
33	--	--	--	--	--	--	--	--	--	--	--
34	--	--	--	--	--	--	--	--	--	--	--
35	1	880	830	869	105	110.00	52.25	48	13.98	20.50	23.27
Total or average	84	28,880	26,590	28,246	106	3,794.15	1,850.34	49	432.51	755.62	755.94

1/In accordance with National Forest Log Scaling Handbook rules.

2/Equals lumber tally volume divided by net log scale times 100.

3/Lumber volume based on surfaced-dry dimensions. Chippable volume based on rough-green dimensions. Residue equals gross log volume minus lumber, sawdust, and shrinkage and planer shavings volume.

4/Equals cubic lumber volume divided by cubic log volume times 100.

Table 9--Log scale, lumber tally, and cubic volumes by scaling diameter, log grade 5, mill-length, ponderosa pine logs

		Scribner log scale		Lumber tally		Volume 3/					
Log scaling diameter1/	Number of logs	Gross	Net	Volume	Recovery ratio2/	Log	Surfaced-dry lumber	Lumber recovery ratio4/	Sawdust	Shrinkage and planer shavings	Residue
Inches		- - - -Board feet- - - -			Percent	- - -Cubic feet- - -		Percent	- - - - - - -Cubic feet- - - - - -		
6	123	1,480	1,450	2,389	165	425.17	130.82	31	45.81	67.92	180.62
7	80	1,720	1,640	2,300	140	383.47	126.01	33	43.76	64.78	148.92
8	68	1,780	1,690	2,687	159	420.33	150.10	36	49.98	72.62	147.63
9	66	2,310	2,250	3,233	144	478.28	183.43	38	58.65	83.86	152.34
10	64	3,250	3,140	4,202	134	628.75	239.17	38	75.56	107.82	206.20
11	55	3,370	3,250	4,558	140	660.99	261.98	40	80.76	116.50	201.75
12	53	3,740	3,640	4,814	132	700.86	276.73	39	84.44	122.29	217.40
13	28	2,470	2,460	3,332	135	446.74	195.38	44	56.84	85.20	109.32
14	44	4,350	4,170	5,510	132	764.71	324.68	42	93.18	139.03	207.82
15	38	4,470	4,600	5,691	124	767.50	349.13	46	92.75	148.06	177.39
16	39	5,960	5,760	7,145	124	950.42	446.26	47	113.84	185.72	204.60
17	37	6,220	6,030	7,322	121	971.62	476.86	49	112.50	195.72	186.54
18	29	5,650	5,430	6,522	120	877.09	426.02	49	99.67	172.29	179.11
19	28	6,090	5,880	6,880	117	889.21	451.01	51	104.24	179.66	154.30
20	23	6,180	5,870	6,416	109	851.63	424.87	50	96.23	169.05	161.48
21	24	6,560	6,470	6,611	102	925.26	443.57	48	98.28	176.99	206.42
22	22	6,960	6,560	7,537	115	987.82	505.77	51	111.90	200.49	169.66
23	16	5,430	5,370	5,416	101	723.16	368.32	51	79.73	147.87	127.24
24	14	5,200	5,080	5,204	102	698.75	354.57	51	76.07	141.53	126.58
25	15	6,430	6,030	6,046	100	822.54	412.29	50	89.09	166.57	154.59
26	8	3,750	3,680	3,460	94	470.72	238.33	51	50.53	96.01	85.85
27	6	3,300	3,180	3,079	97	399.91	204.18	51	46.22	81.90	67.61
28	5	2,900	2,860	2,861	100	356.12	198.13	56	41.28	79.12	37.59
29	2	1,220	1,030	719	70	160.01	49.43	31	10.42	19.69	80.47
30	1	660	660	649	98	83.95	44.67	53	9.37	17.87	12.04
31	--	--	--	--	--	--	--	--	--	--	--
32	1	740	690	439	64	98.13	28.11	29	6.81	11.30	51.91
Total or average	889	102,490	98,870	115,022	116	15,943.14	7,309.99	46	1,827.91	3,049.86	3,755.38

1/In accordance with National Forest Log Scaling Handbook rules.
2/Equals lumber tally volume divided by net log scale times 100.
3/Lumber volume based on surfaced-dry dimensions. Chippable volume based on rough-green dimensions. Residue equals gross log volume minus lumber, sawdust, and shrinkage and planer shavings volume.
4/Equals cubic lumber volume divided by cubic log volume times 100.

Table 10--Log scale, lumber tally, and cubic volumes by scaling diameter, mill-length, dead ponderosa pine logs

		Scribner log scale		Lumber tally		Volume[3]					
Log scaling diameter[1]	Number of logs	Gross	Net	Volume	Recovery ratio[2]	Log	Surfaced-dry lumber	Lumber recovery ratio[4]	Sawdust	Shrinkage and planer shavings	Residue
Inches		- - - -Board feet- - -			Percent	- - -Cubic feet- - -		Percent	- - - - - -Cubic feet- - - - - -		
6	5	50	50	77	154	12.73	4.19	33	1.46	2.19	4.89
7	4	70	70	121	173	15.97	6.74	42	2.27	3.33	3.63
8	7	170	140	257	184	43.27	14.04	32	4.87	7.21	17.15
9	8	290	180	354	197	61.44	19.70	32	6.55	9.53	25.66
10	2	90	80	134	167	1.44	7.64	41	2.39	3.40	5.01
11	7	430	290	598	206	86.44	33.88	39	10.69	15.26	26.61
12	7	460	310	558	180	87.99	31.61	36	10.01	14.28	32.09
13	7	560	390	619	159	97.01	35.19	36	10.93	15.54	35.35
14	7	680	420	780	186	110.07	45.35	41	13.45	19.70	31.57
15	8	1,020	540	1,023	189	159.21	58.37	37	17.78	25.15	57.91
16	4	520	310	543	175	77.01	31.32	41	9.22	13.03	23.44
17	8	1,380	940	1,470	156	219.76	85.39	39	24.78	35.51	74.08
18	3	530	270	351	130	77.04	20.03	26	6.19	8.77	42.05
19	--	--	--	--	--	--	--	--	--	--	--
20	3	800	400	669	167	110.99	38.60	35	11.41	16.28	44.70
21	4	1,200	750	1,139	152	172.61	66.75	39	18.93	27.20	59.73
22	1	330	110	209	190	46.25	11.85	26	3.67	5.26	25.47
23	--	--	--	--	--	--	--	--	--	--	--
24	4	1,550	770	1,343	174	212.69	78.03	37	22.58	31.82	80.26
25	--	--	--	--	--	--	--	--	--	--	--
26	2	1,000	460	718	156	123.97	41.50	33	12.07	16.74	53.66
27	2	820	630	820	130	100.20	47.77	48	13.64	18.79	20.00
28	--	--	--	--	--	--	--	--	--	--	--
29	1	610	490	566	116	75.97	32.85	43	9.46	13.11	20.55
30	1	660	530	679	128	81.23	39.41	49	11.36	15.69	14.77
Total or average	95	13,220	8,130	13,028	160	1,990.29	750.21	38	223.71	317.79	698.58

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[1] In accordance with National Forest Log Scaling Handbook rules.

[2] Equals lumber tally volume divided by net log scale times 100.

[3] Lumber volume based on surfaced-dry dimensions. Chippable volume based on rough-green dimensions. Residue equals gross log volume minus lumber, sawdust, and shrinkage and planer shavings volume.

[4] Equals cubic lumber volume divided by cubic log volume times 100.

Table 11--Log scale, lumber tally, and cubic volumes by scaling diameter, all log grades combined for live, mill-length, ponderosa pine logs

Log scaling diameter[1]	Number of logs	Scribner log scale		Lumber tally		Volume[3]					
		Gross	Net	Volume	Recovery ratio[2]	Log	Surfaced-dry lumber	Lumber recovery ratio[4]	Sawdust	Shrinkage and planer shavings	Residue
Inches		- - - -Board feet- - -			Percent	- - -Cubic feet- - -		Percent	- - - - - -Cubic feet- - - - -		
6	123	1,480	1,450	2,389	165	425.17	130.82	31	46.78	67.92	179.65
7	80	1,720	1,640	2,300	140	383.47	126.01	33	43.76	64.78	148.92
8	68	1,780	1,690	2,687	159	420.33	150.10	36	49.98	72.62	147.63
9	68	2,380	2,310	3,306	143	491.28	187.47	38	59.98	85.78	158.05
10	66	3,350	3,240	4,330	134	646.59	246.38	38	77.85	111.07	211.29
11	57	3,510	3,380	4,737	140	684.85	272.15	40	83.99	121.10	207.61
12	56	3,980	3,850	5,116	133	742.50	293.85	40	89.81	129.93	228.91
13	29	2,570	2,560	3,449	135	462.67	202.62	44	58.78	88.42	118.85
14	49	4,890	4,710	6,139	130	854.52	361.58	42	103.98	155.24	233.72
15	43	5,470	5,210	6,485	124	873.11	396.63	45	106.14	168.65	201.69
16	44	6,760	6,470	8,018	124	1,067.17	500.13	47	128.13	208.75	230.16
17	40	6,760	6,550	7,949	121	1,051.37	514.38	49	122.75	211.05	203.19
18	33	6,490	6,050	7,288	120	996.94	475.48	48	111.69	192.94	216.83
19	37	8,250	8,010	9,236	115	1,195.58	607.01	51	139.92	244.03	204.62
20	28	7,580	7,080	7,655	108	1,039.34	506.09	49	115.23	202.29	215.73
21	37	10,460	10,170	10,650	105	1,462.68	705.25	48	160.33	282.90	314.20
22	33	10,510	9,990	11,047	111	1,466.89	736.89	50	165.36	294.59	270.05
23	30	10,750	10,420	10,497	101	1,412.80	694.98	49	158.86	280.28	278.68
24	21	8,000	7,600	8,060	106	1,073.64	540.44	50	120.31	218.02	194.87
25	28	12,180	11,110	11,099	100	1,538.32	736.06	48	168.08	299.05	335.13
26	21	10,120	9,140	9,319	102	1,260.96	624.41	50	139.98	253.23	243.34
27	14	7,700	7,070	7,234	102	936.28	473.70	51	110.26	191.30	161.02
28	12	6,960	6,800	6,872	101	854.85	455.06	53	103.63	182.26	113.90
29	5	3,050	2,630	2,264	86	389.53	150.25	39	34.06	60.27	144.95
30	3	1,980	1,750	1,745	100	249.79	118.60	47	25.57	47.88	57.74
31	1	710	460	585	127	86.61	36.04	42	9.41	14.78	26.38
32	4	2,960	2,580	2,450	95	376.75	162.36	43	36.84	65.21	112.34
33	1	780	660	716	108	98.11	41.72	43	12.09	17.34	26.96
34	--	--	--	--	--	--	--	--	--	--	--
35	1	880	830	869	105	110.00	52.25	47	13.98	20.50	23.27
36	1	920	680	735	108	116.57	44.17	38	11.93	17.49	42.98
Total or average	1,033	154,930	146,160	165,226	113	22,768.67	10,542.88	46	2,608.49	4,369.67	5,247.63

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[1] In accordance with National Forest Log Scaling Handbook rules.
[2] Equals lumber tally volume divided by net log scale times 100.
[3] Lumber volume based on surfaced-dry dimensions. Chippable volume based on rough-green dimensions. Residue equals gross log volume minus lumber, sawdust, and shrinkage and planer shavings volume.
[4] Equals cubic lumber volume divided by cubic log volume times 100.

Table 12--Lumber grade recovery as a percentage of surfaced-dry lumber tally volume, log grade 1, mill-length, ponderosa pine logs

Log scaling diameter	Number of logs	Total lumber tally	B & Better Select	C Select	D Select	Mould-ing	3 Clear	1 Shop	2 Shop	3 Shop	Shop Out	2 & Better Common	3 Common	4 Common	5 Common	Pitch Select
Inches		Board feet	- - - - - - - Percent of total lumber tally - - - - - - -													
15	1	165	2.42	--	10.91	7.88	--	4.85	--	9.09	10.30	--	27.27	4.24	--	23.03
16	1	92	--	--	17.39	32.61	--	3.26	--	6.52	18.48	6.52	11.96	3.26	--	--
17	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
18	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
19	1	231	4.33	--	10.39	50.65	--	--	7.36	12.99	--	--	2.60	6.06	5.63	--
20	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
21	1	330	12.73	7.27	1.82	28.18	--	2.42	8.79	--	--	8.18	16.06	--	--	14.55
22	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
23	1	286	16.43	24.13	12.59	25.17	--	--	--	--	6.99	--	4.90	6.99	2.80	--
24	1	435	10.57	13.79	13.79	17.01	--	12.87	13.79	4.37	--	7.36	5.52	.92	--	--
25	2	861	5.34	6.04	11.27	18.70	--	--	--	6.74	--	12.54	12.31	14.75	2.09	10.22
26	3	1,278	15.18	23.87	14.95	25.74	--	--	5.40	3.21	--	1.17	5.56	3.52	.31	1.10
27	1	354	19.77	25.42	5.65	36.72	--	6.50	--	--	--	--	1.13	3.95	.85	--
28	2	1,245	4.50	11.81	8.43	25.62	--	5.46	4.90	5.62	1.20	1.69	13.49	3.13	--	14.14
29	1	482	5.39	13.28	19.92	27.18	--	15.15	4.77	6.22	--	2.28	.83	1.87	3.11	--
30	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
31	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
32	1	655	8.70	16.18	11.15	25.95	--	--	5.95	--	--	--	6.11	10.99	7.63	7.33
33	1	716	22.35	18.44	16.06	17.46	--	7.68	6.01	--	--	--	4.19	7.82	--	--
Total or average	17	7,130	10.63	14.71	12.02	24.74	--	4.12	4.78	3.77	.97	3.17	8.19	5.74	1.37	5.78

Table 13--Lumber grade recovery as a percentage of **surfaced-dry** lumber tally volume, log grade 2, mill-length, ponderosa pine logs

Log scaling diameter	Number of logs	Total lumber tally	B & Better Select	C Select	D Select	Mould-ing	3 Clear	1 Shop	2 Shop	3 Shop	Shop Out	2 & Better Common	3 Common	4 Common	5 Common	Pitch Select
Inches		Board feet	- - - - - - - - - - - - - - - - - - - -					Percent of total lumber tally			- - - - - - - - - - - - - - - - - - - -					
12	1	73	--	4.11	30.14	21.92	--	--	--	--	--	34.25	--	9.59	--	--
13	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
14	2	273	4.03	10.99	6.59	20.88	--	--	4.76	--	--	29.67	6.96	--	--	16.12
15	2	305	1.97	20.33	20.33	6.56	--	5.90	--	3.28	--	15.74	20.00	5.90	--	--
16	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
17	2	422	4.27	4.27	24.41	12.32	--	9.48	4.03	--	--	16.82	23.46	--	0.95	--
18	2	453	5.08	9.49	8.17	38.19	--	7.28	13.25	5.08	--	2.87	7.06	2.65	.88	--
19	2	525	14.67	7.81	12.76	12.57	--	3.24	10.29	12.76	--	13.52	10.48	--	--	1.90
20	1	189	--	16.40	9.52	46.03	--	--	--	9.52	--	--	3.17	12.17	3.17	--
21	4	1,249	3.36	9.13	12.57	18.98	--	6.33	17.93	7.69	--	5.20	7.93	8.97	--	1.92
22	5	1,639	4.76	9.40	10.13	24.95	--	6.22	12.51	8.05	1.16	4.58	10.68	6.47	.49	.61
23	5	1,858	6.78	10.71	19.00	29.66	--	1.83	5.54	2.26	--	5.87	13.46	1.67	.43	2.80
24	1	396	--	3.79	5.30	5.81	--	--	2.02	53.03	--	2.02	1.77	15.15	--	11.11
25	4	1,216	1.56	11.27	13.57	16.12	--	3.95	10.94	9.54	--	3.78	4.28	8.14	12.25	4.61
26	5	2,249	6.85	11.16	8.85	25.30	--	4.80	12.89	7.56	.93	3.73	5.60	8.49	2.13	1.69
27	2	1,115	--	5.11	17.94	39.10	--	3.32	7.62	3.59	--	1.52	12.02	6.55	.99	2.24
28	3	1,591	--	2.33	6.91	23.38	1.26	5.53	22.12	12.88	2.51	.88	6.54	9.93	2.26	3.46
29	1	540	15.56	21.48	4.26	8.89	--	9.63	22.59	3.15	--	--	2.22	6.11	6.11	--
30	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
31	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
32	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
33	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
34	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
35	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
36	1	735	--	--	1.36	4.63	--	3.54	10.20	4.22	9.93	--	22.86	36.87	6.39	--
Total or average	43	14,828	4.30	8.82	11.67	22.57	.13	4.60	11.74	7.94	1.03	4.90	9.43	8.05	2.39	2.41

Table 14--Lumber grade recovery as a percentage of surfaced-dry lumber tally volume, log grade 3, mill-length, ponderosa pine logs

Log scaling diameter	Number of logs	Total lumber tally	B & Better Select	C Select	D Select	Mould-ing	3 Clear	1 Shop	2 Shop	3 Shop	Shop Out	2 & Better Common	3 Common	4 Common	5 Common	Pitch Select
Inches		Board feet	Percent of total lumber tally													
9	2	73	--	4.11	17.81	9.59	--	--	--	--	--	12.33	38.36	15.07	2.74	--
10	2	128	--	--	7.03	15.63	--	--	--	--	--	44.53	32.81	--	--	--
11	2	179	4.47	3.35	18.44	4.47	--	--	--	--	--	10.61	45.25	13.41	--	--
12	2	229	--	6.99	24.89	16.59	--	--	--	--	--	14.85	36.68	--	--	--
13	1	117	--	--	--	8.55	--	--	8.55	23.08	--	24.79	35.04	--	--	--
14	3	356	--	11.52	25.84	7.02	--	4.21	3.09	8.99	--	8.99	16.85	11.52	1.97	--
15	2	324	--	7.10	8.02	18.52	--	1.23	8.33	--	3.09	1.23	42.28	.93	7.10	2.16
16	4	781	--	12.55	13.70	22.15	--	.64	11.40	8.58	--	13.57	13.83	2.94	.64	--
17	1	205	--	--	3.41	3.90	--	--	--	--	--	--	4.88	80.98	2.93	3.90
18	2	313	--	2.24	4.15	28.75	--	4.79	19.17	4.15	2.56	--	27.80	3.51	2.88	--
19	6	1,600	--	5.94	4.37	14.06	--	9.50	29.87	11.56	--	14.87	9.56	.25	--	--
20	4	1,050	--	2.19	6.10	15.33	--	9.62	24.10	10.67	1.43	11.52	4.29	14.76	--	--
21	8	2,460	1.10	7.20	11.34	17.20	--	4.31	16.14	16.06	1.50	7.85	10.37	6.30	.65	--
22	6	1,871	.59	7.11	12.61	20.63	--	6.57	21.97	9.73	--	5.61	10.37	4.81	--	--
23	8	2,937	.92	7.15	12.33	18.93	--	3.75	21.48	5.45	2.49	4.90	11.07	9.16	2.08	.31
24	5	2,025	3.75	8.64	10.47	20.20	1.88	7.65	9.19	5.68	4.74	.40	13.58	11.26	.25	2.32
25	7	2,976	1.78	5.24	5.41	17.24	--	7.56	18.62	16.87	2.65	2.28	11.53	9.85	.84	.13
26	5	2,332	--	3.60	5.75	11.84	.77	5.19	34.73	16.60	2.27	1.20	9.01	7.93	.69	.43
27	5	2,686	1.97	5.88	8.19	18.73	--	6.89	17.35	14.18	3.46	2.76	8.67	9.64	.60	1.68
28	2	1,175	--	3.57	6.04	17.45	--	8.34	12.68	7.32	--	1.36	36.09	7.15	--	--
29	1	523	--	4.40	21.03	9.75	--	.57	9.18	21.41	20.65	4.59	8.41	--	--	--
30	2	1,096	1.00	5.38	7.57	16.79	--	2.01	22.99	23.63	6.75	--	4.74	8.30	.82	--
31	1	585	24.79	24.44	5.81	24.10	--	--	2.56	5.81	3.25	1.37	.85	5.81	1.20	--
32	2	1,356	--	1.92	.74	18.29	--	3.69	24.78	25.59	11.73	--	2.21	4.79	4.28	1.99
33	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
34	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
35	1	869	--	--	.58	4.95	--	--	2.30	7.25	2.07	--	15.65	67.20	--	--
Total or average	84	28,246	1.46	6.01	8.53	16.86	.20	5.28	18.42	12.25	2.98	4.66	12.04	9.82	.94	.56

Table 15--Lumber grade recovery as a percentage of surfaced-dry lumber tally volume, log grade 5, mill-length, ponderosa pine logs

Log scaling diameter	Number of logs	Total lumber tally	B & Better Select	C Select	D Select	Moulding	3 Clear	1 Shop	2 Shop	3 Shop	Shop Out	2 & Better Common	3 Common	4 Common	5 Common	Pitch Select
Inches		Board feet	Percent of total lumber tally													
6	123	2,389	--	0.25	0.38	0.42	--	--	0.59	--	--	40.77	35.16	17.33	5.11	--
7	80	2,300	0.30	.09	.70	.39	--	--	--	--	--	37.65	40.22	17.30	3.35	--
8	68	2,687	--	.11	1.67	.56	--	--	.19	--	--	42.05	40.49	12.91	2.01	--
9	66	3,233	.25	.59	.74	.68	--	1.14	.37	--	0.46	42.72	40.27	11.51	1.27	--
10	64	4,202	.10	.33	1.93	1.07	--	1.52	.48	0.36	--	39.62	41.10	11.68	1.81	--
11	55	4,558	--	.20	1.29	1.91	--	2.37	1.95	2.04	.22	29.88	42.50	15.75	1.89	--
12	53	4,814	.15	.89	2.01	2.31	--	4.20	4.42	1.77	.35	28.69	41.11	12.57	1.54	--
13	28	3,332	--	.78	.72	1.59	--	6.09	5.22	5.64	1.26	30.34	38.93	8.34	1.08	--
14	44	5,510	--	1.03	1.91	1.58	--	7.64	9.22	4.54	1.03	25.41	39.35	7.44	.82	0.04
15	38	5,691	.19	.93	1.44	2.60	--	5.83	18.06	9.72	.23	19.47	31.73	8.52	1.27	--
16	39	7,145	.56	1.58	4.17	3.83	--	3.81	16.61	13.42	2.18	13.04	32.51	7.00	1.12	.15
17	37	7,322	.05	.55	1.73	5.67	0.23	5.95	27.25	16.72	1.49	13.81	21.57	4.49	.49	--
18	29	6,522	.11	1.33	1.03	2.09	.31	7.77	29.67	17.19	1.27	10.55	19.84	7.88	.97	--
19	28	6,880	.06	2.01	2.51	5.93	.29	10.41	27.18	13.49	.76	11.35	17.81	6.77	1.44	--
20	23	6,416	.03	2.09	2.79	3.29	--	5.28	33.17	17.11	.94	9.09	18.70	6.94	.58	--
21	24	6,611	.32	.83	1.51	3.37	.26	8.59	29.00	21.96	2.65	6.64	16.50	6.25	2.12	--
22	22	7,537	.24	.90	1.11	2.08	.46	9.84	30.34	19.20	3.16	6.97	16.44	8.04	1.21	--
23	16	5,416	--	.37	.70	4.71	--	10.75	34.14	23.26	1.53	6.76	14.12	3.49	.17	--
24	14	5,204	.21	1.81	3.06	9.45	.42	8.92	38.95	13.76	.90	4.53	11.63	4.02	2.34	--
25	15	6,046	.55	1.64	1.75	7.96	.61	10.88	33.99	19.60	3.24	4.57	11.18	2.88	1.16	--
26	8	3,460	--	1.94	1.48	6.56	.58	13.09	36.21	20.58	1.13	1.68	13.90	3.15	--	--
27	6	3,079	.32	1.43	2.92	7.60	--	7.89	30.30	15.82	4.09	.78	13.48	10.75	4.61	--
28	5	2,861	--	1.71	1.96	11.46	--	4.79	29.88	28.66	5.87	2.59	6.12	6.78	.17	--
29	2	719	--	--	--	2.36	--	4.17	35.74	21.84	15.30	1.11	5.15	5.42	8.90	--
30	1	649	--	--	--	1.54	--	9.24	26.66	32.82	8.47	7.40	11.40	2.47	--	--
31	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
32	1	439	--	--	--	6.15	--	--	3.87	23.01	11.16	--	3.87	28.93	23.01	--
Total or average	**889**	**115,022**	**.16**	**1.08**	**1.79**	**3.90**	**.16**	**6.58**	**21.56**	**13.10**	**1.65**	**15.93**	**24.57**	**7.98**	**1.51**	**.01**

Table 16--Lumber grade recovery as a percentage of surfaced-dry lumber tally volume, mill-length, dead ponderosa pine logs

Log scaling diameter	Number of logs	Total lumber tally	B & Better Select	C Select	D Select	Mould-ing	3 Clear	1 Shop	2 Shop	3 Shop	Shop Out	2 & Better Common	3 Common	4 Common	5 Common	Pitch Select
Inches		Board feet	Percent of total lumber tally													
6	5	77	--	--	--	--	--	--	--	--	--	20.78	58.44	20.78	--	--
7	4	121	--	--	--	--	--	--	--		--	33.06	57.85	5.79	3.31	--
8	7	257	--	1.174	1.17	1.56	--	--	--	--	--	18.68	48.64	28.79	--	--
9	8	354	--	--	1.41	--	--	--	--	--	--	11.02	59.89	27.68	--	
10	2	134	--	--	--	--	--	4.48	--	--	--	11.94	52.24	27.61	3.73	--
11	7	598	--	--	--	--	--	--	--	--	--	10.87	48.83	38.63	1.67	--
12	7	558	--	--	--	.54	--	--	--	--	--	16.85	47.79	31.36	3.76	--
13	7	619	--	--	--	.65	--	--	--	--	--	17.93	55.57	22.62	.81	--
14	7	780	--	.26	1.28	3.21	--	1.15	1.28	1.28	1.03	14.10	26.15	33.08	17.18	--
15	8	1,023	--	--	.49	--	--	--	--	--	--	11.34	55.03	30.60	2.54	--
16	4	543	--	--	2.03	--	--	--	--	--	--	19.52	30.94	38.86	7.18	1.47
17	8	1,470	--	--	.68	.48	--	--	2.31	2.31	--	7.89	36.33	44.29	5.71	--
18	3	351	--	--	--	1.14	--	--	--	--	--	12.54	25.07	39.60	20.51	1.14
19	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
20	3	669	--	--	--	--	--	1.20	--	--	2.24	8.07	31.09	53.51	2.54	1.35
21	4	1,139	--	.79	--	--	--	.97	7.55	1.76	--	3.25	22.27	55.05	7.37	--
22	1	209	--	--	3.35	--	--	--	--	--	--	11.00	35.41	27.27	22.97	--
23	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
24	4	1,343	--	--	1.49	2.76	--	2.83	1.12	1.12	.97	3.05	29.64	45.54	10.13	.37
25	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
26	2	718	--	.70	1.95	7.38	--	--	1.39	--	--	6.13	28.97	46.24	7.24	--
27	2	820	--	--	3.17	1.95	--	--	--	--	--	--	45.24	41.71	5.12	2.80
28	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
29	1	566	--	--	2.47	--	--	--	--	--	--	2.47	28.98	40.11	25.97	--
30	1	679	--	.74	1.91	--	--	--	--	--	--	4.12	38.14	47.86	6.63	.59
Total or average	95	13,028	--	.18	1.06	1.17	--	.67	1.19	.61	.28	8.92	37.82	40.24	7.45	.41

Table 17--Lumber grade recovery as a percentage of surfaced-dry lumber tally volume, all log grades combined for live, mill-length ponderosa pine logs

Log scaling diameter	Number of logs	Total lumber tally	B & Better Select	C Select	D Select	Mould-ing	3 Clear	1 Shop	2 Shop	3 Shop	Shop Out	2 & Better Common	3 Common	4 Common	5 Common	Pitch Select
Inches		Board feet	Percent of total lumber tally													
6	123	2,389	--	0.25	0.38	0.42	--	--	0.59	--	--	40.77	35.16	17.33	5.11	--
7	80	2,300	0.30	.09	.70	.39	--	--	--	--	--	37.65	40.22	17.30	3.35	--
8	68	2,687	--	.11	1.67	.56	--	--	.19	--	--	42.05	40.49	12.91	2.01	--
9	68	3,306	.24	.66	1.12	.88	--	1.12	.30	--	0.45	42.04	40.23	11.58	1.30	--
10	66	4,330	.09	.32	2.08	1.50	--	1.48	.46	0.35	--	39.77	40.85	11.34	1.76	--
11	57	1,737	.17	.32	1.94	2.00	--	2.28	1.88	1.96	.21	29.15	42.60	15.66	1.82	--
12	56	5,116	.14	1.21	3.44	3.22	--	3.95	4.16	1.66	.33	28.15	40.32	11.96	1.45	--
13	29	3,449	--	.75	.70	1.83	--	5.88	5.33	6.22	1.22	30.15	38.79	8.06	1.04	--
14	49	6,139	.18	2.08	3.50	2.75	--	7.10	8.66	4.59	.93	24.64	36.60	7.35	.85	0.75
15	43	6,485	.32	2.13	2.90	3.72	--	5.58	16.27	8.91	.62	17.89	31.60	7.91	1.46	.69
16	44	8,018	.50	2.63	5.25	5.90	--	3.49	15.91	12.87	2.16	13.02	30.46	6.56	1.06	.14
17	40	7,949	.28	.73	2.98	5.98	0.21	5.99	25.31	15.40	1.37	13.61	21.24	6.23	.58	.10
18	33	7,288	.41	1.88	1.60	5.47	.27	7.62	28.20	15.88	1.25	9.62	19.39	7.37	10.40	--
19	37	9,236	.98	2.97	3.62	8.84	.22	9.58	26.19	13.10	.56	11.87	15.67	5.23	1.07	.11
20	28	7,655	.03	2.46	3.41	6.00	--	5.75	31.10	16.05	.98	9.20	12.02	8.14	.56	--
21	37	10,650	1.24	3.47	5.09	91.60	.16	7.14	15.99	18.24	1.99	6.80	14.06	6.38	1.46	.68
22	33	11,047	.97	3.21	4.40	8.62	.32	8.75	26.28	15.94	2.33	6.38	14.56	7.26	.90	.09
23	30	10,497	1.90	4.74	7.52	13.66	--	6.92	24.61	13.93	1.68	5.90	12.90	4.85	.82	.58
24	21	8,060	1.65	4.27	5.61	12.38	.74	38.37	28.30	13.15	1.77	3.52	11.30	6.22	1.58	1.13
25	28	11,099	1.36	4.00	4.77	12.17	.33	8.39	24.70	16.77	2.48	4.49	10.60	6.24	2.36	1.33
26	21	9,319	3.73	7.56	6.06	15.03	.41	7.32	25.99	14.06	1.21	1.98	9.53	5.69	.73	.66
27	14	7,234	1.84	4.82	7.33	18.01	--	6.74	20.51	12.55	3.03	1.59	10.86	9.36	2.38	.97
28	12	6,872	.81	4.00	4.98	17.81	.29	5.69	20.62	17.18	3.24	1.82	12.67	6.91	.60	3.36
29	5	2,264	4.86	8.97	10.11	10.91	--	6.98	19.88	13.96	9.63	1.90	4.28	3.58	4.95	--
30	3	1,745	.63	3.38	4.76	11.12	--	4.70	24.36	27.05	7.39	2.75	7.22	6.13	.52	--
31	1	585	24.79	24.44	5.84	24.10	--	--	2.56	5.81	3.25	1.37	.85	5.81	1.20	--
32	4	2,450	2.33	5.39	3.39	18.16	--	2.04	16.00	18.29	8.49	--	3.55	10.78	8.53	3.06
33	1	716	22.35	18.44	1.06	17.46	--	7.68	6.00	--	--	--	4.19	7.82	--	--
34	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
35	1	869	--	--	.58	4.95	--	--	2.30	7.25	2.07	--	15.65	67.20	--	--
36	1	735	--	--	1.36	4.62	--	3.54	10.20	4.22	9.93	--	22.86	36.87	6.39	--
Total or average	**1,033**	**165,226**	**1.21**	**3.20**	**4.27**	**8.69**	**.16**	**6.08**	**19.42**	**12.08**	**1.79**	**12.47**	**20.37**	**8.20**	**1.49**	**.57**

Plank, Marlin E. Lumber recovery from ponderosa pine in western Montana. Res. Pap. PNW-297. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1982. 24 p.

Lumber grade yields and recovery ratios are shown for a sample of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) in western Montana. About 9 percent of the lumber produced was in Select grades, 48 percent in Shop grades, and 43 percent in Common grades. Information on log scale and yield is presented in tables by log grade and diameter class.

KEYWORDS: Lumber recovery, lumber yield, ponderosa pine, *Pinus ponderosa*, Montana.

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Aboveground Tree Biomass on Productive Forest Land in Alaska

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Abstract

Yarie, John; Mead, Delbert. Aboveground tree biomass on productive forest land in Alaska. Res. Pap. PNW-298. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1982 16 p.

Total aboveground woody biomass of trees on forest land that can produce 1.4 cubic meters per hectare per year of industrial wood in Alaska is 1.33 billion metric tons green weight. The estimated energy value of the standing woody biomass is 11.9 x 10^{15} Btu's. Statewide tables of biomass and energy values for softwoods, hardwoods, and species groups are presented.

Keywords: Biomass, energy, wood utilization, Alaska.

Summary

Compilation of tree biomass in Alaska was part of a nationwide state-of-the-art project undertaken in 1980. This project was conceived because economic interest in forest biomass has risen dramatically in recent years concurrent with interest in alternative fuels and development of new technologies that could use total tree biomass. The project pulled together much existing information on the subject and enabled us to make estimates of biomass supply; it also provided an opportunity to assess existing knowledge and identify species for which additional research is needed.

Biomass values were developed by applying biomass equations for individual species to stand tables compiled from existing inventory data. Stand tables used in this compilation were built with data gathered from many years of aerial photo interpretation and ground sampling by Alaska's Renewable Resources Evaluation project. Biomass equations were developed by many researchers over a period of years. Sources of the equations are listed in appendix table 8.

All biomass values were calculated in pounds of green weight for two tree categories, bole and top. Data are presented by coastal and interior geographic units. Coastal forest areas are typically high biomass (176 tons/acre) Sitka spruce-hemlock-cedar stands and account for 85 percent of total biomass in the State. Interior areas have lower biomass (55 tons/acre) and account for only 15 percent of the total. White spruce, black spruce, birch, and aspen are the predominant species.

Information in this report is a best estimate based on current data. Only areas previously inventoried were included, and inventory data represents the more densely forested areas of the State judged to be capable of producing 20 cubic feet of bole wood per acre per year. Obviously, large areas of the State and substantial biomass were excluded; however, areas of highest biomass density and greatest economic potential are included. No estimate of sample error is provided because of the large number of equations and inventory units used for the final estimates. Caution is urged in applying these estimates except as a general planning tool.

Introduction

The portion of alternative energy sources being used to satisfy total energy demand is increasing in many countries throughout the world. As with oil and coal, the availability of these resources is important to know.

Wood is one renewable source of energy that is often considered for alternative energy. As a first step in determining the potential energy in the Nation's forest trees,[1] traditional, product-oriented forest inventories have to be reanalyzed to estimate total forest biomass. This report is the result of such an effort for the State of Alaska. The information should be considered within the restrictions specified; it represents a preliminary best estimate, compiled from available data.

Methods

Standing tree biomass (appendix tables 5, 6, and 7) was estimated from stand-table data[2] using biomass equations (appendix table 8) for each major species found in the State. The stand-tables were constructed for both of the State's major resource areas: coastal and interior (fig. 1).

All biomass values were calculated in pounds of green weight from the equations shown in appendix tables 8 and 9. Standing tree biomass was calculated for two categories, bole and top. Bole was defined as the main stem of the tree including wood and bark from a 1-foot (30.5-cm) stump to a 4-inch- (10.2-cm-) diameter outside bark (d.o.b.) top. Top was defined as the main stem above a 4-inch d.o.b. top and all live branches, excluding foliage but including bark. A 3-inch (7.6-cm) top diameter was used for black cottonwood. Total biomass was the bole plus the top.

Some adjustments had to be made in applying these equations:

- Sometimes, predicted values derived from bole-biomass equations were greater than predicted values from total-stem equations (from a 1-foot stump to a 0 d.o.b. top, excluding branches). This occurred only in extrapolating beyond the range of the data used to develop the regression equation. This extrapolation was necessary because the true range of inventoried tree sizes was greater than the range in data used to develop the regression equation (table 5). A top-to-stem weight ratio (table 9) was used to proportion total stem weight into that above and below the 4-inch top diameter. The top-to-stem weight ratio was calculated using a ratio computed from a sample of actual bole weights or volumes to total stem weights or volumes for each diameter class. Above a certain diameter class, the species-specific, top-to-stem weight ratio was assumed to be constant (table 9).
- No biomass equations were available for Sitka spruce, so a volume equation had to be used. The factor used to convert from stem volume to green weight is presented in table 9.
- The equation for red alder branches predicts negative values within the range of stand-table diameters, so a constant value of 143.3 pounds (65 kg) was assumed above a d.b.h. of 16 inches (40.6 cm). This assumption probably results in a 10-percent or less underestimate of red alder biomass.

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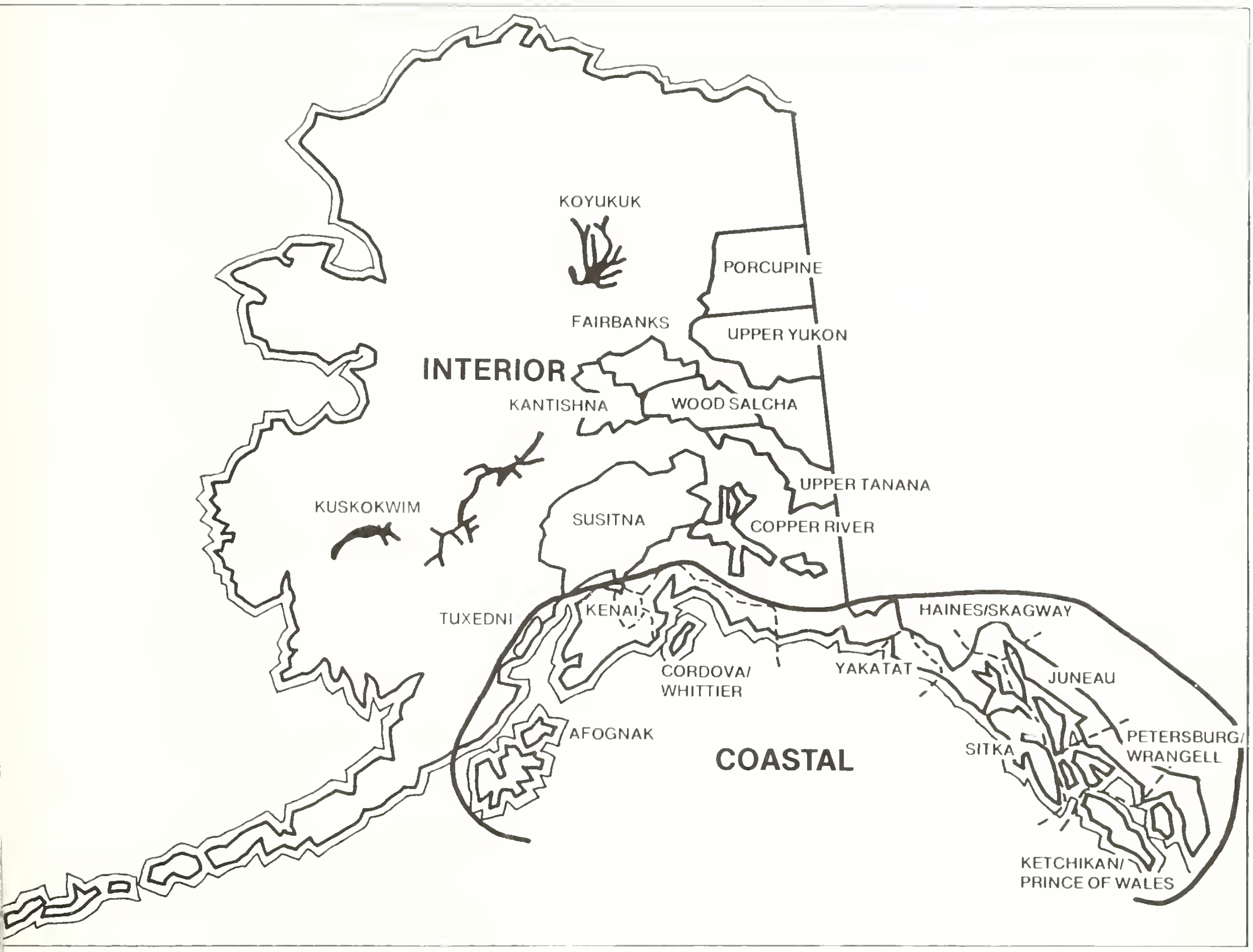
[1] See "Glossary" for definitions of terms used in this paper.

[2] Stand-table data were taken from published reports for the Susitna, Fairbanks, Upper Koyukuk, Copper River, Tuxedni, Kuskokwim, and Haines-Skagway units (Hegg 1974a, b, c, 1975, 1979; Hegg and Sievering 1979; LaBau and Hutchinson 1976. Data were also taken from unpublished reports compiled by the Renewable Resources Evaluation Unit, Forestry Sciences Laboratory, Suite 106, 2221 East Northern Lights Blvd., Anchorage, Alaska 99508, for the following inventory units: Juneau, 1970; Sitka, 1971; Petersburg, 1972; Kantishna, 1973; Prince of Wales, 1973; Ketchikan, 1974; Upper Tanana, 1974; Wood-Salcha, 1975; Yakatat, 1975; Afognak, 1976; Cordova-Whittier, 1977; and Kenai, 1978. These reports are on file at the Forestry Sciences Laboratory.



gure 1.-Inventory units included in the
boveground tree biomass study.

ndirect methods were used to estimate omass of rough and rotten trees ecause stand tables were unavailable. he ratio of rough and rotten trees to rowing stock was obtained from the view draft of a USDA Forest Service aper.[3] The ratio was calculated separatey for softwoods and hardwoods in terior and coastal Alaska. Totals were hen added into the tables, based on he proportion of the individual species eight to total weight.

Total biomass of rough and rotten trees for coastal Alaska was only 7 percent of the growing-stock volume, so the error is probably less than 5 percent for individual species. The percentage of rough and rotten trees found in interior Alaska was even less.

Energy content was calculated using conversion factors given in Cheremisinoff (1980) for wood. The energy values listed in our tables are slight underestimates because bark and wood were considered together. Bark usually has a higher energy value than wood.

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[3] ppendix table 8 in "An analysis of the ti ber situation in the United States, 1952-230," Washington, DC; U.S. Department of Ariculture, Forest Service. Paper in review.

Discussion

Statewide estimates of aboveground forest biomass were compiled for Alaska in late 1980 as part of a nationwide assessment of forest biomass. The estimates were compiled from existing forest-inventory data of productive forest lands in the State. Units that had previously been inventoried (fig. 1) include:

Coastal	Afognak, 1976
	Cordova/Whittier, 1977
	Haines/Skagway, 1965
	Juneau, 1970
	Kenai, 1978
	Ketchikan/Prince of Wales, 1974
	Petersburg/Wrangell, 1972
	Sitka, 1971
	Yakatat, 1975
Interior	Copper River, 1968
	Fairbanks, 1970
	Kantishna, 1973
	Koyukuk, 1971
	Kuskokwim, 1967
	Susitna, 1964-65
	Tuxedni, 1971
	Upper Tanana, 1974
	Wood-Salcha, 1975

These units include most of southeast Alaska and substantial portions of the southcentral coast. Early interior inventories, such as the Kuskokwim and Koyukuk units, were centered along river bottoms and used available aerial photographs; later inventories included entire river basins (Susitna and Tanana).

The forest-land area and biomass listed in the following tables reflect only the amount of productive forest land inventoried in the above units. These units represent major forest areas of the State, but substantial, marginally productive forest areas remain uninventoried. We estimate that, if all forest lands in Alaska were included, the total biomass estimate would be at least double. A preliminary estimate of 100 million green tons of aboveground tree biomass (Yarie, unpub. data) for an inventory unit completed too late for inclusion in this report is about 38 percent of the total estimate presented in table 1 for interior Alaska. This unit represents only 9,000,000 acres in the upper Yukon drainage. In addition, several other units in the interior still remain uninventoried.

At the time stand-table data were compiled, patterns of forest ownership in Alaska were undergoing changes because of the Alaska Lands Bill. Large amounts of land are changing ownership as the Federal Government relinquishes title to the State of Alaska and Native corporations. Also, when passage of the bill was pending, large amounts of land tentatively selected by the State were readied for conveyance to the State's boroughs, municipalities, and private citizens via land sales and homesite programs. Therefore, identifying biomass by ownership class is impossible, and no biomass data are presented by class of ownership.

We can expect substantial changes in the amount and size-class distribution of the State's forest biomass as land-use changes occur along with changing ownership. The State has already undertaken several large land-clearing operations as it attempts to establish agricultural projects; also, more land is available for private use and development. Some of the State's more heavily forested areas, formerly administered by the USDA Forest Service, have been selected by Native corporations. As a result, we could expect changes in timber-sale patterns and subsequent biomass distribution.

Total biomass for the inventoried units is estimated at 1.47 billion tons green weight (1.33 billion metric tons (m.t.)). A conservative dry-weight estimate would be 0.7 billion tons (0.63 billion m.t.) (table 1). Coastal Alaska (fig. 1) accounts for 85 percent of the total biomass (1.12 billion m.t.); only 15 percent of the State's total is found in interior Alaska (table 1). Ninety-two percent of the total can be accounted for by growing-stock trees (1.22 billion m.t.), and only a small portion is rough and rotten material (4 percent or 53 million m.t.). The remaining 4 percent (54 million m.t.) are classed as saplings (table 1).

The vast differences in forest structure between coastal and interior forests (figs. 1, 2, and 3) are shown in tables 2, 3, and 4. Productive forest land in coastal Alaska averages 176 green tons/acre (395 m.t./ha); interior lands average only 55 green tons/acre (124 m.t./ha) (table 2). Total sapling biomass in the interior is about 3 times greater per acre than on the coast. The difference in sapling biomass results from large differences in fire frequency and response of species to fire between interior and coastal Alaska.

Most (95 percent) of total biomass found in interior Alaska is in trees less than 20 inches (51 cm) in diameter at breast height (d.b.h.); in coastal Alaska, 63 percent of the total biomass is in trees larger than 20 inches d.b.h. (tables 3 and 4).

Softwoods accounted for 99 percent of the total coastal biomass, but only 43 percent of the total interior biomass (tables 3 and 4). Western hemlock and spruce species accounted for 75 percent of the total aboveground woody biomass on productive forest lands in Alaska (tables 3 and 4). Mountain hemlock ("Other softwoods," table 3) and paper birch were next, accounting for only 8 and 6 percent of the total aboveground woody biomass, respectively (tables 3 and 4).

Table 1—Total green weight of aboveground tree biomass on commercial forest land in Alaska by class of timber, species group, and region

Region, species group	Total biomass			Growing stock			Rough and rotten			Saplings		
	Total	Bole	Top	Total	Bole	Top	Total	Bole	Top	Total	Bole	Top
					Million green tons							
Coastal:												
Softwoods	1232.7	927.8	304.9	1160.0	880.9	279.1	51.6	39.2	12.4	21.1	7.7	13.4
Hardwoods	9.5	6.6	2.9	8.5	6.1	2.4	0.4	0.3	0.1	0.6	0.2	0.4
Total	1242.2	934.4	307.8	1168.5	887.0	281.5	52.0	39.5	12.5	21.7	7.9	13.8
Interior:												
Softwoods	97.0	69.2	27.8	90.0	66.9	23.1	0.8	0.6	0.2	6.2	1.7	4.5
Hardwoods	129.0	67.5	61.5	94.3	57.9	36.4	3.9	2.4	1.5	30.8	7.2	23.6
Total	226.0	136.7	89.3	184.3	124.8	59.5	4.7	3.0	1.7	37.0	8.9	28.1
Alaska total	1468.2	1071.1	397.1	1352.8	1011.8	341.0	56.7	42.5	14.2	58.7	16.8	41.9

Table 1A—Total energy value of aboveground tree biomass on commercial forest land in Alaska by class of timber, species group, and region

Region, species group	Total biomass			Growing stock			Rough and rotten			Saplings		
	Total	Bole	Top	Total	Bole	Top	Total	Bole	Top	Total	Bole	Top
					Quads[1/]							
Coastal:												
Softwoods	9.991	7.520	2.471	9.402	7.140	2.262	0.418	0.318	0.100	0.171	0.062	0.109
Hardwoods	0.074	0.051	0.023	0.066	0.047	0.019	0.003	0.002	0.001	0.005	0.002	0.003
Total	10.065	7.571	2.494	9.468	7.187	2.281	0.421	0.320	0.101	0.176	0.064	0.112
Interior:												
Softwoods	0.758	0.541	0.217	0.703	0.523	0.180	0.007	0.005	0.002	0.048	0.013	0.035
Hardwoods	1.090	0.570	0.520	0.797	0.489	0.308	0.033	0.020	0.013	0.260	0.061	0.199
Total	1.848	1.111	0.737	1.500	1.012	0.488	0.040	0.025	0.015	0.308	0.074	0.234
Alaska total	11.913	8.682	3.231	10.968	8.199	2.769	0.461	0.345	0.116	0.484	0.138	0.346

[1/] Quads = (10^{15} Btu's). Btu's in quads (10^{15} Btu's) for air-dry material (moisture content = 12 percent).

Figure 2.-A coastal Sitka spruce stand illustrating high biomass per acre in trees of large diameter.

Table 2—Green weight of aboveground biomass on productive forest land in Alaska by class of timber, species group, and region

Region, species group	Total biomass			Growing stock			Rough and rotten			Saplings		
	Total	Bole	Top	Total	Bole	Top	Total	Bole	Top	Total	Bole	Top
	Green tons per acre											
Coastal:												
Softwoods	175.08	131.78	43.30	164.76	125.12	39.64	7.33	5.57	1.76	2.99	1.09	1.90
Hardwoods	1.35	0.94	0.41	1.21	0.87	0.34	0.05	0.04	0.01	0.09	0.03	0.06
Total	176.43	132.72	43.71	165.97	125.99	39.98	7.38	5.61	1.77	3.08	1.12	1.96
Interior:												
Softwoods	23.60	16.84	6.76	21.90	16.28	5.62	0.20	0.15	0.05	1.50	0.41	1.09
Hardwoods	31.38	16.42	14.96	22.95	14.09	8.86	0.94	0.58	0.36	7.49	1.75	5.74
Total	54.98	33.26	21.72	44.85	30.37	14.48	1.14	0.73	0.41	8.99	2.16	6.83
Alaska total	131.68	96.06	35.62	121.33	90.74	30.58	5.09	3.81	1.28	5.26	1.51	3.75

Figure 3.-An interior white spruce stand llustrating lower biomass per acre with most of the biomass in sapling-sized trees.

Table 3—Total green weight of aboveground softwood tree biomass on commercial forest land in Alaska by species, diameter class, and region

Region and diameter class	Total softwoods	True firs	Spruces	Western hemlock	Western red cedar	Other cedars	Lodgepole pine	Other softwoods
Inches	Million green tons							
Coastal:								
1.0-5.0	21.8	0.01	2.8	14.1	0.4	1.1	0.0	3.4
5.0-9.0	74.8	0.02	11.3	45.1	1.3	5.0	0.05	12.0
9.0-19.0	359.3	0.05	79.0	191.0	11.5	30.7	0.5	46.5
19.0-29.0	412.2	0.01	104.4	226.1	15.4	23.8	0.3	42.2
29.0+	364.6	0.01	135.4	194.6	12.4	6.3		15.9
Total	1232.7	0.1	332.9	670.9	41.0	66.9	0.85	120.0
Interior:								
1.0-5.0	6.2		6.2					
5.0-9.0	27.6		27.6					
9.0-19.0	60.8		60.8					
19.0-29.0	2.2		2.2					
29.0+	0.2		0.2					
Total	97.0		97.0					
Alaska total	1329.7	0.1	429.9	670.9	41.0	66.9	0.85	120.0

Table 3A—Total energy value of aboveground softwood tree biomass on commercial forest land in Alaska by species, diameter class, and region

Region and diameter class	Total softwoods	True firs	Spruces	Western hemlock	Western red cedar	Other cedars	Lodgepole pine	Other softwoods
Inches	Quads 1/							
Coastal:								
1.0-5.0	0.178	0.0001	0.022	0.117	0.003	0.008		0.028
5.0-9.0	0.610	0.0002	0.088	0.373	0.010	0.039	0.0005	0.099
9.0-19.0	2.915	0.0005	0.617	1.581	0.089	0.237	0.005	0.385
19.0-29.0	3.342	0.0001	0.816	1.871	0.119	0.184	0.003	0.349
29.0+	2.946	0.0001	1.058	1.611	0.096	0.049		0.132
Total	9.991	0.001	2.601	5.553	0.317	0.517	0.009	0.993
Interior:								
1.0-5.0	0.048		0.048					
5.0-9.0	0.216		0.216					
9.0-19.0	0.475		0.475					
19.0-29.0	0.017		0.017					
29.0+	0.002		0.002					
Total	0.758		0.758					
Alaska total	10.749	0.001	3.359	5.553	0.317	0.517	0.009	0.993

1/Quad = (10^{15} Btu's) for air-dry material.

Table 4—Total green weight of aboveground hardwood tree biomass on commercial forest land in Alaska by species, diameter class, and region

Region and diameter class	Total all hardwoods	Cottonwood and aspen	Red alder	Other hardwoods
Inches		Million green tons		
Coastal:				
1.0-5.0	0.5	0.1	0.2	0.2
5.0-9.0	1.5	0.4	0.9	0.2
9.0-19.0	4.5	2.3	2.0	0.2
19.0-29.0	1.8	1.7	0.1	0.02
29.0+	1.0	1.0	0.02	
Total	9.3	5.5	3.22	0.62
Interior:				
1.0-5.0	31.7	5.6		26.1
5.0-9.0	45.9	13.6		32.3
9.0-19.0	41.4	13.5		27.9
19.0-29.0	7.6	7.3		0.3
29.0+	2.4	2.4		
Total	129.0	42.4		86.6
Alaska total	138.3	47.9	3.22	87.22

Table 4A—Total energy value of aboveground hardwood tree biomass on commercial forest land in Alaska by species, diameter class, and region

Region and diameter class	Total all hardwoods	Cottonwood and aspen	Red alder	Other hardwoods
Inches		Quads[1]		
oastal:				
1.0-5.0	0.005	0.001	0.002	0.002
5.0-9.0	0.012	0.003	0.007	0.002
9.0-19.0	0.036	0.018	0.016	0.002
19.0-29.0	0.014	0.013	0.0008	0.0001
29.0+	0.007	0.007	0.0002	
Total	0.074	0.042	0.026	0.006
nterior:				
1.0-5.0	0.273	0.042		0.231
5.0-9.0	0.390	0.104		0.286
9.0-19.0	0.350	0.103		0.247
19.0-29.0	0.059	0.056		0.003
29.0+	0.018	0.018		
Total	1.090	0.323		0.767
laska total	1.164	0.365	0.026	0.773

/Quad = (10^{15} Btu's) for air-dry material.

The total proportion of biomass of bole to top was 3 to 1 for coastal Alaska and 1.5 to 1 for interior. The difference is because the ratio of bole to top is 1 to 1 for interior hardwoods and 2 to 1 for all interior growing stock. Although utilization could be increased by a higher percentage in interior forests if the complete tree were used, coastal Alaskan forests contain about 3.5 times more top biomass than the interior forests.

Total energy content in aboveground tree biomass minus foliage is estimated as 11.913 quads (10^{15} Btu's) (table 1A). Coastal Alaska again accounts for the highest portion or 10.065 quads; only 1.848 quads were found in productive interior forests. Total energy content in aboveground tree biomass per hectare is 3.54 billion Btu's in coastal forests and 1.11 billion Btu's in interior forests. The same general trends found in biomass are also found when the data are converted to energy content.

Based on data collected by Goldsmith and Lane (1978) for 1976, the estimated aboveground biomass could meet all of Alaska's energy demands (at 1976 levels) for 55 years. Eliminating energy required by transportation and petroleum processing, the current biomass reserves could supply energy for electricity conversions, heating, and miscellaneous uses for 123 years at the rate of energy consumption in 1976. This latter figure is close to the suggested rotation age for many of Alaska's forest types.

Glossary

Bole biomass—Green weight of the wood and bark of the main stem of a tree from a 1-foot stump to a 4-inch top diameter outside bark (d.o.b.). (A 3-inch d.o.b. top was used for cottonwood.)

Diameter class—A classification of trees based on diameter outside bark, measured at breast height (4½ feet (1.37 m) above the ground).

Forest trees—Woody plants having a well-developed stem and usually more than 12 feet (3.65 m) in height at maturity.

Growing stock trees—Live trees of commercial species that are capable of producing at least one 12-foot sawlog, have no serious defect in quality limiting present or prospective use for timber products, are of relatively high vigor, and contain no pathogens that may result in death or serious deterioration before rotation age.

Productive forest land—Land at least 16.7-percent stocked by forest trees of any size, or formerly having had such tree cover and not currently developed for nonforest use. This land must also be capable of producing 20 cubic feet/acre per year of industrial wood.

Quads—An energy value equivalent at 10^{15} British thermal units (Btu's).

Saplings—Live trees 1.0-4.9 inches (2.54-12.5 cm) in diameter at breast height.

Seedlings—Live trees less than 1.0 inch (2.54 cm) in diameter at breast height.

Stand table—A table of tree numbers by species and diameter class.

Top biomass—Green weight of the wood and bark of the main tree stem above a 4-inch top diameter outside bark plus all live branches minus foliage.

Total biomass—Green weight of wood and bark above a 1-foot stump (bole + top).

Literature Cited

Adamovich L.L. Engineering characteristics of Canadian trees -centre of gravity and green weight components of four species in interior British Columbia. Info. Rep. FMR-X-74.29. Forest Management Institute; Ottawa, Canada, 1975. 64 p.

Cheremisinoff, N.P. Wood for energy production. Ann Arbor, MI: Ann Arbor Science; 1980. 152 p.

Fujimori, T.; Kawanabe, S.; Saito, H.; Grier, C.; Shidei, T. Biomass and primary production in forests of three major vegetation zones of the northwestern United States. J. Jap. For. Soc. 58: 360-373; 1976.

Gholz, H.; Grier, C.; Campbell, A.; Brown, A. Equations for estimating biomass and leaf area of plants in the Pacific Northwest. Res. Pap. 41. Corvallis, OR: Forest Research Laboratory. Oregon State University; 1979. 40 p.

Goldsmith, S.; Lane, T. Oil and gas consumption in Alaska 1976-2000. Fairbanks, AK: University of Alaska, Institute of Social Economic Research; 1978. 58 p.

Hegg, Karl M. Forest resources of the Susitna Valley, Alaska. Resour. Bull. PNW-32. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1974a. 42 p.

Hegg, Karl M. Timber resource statistics for the Fairbanks block Tanana inventory unit, Alaska, 1970. Resour. Bull. PNW-59. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1974b. 36 p.

Hegg, Karl M. Forest statistics for the Upper Koyukuk River, Alaska, 1971. Resour. Bull. PNW-54. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1974c. 26 p.

Hegg, Karl M. Timber resources statistics for the Copper River inventory unit, Alaska, 1968. Resour. Bull. PNW-62. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1975. 55 p.

Hegg, Karl M. Timber resources statistics for the Tuxedni Bay inventory unit, Alaska, 1971. Resour. Bull. PNW-88. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1979. 43 p.

Hegg, Karl M.; Sieverding, Harold. Timber resources of the Kuskokwim flood plain and adjacent upland. Resour. Bull. PNW-87. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1979. 40 p.

ohnson, F.A. Volume tables for Pacific Northwest trees. Agric. Handb. 92. Washington, DC: U.S. Department of Agriculture, Forest Service; 1955. 122 p.

Kurucz, J. Component weights of Douglas-fir, western hemlock and western red cedar biomass for simulation of amount and distribution of forest fuels. Univ. of British Columbia, Faculty of Forestry, M.F. thesis; 1969. 116 p.

LaBau, V.J.; Hutchinson, O.K. Timber supply and use in the Haines-Skagway area, Alaska. Resour. Bull. PNW-67. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1976. 44 p.

Markwardt, L.; Wilson, T. Strength and related properties of woods grown in the United States. Tech. Bull. 479. Washington, DC: U.S. Department of Agriculture; 1935. 99 p.

Peterson, E.; Chan, Y.; Cragg, J. Above ground standing crop, leaf area and caloric value in an aspen clone near Calgary, Alberta. Can. J. Bot. 48: 1459-1469; 1970.

Smith, J.H.G.; Kozak, A. Thickness, moisture content, and specific gravity of inner and outer bark of some Pacific Northwest trees. For. Prod. J. 21: 38-40; 1971.

Zavitkovski, J.; Stevens, R. Primary production of red alder ecosystems. Ecology. 53: 235-242; 1972.

Table 5—Total green weight of aboveground softwood tree biomass on productive forest land in coastal Alaska [1]

	Alaska yellow cedar		Lodgepole pine		Mountain hemlock		Sitka spruce		True firs		Western red cedar		Western hemlock		White spruce	
Diameter class	Bole	Top	Bole	Top	Bole	Top	Bole	Top	Bole	Top	Bole	Top	Bole	Top	Bole	Top
Inches							Thousands of tons of growing stock									
1.0 - 2.9	0	70	0	1	0	108	0	29	0	0	0	20	0	533	0	0
3.0 - 4.9	340	700	0	0	1118	2101	1568	1080	3	6	122	251	4491	8438	0	0
5.0 - 6.9	1652	710	27	18	3847	1656	3184	761	17	5	409	176	13101	5639	0	0
7.0 - 8.9	1741	708	2	0	4507	1523	5810	1018	1	0	419	170	18251	6167	0	0
9.0 - 10.9	3398	1204	46	13	5595	1733	8276	1169	37	9	1134	402	22353	6925	17	6
11.0 - 12.9	4065	1133	2	0	7207	2417	11480	1521	1	0	1205	336	25226	8461	8	2
13.0 - 14.9	4925	1357	2	0	7044	2529	14514	1965	2	0	1519	419	25778	9256	19	5
15.0 - 16.9	5212	1423	161	30	6828	2314	15083	2081	1	0	2116	578	29750	10081	16	4
17.0 - 18.9	5243	1420	218	43	6549	2351	17131	2403	1	0	2576	698	33269	11944	11	2
19.0 - 20.9	5305	1355	116	18	6790	2567	18674	2659	1	0	2709	692	32613	12331	5	1
21.0 - 22.9	4003	1015	74	12	6966	2761	18273	2637	2	0	2448	621	31390	12440	6	1
23.0 - 24.9	3374	850	29	5	5486	2270	17674	2582	1	0	1856	468	33747	13962	0	0
25.0 26.9	3059	767	28	4	5027	2164	16119	2382	3	1	2279	571	28024	12064	0	0
27.0 - 28.9	2492	621	0	0	4426	1977	16500	2464	4	1	2487	620	27656	12352	0	0
29.0 - 30.9	1671	415	0	0	2837	1311	13661	2060	3	1	1969	488	21117	9761	0	0
31.0 - 32.9	1274	315	0	0	2341	1118	14414	2194	2	0	1238	306	22518	10748	0	0
33.0 - 34.9	711	175	0	0	1488	732	11728	1801	2	0	1874	460	17699	8708	0	0
35.0 - 36.9	409	100	0	0	999	506	12676	1962	2	0	1133	277	14976	7581	0	0
37.0 - 38.9	165	40	0	0	1006	523	9191	1434	1	0	751	183	11521	5992	0	0
39.0 - 40.9	140	34	0	0	461	246	7723	1214	1	0	564	137	9397	5015	0	0
41.0 - 42.9	103	25	0	0	538	294	7224	1143	1	0	423	102	8653	4732	0	0
43.0 - 44.9	111	27	0	0	44	25	6119	975	0	0	354	85	5745	3216	0	0
45.0 - 46.9	0	0	0	0	217	124	5780	926	0	0	352	85	3900	2232	0	0
47.0 - 48.9	174	42	0	0	146	86	3538	571	0	0	266	64	3302	1931	0	0
49.0 - 50.9	36	9	0	0	0	0	3047	494	0	0	238	57	1720	1026	0	0
51.0 - 52.9	0	0	0	0	124	75	2770	452	0	0	176	42	456	277	0	0
53.0 - 54.9	0	0	0	0	0	0	2870	471	0	0	0	0	1127	699	0	0
55.0 - 56.9	0	0	0	0	0	0	1756	290	0	0	0	0	583	368	0	0
57.0 - 58.9	0	0	0	0	0	0	1051	174	0	0	0	0	160	103	0	0
59.0 - 60.9	0	0	0	0	0	0	2889	481	0	0	184	43	391	256	0	0
61.0 - 62.9	0	0	0	0	0	0	5659	947	0	0	0	0	284	189	0	0
Total	49605	14513	705	144	81592	33511	276380	42337	85	26	30803	8352	449196	193430	81	21

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[1] Totals may be off because of rounding.

able 6—Total green weight of aboveground hardwood tree biomass on productive orest land in coastal Alaska [1]

Diameter class	Aspen		Black cottonwood		Red alder		Paper birch	
	Bole	Top	Bole	Top	Bole	Top	Bole	Top
Inches	Thousand green tons of growing stock							
1.0 - 2.9	0	0	0	9	0	72	0	12
3.0- 4.9	0	0	68	20	21	143	70	127
5.0 - 6.9	1	1	110	36	272	287	90	99
7.0 - 8.9	1	0	166	57	182	95	23	20
9.0 - 10.9	10	3	280	99	380	114	39	29
11.0 - 12.9	9	2	226	82	323	82	52	35
13.0 - 14.9	3	1	452	166	441	87	33	20
15.0 - 16.9	0	0	402	149	234	40	8	5
17.0 - 18.9	0	0	265	99	156	23	9	5
19.0 - 20.9	0	0	209	79	25	4	8	4
21.0 - 22.9	0	0	322	122	23	2	4	2
23.0 - 24.9	0	0	201	76	0	0	0	0
25.0 - 26.9	0	0	279	107	0	0	0	0
27.0 - 28.9	0	0	169	65	0	0	2	1
29.0 - 30.9	0	0	74	28	15	2	0	0
31.0 - 32.9	0	0	157	60	0	0	0	0
33.0 - 34.9	0	0	85	33	0	0	0	0
35.0 - 36.9	0	0	79	31	0	0	0	0
36.0 - 38.9	0	0	52	20	0	0	0	0
39.0 - 40.9	0	0	116	45	0	0	0	0
41.0 - 42.9	0	0	49	19	0	0	0	0
43.0 - 44.9	0	0	40	16	0	0	0	0
45.0 - 46.9	0	0	18	7	0	0	0	0
Total	23	7	3818	1425	2072	951	337	360

[1] Totals may be off because of rounding.

able 7—Total green weight of aboveground tree biomass on productive forest land in interior Alaska [1]

ameter ass	Aspen		Balsam poplar		Black cottonwood		Paper birch		Black spruce		White spruce	
	Bole	Top	Bole	Top	Bole	Top	Bole	Top	Bole	Top	Bole	Top
ches	Thousand green tons of growing stock											
.0 - 2.9	0	109	0	78	0	16	0	8010	0	19	0	339
.0 - 4.9	534	2970	197	1114	265	80	6159	11226	65	114	1584	4056
.0 - 6.9	2198	1789	1365	1113	450	148	7677	8454	611	285	5882	4203
.0 - 8.9	2103	771	1592	574	818	282	8132	7060	395	94	11109	4862
.0 - 10.9	1152	223	1696	314	522	185	7196	5380	76	11	15048	5033
.0 - 12.9	435	82	1579	262	742	268	4521	3041	41	4	12481	3526
.0 - 14.9	117	22	1040	162	954	350	2828	1756	4	0	9973	2505
.0 - 16.9	76	14	453	68	811	301	1072	625	0	0	6273	1445
.0 - 18.9	35	7	200	29	720	269	378	210	0	0	3137	679
.0 - 20.9	0	0	169	24	1345	506	161	86	0	0	1658	340
.0 - 22.9	0	0	0	0	1052	398	51	26	0	0	64	13
.0 - 24.9	0	0	0	0	749	285	0	0	0	0	12	3
.0 - 26.9	0	0	358	48	755	288	0	0	0	0	0	0
.0 - 28.9	0	0	0	0	833	319	0	0	0	0	11	2
.0 - 30.9	0	0	69	9	471	181	0	0	0	0	141	29
.0 - 32.9	0	0	0	0	526	203	0	0	0	0	0	0
.0 - 34.9	0	0	0	0	257	99	0	0	0	0	0	0
.0 - 36.9	0	0	0	0	0	0	0	0	0	0	0	0
.0 - 38.9	0	0	0	0	151	59	0	0	0	0	0	0
.0 - 40.9	0	0	0	0	100	39	0	0	0	0	0	0
.0 - 42.9	0	0	0	0	66	26	0	0	0	0	0	0
.0 - 44.9	0	0	0	0	0	0	0	0	0	0	0	0
.0 - 46.9	0	0	0	0	0	0	0	0	0	0	0	0
.0 - 48.9	0	0	0	0	0	0	0	0	0	0	0	0
.0 - 50.9	0	0	0	0	0	0	0	0	0	0	0	0
Total	6650	5988	8718	3794	11590	4302	38175	45874	1191	528	67375	27034

[1] otals may be off because of rounding.

Table 8—Documentation of methodology, equations, and moisture content values

Species or species group	Equation used	Diameter ranges		Source
		Equation	Stand table	
		Inches		
White spruce	Bole green wt (kg) = $24.042 - 8.974D + 0.76D^2$ Top green wt (kg) = $(1-CF)(14.9754 - 4.313D + 0.667D^2)$ Branch dry wt (kg) = $2.59 - 7.56D + 0.07D^2$ Branch moisture content = 95.65 percent	1.5-19.7	1.0-30.0	Yarie and Van Cleve, personal communication
Black spruce	Bole green wt (kg) = $CF(1.7144 - 1.023D + 0.353D^2)$ Top green wt (kg) = $(1-CF)(1.7144 - 1.023D + 0.353D^2)$ Branch dry wt (kg) = $-0.1261 + 0.128D + 0.003D^2$ Branch moisture content = 62.26 percent	1.0-5.0	1.0-14.0	Yarie and Van Cleve, personal communication
Aspen	Bole dry wt (kg) = $CF(10^{(-1.893 + 2.3564 \log D)}$ Top dry wt (kg) = $(1-CF)(10^{(-1.1893 + 2.3564 \log D)})$ Branch dry wt (kg) = $10^{(-2.0987 + 2.3708 \log D)}$ Bole, top, and branch moisture content = 62.58 percent	1.0-14.0	1.0-18.0	Peterson et al. 1970 Van Cleve, personal communication
Paper birch	Bole green wt (kg) = $-13.18 + 0.355D^2$ Top green wt (kg) = $-4.768 + 3.609D + 0.02D^2$ Branch dry wt (kg) = $-0.8166 + 0.013D + 0.056D^2$ Branch moisture content = 72.77 percent	1.7-14.2	1.0-28.0	Yarie and Van Cleve, personal communication
Balsam poplar	Bole green wt (kg) = $8.8429 - 9.383D + 0.92D^2$ Top green wt (kg) = $(1-CF)\ (-7.6691 - 0.952D + 0.646D^2)$ Branch dry wt (kg) = $-0.026D + 0.041D^2$ Branch moisture content = 80.87 percent	1.6-18.3	1.0-31.0	Yarie and Van Cleve, personal communication
Black cottonwood	Bole green wt (lb) = $4.237D + 1.253D^2$ Top and branch green wt (lb) = $0.503D^2$	8.4-25.3	1.0-46.0	Yarie from State of Alaska data
Hemlock	ln STEMWOOD dry wt (kg) = $-2.172 + 2.257\ (\ln D)$ ln STEMBARK dry wt (kg) = $-4.373 + 2.258\ (\ln D)$ ln BRANCH dry wt (kg) = $-5.149 + 2.778\ (\ln D)$ Wood moisture content = 83.2 percent Branch moisture content = 84.73 percent Bark moisture content = 121.4 percent	6.0-30.7	1.0-62.0	Gholz et al. 1979 Kurucz 1969
Cedar	ln STEMWOOD dry wt (kg) = $-2.0927 + 2.1863\ (\ln D)$ ln STEMBARK dry wt (kg) = $-4.1934 + 2.1101\ (\ln D)$ ln BRANCH dry wt (kg) = $-3.2661 + 2.0877\ (\ln D)$ Wood moisture content = 96.3 percent Bark moisture content = 115.73 percent Branch moisture content = 98.05 percent	6.1-23.7	1.0-62.0	Gholz et al. 1979 Kurucz 1969

Table 8—Documentation of methodology, equations, and moisture content values (continued)

Species or species group	Equation used	Diameter ranges: Equation	Diameter ranges: Stand table	Source
		-------- Inches	-------	
Lodgepole pine	Bole dry wt (kg) = $CF(e^{(-2.9848 + 2.4287(\ln D))})$	1.0-11.3	1.0-26.0	Gholz et al. 1979
	Top dry wt (kg) = $(1-CF)(e^{(-2.9848 + 2.4287(\ln D))})$			
	Branch dry wt (kg) = $e^{(-4.6004 + 2.3533(\ln D))}$ Bole, top, and branch moisture content = 66 percent			Markwardt and Wilson 1935 Smith and Kozak 1971
Red alder	Bole dry wt (kg) = $CF(0.02 + 1.60(\frac{D^2H}{100}) - 0.0005(\frac{D^2H}{100})^2)$	5.0-300 [1]	10-30.0	Zavitkovski and Stevens 1972
	Top dry wt (kg) = $(1-CF)(0.02 + 1.60(\frac{D^2H}{100}) - 0.0005(\frac{D^2H}{100})^2)$			
	Branch dry wt (kg) = $0.01 + 0.48(\frac{D^2H}{100})$			
	Bole, top, and branch moisture content = 90 percent			Smith and Kozak 1971 Markwardt and Wilson 1935
True firs	ln STEMWOOD dry wt (kg) = $-3.5057 + 2.5744 (\ln D)$ ln STEMBARK dry wt (kg) = $-6.1166 + 2.8421 (\ln D)$ ln BRANCH dry wt (kg) = $-5.2370 + 2.6261 (\ln D)$	3.4-44.0	1.0-42.0	Gholz et al. 1979
	Wood moisture content = 49.2 percent			Markwardt and Wilson 1935
	Bark moisture content = 63.98 percent Branch moisture content = 51.77 percent			Smith and Kozak 1971
Sitka spruce	log wood volume = $0.9495(\log (\frac{D^2}{(0.5/D)+0.0132}))-1.2069$	-------	1.0-62.0	Fujimori et al. 1976
	Bark volume = .06 (wood volume) Stem green wt (kg) = (wood volume + bark volume) (0.5872)			
	log branch dry wt (kg) = $1.0554(\log (\frac{D^2}{(0.5/D)+0.0132}))-3.2569$			
	Branch moisture content = 42 percent			Markwardt and Wilson 1935

[1] This is the range of the independent variable $(\frac{D^2H}{100})$ and not an actual diameter range.

For all equations:

D = diameter at breast height in centimeters.
H = tree height in meters.
CF = Top to stem weight ratio conversion factor to be applied to stemwood equation to determine top and/or bole weight (table 9).
log = common logarithm.
ln = natural logarithm.

Bole is the main stem (wood and bark) to a 4-inch (10.1-cm) top, except for black cottonwood, which was taken to a 3-inch (7.6-cm) top.
Top is the main stem (wood and bark) above the bole.
Branch is all live branches (wood and bark).
Stem is the sum of bole and top for either wood or bark (that is, stemwood).

Table 9—Documentation on methodology, conversion factors

Species or species group	Top to stem weight ratio conversion factor (CF)	Source
White spruce	CF = bole weight/stem weight at each diameter class midpoint until 22 inches. At 22 inches and above CF = 0.98.	Yarie and Van Cleve, personal communication
Black spruce	Used white spruce CF.	
Balsam poplar	CF = bole weight/stem weight at each diameter class midpoint until 12 inches. At 12 inches and above CF = 0.95.	Yarie and Van Cleve, personal communication
Aspen, red alder	Used balsam poplar CF.	
True firs, hemlock, and cedar	CF = bole volume/stem volume at each diameter class midpoint until the following diameters were reached: True firs, d.b.h. = 16-in CF = 0.98 Hemlock, d.b.h. = 16-in CF = 0.98 Cedar, d.b.h. = 20-in CF = 0.95	Johnson 1955
Sitka spruce	CF = bole volume/stem volume at each diameter class midpoint until 12 inches. At 12 inches and above, CF = 0.94. The value of 0.5872 was calculated as: $(\mathrm{lbs/ft}^3)(\mathrm{ft}^3/\mathrm{dm}^3)\ (\mathrm{kg/lb})$ for both wood and bark to convert stem volume into green-stem weight.	Johnson 1955
Lodgepole pine	CF = bole weight/stem weight at each diameter class midpoint until 20 inches. At 20 inches, CF = 0.99.	Adamovich 1975

Yarie, John; Mead, Delbert. Aboveground tree biomass on productive forest land in Alaska. Res. Pap. PNW-298. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1982. 16 p.

Total aboveground woody biomass of trees on forest land that can produce 1.4 cubic meters per hectare per year of industrial wood in Alaska is 1.33 billion metric tons green weight. The estimated energy value of the standing woody biomass is 11.9 x 10^{15} Btu's. Statewide tables of biomass and energy values for softwoods, hardwoods, and species groups are presented.

Keywords: Biomass, energy, wood utilization, Alaska.

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Western Hemlock as a Veneer Resource

Thomas D. Fahey and Richard O. Woodfin, Jr.

CLEMSON UNIVERSITY
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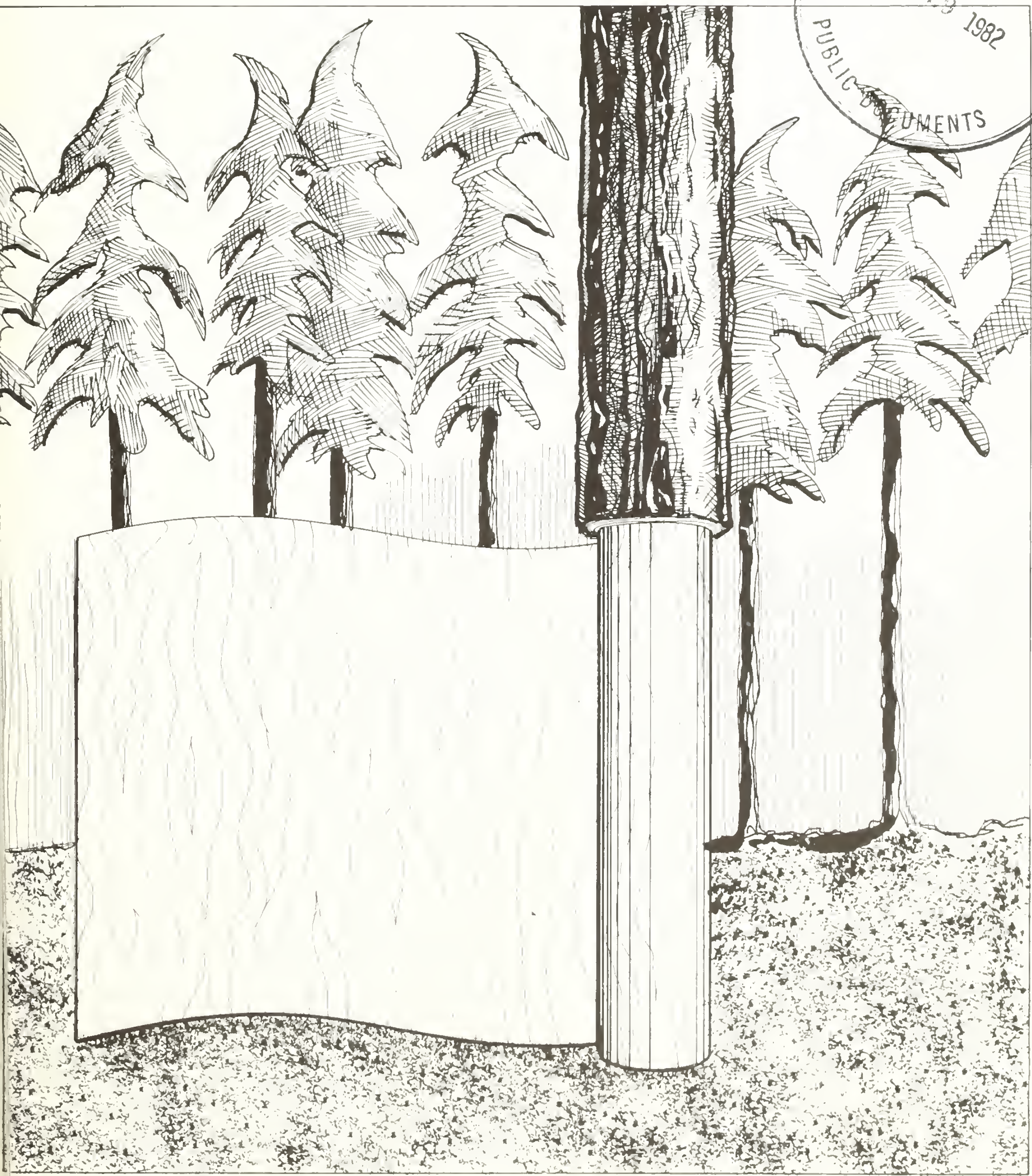

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bstract

Fahey, Thomas D.; Woodfin, Richard O., Jr. Western hemlock as a veneer resource. Res. Pap. PNW-299. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1982. 24 p.

Presents recovery of veneer grade and volume from western hemlock from Oregon and Washington. Veneer grade recovery varied by grade and size of logs. Veneer volume recovered was about 45 percent of the cubic volume of the log and varied somewhat with log diameter.

Keywords: Veneer yield, veneer recovery, western hemlock, *Tsuga heterophylla*.

ummary

This paper reports on a study of veneer grade yield from western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) trees from 38 plots in northwestern Washington and west-central Oregon. Veneer was peeled from blocks bucked from 391 long logs (167 trees). There was no significant difference in veneer recovery volumes between areas. Yields are shown for three nominal thicknesses of veneer (3/16-, 1/6-, and 1/8-inch) from logs ranging in diameter from 11 to 45 inches. About 45 percent of log volume was recovered as dry untrimmed veneer. Veneer grade recovered varied with the grade of log. For grade 3 saw logs, 66 percent of the veneer recovered was grade D. Grade 2 saw logs produced 47 percent grade D veneer. The highest grade logs, Peeler and No. 1 saw logs, produced only about 22 percent grade D veneer, with more than 40 percent in grades B patch and better. Results are applicable to production decisions, log allocation studies, and stand valuation decisions (by industry and land managers) for the range of timber size and quality sampled.

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ntroduction

Western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) comprises about 25 percent of the total commercial softwood sawtimber inventory in Alaska, Oregon, and Washington—about 240 billion board feet.

This paper presents combined veneer grade and veneer volume recovery information from research conducted at two mills to evaluate yield for western hemlock over its range in Oregon and Washington. The species is not a major raw material for veneer but is well accepted for construction plywood and inner plies and is beginning to be used more widely. Lutz (1971) reported peeling characteristics but included no information on product yield.

The recovery of veneer by grade from small diameter hemlock logs peeled on a 4-foot core lathe has been described by Fahey (1978).

Reports of veneer recovery for other species are available for comparison (Woodfin 1974, Woodfin and Pong 1974, Fahey 1974), as is a report on western hemlock lumber (Woodfin and Snellgrove 1976).

The primary objective of this research is to develop veneer grade and volume recovery by size and grade of western hemlock logs. This paper includes tables of veneer grade recovery by size and grade of log and by volume of products recovered during processing.

Yields presented will provide the mill manager with estimates of veneer grade recovery for making or adjusting log allocations between processing centers. In addition, this paper contains information required by resource managers to establish diameter and log grade values based on peeling western hemlock.

lethods

ample Selection

Timber for the studies came from the Olympic Peninsula of Washington State and from the central Cascade Range and the Coast Ranges of Oregon. Figure 1 shows the approximate location of sample areas.

The trees were selected from 38 sample areas picked to represent the size and quality of commercial western hemlock west of the Cascade Range. Diameter at breast height (d.b.h.) of sample trees ranged from about 13 to 58 inches. Trees with d.b.h. larger than 60 inches were excluded because they are so rare that a representative sample could not be selected. Trees smaller than 12-inch d.b.h. were not selected because they would not provide a chuckable veneer bolt.

The trees were distributed over a range of quality by applying log grades for coast Douglas-fir (Lane et al. 1973) to the first 16 feet of the tree bole with a 2-foot stump and trim allowance. Grades were applied without regard to visible defect. Sample trees showing no visible defect were selected as well as those with obvious defects. Basal wounds or scars, *Echinodontium tinctorium* conks, older stem breaks, frost cracks, and seams were considered defect indicators for sample stratification. The existing log grades for western hemlock were not used in stratifying the sample because they are excessively restrictive in defining surface characteristics.[1]

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[1] Log grade descriptions for hemlock, silver and white fir. Form R-6 2440-19E (3/1/63), 14 p. USDA For. Serv. Pacific Northwest Region, Portland, Oreg.

Figure 1.—Approximate location of sample areas.

Harvesting and Processing

Trees selected for the study were felled and bucked into long (woods length) logs suitable for rebucking as peeler blocks. Each log and subsequent bucked block was identified by tree number and position in the tree so yield could be related to quality and size of the piece.

Logs were transported to a cooperating veneer mill where they were scaled according to USDA Forest Service methods for timber from the west side of the Cascade Range.[2] They were then graded according to the USDA Forest Service Region 6 log grade description for hemlock (see footnote 1).

The study logs were bucked into block lengths of 102 inches at one mill and 103 inches at the other, and all suitable blocks were peeled according to each mill's practice. Neither mill used a temperature conditioning period before peeling the blocks.

The veneer was marked for identification under production conditions at the lathe. This permits veneer volume and grade yields to be measured for each block.

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[2] USDA Forest Service R-6 Supplement to National Forest Log Scaling Handbook for West-Side Log Scaling. April 1969.

Both mills in this study had 8-foot lathes and clipped green veneer for grade recovery. Green veneer was sorted by half sheets, strips of random widths, and 4-foot core stock ("fishtails"[3]). Neither mill produced full sheets (4 x 8 feet) from hemlock.

At one plant, all blocks were peeled into nominal 1/6-inch veneer. At the other plant, blocks having potentially high grade veneer were peeled into 1/8-inch veneer; lower quality blocks were peeled into 3/16-inch veneer. This tabulation shows veneer target sizes recorded at each mill by condition:

Veneer	Rough green	Rough dry
	Inches	
Nominal thickness:		
1/8-inch	0.139	0.127
3/16-inch	.218	.205
1/6-inch	—	.171
Width:		
Half sheets	26	25
Length:		
8 feet	101	101
4 feet	51	51

The thickness of the nominal 3/16-inch veneer is a problem that will be addressed in "Application of Results." Mill personnel referred to this particular peel as 3/16 inch. The dry thickness was 1/5-inch plus and the green thickness was 7/32 inch.

Actual dry thickness was used in calculating volume, but in this paper we will refer to it as 3/16 inch. The veneer was dried and then graded by or under the supervision of quality supervisors from the American Plywood Association (APA) or Timber Engineering Company (TECO).

ompilation of Data

Veneer yields are based on the grade and tally of all veneer—individual, dry, untrimmed pieces as they come from the dryer. Veneer losses in dry veneer handling and plywood production have been reported (Woodfin 1973). Information on western hemlock in that article is based on veneer from the Washington sample.

The amount of dry, untrimmed veneer recovered from each peeled block was determined by a count of half sheets and by measurement of the actual width of each 8-foot random strip and each fishtail. The average untrimmed width of half sheets plus the total width of strips and the average thickness of dry veneer were used to calculate yield. A computer program (Woodfin and Mei 1967) was used to compile the data.

---

[3] Fishtails are 4-foot long pieces of veneer produced when the blocks are reduced to a uniform cylinder.

Veneer volumes presented in this paper and plywood production figures reported by industry are in terms of square feet of veneer (or plywood) converted to the common base of 3/8-inch thickness. A yield of square feet of nominal 1/6-inch veneer (actual thickness 0.171 dry) is divided by the factor 0.375 to convert to the 3/8-inch basis. Similar factors are used for other veneer thicknesses. Nominal rather than actual thickness is commonly used by industry. We use actual thickness because there are differences among mills, or within the same mill at different times, in the actual thickness of nominal veneers.

Cubic volumes were computed for each log or block and for the total yield of usable veneer, peeler core, reject grade veneer, and the residual components of the log. Cubic volumes of individual peeler blocks were summed to obtain the volume of the long log. The cubic-foot volume of blocks was computed by the formula:

$\text{Cubic-foot volume}=0.001818L(D^2_S+D_SD_L+D^2_L)$
(Grosenbaugh 1963);

where 0.001818 is a constant,
L is the actual length in feet,
D_S is the average small-end diameter in inches, and
D_L is the average large-end diameter in inches.

An estimate of the volume of residue was obtained by subtracting the dry veneer and peeler core volumes from the cubic-foot log volume. The residue total includes spur trim, roundup loss, green veneer lost at the clipper, and veneer shrinkage.

Model Selection and Analysis

Data from both studies were analyzed for two purpose: (1) to determine the model that best predicts volume recovery and (2) to test for differences in recovery between the two studies.

In choosing the model, these relationships were tested:

$y=b_0+b_1D;$

$y=b_0+b_1D+b_2D^2;$

$y=b_0+b_1 1/D+b_2 1/D^2;$

where: y=cubic feet of veneer, and
d=small end diameter (inches).

The best model—$y=b_0b_1(1/D)+b_2(1/D^2)$—was selected, based on the sum of squares explained by regression and F value. Covariance analysis using this model showed no difference between the two studies in either slopes or adjusted means, and the samples were combined.

Analysis of veneer grade recovery assumed that veneer grade would vary by log grade. The models used for volume were tested for veneer grade, and the appropriate model was selected by use of the sum of squares explained by regression and F value.

esults and iscussion

The 391 long logs in these studies had an average scaling diameter of 22 inches (range, 11 to 45 inches). All logs were at least one-third sound as determined by the scaler. Table 1 summarizes the sample characteristics and recovery by log grade.

The geographic range of western hemlock suggests a variation in timber quality and for potential product recovery. This was tested with covariance analysis, and no significant difference was detected. The two studies reported here are combined as a single sample from western Oregon and Washington.

Table 1—Summary of woods-length western hemlock logs peeled in the study, by log grade

Log grade	Number of logs	Average log diameter	Average scale		Defect	Veneer recovery ratio[1]
			Gross	Net		
		Inches	- Board feet -		Percent	
Peeler	8	29.9	1,254	1,065	15	2.60
No. 1	10	33.6	1,760	1,497	15	2.45
No. 2	285	23.0	779	678	13	2.45
No. 3	88	18.6	435	344	21	1.69
All grades	391	22.4	736	632	14	2.36

[1] Square feet (3/8-inch basis) per board foot of net log scale. Veneer measurements are actual dry, untrimmed sizes.

covery by Veneer ade and Item

Veneer grade recovery varies by both log grade and log diameter; average veneer grade for each grade of log is in table 2. The recovery by grade, item, and veneer thickness for each log grade and for the total study is in appendix tables 4 through 8. The production by item was about 70 percent half sheets, 25 percent 8-foot strips, and 5 percent 4-foot strips for all log grades, except grade 3 which had more strips in both lengths. This percentage distribution of strips and fishtails is common to other veneer studies (Fahey 1974, Woodfin 1974). Note the increase in D grade veneer between the Peeler grade logs, 22.8 percent (table 4), and the No. 3 grade logs, 66.0 percent (table 7). Of equal importance is the fact that this trend holds for each veneer thickness peeled.

Recovery of veneer grades by log size and log grade may be more useful than averages to managers. Figure 2 shows the veneer grade plotted over log diameter by log grade.

Veneer grade by individual log grade and diameter class is in appendix tables 14-18. We suggest using figure 2 to estimate grade rather than these tables for any log grade and diameter group having less than 20 logs. These curves were developed by using covariance analysis of Peeler grade and grade 1 combined, grade 2, and grade 3 logs.

Table 2—Average veneer recovery from woods-length western hemlock logs, by log grade

Log grade	Log sample	Veneer volume, 3/8-inch basis	Veneer grade					
			A	A patch	B	B patch	C	D
	Number	Square feet	Percent					
Peeler	8	22,103	0.5	6.0	23.3	18.0	29.4	22.8
No. 1	10	36,684	.1	1.0	23.2	18.1	36.0	21.6
No. 2	285	474,105	.2	1.0	5.2	11.5	35.5	46.6
No. 3	88	51,087	0	.2	2.7	5.3	25.8	66.0
All grades	391	583,979	.2	1.1	6.8	11.7	34.4	45.8

For high grade logs, there was no relationship between diameter and recovery of veneer grade. For grade 2 saw logs, the percentage of D grade veneer stayed constant over the range of diameters, but the percentage of grade C veneer decreased. Percentage of B and Better increased with log size. For grade 3 saw logs, all groupings of veneer grade varied with log diameter. The percentage recovered as grade B and Better and grade D veneer increased, whereas the percentage in grade C declined.

The total variation in recovery by veneer grade is very high. Variation in groupings of veneer grade explained by grading and regression is:

Source of variation	D	C and D	B and Better
	Percent		
Regression only	9.6	44.7	44.7
Log grading only	54.0	39.7	39.7
Grading and regression	65.6	63.5	63.5

The interpretation of this tabulation and figure 2 is that the percentage of grade D veneer is strongly related to log grade, but not to diameter. Grade C and the B and Better veneer are related to both log grade and size. The variation in percentage of C and D is identical to the variation in B and Better because one grade grouping is the reciprocal of the other.

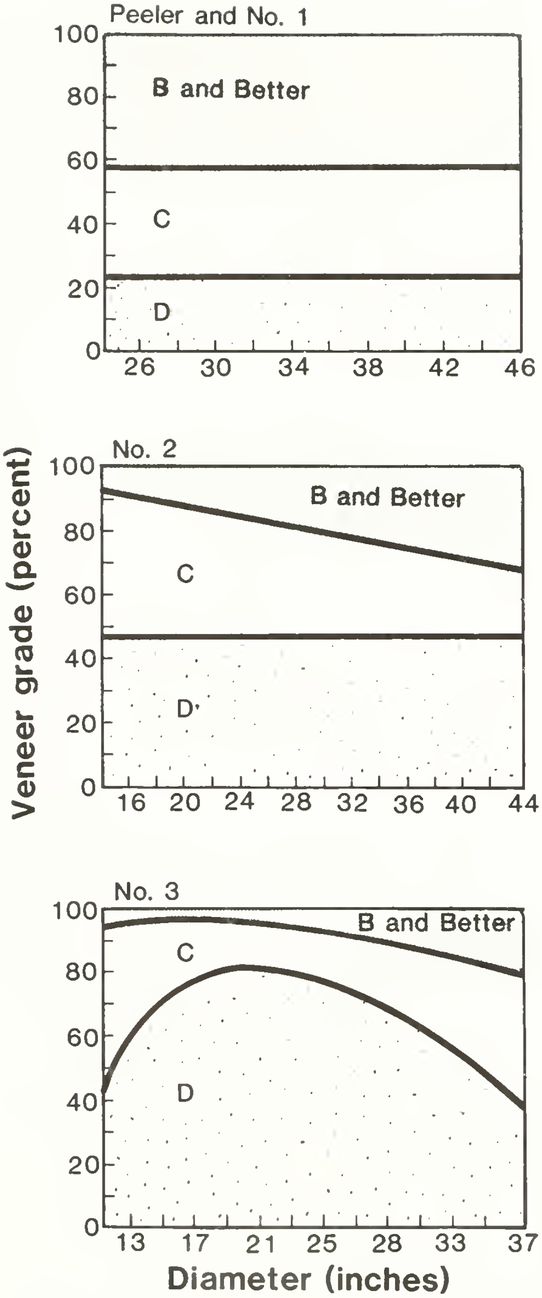

Figure 2.—Combined recovery of veneer grade by diameter for log grades Peeler and No. 1, No. 2, and No. 3.

Volume Recovery

The usual term for reporting results of veneer recovery is the veneer recovery ratio or square feet of veneer (3/8-inch basis) divided by net log scale. Veneer recovery ratio by log grade and for all log grades combined is presented in table 1. Recovery ratio by log grade and diameter class is in appendix tables 9-13. The overall average for all log grades was 2.36 square feet of 3/8-inch veneer per board foot of net log scale. Variation was so great in relation to Scribner volume that we chose not to present curved recovery by diameter for Scribner scale.

The log cubic volume and cubic feet of veneer, below grade veneer, core, and residue by log grade and diameter class are presented in detail in appendix tables 9-13. Average cubic recovery by log grade and for all grades combined is in table 3.

Table 3—Summary of cubic recovery of dry veneer as a percent of log cubic volume, by log grade

Log grade	Graded veneer	Below grade veneer	Core	Residual value[1]
		Percent		
Peeler	50.9	2.2	18.3	28.6
No. 1	48.2	1.4	20.9	29.5
No. 2	47.2	3.7	16.4	32.7
No. 3	26.6	5.9	21.4	46.2
All grades	44.4	3.8	17.5	34.3

[1] Includes block roundup, spur trim, and clipper loss which are chippable volume; also includes shrinkage from green to dry veneer.

The difference in recovery between grades was not tested because of the small sample of Peeler and No. 1 log grades and a major difference in diameter distribution between grade 2 and 3 logs. (All logs 13 inches or less are grade 3 regardless of their quality characteristics.)

There is a relationship between log diameter and percentage of cubic volume recovered as graded veneer (fig. 3). The correlation between diameter and percent recovery explains only 4 percent of the total variation. It provides a better estimator of log recovery than the mean, but only slightly better. Above 14 inches there is little increase in recovery as diameter increases. This is contrary to normal expectation but is a pattern that has repeatedly occurred (Fahey 1974, Woodfin 1974, Woodfin and Pong 1974).

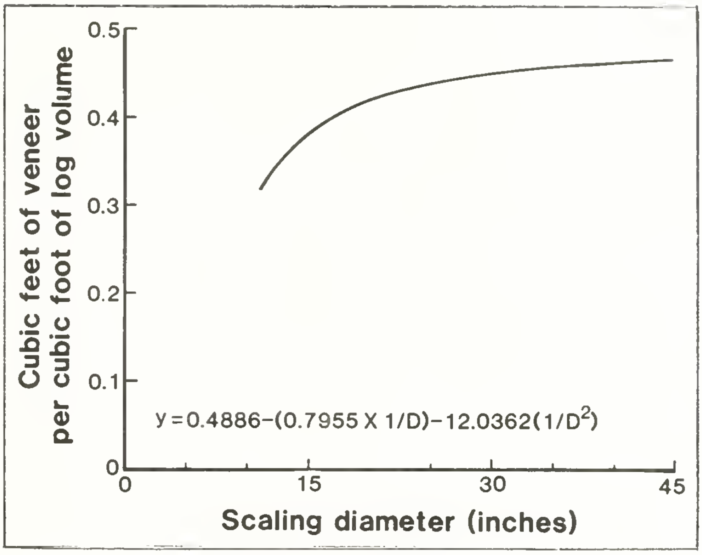

Figure 3.—Veneer recovery ratio—cubic feet of veneer volume per cubic foot of log volume by log diameter of western hemlock.

pplication of Results

Results from this study can be used to estimate veneer recovery from western hemlock, or in conjunction with the lumber recovery data[4] from the same locations, to develop log allocation models.

Information in this report is compiled on a square-foot, 3/8-inch basis and is computed on the actual dimensions of dry veneer. Conversion to finished panels is relatively simple. A panel layup study done with the Washington portion of this study (Woodfin 1973) showed that 14 percent of veneer volume was lost during stringing, reclip, patching, layup, and panel trim.

Industry often calculates square feet of green veneer on a nominal basis. There are several ways to convert the figures in the report to nominal sizes.[5]

ubic Volume

The actual volume of logs can be accounted for by using cubic volumes as a starting point. The breakdown by components for 100 cubic feet of log volume is shown in figure 4. The volume of finished panel is estimated to be 37.3 cubic feet, with a total of 45.2 cubic feet green volume (core, roundup, spur trim, and clipper loss) available for chips. In addition, 10.9 cubic feet of dry material (panel trim and below grade veneer) is available for fuel or particle board. Shrinkage is 6.6 cubic feet for dried wood. The 37.3 cubic feet of trimmed panel can be used to estimate the square foot (3/8-inch) panel volume.

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[4] Unpublished data on file at Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

[5] Details for calculating conversions are available at the Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

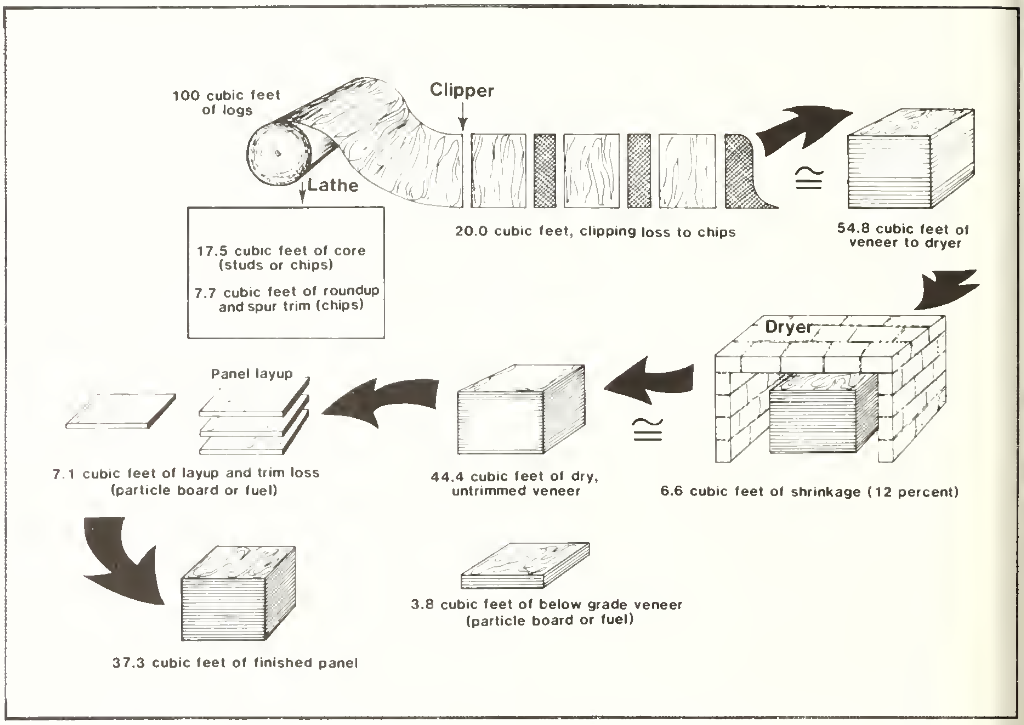

Figure 4.—Distribution of log volume.

The calculations are:

Veneer volume of 583,979 square feet (3/8-inch basis) divided by log volume of 41,777 cubic feet equals 13.98 times 0.84 recovery times 100 cubic feet equals 1,174 square feet of plywood (3/8-inch basis) per 100 cubic feet of log volume.

Cubic volumes by log grade and diameter are shown in appendix tables 9-13, but shrinkage is included in residue. Dividing the dry veneer volume plus the below-grade volume by 0.88 gives the volume of green veneer. Multiplying green veneer volume by 0.12 gives the volume of shrinkage. This should be subtracted from the reported residue to get an estimate of the true chippable volume.

Veneer recovery by log size can be estimated from the regression line or the equation in figure 3. Veneer recovery ratio for 17-inch logs was about 0.40 cubic foot of veneer per cubic foot of gross log volume.[6] One cubic foot of veneer is equal to 32 square feet on a 3/8-inch basis. Yield is 32x0.40=12.8 square feet per cubic foot of a 17-inch log. Panel layup and trim losses would reduce this volume.

Metric Conversions

1 inch = 2.54 centimeters
1 foot = 0.3048 meter
1 square foot = 0.0929 square meter
1 cubic foot = 0.02832 cubic meter

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[6] From the regression model the value is calculated as: $y=0.4886-(0.7955\times1/17)-12.0362(1/17^2)=0.4002$ or 40 percent.

Literature Cited

Fahey, Thomas D. Veneer recovery from second-growth Douglas-fir. Res. Pap. PNW-173. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1974. 22 p.

Fahey, Thomas D. Veneer recovery at a high-speed core lathe. For. Prod. J. 28(4): 19-20; 1978.

Grosenbaugh, L. R. Some suggestions for better sample tree measurement. Soc. Am. For. Proc. 1963: 36-52; 1963.

Lane, Paul H.; Woodfin, Richard O., Jr.; Henley, John W.; Plank, Marlin E. New timber cruising grades for coast Douglas-fir. Res. Pap. PNW-151. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1973. 12 p.

Lutz, J. F. Veneer species that grow in the United States. Res. Pap. FPL-167. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory; 1971. 127 p.

Woodfin, Richard O., Jr. Wood losses in plywood production—four species. For. Prod. J. 23(9): 98-106; 1973.

Woodfin, Richard O., Jr. Veneer yields by the new timber cruising grades for old-growth Douglas-fir. Res. Pap. PNW-174. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1974. 34 p.

Woodfin, Richard O., Jr.; Mei, M. A. Computer program for calculating veneer recovery volume and value. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1967. 39 p.

Woodfin, Richard O., Jr.; Pong, W. Y. Veneer recovery of red and white fir—California. Res. Pap. PNW-171. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1974. 48 p.

Woodfin, Richard O., Jr.; Snellgrove, Thomas A. Western hemlock in southeast Alaska—utilization, lumber recovery, and chip yield. Res. Pap. PNW-208. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1976. 33 p.

Appendix

Tables 4 to 8	Distribution of veneer grade of western hemlock logs
Tables 9 to 13	Log scale, veneer recovery, and cubic volumes, by grade of western hemlock logs
Tables 14 to 18	Recovery of veneer grade from western hemlock logs, by scaling diameter

Table 4—Distribution of veneer grade and item by thickness, Peeler grade western hemlock logs

Size of veneer item	Veneer grade						Total veneer volume	
	A	A patch	B	B patch	C	D		
	Percent						Square feet, 3/8-inch basis	Percent
Half sheets:								
1/8-inch	1.5	16.7	13.6	22.7	33.7	11.8	5,555	
1/6-inch	0	2.8	29.4	18.1	23.9	25.7	9,735	
3/16-inch	0	0	0	0	0	0	0	
Total							15,290	69.2
Random width, 8-foot:								
1/8-inch	0	0	.9	30.6	59.0	9.5	588	
1/6-inch	.6	1.8	25.7	12.4	29.8	29.7	5,805	
3/16-inch	0	0	0	0	0	0	0	
Total							6,393	28.9
Random width, 4-foot:								
1/8-inch	0	0	9.3	14.3	49.0	27.4	420	
1/6-inch	0	0	0	0	0	0	0	
3/16-inch	0	0	0	0	0	0	0	
Total							420	1.9
Total or average	.5	6.0	23.3	18.0	29.4	22.8	22,103	100.0

Table 5—Distribution of veneer grade and item by thickness, grade 1 western hemlock logs

Size of veneer item	Veneer grade						Total veneer volume	
	A	A patch	B	B patch	C	D		
	Percent						Square feet, 3/8-inch basis	Percent
Half sheets:								
1/8-inch	0.8	7.6	18.9	12.7	49.2	10.8	4,478	
1/6-inch	0	.1	31.9	14.3	31.3	22.4	18,919	
3/16-inch	0	0	0	75.1	23.4	1.5	3,279	
Total							26,676	72.6
Random width, 8-foot:								
1/8-inch	0	0	6.4	11.2	68.1	14.3	1,642	
1/6-inch	.1	.1	19.8	5.4	39.1	35.5	7,587	
3/16-inch	0	0	0	72.9	17.2	9.9	343	
Total							9,572	26.1
Random width, 4-foot:								
1/8-inch	0	0	2.2	22.6	43.1	32.1	371	
1/6-inch	0	0	0	0	0	0	0	
3/16-inch	0	0	0	0	0	100.0	65	
Total							436	1.2
Total or average	.1	1.0	23.2	18.1	36.0	21.6	36,684	100.0

Table 6—Distribution of veneer grade and item by thickness, grade 2 western hemlock logs

Size of veneer item	Veneer grade						Total veneer volume	
	A	A patch	B	B patch	C	D		
	Percent						Square feet, 3/8-inch basis	Percent
Half sheets:								
1/8-inch	0.6	3.4	3.9	15.7	34.5	41.9	118,589	
1/6-inch	[1]	.3	5.8	11.3	31.0	51.6	173,222	
3/16-inch	0	0	.9	16.6	37.6	44.9	36,972	
Total							328,783	69.4
Random width, 8-foot:								
1/8-inch	[1]	.2	8.8	6.3	55.4	29.3	37,605	
1/6-inch	.1	.1	8.1	4.4	32.3	55.0	61,350	
3/16-inch	0	0	.5	16.2	39.5	43.0	24,499	
Total							123,454	26.0
Random width, 4-foot:								
1/8-inch	0	0	7.8	10.0	40.2	42.0	14,487	
1/6-inch	0	0	0	0	0	0	0	
3/16-inch	0	0	0	0	48.8	51.2	7,381	
Total							21,868	4.6
Total or average	.2	1.0	5.2	11.5	35.5	46.6	474,105	100.0

[1] Less than 0.05.

Table 7—Distribution of veneer grade and item by thickness, grade 3 western hemlock logs

Size of veneer item	Veneer grade						Total veneer volume	
	A	A patch	B	B patch	C	D		
	Percent						Square feet, 3/8-inch basis	Percent
Half sheets:								
1/8-inch	0	1.0	0.6	3.9	25.0	69.5	1,879	
1/6-inch	0	.5	2.5	6.1	23.6	67.3	19,421	
3/16-inch	0	0	3.6	7.0	13.1	76.3	6,887	
Total							28,187	55.2
Random width, 8-foot:								
1/8-inch	0	0	10.6	0	54.0	35.4	814	
1/6-inch	0	0	4.9	1.9	27.9	65.3	10,357	
3/16-inch	0	0	.8	9.6	29.1	60.5	7,941	
Total							19,112	37.4
Random width, 4-foot:								
1/8-inch	0	0	1.5	3.6	49.6	45.3	662	
1/6-inch	0	0	0	0	0	0	0	
3/16-inch	0	0	0	0	39.9	60.1	3,126	
Total							3,788	7.4
Total or average	0	.2	2.7	5.3	25.8	66.0	51,087	100.0

Table 8—Distribution of veneer grade and item by thickness, all log grades of western hemlock logs

Size of veneer item	Veneer grade						Total veneer volume	
	A	A patch	B	B patch	C	D		
	Percent						Square feet, 3/8-inch basis	Percent
Half sheets:								
1/8-inch	0.7	4.1	4.8	15.7	34.8	39.9	130,501	
1/6-inch	0	.4	8.8	11.4	30.1	49.3	221,297	
3/16-inch	0	0	1.3	19.2	33.0	46.5	47,138	
Total							398,936	68.3
Random width, 8-foot:								
1/8-inch	1/	.1	8.7	6.8	55.9	28.5	40,649	
1/6-inch	.1	.2	9.9	4.7	32.3	52.8	85,099	
3/16-inch	0	0	.6	15.2	36.8	47.4	32,783	
Total							158,531	27.2
Random width, 4-foot:								
1/8-inch	0	0	7.4	10.1	40.9	41.6	15,940	
1/6-inch	0	0	0	0	0	0	0	
3/16-inch	0	0	0	0	45.9	54.1	10,572	
Total							26,512	4.5
Total or average	.2	1.1	6.8	11.7	34.4	45.8	583,979	100.0

Table 9—Log scale, veneer recovery, and cubic volume by scaling diameter, Peeler grade western hemlock logs

Log scaling diameter	Number of logs	Scale[1]		Veneer recovery		Cubic volume					
		Gross	Net	Volume	Recovery ratio	Log	Veneer	Veneer recovery	Below grade veneer	Core	Residue[2]
Inches		- Board feet -		Square feet		- Cubic feet -		Percent	- - - - Cubic feet - - - - -		
26	1	820	690	1,277	1.85	105.88	41.17	38.9	--	19.46	45.25
27	1	1,160	1,160	3,144	2.71	163.41	101.22	61.9	0.47	13.43	48.29
28	2	2,480	2,330	5,057	2.17	336.02	162.75	48.4	5.20	47.94	120.13
29	0	--	--	--	--	--	--	--	--	--	--
30	0	--	--	--	--	--	--	--	--	--	--
31	2	3,020	2,460	6,450	2.62	434.16	203.61	46.9	9.11	109.22	112.22
32	0	--	--	--	--	--	--	--	--	--	--
33	1	1,670	1,180	3,859	3.27	222.75	124.24	55.8	.20	52.46	45.85
34	0	--	--	--	--	--	--	--	--	--	--
35	1	880	690	2,316	3.36	123.93	72.44	58.4	16.20	11.22	24.07
Total or average	8	10,030	8,510	22,103	2.60	1,386.15	705.43	50.9	31.18	253.73	395.81

[1] USDA Forest Service R-6 Supplement to National Forest Log Scaling Handbook for West-Side Log Scaling. April 1969.

[2] Includes shrinkage.

Table 10—Log scale, veneer recovery, and cubic volume by scaling diameter, grade 1 western hemlock logs

Log scaling diameter	Number of logs	Scale[1]		Veneer recovery		Cubic volume					
		Gross	Net	Volume	Recovery ratio	Log	Veneer	Veneer recovery	Below grade veneer	Core	Residue[2]
Inches		- Board feet -		Square feet		- Cubic feet -		Percent	- - - - Cubic feet - - - - -		
26	1	1,060	980	3,687	3.76	151.40	115.24	76.1	2.98	13.40	19.78
27	0	--	--	--	--	--	--	--	--	--	--
28	1	1,240	1,130	3,529	3.12	170.00	110.27	64.9	9.48	14.22	36.03
29	1	1,290	890	1,886	2.12	177.01	60.70	34.3	.56	53.52	62.23
30	0	--	--	--	--	--	--	--	--	--	--
31	2	3,020	2,840	5,730	2.02	423.91	184.37	43.5	.85	75.38	163.31
32	0	--	--	--	--	--	--	--	--	--	--
33	0	--	--	--	--	--	--	--	--	--	--
34	0	--	--	--	--	--	--	--	--	--	--
35	2	3,720	3,420	10,039	2.94	543.70	323.11	59.4	2.50	56.79	161.30
36	0	--	--	--	--	--	--	--	--	--	--
37	1	1,670	1,300	2,962	2.28	219.51	92.54	42.2	15.33	25.74	85.90
38	0	--	--	--	--	--	--	--	--	--	--
39	1	2,380	2,060	6,746	3.27	350.23	217.11	62.0	.93	52.30	79.89
40	0	--	--	--	--	--	--	--	--	--	--
41	0	--	--	--	--	--	--	--	--	--	--
42	0	--	--	--	--	--	--	--	--	--	--
43	0	--	--	--	--	--	--	--	--	--	--
44	0	--	--	--	--	--	--	--	--	--	--
45	1	3,220	2,350	2,105	.90	392.61	67.82	17.3	.11	215.70	108.98
Total or average	10	17,600	14,970	36,684	2.45	2,428.37	1,171.16	48.2	32.74	507.05	717.42

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[1] USDA Forest Service R-6 Supplement to National Forest Log Scaling Handbook for West-Side Log Scaling. April 1969.

[2] Includes shrinkage.

Table 11—Log scale, veneer recovery, and cubic volume by scaling diameter, grade 2 western hemlock logs

og caling iameter	Number of logs	Scale[1]		Veneer recovery		Cubic volume					
		Gross	Net	Volume	Recovery ratio	Log	Veneer	Veneer recovery	Below grade veneer	Core	Residue[2]
nches		- Board feet -		Square feet		- - Cubic feet - -		Percent	- - - - Cubic feet - - - - -		
4	22	4,180	3,830	10,474	2.73	869.97	335.61	38.6	16.64	209.25	308.47
5	22	6,030	5,470	14,923	2.73	1,141.59	477.61	41.8	17.40	277.13	369.45
6	25	7,570	7,210	17,193	2.38	1,300.27	553.10	42.5	21.87	258.27	467.03
7	19	6,370	5,990	15,783	2.63	1,085.94	502.75	46.3	42.14	210.46	330.59
8	15	5,860	5,560	14,208	2.56	961.84	452.83	47.1	32.81	190.42	285.78
9	20	8,700	8,280	22,315	2.70	1,423.69	710.13	49.9	31.52	273.68	408.36
0	19	10,110	9,030	22,139	2.45	1,620.33	702.97	43.4	51.67	308.40	557.29
1	10	6,190	5,700	15,426	2.71	960.21	495.76	51.6	6.36	123.33	334.76
2	11	7,510	6,550	15,927	2.43	1,163.35	502.91	43.2	50.70	351.70	358.04
3	13	9,430	8,640	22,432	2.60	1,415.87	714.36	50.4	47.03	269.08	385.40
4	14	11,170	9,910	23,645	2.39	1,623.96	752.95	46.4	42.99	264.40	563.62
5	8	8,140	7,260	15,077	2.08	1,112.74	480.51	43.2	39.66	233.29	359.28
6	5	5,060	4,630	12,590	2.72	761.03	400.63	52.6	35.24	100.27	224.89
7	5	5,800	5,270	15,169	2.88	838.76	482.53	57.5	32.98	102.78	220.47
8	9	9,580	8,630	19,149	2.22	1,287.73	607.23	47.2	74.33	171.15	435.02
9	9	10,710	8,940	22,857	2.56	1,497.28	721.12	48.2	97.44	183.90	494.82
0	5	6,260	5,170	12,210	2.36	808.60	387.10	47.9	27.59	105.74	288.17
1	4	5,240	4,480	10,140	2.26	740.76	322.93	43.6	19.67	111.13	287.03
2	6	8,280	6,670	14,418	2.16	1,033.11	451.35	43.7	45.62	164.71	371.43
3	7	11,730	9,900	25,050	2.53	1,664.69	798.26	48.0	32.01	265.11	569.31
4	10	15,400	13,120	33,989	2.59	2,264.20	1,078.55	47.6	80.80	295.33	309.52
5	3	5,140	4,080	8,641	2.12	641.55	270.06	42.1	38.51	120.29	212.69
6	3	5,480	4,720	10,187	2.16	811.02	321.74	39.7	42.50	107.88	338.90
7	2	3,860	3,150	7,473	2.37	442.27	233.52	52.8	11.38	32.68	164.69
8	6	10,300	8,430	21,690	2.57	1,258.12	677.80	53.9	89.81	168.60	321.91
9	2	4,200	3,210	10,018	3.12	678.46	318.30	46.9	12.80	134.00	213.36
0	5	11,000	8,400	13,008	1.55	826.39	411.00	49.7	39.79	120.97	254.63
1	0	--	--	--	--	--	--	--	--	--	--
2	3	6,540	5,750	15,922	2.77	856.72	497.64	58.1	65.02	82.13	211.93
3	2	3,670	3,230	7,101	2.20	468.34	221.95	47.4	26.81	56.77	162.81
4	1	2,410	2,100	4,951	2.36	311.56	154.73	49.7	15.60	41.44	99.79
otal or average	285	221,920	193,310	474,105	2.45	31,870.35	15,037.93	47.2	1,188.69	5,234.29	10,409.44

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[1] Forest Service R-6 Supplement to National Forest Log Scaling Handbook for West-Side Log Scaling. April 1969.

[2] Includes shrinkage.

Table 12—Log scale, veneer recovery, and cubic volume by scaling diameter, grade 3 western hemlock logs

Log scaling diameter	Number of logs	Scale[1]		Veneer recovery		Cubic volume					
		Gross	Net	Volume	Recovery ratio	Log	Veneer	Veneer recovery	Below grade veneer	Core	Residue[2]
Inches		- Board feet -		Square feet		- - Cubic feet - -		Percent	- - - - Cubic feet - - - - -		
11	1	120	70	147	2.10	36.57	4.72	12.9	2.31	8.84	20.70
12	6	880	810	1,981	2.45	180.72	63.47	35.1	1.36	51.67	64.22
13	20	2,930	2,740	7,122	2.60	587.68	229.29	39.0	2.87	151.00	204.52
14	6	950	890	1,938	2.18	208.78	62.34	29.8	5.81	49.94	90.69
15	4	680	520	805	1.55	122.03	25.90	21.2	.37	48.78	46.98
16	6	1,700	1,300	2,448	1.88	356.26	77.60	21.8	35.78	75.94	166.94
17	6	1,560	1,340	1,753	1.31	252.73	56.21	22.2	6.52	79.81	110.19
18	8	2,830	2,490	3,842	1.54	536.39	122.64	22.9	43.68	127.16	242.91
19	1	510	370	335	.91	66.81	10.47	15.7	4.04	8.36	43.94
20	3	1,330	1,030	1,785	1.73	192.33	57.47	29.9	2.20	64.07	68.59
21	4	1,750	1,080	2,202	2.04	321.63	68.90	21.4	17.68	76.44	158.61
22	1	350	300	598	1.99	57.09	18.65	32.7	5.37	8.87	24.20
23	3	1,600	1,230	1,117	.91	226.04	35.14	15.5	18.79	49.73	122.38
24	3	1,770	1,330	1,943	1.46	262.62	62.17	23.7	26.50	53.77	120.18
25	2	1,960	1,360	1,305	.96	208.86	41.90	20.1	4.66	36.21	126.09
26	3	2,680	1,720	2,233	1.30	380.17	70.81	18.6	13.82	114.11	181.43
27	1	680	450	255	.57	78.49	8.24	10.5	.85	15.78	53.62
28	2	2,480	2,100	3,862	1.84	391.60	117.33	30.0	4.24	55.82	214.21
29	0	--	--	--	--	--	--	--	--	--	--
30	2	2,390	1,860	2,633	1.42	369.34	82.38	22.3	43.15	37.83	205.98
31	0	--	--	--	--	--	--	--	--	--	--
32	1	1,560	1,510	2,103	1.39	229.55	65.72	28.6	42.92	20.52	100.39
33	1	1,270	660	1,953	2.96	192.17	61.01	31.7	20.84	17.90	92.42
34	1	850	650	240	.37	64.35	7.48	11.6	6.29	16.74	33.84
35	0	--	--	--	--	--	--	--	--	--	--
36	3	5,420	4,430	8,487	1.92	770.23	268.19	34.8	47.68	132.37	321.99
Total or average	88	38,250	30,240	51,087	1.69	6,092.44	1,618.03	26.6	357.73	1,301.66	2,815.02

[1] USDA Forest Service R-6 Supplement to National Forest Log Scaling Handbook for West-Side Log Scaling. April 1969.

[2] Includes shrinkage.

Table 13—Log scale, veneer recovery, and cubic volume by scaling diameter for all log grades, western hemlock logs

Log scaling diameter	Number of logs	Scale[1]		Veneer recovery		Cubic volume					
		Gross	Net	Volume	Recovery ratio	Log	Veneer	Veneer recovery	Below grade veneer	Core	Residue[2]
Inches		Board feet		Square feet		Cubic feet		Percent	Cubic feet		
11	1	120	70	147	2.10	36.57	4.72	12.9	2.31	8.84	20.70
12	6	880	810	1,981	2.45	180.72	63.47	35.1	1.36	51.67	64.22
13	20	2,930	2,740	7,122	2.60	587.68	229.29	39.0	2.87	151.00	204.52
14	28	5,130	4,720	12,412	2.63	1,078.75	397.95	36.9	22.45	259.19	399.16
15	26	6,710	5,990	15,728	2.63	1,263.62	503.51	39.8	17.77	325.91	416.43
16	31	9,270	8,510	19,641	2.31	1,656.53	630.70	38.1	57.65	334.21	633.97
17	25	7,930	7,330	17,536	2.39	1,338.67	558.96	41.8	48.66	290.27	440.78
18	23	8,690	8,050	18,050	2.24	1,498.23	575.47	38.4	76.49	317.58	528.69
19	21	9,210	8,650	22,560	2.62	1,490.50	720.60	48.3	35.56	282.04	452.30
20	22	11,440	10,060	23,924	2.38	1,812.66	760.44	42.0	53.87	372.47	625.88
21	14	7,940	6,780	17,628	2.60	1,281.84	564.66	44.0	24.04	199.77	493.37
22	12	7,860	6,850	16,525	2.41	1,220.44	521.56	42.7	56.07	260.57	382.24
23	16	11,030	9,870	23,549	2.39	1,641.91	749.50	45.6	65.82	318.81	507.78
24	17	12,940	11,240	25,588	2.28	1,886.58	815.12	43.2	69.49	318.17	683.80
25	10	10,100	8,620	16,382	1.90	1,321.60	522.41	39.5	44.32	269.50	485.37
26	10	9,620	8,020	19,787	2.47	1,398.48	627.85	44.9	52.04	247.24	471.35
27	7	7,640	6,880	18,568	2.70	1,080.66	591.99	54.8	34.30	131.99	322.38
28	14	15,780	14,190	31,597	2.23	2,185.35	997.58	45.6	93.25	289.13	805.39
29	10	12,000	9,830	24,743	2.52	1,674.29	781.82	46.7	98.00	237.42	557.05
30	7	8,650	7,030	14,843	2.11	1,177.94	469.48	39.8	70.74	143.57	494.15
31	8	11,280	9,780	22,320	2.28	1,598.83	710.91	44.4	29.63	295.73	562.56
32	7	9,840	8,180	16,521	2.02	1,262.66	517.07	41.0	88.54	185.23	471.82
33	9	14,670	11,740	30,862	2.63	2,079.61	983.51	47.3	53.05	335.47	707.58
34	11	16,250	13,770	34,229	2.49	2,328.55	1,086.03	46.6	87.09	312.07	843.36
35	6	9,740	8.190	20,996	2.56	1,309.18	665.61	50.8	57.21	188.30	398.06
36	6	10,900	9,150	18,674	2.04	1,581.25	589.93	37.3	90.18	240.25	660.89
37	3	5,530	4,450	10,435	2.34	661.78	326.06	49.3	26.71	58.42	250.59
38	6	10,300	8,430	21,690	2.57	1,258.12	677.80	53.9	89.81	168.60	321.91
39	3	6,580	5,270	16,764	3.18	1,028.69	535.41	52.0	13.73	186.30	293.25
40	5	11,000	8,400	13,008	1.55	826.39	411.00	49.7	39.79	120.97	254.63
41	0	--	--	--	--	--	--	--	--	--	--
42	3	6,540	5,750	15,922	2.77	856.72	497.64	58.1	65.02	82.13	211.93
43	2	3,670	3,230	7,101	2.20	468.34	221.95	47.4	26.81	56.77	162.81
44	1	2,410	2,100	4,951	2.36	311.56	154.73	49.7	15.60	41.44	99.79
45	1	3,220	2,350	2,105	.90	392.61	67.82	17.3	.11	215.70	108.98
Total or average	391	287,800	247,030	583,979	2.36	41,777.31	18,532.55	44.4	1,610.34	7,296.73	14,337.69

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[1] USDA Forest Service R-6 Supplement to National Forest Log Scaling Handbook for West-Side Log Scaling. April 1969.

[2] Includes shrinkage.

Table 14—Recovery of veneer grade by scaling diameter, Peeler grade western hemlock logs

Log scaling diameter	Number of logs	Veneer volume, 3/8-inch basis	Veneer grade					
			A	A patch	B	B patch	C	D
Inches		Square feet	Percent					
26	1	1,277	0	0	20.0	13.9	24.9	41.2
27	1	3,144	0	2.1	23.0	20.5	18.0	36.4
28	2	5,057	.5	1.3	39.0	13.4	21.8	24.0
29	0	--	--	--	--	--	--	--
30	0	--	--	--	--	--	--	--
31	2	6,450	1.3	15.0	17.0	30.5	19.5	16.7
32	0	--	--	--	--	--	--	--
33	1	3,859	.3	5.4	27.7	10.7	42.0	13.9
34	0	--	--	--	--	--	--	--
35	1	2,316	0	0	1.7	4.4	70.3	23.6
Total or average	8	22,103	.5	6.0	23.3	18.0	29.4	22.8

Table 15—Recovery of veneer grade by scaling diameter, grade 1 western hemlock logs

Log scaling diameter	Number of logs	Veneer volume, 3/8-inch basis	Veneer grade					
			A	A patch	B	B patch	C	D
Inches		Square feet	Percent					
26	1	3,687	0	0	0	73.6	22.4	4.0
27	0	--	--	--	--	--	--	--
28	1	3,529	0	4.4	20.5	7.2	62.5	5.4
29	1	1,886	0	.4	5.3	2.7	55.5	36.1
30	0	--	--	--	--	--	--	--
31	2	5,730	0	0	17.8	8.9	43.4	29.9
32	0	--	--	--	--	--	--	--
33	0	--	--	--	--	--	--	--
34	0	--	--	--	--	--	--	--
35	2	10,039	0	.1	21.4	11.8	41.2	25.5
36	0	--						
37	1	2,962	1.2	6.3	8.0	19.6	43.1	21.8
38	0	--						
39	1	6,746	.1	.1	45.8	17.1	12.6	24.3
40	0	--	--	--	--	--	--	--
41	0	--	--	--	--	--	--	--
42	0	--	--	--	--	--	--	--
43	0	--	--	--	--	--	--	--
44	0	--	--	--	--	--	--	--
45	1	2,105	0	0	55.7	10.0	17.7	16.6
Total or average	10	36,684	.1	1.0	23.2	18.1	36.0	21.6

Table 16—Recovery of veneer grade by scaling diameter, grade 2 western hemlock logs

Log scaling diameter	Number of logs	Veneer volume, 3/8-inch basis	Veneer grade					
			A	A patch	B	B patch	C	D
Inches		Square feet	Percent					
14	22	10,474	0	0	1.7	6.9	45.9	45.5
15	22	14,923	.1	.2	3.7	6.4	42.1	47.5
16	25	17,193	0	0	.9	6.0	35.4	57.7
17	19	15,783	0	0	1.0	10.5	39.0	49.5
18	15	14,208	0	.3	2.4	7.3	53.1	36.9
19	20	22,315	0	.5	2.8	6.2	48.8	41.7
20	19	22,139	.1	.6	4.1	4.6	48.7	41.9
21	10	15,426	0	0	6.5	7.6	40.6	45.3
22	11	15,927	0	.9	5.3	7.6	40.5	45.7
23	13	22,432	0	.4	3.8	15.3	36.5	44.0
24	14	23,645	0	0	4.1	8.0	35.5	52.4
25	8	15,077	.1	.2	9.9	11.1	37.7	41.0
26	5	12,590	.2	4.1	8.3	14.1	24.8	48.5
27	5	15,169	0	2.0	5.2	12.3	37.6	42.9
28	9	19,149	.2	.8	5.7	12.2	25.8	55.3
29	9	22,857	0	.1	6.2	5.6	39.0	49.1
30	5	12,210	0	.3	5.6	9.8	29.3	55.0
31	4	10,140	0	.3	5.8	15.0	24.7	54.2
32	6	14,418	.2	4.3	5.0	17.8	23.0	49.7
33	7	25,050	.1	.7	5.7	10.4	21.7	61.4
34	10	33,989	.3	1.0	11.0	13.3	23.6	50.8
35	3	8,641	0	0	1.0	10.4	53.8	34.8
36	3	10,187	.3	1.2	8.6	15.5	31.0	43.4
37	2	7,473	1.3	2.6	6.8	17.4	36.2	35.7
38	6	21,690	1.4	3.1	4.5	16.2	31.9	42.9
39	2	10,018	0	0	5.0	19.1	15.1	60.8
40	5	13,008	.1	.4	7.5	21.2	34.0	36.8
41	0	--	--	--	--	--	--	--
42	3	15,922	.5	4.0	3.9	23.9	38.9	28.8
43	2	7,101	.5	2.8	5.5	17.2	49.5	24.5
44	1	4,951	0	2.4	2.9	17.8	45.9	31.0
Total or average	285	474,105	.2	1.0	5.2	11.5	35.5	46.6

Table 17—Recovery of veneer grade by scaling diameter, grade 3 western hemlock logs

Log scaling diameter	Number of logs	Veneer volume, 3/8-inch basis	Veneer grade					
			A	A patch	B	B patch	C	D
Inches		Square feet	- - - - - - - - - -		Percent		- - - - - - - - - -	
11	1	147	0	0	0	0	0	100.0
12	6	1,981	0	0	0	4.1	58.4	37.5
13	20	7,122	0	0	.4	5.3	42.5	51.8
14	6	1,938	0	0	.2	0	11.9	87.9
15	4	805	0	0	0	0	14.2	85.8
16	6	2,448	0	0	1.6	2.2	17.4	78.8
17	6	1,753	0	0	.9	1.0	27.3	70.8
18	8	3,842	0	0	.4	3.0	12.6	84.0
19	1	335	0	0	0	3.6	52.2	44.2
20	3	1,785	0	0	.6	4.5	11.2	83.7
21	4	2,202	0	0	0	1.7	14.7	83.6
22	1	598	0	0	0	.5	29.6	69.9
23	3	1,117	0	0	7.2	1.3	25.9	65.6
24	3	1,943	0	0	1.2	5.8	15.8	77.2
25	2	1,305	0	0	.9	2.4	9.0	87.7
26	3	2,233	0	0	10.8	.4	15.3	73.5
27	1	255	0	0	35.3	9.4	11.8	43.5
28	2	3,862	0	0	2.3	2.9	21.6	73.2
29	0	--	--	--	--	--	--	--
30	2	2,633	0	0	.4	7.3	24.5	67.8
31	0	--	--	--	--	--	--	--
32	1	2,103	0	0	.4	1.8	20.8	77.0
33	1	1,953	0	0	6.5	17.5	20.2	55.8
34	1	240	0	0	6.7	2.9	52.9	37.5
35	0	--	--	--	--	--	--	--
36	3	8,487	0	1.5	7.0	12.4	33.5	45.6
Total or average	88	51,087	0	.2	2.7	5.3	25.8	66.0

Table 18—Recovery of veneer grade by scaling diameter, all grades of western hemlock logs

Log scaling diameter	Number of logs	Veneer volume, 3/8-inch basis	Veneer grade					
			A	A patch	B	B patch	C	D
Inches		Square feet	Percent					
8	0	--						
9	0	--						
10	0	--						
11	1	147	0	0	0	0	0	100.0
12	6	1,981	0	0	0	4.1	58.4	37.5
13	20	7,122	0	0	0.4	5.3	42.5	51.8
14	28	12,412	0	0	1.5	5.8	40.5	52.2
15	26	15,728	.1	.2	3.5	6.1	40.6	49.5
16	31	19,641	0	0	1.0	5.5	33.2	60.3
17	25	17,536	0	0	1.0	9.5	37.8	51.7
18	23	18,050	0	.2	1.9	6.4	44.5	47.0
19	21	22,650	0	.5	2.8	6.2	48.7	41.8
20	22	23,924	.1	.6	3.9	4.6	45.8	45.0
21	14	17,628	0	0	5.7	6.9	37.3	50.1
22	12	16,525	0	.9	5.1	7.4	40.1	46.5
23	16	23,549	0	.3	3.9	14.6	36.0	45.2
24	17	25,588	0	0	3.9	7.8	34.0	54.3
25	10	16,382	.1	.2	9.2	10.4	35.5	44.6
26	10	19,787	.1	2.6	7.8	23.6	23.3	42.6
27	7	18,568	0	2.0	8.6	13.7	33.9	41.8
28	14	31,597	.2	1.2	12.2	10.7	28.8	46.9
29	10	24,743	0	.2	6.2	5.4	40.1	48.1
30	7	14,843	0	.2	4.7	9.4	28.4	57.3
31	8	22,320	.4	4.5	12.1	17.9	28.0	37.1
32	7	16,521	.2	3.7	4.4	15.8	22.7	53.2
33	9	30,862	.1	1.3	8.5	10.9	24.1	55.1
34	11	34,229	.3	1.0	10.9	13.2	23.8	50.8
35	6	20,996	0	0	10.9	10.4	49.5	29.2
36	6	18,674	.2	1.3	7.9	14.1	32.1	44.4
37	3	10,435	1.3	3.7	7.1	18.1	38.1	31.7
38	6	21,690	1.4	3.1	4.5	16.2	31.9	42.9
39	3	16,764	0	0	21.5	18.3	14.1	46.1
40	5	13,008	.1	.4	7.5	21.2	34.0	36.8
41	0	--	--	--	--	--	--	--
42	3	15,922	.5	4.0	3.9	23.9	38.9	28.8
43	2	7,101	.5	2.8	5.5	17.2	49.5	24.5
44	1	4,951	0	2.4	2.9	17.8	45.9	31.0
45	1	2,105	0	0	55.7	10.0	17.7	16.6
Total or average	391	583,979	.2	1.1	6.8	11.7	34.4	45.8

Fahey, Thomas D.; Woodfin, Richard O., Jr. Western hemlock as a veneer resource. Res. Pap. PNW-299. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1982. 24 p.

Presents recovery of veneer grade and volume from western hemlock from Oregon and Washington. Veneer grade recovery varied by grade and size of logs. Veneer volume recovered was about 45 percent of the cubic volume of the log and varied somewhat with log diameter.

Keywords: Veneer yield, veneer recovery, western hemlock, *Tsuga heterophylla*.

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PNW-300
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Lumber Recovery From Young-Growth Red and White Fir in Northern California

W.Y. Pong

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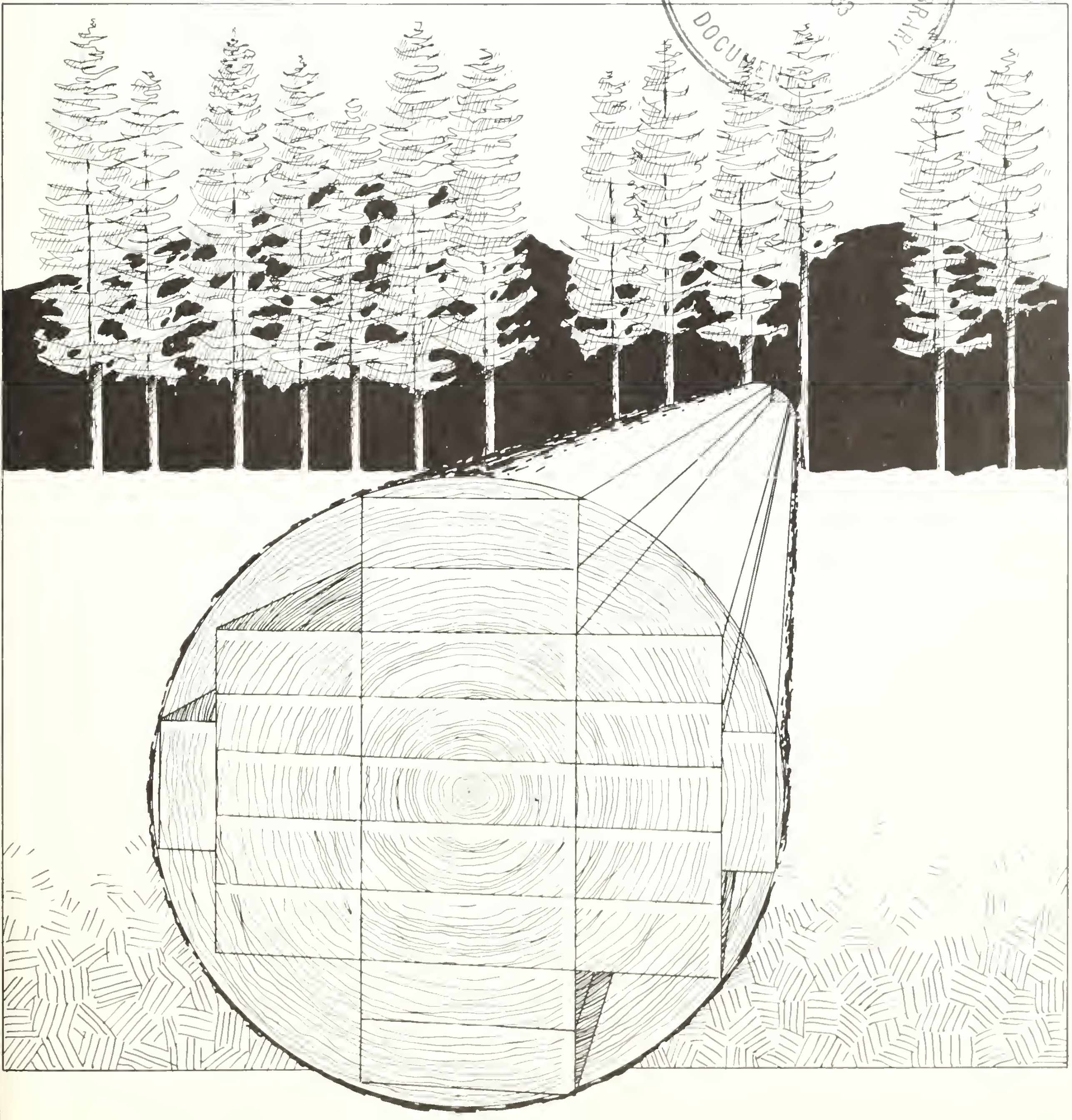

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bstract

Pong, W.Y. Lumber recovery from young-growth red and white fir in northern California. Res. Pap. PNW-300. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1982. 14 p.

umber recovery data from 1,106 logs
rom 341 young-growth white fir (*Abies*
oncolor (Gord. & Glend.) Lindl. ex
ildebr.) and red fir (*A. magnifica* A.
lurr) trees are presented. All logs were
rocessed through a quad-band
eadsaw. Nominal 2x4's and 2x6's
nade up over 93 percent of the lumber
olume; nearly 70 percent was No. 2
Standard) and better. Average overrun
as 54 percent of net log scale.

ubic recovery of lumber in rough-
reen and surfaced-dry conditions
veraged, respectively, 53 and 42
ercent of gross cubic log volume. The
umber recovery factor averaged 7.5
oard feet per cubic foot of gross log
olume processed. Recoveries were
igher for larger logs.

tandards for minimum thickness and
idth of rough-green lumber were
xceeded in both the 2x4's and 2x6's.
reater tolerances (allowance for
urfacing), however, were used in
roducing 2x4's than 2x6's. As a result,
e board feet of lumber recovered
om each cubic foot of lumber
rocessed (BFL/CFL ratio) from
maller logs was reduced since these
gs were sawn primarily into 2x4's.
he average BFL/CFL ratio for all logs
as 14.12.

eywords: Lumber recovery, young
rowth, red fir, *Abies magnifica,* white
, *Abies concolor,* California
orthern).

Summary

Lumber recovery data from processing through a quad-band sawmill 1,106 logs from 341 young-growth white fir (*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.) and red fir (*A. magnifica* A. Murr.) trees selected from the southern Cascade Range of northern California are presented. Over 93 percent of the lumber volume produced was nominal 2x4's and 2x6's. Nearly 70 percent of the lumber graded out as 2-inch No. 2 (Standard) and better. The recovery volume of Economy and No. 3 (Utility) lumber decreased for larger logs. A corresponding increase in upper grades of lumber was recorded from the larger logs.

Overrun for the 1,106 logs was 54 percent; higher overruns were recorded for the smaller diameter logs.

Cubic recovery of surfaced-dry lumber ranged from 34 to 45 percent of gross log volume. Cubic recovery of rough-green lumber ranged from 45 to 57 percent. For all logs, the cubic recovery averaged 42 percent for surfaced lumber and 53 percent for lumber in a green unsurfaced condition.

The lumber recovery factor (LRF) — that is, the board feet of lumber recovered from each gross cubic foot of log processed — varied from 6.2 to 8.1. The average LRF for the 1,106 logs was 7.5 board feet per cubic foot. A higher LRF was recorded for larger logs, the maximum in logs 13 to 14 inches in diameter.

Minimum standards of thickness and width for rough-green lumber were exceeded in both the 2x4's and 2x6's. Sawing tolerances, however, were greater in producing 2x4's than 2x6's. Because of this, the board feet of lumber recovered from each cubic foot of lumber processed (BFL/CFL ratio) was lower for smaller diameter logs since these were sawn primarily into 2x4's. The BFL/CFL ratios ranged from 14.00 to 14.22 board feet per cubic foot. The average for all logs was 14.12.

Procedure

Sample Selection

A total of 341 red fir and white fir trees, considered representative of the range of size and quality of young-growth true fir timber in the southern Cascade Range of northern California, were selected from two areas of the Lassen National Forest (fig. 1). The trees were from stands considered typical young-growth timber stands in that general locale. Individual trees were stratified on the basis of size (diameter at 4½ feet above ground level on the uphill side) and defect (USDA Forest Service 1966). Trees ranged from 7.5- to 24.0-inch d.b.h. An attempt was made to select an equal number of trees in each 1-inch diameter class; this was accomplished except for larger trees (table 1). Because wood of white fir and red fir is similar in structure and properties and because the lumber is graded and sold under the same rules, species information — though recorded — was not used as a basis of stratification during tree selection. Age was checked by increment borings at breast height and ring counts on the stump at the time of felling. All trees selected were under 140 years.

Field Measurements

Before the trees were felled, surface characteristics for the first 32 feet were recorded by relative position (diagramed) (Jackson and others 1963, Pong and Jackson 1971), and other important details of each tree (for example — crook, lean, dominance, broken top, major surface characteristics located above 32 feet) were noted and recorded. Each tree was identified by number, then felled and bucked into lengths according to industry practice. Maximum length of bucked logs was 48 feet plus trim.

While the tree was on the ground and before it was disturbed, characteristics on the visible log surface were again checked for accurate description of type and size. All logs were tagged and numbered by tree and by location in the main stem. Minimum utilization standards applied during the logging operation were 8-foot length, 6-inch scaling diameter,[2] and 25 percent sound. Cull logs (logs less than 25 percent sound) and logs not meeting minimum size requirements were left in the woods. All other logs were removed from the woods and hauled to the sawmill site and dry decked until the sawmill phase of the study.

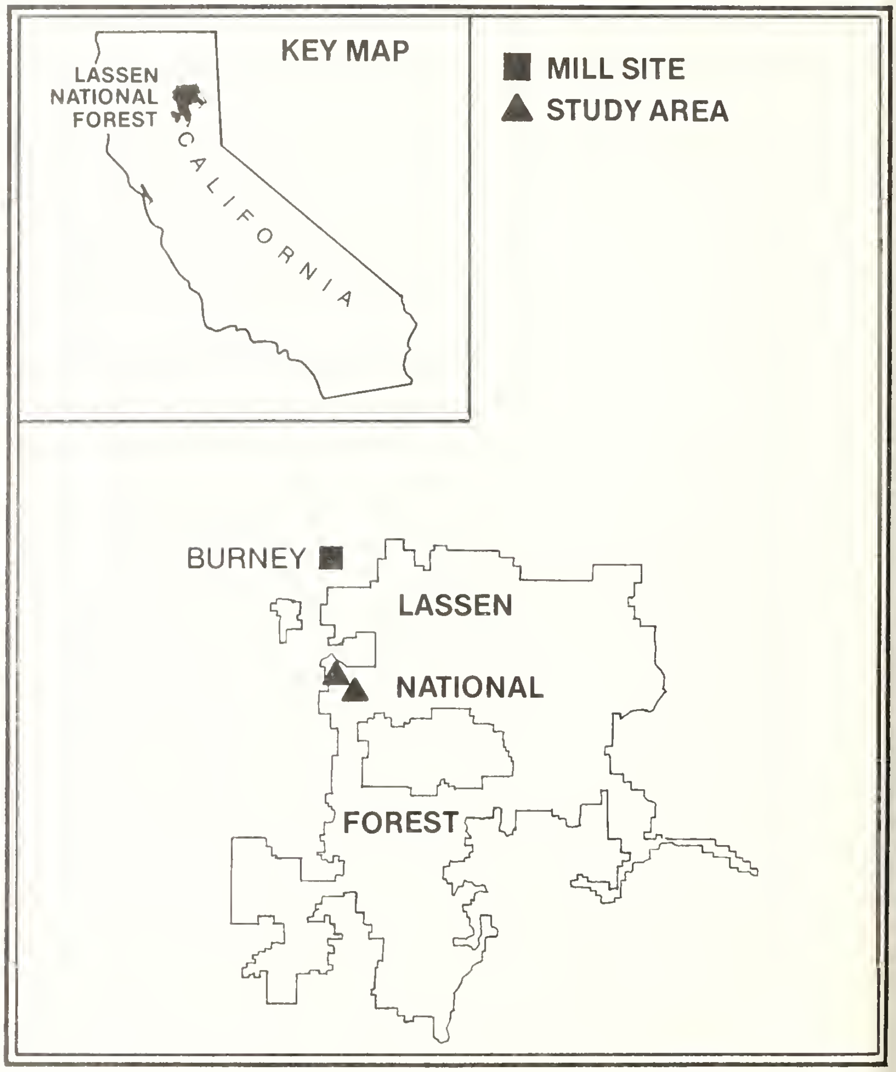

Figure 1. — Approximate location of study areas for young-growth true fir trees and location of mill.

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[2] The average diameter, inside bark at the small end of the log, rounded up to the nearest inch.

Table 1 — Distribution of young-growth red and white fir trees by size in study sample, Lassen National Forest

D.b.h. class (range)[1]	Number of trees
Inches	
7 (6.6 - 7.5)	1
8 (7.6 - 8.5)	23
9 (8.6 - 9.5)	20
10 (9.6 - 10.5)	25
11 (10.6 - 11.5)	20
12 (11.6 - 12.5)	22
13 (12.6 - 13.5)	25
14 (13.6 - 14.5)	22
15 (14.6 - 15.5)	22
16 (15.6 - 16.5)	22
17 (16.6 - 17.5)	25
18 (17.6 - 18.5)	24
19 (18.6 - 19.5)	22
20 (19.6 - 20.5)	23
21 (20.6 - 21.5)	19
22 (21.6 - 22.5)	19
23 (22.6 - 23.5)	4
24 (23.6 - 24.5)	3
Total	341

[1] Diameter of tree at breast height (4-1/2 feet above ground level on the uphill side).

Table 2 — Distribution of young-growth red and white fir saw logs in study sample, by diameter and length, Lassen National Forest

Diameter	Log length (feet)							Total
	8	10	12	14	16	18	20	
Inches	Number							
6	0	14	44	31	42	17	75	223
7	0	7	11	6	19	3	15	61
8	0	6	25	20	20	4	21	96
9	1	11	17	22	38	6	15	110
10	2	5	19	12	47	7	19	111
11	1	2	16	6	43	4	20	92
12	0	1	13	7	47	8	22	98
13	1	1	9	4	55	2	8	80
14	0	0	11	2	60	0	7	80
15	0	2	2	1	46	0	9	60
16	0	2	3	0	35	0	5	45
17	0	0	5	0	16	0	3	24
18	0	1	2	0	14	0	2	19
19	0	2	0	0	4	0	0	6
20	0	0	0	0	1	0	0	1
Total	5	54	177	111	487	51	221	1,106

Log Grading and Scaling

Before the logs were sawed, each woods-length log was bucked into mill-length logs (20-foot maximum). These were tagged by tree and log location in the tree. Before the logs were debarked, each mill-length log was scaled by USDA Forest Service scalers applying current scaling methods (USDA Forest Service 1969). Grades for these logs were determined from log diagrams using Forest Service grades for white fir (Wise and May 1958) modified for the study (see appendix). There were 1,106 mill-length logs, ranging from 6 to 20 inches in diameter and from 8 to 20 feet in length (table 2); all were Grade III, High Common logs.

Processing

Each log was sawed to meet scheduled mill production needs through the manufacture of 2x4 and 2x6 lumber items. Sawing practices conformed to general industry practice in California of maximizing lumber production and grade and were geared to produce Board and Dimension grades of lumber. All lumber was sawed to meet West Coast Lumber Inspection Bureau (WCLIB) specifications of grades and sizes (West Coast Lumber Inspection Bureau 1970).

Equipment in the sawmill included a debarker, computer controlled quad-band headsaw, single band resaw, two double arbor edgers, a gang trim saw, an automatic pocket drop sorter, and a lumber stacking and stickering machine.

When they were sawed, logs were assigned a sequential sawing number cross-referenced to the tree log number. Lumber from each log was tracked through the processing phase by a coded combination of colors and the subsequent marking of each piece of lumber with the sequential sawing number of each log. All rough-green lumber was sorted by width, thickness, and length. Dimension lumber was dried in modern, single track, internal fan, cross-circulation kilns; Board grades of lumber were air dried.

Dimension grades of lumber were surfaced four sides and graded. Board grades of lumber were not surfaced but were sent through the planer and graded in a rough-dry condition with an anticipated surfaced-dry grade (West Coast Lumber Inspection Bureau 1970). A hand and voice tally (on magnetic tape) and a photographic tally were made of each piece of lumber on the infeed of the planer; hand and photographic tallies were made on the outfeed. Grading of the lumber was under the general supervision of a WCLIB grading inspector, and all items were graded according to the national grading rules for dimension lumber and appropriate regional rules as published by the WCLIB (West Coast Lumber Inspection Bureau 1970).

Tallied data for each piece of lumber included length, width, thickness, grade, and sequential sawing number of the log.

Data Compilation

The hand-tallied, surfaced-dry lumber data were edited and corrected using the photographic tally made on the planer outfeed. The hand tally of sequential sawing numbers made on the planer infeed was edited and corrected using both the voice and photographic tally. The corrected hand tallies were then matched and merged.

All data were transferred to punchcards and compiled using computer programs written specifically for handling recovery data (Henley and Hoopes 1967).

Compiled board-foot volumes of lumber tally presented in this paper are based on nominal dimensions of the lumber produced; cubic volumes were computed using rough-green and surfaced-dry lumber sizes.

Gross cubic log volumes were computed by the formula (Grosenbaugh 1966):

$$V = 0.005454 \frac{(D_s^2 + D_s D_e + D_e^2)}{3} L \quad ;$$

where:

V = gross cubic-foot log volume;

D_s = average small end scaling diameter inside bark in inches;

D_e = average large end scaling diameter inside bark in inches; and

L = log scaling length in feet.

Losses in cubic volume of lumber resulting from drying and surfacing were determined by subtracting computed surfaced-dry lumber volumes from corresponding green lumber volumes. Volume of wood converted to sawdust was calculated by applying an average saw kerf of 0.135 inch to one-half the rough-green surface area of each piece of lumber produced. Green lumber dimensions used in this computation and in computing green cubic lumber volume were based on sample measurements of rough-green lumber.

Volumes of chippable residue were determined by subtracting from the gross cubic log volumes the cubic volumes of rough-green lumber (that is, the volume of surfaced-dry lumber plus the losses of volume from surfacing and drying) and the calculated sawdust volumes.

Data Analysis

The compiled data were analyzed by analysis of variance using the programs BIMED (Dixon 1967) and SPSS (Nie and others 1975) for selecting the curve forms for regressing the recovery data to log diameter. For regression purposes, the sample of logs was assumed to be an independent random sample from young-growth red and white fir. Several curve forms using log diameter and various transformations of log diameter as independent variables were tried. Dependent variables regressed were: (1) overrun (percent of lumber tally volume greater than net log scale), (2) surfaced-dry cubic lumber recovery ratio (percent of gross cubic log volume recovered as surfaced-dry cubic volume of lumber), and (3) lumber recovery factor (LRF) (board feet of lumber recovered from each gross cubic foot of log processed) (Fahey and Woodfin 1976).

The final curve forms selected for regressing recovery data to log diameter were based primarily on the regression models having the highest coefficient of determination and lowest standard deviation from regression. In some cases, the magnitude of these measures was comparable for the different models that were tried; the curve form selected, in these instances, was based more on the general shape of the curve through the range of data regressed than on the statistics of the model. Curve forms that did not conform to the general logical relationship between the variables as defined by current knowledge were rejected.

Results

Table 3 — Log scale, lumber tally, and cubic volumes by scaling diameter of young-growth red and white fir sawn-length logs in study sample, Lassen National Forest

		Log scale[1]			Lumber tally		Cubic tally							
									Drying and surfacing losses[6]	Lumber recovery and loss ratio[7]				
Log scaling diameter	Number of logs	Gross	Net	Defect	Volume[2]	Recovery ratio[3]	Log[4]	Lumber[5]		Surfaced-dry	Rough-green	Loss[8]	Sawdust	Chippable residue
Inches		Board feet		Percent	Board feet	Percent	Cubic feet			Percent			Cubic feet	
6	223	3,570	3,560	0[9]	7,333	206.0	1,154.67	402.04	121.56	34.8	45.3	10.5	61.89	569.18
7	61	1,510	1,480	2.0	2,311	156.1	369.33	126.55	38.01	34.3	44.6	10.3	19.39	185.38
8	96	2,370	2,340	1.3	4,351	185.9	664.79	240.32	68.49	36.1	46.5	10.3	35.51	320.47
9	110	3,870	3,820	1.3	6,528	170.9	943.30	363.35	99.39	38.5	49.1	10.5	52.14	428.42
10	111	5,840	5,760	1.4	8,859	153.8	1,189.54	496.99	131.84	41.8	52.9	11.1	69.93	490.78
11	92	5,980	5,800	3.0	9,575	165.1	1,207.78	541.49	136.42	44.8	56.1	11.3	73.56	456.31
12	98	8,000	7,900	1.3	12,374	156.6	1,563.69	699.48	176.00	44.7	56.0	11.3	94.89	593.32
13	80	7,740	7,560	2.3	11,031	145.9	1,409.44	622.41	159.12	44.2	55.4	11.3	85.38	542.53
14	80	8,770	8,510	3.0	13,079	153.7	1,681.79	734.30	191.44	43.7	55.0	11.4	101.94	654.11
15	60	8,580	8,370	2.4	11,903	142.2	1,486.31	661.92	179.61	44.5	56.6	12.1	94.30	550.48
16	45	7,140	6,880	3.6	9,677	140.7	1,255.85	538.06	144.55	42.8	54.4	11.5	76.11	497.13
17	24	4,270	4,050	5.2	5,834	144.0	780.83	325.81	86.74	41.7	52.8	11.1	45.83	322.45
18	19	3,930	3,750	4.6	4,834	128.9	652.02	269.74	72.16	41.4	52.4	11.1	38.11	272.01
19	6	1,260	1,230	2.4	1,676	136.3	206.53	93.72	24.64	45.4	57.3	11.9	13.08	75.09
20	1	280	280	0	303	108.2	42.35	16.81	4.49	39.7	50.3	10.6	2.37	18.68
Total or average[10]	1,106	73,110	71,290	2.5	109,668	153.8	14,608.22	6,132.99	1,634.46	42.0	53.2	11.2	864.43	5,976.34

[1] Scribner scale.
[2] Based on nominal lumber dimensions.
[3] Percent of net log scale.
[4] Gross volume.
[5] Based on actual size of surfaced-dry lumber.
[6] Calculated loss of volume from shrinkage and planer shavings.
[7] Percent of gross cubic log volume.
[8] Based on actual loss of volume.
[9] Less than 0.5 percent.
[10] Weighted by volume.

Log Scale, Lumber Tally, and Cubic Volumes

Table 3 summarizes the log scale, surfaced-dry lumber tally, and cubic volume of the logs. Defect ranged from 0 to 5.2 percent, the more defective logs occurring in logs with larger diameters. The defect for all logs averaged 2.5 percent ($CI_{95} = \pm 0.53$)[3]

Higher values of overrun — that is, percent of board-foot lumber volume greater than Scribner net log scale (equivalent to lumber recovery ratio minus 100) — were recorded for logs with smaller diameters. The regression curve of overrun to log scaling diameter (significantly correlated at the 1-percent level) and the scattergram are presented in figure 2. Board-foot lumber recovery ratio (overrun plus 100) ranged from 108.2 to 206.0 percent of Scribner net log scale and averaged 153.8 percent ($CI_{95} = \pm 2.07$) (table 3).

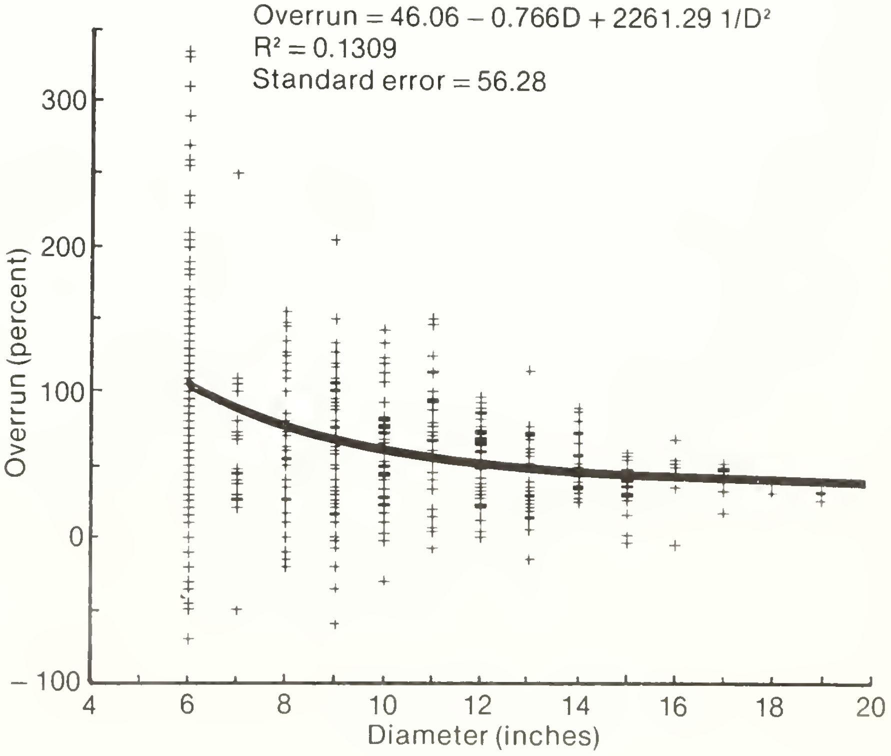

Figure 2. — Overrun (percent of board-foot lumber volume greater than net log scale) for logs from young-growth red and white fir, by scaling diameter.

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[3] Confidence interval at the 95-percent level.

Cubic volumes of surfaced-dry lumber recovered from the logs varied from 34.3 to 45.4 percent of gross cubic log volumes. Comparable cubic volume recovered for rough-green lumber (that is, the volume of surfaced lumber plus drying and surfacing losses), varied from 44.6 to 57.3 percent. The cubic-foot recovery ratio for all logs combined for surfaced-dry lumber averaged 42.0 percent ($CI_{95} = \pm 0.67$) and for rough-green lumber 53.2 percent ($CI_{95} = \pm 0.83$) (table 3). A curve regressing the cubic recovery ratio of surfaced-dry lumber to log scaling diameter (significantly correlated at the 1-percent level) and the scattergram are presented in figure 3. Cubic recovery of surfaced material was greater for larger logs, indicating a greater proportion of the cubic volume of larger logs is converted to products and less is lost to slabs to produce lumber of minimum width. There is, however, concomitant increase in the proportion of the volume lost to defect and to drying and surfacing (table 3), both of which reduce the recoverable cubic volume of dry lumber that can be sawn from larger logs. Losses caused by surfacing and drying varied from 10.3 to 12.1 percent of gross cubic log volume and averaged 11.2 percent for all logs ($CI_{95} = \pm 0.17$). Greater losses were recorded for logs larger than 10 inches in diameter.

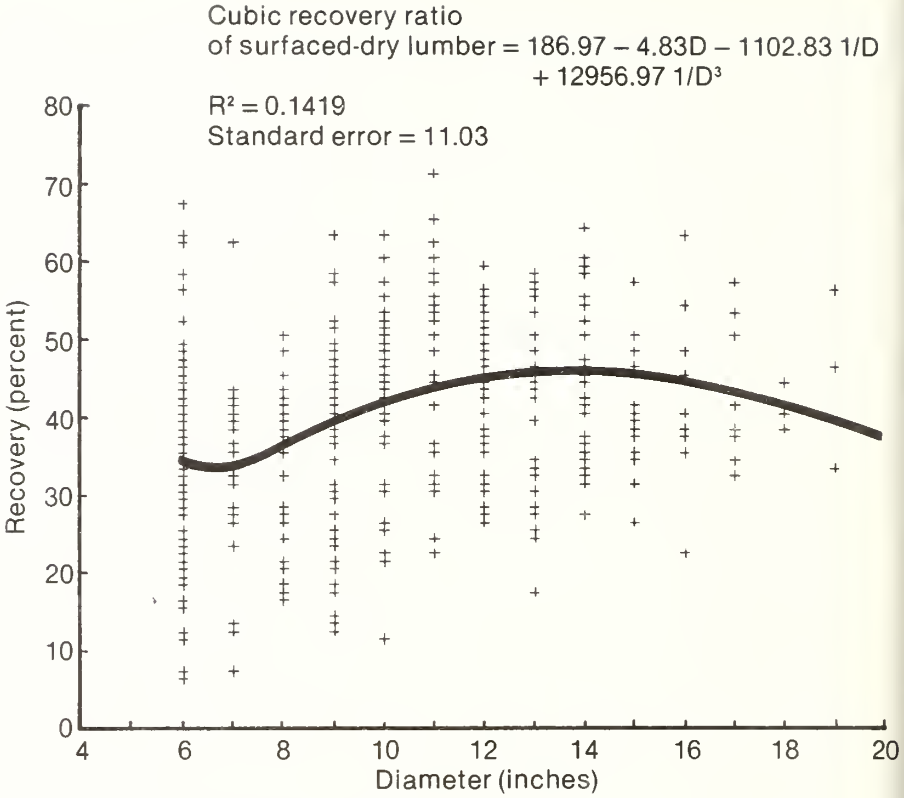


Figure 3. — Cubic volume of surfaced-dry lumber recovered as percent of gross cubic volume of logs from young-growth red and white fir, by scaling diameter.

Distribution of Lumber Grades and Sizes

The percentage yields of various grades and sizes of surfaced-dry lumber produced from the study logs are presented in table 4.

Except for a small volume of 1-inch boards (3.52 percent), all the lumber produced was in 2-inch Dimension grades; nominal 2x4's (43.31 percent) and 2x6's (49.96 percent) were the bulk (93.27 percent) of the lumber tally volume (table 4). A small percentage (3.21) of 2x3's made up the remainder.

Nearly 70 percent of the lumber graded out as 2-inch No. 2 (Standard) and better lumber. Over 72 percent of the lumber items graded out as No. 2 (Standard) and better.

Lumber Grade Yield by Log Diameter

The percentage distributions of lumber grade volume by log scaling diameter are presented in table 5 and figures 4 and 5. Both Economy and No. 3 (Utility) recorded a decrease in recovery volume as log size increased. Percent yield for the remaining grades of lumber increased as log diameter increased (table 5 and fig. 4). The combined effect of these increases is reflected in a greater percentage of No. 2 (Standard) and better lumber recovered from larger logs (fig. 5).

Table 4 — Lumber tally of Board and Dimension lumber, by thickness, width, and lumber grade, for sawn-length logs of young-growth red and white fir in study sample, Lassen National Forest

Thickness	Width	Lumber tally volume	Lumber grade					
			Select structural	No. 1[1]	No. 2[2]	No. 3[3]	Economy	Total
Inches		Board feet	Percent of lumber tally					
1 (4/4)	4	2,015	--	0.76	0.57	0.29	0.22	1.84
	6	1,842	--	.49	.62	.30	.27	1.68
Total Board items		3,857	--	1.25	1.19	.59	.49	3.52
2 (8/4)	3	3,527	0	.63	1.25	.98	.35	3.21
	4	47,496	5.58	13.39	13.28	7.81	3.25	43.31
	6	54,788	6.65	12.17	17.04	10.77	3.33	49.96
Total Dimension items		105,811	12.23	26.19	31.57	19.56	6.93	96.48
			Percent					
Total of grades (percent)		--	12.23	27.44	32.76	20.16	7.41	100.00
			Board Feet					
Total volume		109,668	13,408	30,095	35,933	22,108	8,124	--

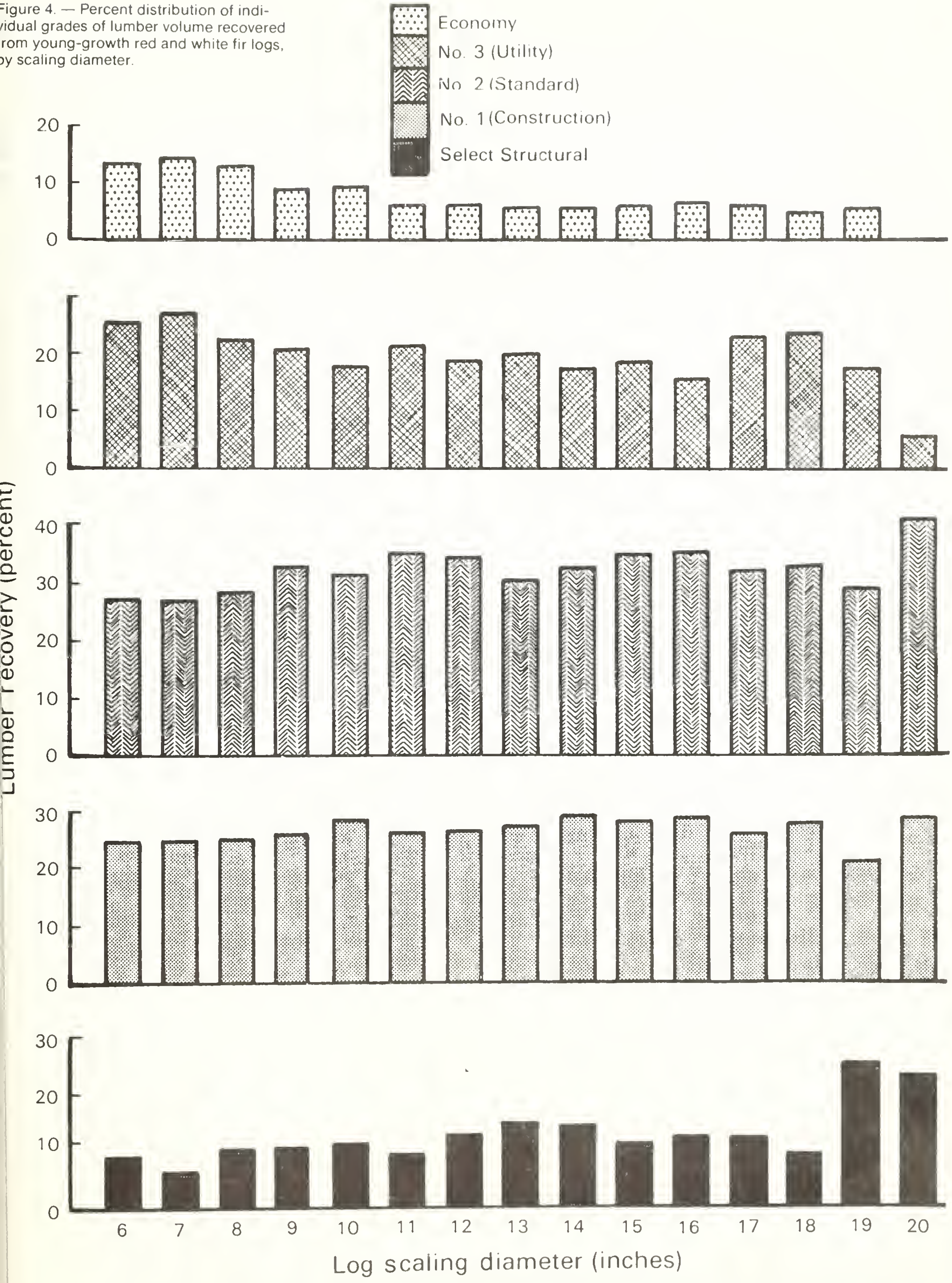
[1] Includes Construction grade 2x3's, 2x4's, and 1-inch boards.
[2] Includes Standard grade 2x3's, 2x4's, and 1-inch boards.
[3] Includes Utility grade 2x3's, 2x4's, and 1-inch boards.

Table 5 — Lumber grade yields by log scaling diameter of young-growth red and white fir sawn-length logs in study sample, Lassen National Forest

Log scaling diameter	Number of logs	Lumber tally volume	Lumber Grade				
			Select structural	No. 1[1]	No. 2[2]	No. 3[3]	Economy
Inches		Board feet	Percent of lumber tally volume[4]				
6	223	7,333	8.89	24.90	27.12	25.81	13.27
7	61	2,311	6.79	25.01	27.04	27.09	14.06
8	96	4,351	10.48	25.33	28.34	22.55	13.31
9	110	6,528	10.59	26.23	32.94	21.26	8.99
10	111	8,859	11.81	29.00	31.75	18.12	9.32
11	92	9,575	9.61	26.59	35.61	21.86	6.33
12	98	12,374	13.27	26.82	34.74	19.12	6.04
13	80	11,031	15.13	27.91	30.79	20.20	5.97
14	80	13,079	14.37	29.48	32.59	17.68	5.88
15	60	11,903	11.57	28.17	35.31	19.01	5.94
16	45	9,677	12.70	29.10	35.59	15.88	6.73
17	24	5,834	12.34	26.12	32.26	22.99	6.29
18	19	4,834	9.64	28.24	33.47	23.93	4.72
19	6	1,676	25.84	21.60	28.82	17.84	5.91
20	1	303	23.43	29.04	41.58	5.94	0
Total or average	1,106	109,668	12.23	27.44	32.76	20.16	7.41

[1] Includes Construction grade 2x3's, 2x4's, and 1-inch boards.
[2] Includes Standard grade 2x3's, 2x4's, and 1-inch boards.
[3] Includes Utility grade 2x3's, 2x4's, and 1-inch boards.
[4] Percentages for all grades combined may not total to 100 because of rounding.

Figure 4. — Percent distribution of individual grades of lumber volume recovered rom young-growth red and white fir logs, by scaling diameter.



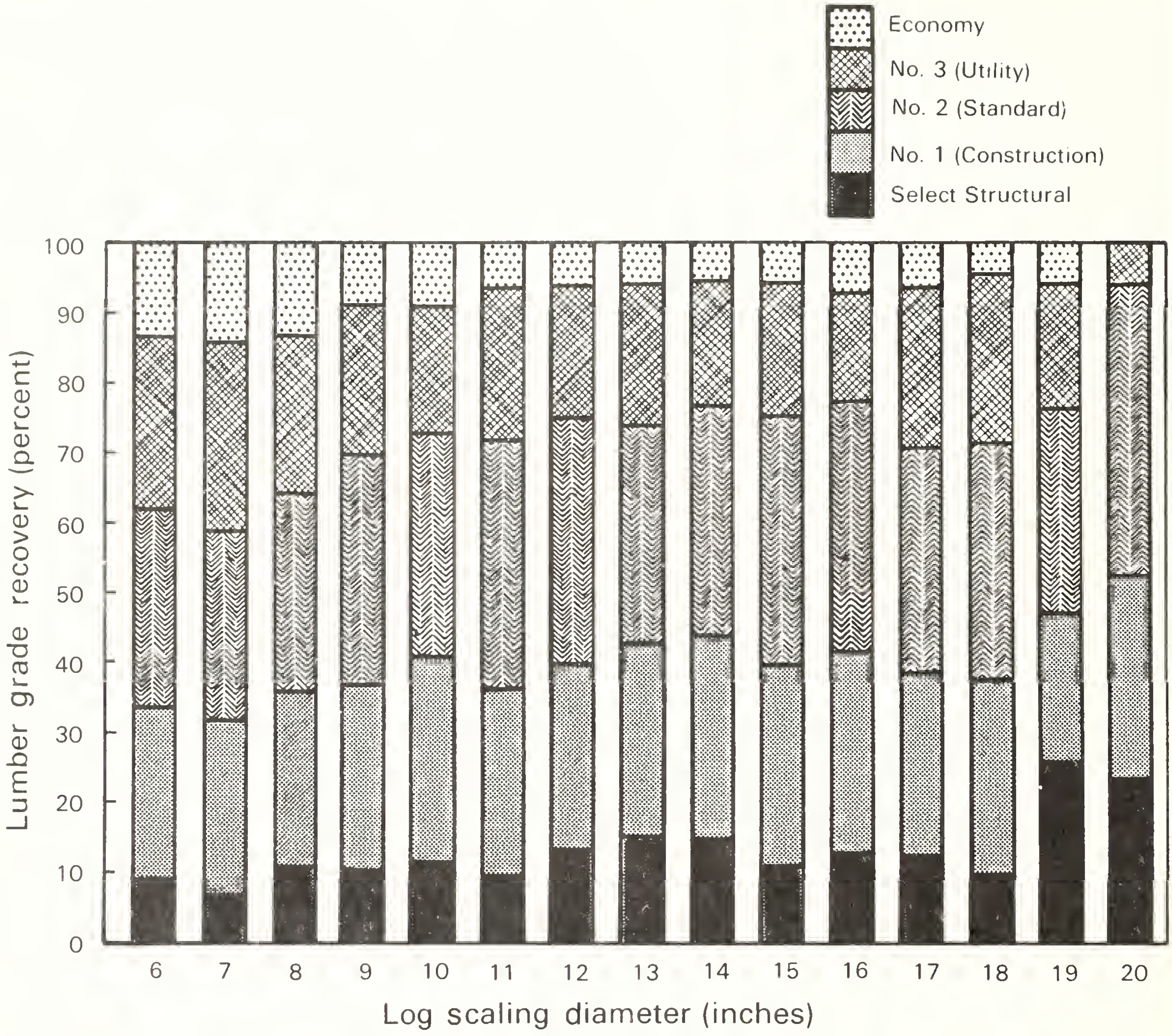


Figure 5. — Percent of lumber grade volumes recovered from young-growth red and white fir logs, by scaling diameter.

Lumber Recovery Factor

Table 6 — Lumber recovery factor and the nominal board-foot volume of lumber tallied per cubic-foot volume of green lumber, by log scaling diameter of young-growth red and white fir sawn-length logs in study sample, Lassen National Forest

Log scaling diameter	Number of logs	Lumber tally volume1/	Log volume2/	Lumber volume3/	Lumber recovery factor4/	BFL/CFL5/
Inches		Board feet	- - -Cubic feet- - -		Board feet per cubic foot	
6	223	7,333	1,154.67	523.60	6.3	14.00
7	61	2,311	369.33	164.56	6.3	14.04
8	96	4,351	664.79	308.81	6.5	14.09
9	110	6,528	943.30	462.74	6.9	14.11
10	111	8,859	1,189.54	628.83	7.4	14.09
11	92	9,575	1,207.78	677.91	7.9	14.12
12	98	12,374	1,563.69	875.48	7.9	14.13
13	80	11,031	1,409.44	781.53	7.8	14.11
14	80	13,079	1,681.79	925.74	7.8	14.13
15	60	11,903	1,486.31	841.53	8.0	14.14
16	45	9,677	1,255.85	682.61	7.7	14.18
17	24	5,834	780.83	412.55	7.5	14.14
18	19	4,834	652.02	341.90	7.4	14.14
19	6	1,676	206.53	118.36	8.1	14.16
20	1	303	42.35	21.30	7.5	14.22
Total or average6/	1,106	109,668	14,608.22	7,767.45	7.5	14.12

1/Nominal lumber dimensions.
2/Gross volume.
3/Actual green size.
4/A ratio of the nominal board-foot volume of lumber recovered from each gross cubic foot of log processed.
5/Nominal board-foot volume of lumber (BFL) tallied per measured cubic foot volume of green lumber (CFL).
6/Weighted by volume.

The board feet of lumber recovered from each gross cubic foot of log processed — that is, the lumber recovery factor (Fahey and Woodfin 1976) — varied from 6.3 to 8.1 board feet per cubic foot (table 6). The LRF for all logs combined averaged 7.5 ($CI_{95} = \pm0.12$). A curve regressing lumber recovery factor to log scaling diameter (significantly correlated at the 1-percent level) and the scattergram of LRF are presented in figure 6. LRF increased as log size increased, up to diameters of 13 to 14 inches and then decreased in the larger logs. As expected, the cubic and LRF curves are similar since the cubic recovery volumes are a direct conversion of the board-foot volumes using the actual surfaced dimensions of the boards. Since over 93 percent of the volume produced was 2x4's and 2x6's (table 4), such a conversion was nearly uniform over the diameter range of logs included in the study.

Board Feet Per Cubic Foot of Lumber

The board feet of lumber recovered from each cubic foot of rough-green lumber processed (BFL/CFL) (Fahey and Woodfin 1976) varied from 14.00 to 14.22 board feet per cubic foot and averaged 14.12 ($CI_{95} = \pm0.0077$) (table 6). Higher BFL/CFL ratios were recorded for the larger logs suggesting that lumber sawn from these logs was closer to the green targeted sizes (minimum standards of thickness and width of rough-green lumber) than that from the smaller logs. Measurements of green lumber showed that the specification standards for minimum thickness and width of rough unseasoned lumber (West Coast Lumber Inspection Bureau 1970) were exceeded for 2x4's and 2x6's (table 7). Furthermore, oversizing of the green lumber dimensions was greater in the 2x4's than the 2x6's. This was particularly evident in the width of the rough-green 2x4's which exceeded the minimum targeted

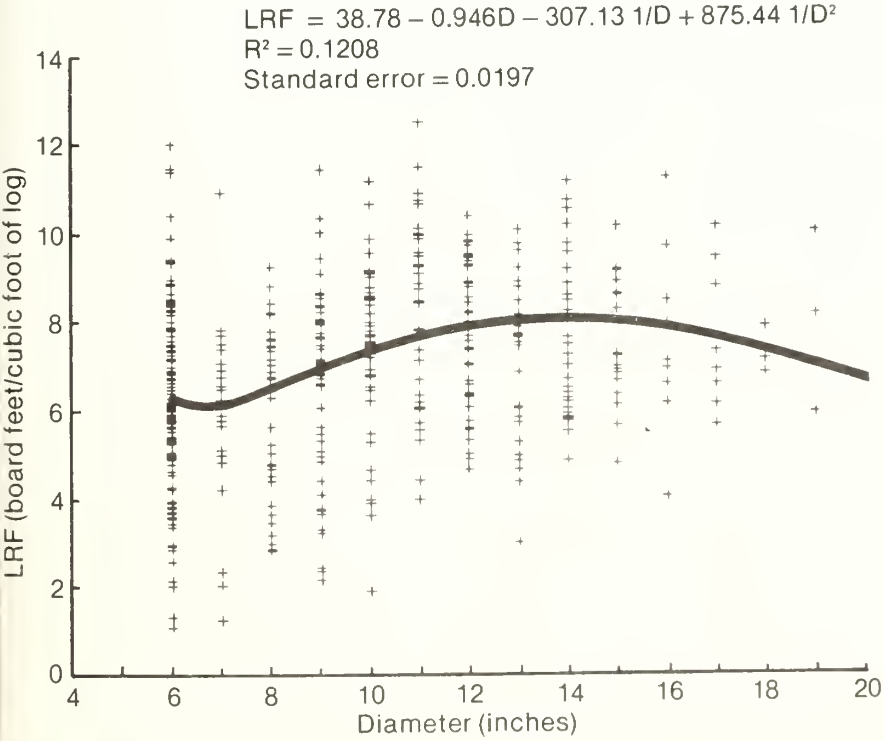


Figure 6. — Lumber recovery factor (LRF) — nominal board-foot volume of lumber recovered from each gross cubic foot of log processed — for young-growth red and white fir logs, by log scaling diameter.

Table 7 — Average thickness and width of 2x4 and 2x6 lumber sawn from young-growth red and white fir logs in study sample, Lassen National Forest

Sawing profile	Lumber item	Thickness			Width		
		Actual	Target[1]	Difference	Actual	Target[1]	Difference
		- -1/32-inch- -		Percent	- -1/16-inch- -		Percent
2x4	2x4	54.58	54.00	1.07	63.69	59.00	7.95
	2x6	54.43	54.00	.80	94.98	92.00	3.24
2x6	2x4	54.90	54.00	1.67	63.07	59.00	6.90
	2x6	54.65	54.00	1.20	94.63	92.00	2.86

[1] Target sizes are based on the 1970 edition of West Coast Lumber Inspection Bureau's "Standard Grading Rules for West Coast Lumber," No. 16, p. 157, sec. 250 and 250-a, under "Size Standards Minimum Rough Sizes, Thicknesses and Widths, Dry or Unseasoned."

size by almost 7 to 8 percent (8/32 to 9/32 inch), whereas the 2x6's were oversize in width by only about 3 percent (5/32 to 6/32 inch).

Primary breakdown of logs in the sawmill was through a quad-band headsaw which was controlled by computer to cut either a 2x4 or 2x6 profile. There was no provision for recycling cants through the headsaw. Because of this, the size of cants produced at the headsaw was mainly controlled by log size; smaller logs produced 4-inch cants and larger logs, 6-inch cants. Any difference in sawing tolerances of the quad-band headsaw that may be specific to a given cant size will, therefore, be reflected in the observed changes in the BFL/CFL ratios with log size. Results suggest that oversizing of the 2x4's had a greater impact in reducing the BFL/CFL ratios of the smaller logs than the larger logs, since the smaller logs were cut primarily into 2x4's regardless of profile.

Conclusions

This report presents lumber recovery data from the processing of 1,106 logs from 341 young-growth white and red fir trees from the southern Cascade Range of northern California.

Diameters of study logs ranged from 6 to 20 inches inside bark at the small end and were all Grade III, High Common logs. Defect ranged from 0 to 5 percent; the more defective logs occurred in the larger diameters.

Overrun for all logs averaged 54 percent. As expected, the smaller logs had greater overrun. Board-foot lumber recovery was 108 to 206 percent of Scribner net log scale.

Cubic recovery of surfaced-dry lumber varied from 34 to 45 percent of gross cubic log volume. Comparable values for green, unsurfaced lumber were 45 to 57 percent. Cubic recovery from all logs averaged 42 percent for surfaced lumber and 53 percent for green, unsurfaced lumber. Greater cubic recovery was recorded for larger logs.

Though cubic recovery was greater for larger logs, the proportion of the volume lost during drying and surfacing the material from these logs was greater. Losses ranged as low as 10.3 percent of gross cubic volume in smaller logs to a high of 12.1 percent in larger logs.

Over 93 percent of the lumber produced was Dimension grade 2x4's and 2x6's. A small percentage (3.5) was 1-inch boards, and the remainder (3.2 percent) was 2x3's. Nearly 70 percent of the lumber graded out as 2-inch No. 2 (Standard) and better lumber. The volumes of both Economy and No. 3 (Utility) recovered dropped as log size increased. This resulted in increased yield of No. 2 (Standard) and better lumber.

The lumber recovery factor varied from 6.3 to 8.1. The average for all logs was 7.5 board feet per cubic foot. A greater LRF was recorded for larger logs than for smaller logs.

Minimum standards for thickness and width of rough unseasoned lumber were exceeded in both the 2x4's and 2x6's. Sawing tolerances used in producing 2x4's, however, were greater than those used to produce 2x6's. Because of this, oversize 2x4's had a greater impact in reducing the board feet of lumber recovered from each cubic foot of rough-green lumber processed (BFL/CFL ratio) for smaller logs than for larger logs since the smaller logs were cut primarily into 2x4's.

Metric Equivalents

1 inch = 2.54 centimeters
1 foot = 0.304 8 meter
1 cubic foot = 0.028 32 cubic meter

Literature Cited

Bolsinger, Charles L. Timber resources of northern interior California. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1976. 75 p.

Dixon, W.J., ed. BMD biomedical computer programs. Univ. Cal. publ. autom. comput. 2. Berkeley, CA: University of California Press; 1967: 233-257.

Fahey, Thomas D.; Woodfin, Richard O., Jr. The cubics are coming: predicting product recovery from cubic volume. J. For. 74(11): 739-743; 1976.

Grosenbaugh, L.R. Tree form: definition, interpolation, extrapolation. For. Chron. 42(4): 444-457; 1966.

Henley, John W.; Hoopes, Jill M. An electronic computer program for calculating saw log lumber recovery and value. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1967. 47 p.

Jackson, George H.; Henley, John W.; Jackson, Willard L. Log diagraming guide for western softwoods. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1963. 32 p.

Nie, H.H.; Hull, C.H.; Jenkins, J.G. [and others]. Statistical package for the social sciences. 2d ed. McGraw-Hill Book Co.; 1975.

Pong, W.Y.; Jackson, G.H. Diagraming surface characteristics of true fir logs. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1971. 7 p.

U.S. Department of Agriculture, Forest Service. Cull indicators for Douglas-fir, white fir, and red fir. FSH 2-2425, Reg. 5, Suppl. 89. San Francisco, CA: U.S. Department of Agriculture, Forest Service; 1966.

U.S. Department of Agriculture, Forest Service. National Forest log scaling handbook. FSH 2443.71. Washington, DC: U.S. Government Printing Office; 1969.

U.S. Department of Agriculture, Forest Service. The outlook for timber in the United States. For. Resour. Rep. 20. Washington, DC; 1973. 397 p.

West Coast Lumber Inspection Bureau. WCLIB standard grading rules for west coast lumber. No. 16. Portland, OR; 1970. 213 p.

Wise, H.F.; May, R.H. Lumber grade recovery from old-growth white fir on the Sequoia National Forest, California. Berkeley, CA: U.S. Department of Agriculture, Forest Service, California Region and California Forest and Range Experiment Station; 1958. 11 p.

Appendix

White Fir Log Grades[4]

Grade 1, select logs. — Logs are at least 90 percent surface clear, straight and generally smooth. Spiral grain is not to exceed 1 in 5. A straight grained frost crack is permitted in an otherwise high-grade log. This grade allows any *one* of the following:

1. One branch or branch stub in the central zone (the part of the log more than 1 foot from either end) larger than 3 inches in diameter.
2. Two scattered branches or branch stubs in the central zone less than 3 inches in diameter or four scattered pin (½-inch diameter) branches or branch stubs.
3. Any number of branches or branch stubs of any size within 1 foot of one end.
4. Concentrated grouping of branches or branch stubs of any size or other defects affecting not over one-fourth of the circumference for a length of 6 feet from one end.
5. A line of branches or branch stubs less than 3 inches in diameter for the full length of the log (one larger branch or branch stub permitted) that affects a strip of the circumference not wider than three-tenths of the log diameter (inside bark) at the small end.

Grade II, shop logs. — Logs are 50 percent surface clear in length or circumference. Also includes shop logs on which the branches or branch stubs, or other defects, are so distributed as to produce factory cuttings. On such logs, 50 percent or more of the surface should be in clear areas, at least 8 feet in length and 6 inches or more in width between branches, branch stubs, and other defects.

Grade III, high common logs. — Logs are less than 50 percent surface clear and can have any combination of branches and branch stubs or other defects that are not permitted on the higher grades. Any number of branches and branch stubs not over 3 inches in diameter (inside bark).

Grade IV, low common logs. — This grade allows logs not qualifying for grades I, II, or III.

General Specifications and Definitions

These grades are for application to merchantable sound sapwood 16-foot logs as cruised in standing trees.

Minimum merchantability requirements are 8-foot length, 6-inch top d.i.b., and net scale at least 25 percent of gross scale.[5]

Branches and branch stubs include live and dead material. So-called knot indicators or overgrown limbs are not considered for grading logs.

Defects include:

1. Scars or seams resulting from lightning, fire, or mechanical damage, providing they are old enough that the underlying wood is stained, pitchy, checked, or otherwise degraded.
2. Large burls that cover more than one-quarter of the log circumference.
3. Unsound burls that are partially dead or show heavy flow of pitch or exudate.
4. Cracks resulting from frost, wind, or other natural causes.
5. Cankers resulting from mistletoe, rusts, or other causes.

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[4] Wise and May (1958); modified as shown in footnote 5.

[5] Changed from 10-foot length, 10-inch top d.i.b., and net scale at least 33-1/3 percent of gross scale.

Pong, W.Y. Lumber recovery from young-growth red and white fir in northern California. Res. Pap. PNW-300. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1982. 14 p.

Lumber recovery data from 1,106 logs from 341 young-growth white fir (*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.) and red fir (*A. magnifica* A. Murr) trees are presented. All logs were processed through a quad-band headsaw. Nominal 2x4's and 2x6's made up over 93 percent of the lumber volume; nearly 70 percent was No. 2 (Standard) and better. Average overrun was 54 percent of net log scale.

Cubic recovery of lumber in rough-green and surfaced-dry conditions averaged, respectively, 53 and 42 percent of gross cubic log volume. The lumber recovery factor averaged 7.5 board feet per cubic foot of gross log volume processed. Recoveries were higher for larger logs.

Standards for minimum thickness and width of rough-green lumber were exceeded in both the 2x4's and 2x6's. Greater tolerances (allowance for surfacing), however, were used in producing 2x4's than 2x6's. As a result, the board feet of lumber recovered from each cubic foot of lumber processed (BFL/CFL ratio) from smaller logs was reduced since these logs were sawn primarily into 2x4's. The average BFL/CFL ratio for all logs was 14.12.

Keywords: Lumber recovery, young growth, red fir, *Abies magnifica*, white fir, *Abies concolor*, California (northern).

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Twenty-Year Growth of Ponderosa Pine Saplings Thinned to Five Spacings in Central Oregon

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Abstract

Barrett James W. Twenty-year growth of ponderosa pine saplings thinned to five spacings in central Oregon. Res. Pap. PNW-301. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1982. 18 p.

Diameter, height, and volume growth and yield are given for plots thinned to 1000, 500, 250, 125, and 62 trees per acre in a 40- to 70-year-old stand of suppressed ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) saplings in central Oregon. Trees averaged about 1-inch in diameter and 8 feet in height at the time of thinning. Considerations for choosing tree spacing for precommercial thinning in this type of stand are discussed.

Keywords: Thinning effects, stand density, precommercial thinning, ponderosa pine, *Pinus ponderosa*.

Summary

Tree spacing and understory vegetation had pronounced effects on diameter, height, and volume increment in a 40- to 70-year-old stand of suppressed ponderosa pine saplings in central Oregon. Trees averaged about 1 inch in diameter and 8 feet in height before thinning. At the widest spacing, with understory vegetation controlled, trees grew an average of 0.47 inches in diameter per year compared to only 0.13 inch at the narrowest spacing where understory vegetation was left to develop naturally.

Stand density and understory vegetation have had significant effects on height growth throughout 20 years of observation following thinning. Understory vegetation has had the greatest effect on height growth at the wider spacings, reducing growth from 15 to 50 percent during some periods.

Twenty years after thinning, low density plots contain less wood fiber than high density plots. On the other hand, widely spaced trees are much larger than narrowly spaced trees and collectively are now producing almost as much wood volume annually as high density plots.

Even though most of the trees left after thinning were 70 years old, stagnated, and suppressed by overstory, they have responded well to overstory removal and release, and trees at the three widest spacings appear capable of producing a usable crop of timber despite their advanced age.

Introduction

Millions of acres of commercial ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) forest land east of the Cascade Range in Washington and Oregon have a dense understory of suppressed trees overtopped by mature trees ready for harvest (fig. 1). In most areas where the overstory has been harvested, trees are being thinned, although some areas are being left to develop without thinning. Past research in the Pacific Northwest by Mowat (1953, 1961) and Barrett (1963, 1968, 1970) and personal observations have now convinced most managers that thinning overstocked stands after overstory harvest is necessary.

Managers prefer precommercial thinning to spacing that will result in a salable product the next time the stand must be thinned. If conservative spacing is selected for precommercial thinning on the assumption that there will be a market for roundwood in the future, and this market does not occur, a second precommercial thinning may be necessary. Constantly escalating costs of precommercial thinning add to the importance of selecting a realistic spacing on the first thinning. Leaving too many trees can be just as poor a choice as leaving too few. Leaving too few trees also forfeits some wood production before the site is completely occupied by tree roots and crowns. Many managers concentrate on producing trees of a certain size in a given time and want to know how many trees will reach the target diameter.

This spacing study is one of several established in ponderosa pine in the Pacific Northwest in the late 1950's and early 1960's. It is similar in design to the Methow study in north-central Washington (Barrett 1981), and some results of the two studies will be compared. The intent of studies of this kind was to provide forest managers with enough information from different treatments so they could choose tree spacing that would yield products compatible with management objectives. This is one reason for the widely divergent spacings in this study.

Figure 1.—Mature ponderosa pine stand with a dense, suppressed 40- to 70-year-old sapling understory before thinning to various densities.

Experiments in managing young, suppressed stands in the Pacific Northwest have changed over the past 40 years. The first experiments usually involved two plots, one thinned to a conservative spacing of 6 or 9 feet, the other left unthinned (Mowat 1953). Later, experiments in crop-tree thinning were established (Barrett 1969). All studies showed that suppressed, understory trees are capable of substantial response to thinning.

The full potential for diameter growth of second-growth ponderosa pine was not visualized until a study of free-growing trees was reported by Dahms and Silen in 1956.[1] They observed young trees free from competition growing at the rate of 6 to 7 inches per decade. They also found that heavy competition from brush reduced the growth rate to about 3 inches per decade. Thus, a tentative rate for maximum diameter growth was suggested and the importance of brushy understory competition was established. This work by Dahms and Silen suggested that the next thinning study should sample a wide range of spacings and should attempt to quantify the effect of brush competition on tree growth.

The Methow study, established about 4 years later, tested spacings of 9.3, 13.2, 18.7, and 26.4 feet as well as growth in unthinned plots (Barrett 1981). It showed that dense, suppressed ponderosa pine responded to increased space with more diameter and height growth. This study also showed that wider spacings produced large diameter trees in 20 years after thinning but that very wide spacings (26.4 feet) where the understory is predominantly pine grass can sacrifice substantial yields of wood fiber during the early part of a rotation.

This paper presents 20-year results from a spacing study in central Oregon. It was designed to give managers a wide range of alternatives for spacing in dense, suppressed sapling stands. The main objectives of the study are to determine:

1. Rates of diameter and height growth with various spacings.
2. Effects on tree growth of competition from understory vegetation.
3. Effect of spacing on periodic volume increment and yield.
4. Growing time after thinning needed to produce trees of usable sizes at various spacings.

Previous results from this study have been reported by Barrett (1965, 1970, 1973).

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[1] Walter G. Dahms and Roy R. Silen, "An Informal Study of Free-growing Ponderosa Pine Trees." Unpublished report on file at Pacific Northwest Forest and Range Experiment Station, Silviculture Laboratory, Bend, Oregon, 1956.

The Study Area

This spacing study is 35 miles southwest of Bend, Oregon, in the Pringle Falls Experimental Forest. Access to the study area is usually easy from May 15 to October. Plots are well marked and a map of the area may be obtained from the USDA Forest Service Silviculture Laboratory in Bend. Interested people are encouraged to visit the study plots.

Before the study was installed the stand consisted of old-growth ponderosa pine, averaging 17,000 board feet per acre with a 40- to 70-year-old suppressed sapling understory typical of thousands of acres of pine forests in central Oregon. Saplings averaged 1 inch in diameter, 8 feet in height, and 7,000 stems per acre. There were about 20 overstory trees per acre, averaging 350 board feet per tree. Ground vegetation consisted mainly of antelope bitterbrush (*Purshia tridentata* (Pursh) DC.), snowbrush (*Ceanothus velutinus* Dougl. ex Hook.), and greenleaf manzanita (*Arctostaphylos patula* Greene). Scattered plants of Ross sedge (*Carex rossii* Boott) could be found over the whole experimental area. The plots are in a transition zone between ponderosa pine/bitterbrush-manzanita/sedge and ponderosa pine/bitterbrush-snowbrush/sedge plant communities (Volland 1976).

Study plots are on an east-facing slope at 4,400 feet elevation and cover approximately 160 acres. Annual precipitation averages 24 inches, 85 percent of which falls between October 1 and April 30. A snowpack of 24 inches is common from January to March. Daytime temperatures during the growing season are cool with occasional frosts at night. Site index of old-growth pine in the area indicates a height of 78 feet at age 100 (Meyer 1961). The Lapine, Shanahan intergrade soil, a Typic Cryorthent, was developed in dacite pumice originating from the eruption of Mount Mazama (Crater Lake) 6,500 years ago. The pumice averages 33 inches deep and is underlain by a sandy loam paleosol developed in older volcanic ash containing cinders and basalt fragments.

Experimental Design and Methods

Study design consists of 30 rectangular 0.192-acre plots, 79.2 by 105.6 feet (fig. 2). Each plot is surrounded by a buffer strip 33 feet wide which is treated the same as the inner plot. A plot contains 192 milacres and is divided into 12 subplots of 16 milacres as indicated in figure 2. This arrangement aided in selecting leave trees evenly distributed throughout the plot. In addition, it allowed easy growth comparisons of the largest diameter, evenly distributed trees within subplots.

Plots were thinned to average spacings of 6.6, 9.3, 13.2, 18.7, and 26.4 feet. Treatments contained the following numbers of trees:
6.6 feet, 192 trees per plot (1,000 trees per acre) (fig. 3)
9.3 feet, 96 trees per plot (500 trees per acre)
13.2 feet, 48 trees per plot (125 trees per acre) (fig. 4)
18.7 feet, 24 trees per plot (125 trees per acre)
26.4 feet, 12 trees per plot (62 trees per acre) (fig. 5)
Each spacing was replicated six times. Understory vegetation was removed by herbicides and mechanical means approximately every 4 years on three of the six replications.[2] A buffer area one-half chain wide around each plot was treated the same as the inner plot.

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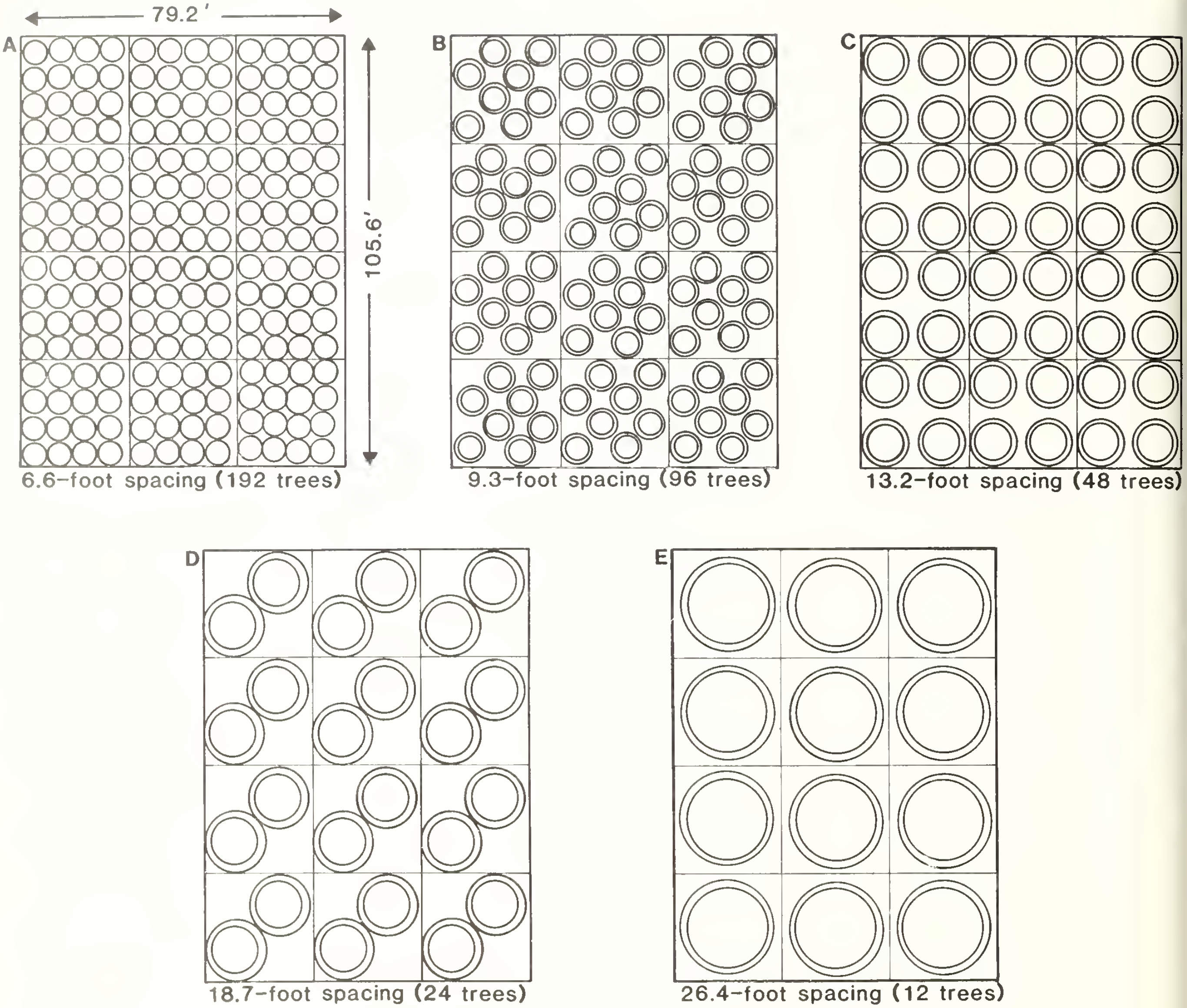
[2] Statistically, the experiment is a split-plot experiment. Whole-plot treatments are arranged as a 5-by-2 factoral in a completely randomized design. Whole-plot treatments are replicated three times. Split-plot treatments are time periods of remeasurement after installation. Five periods of 4 years each were used. Analysis of variance was used to judge the significance of treatment effect. The period effects were partitioned into orthogonal polynomial effects in order to look at the relationships of responses over time.



6.6-foot spacing (192 trees)

9.3-foot spacing (96 trees)

13.2-foot spacing (48 trees)

18.7-foot spacing (24 trees)

26.4-foot spacing (12 trees)

Figure 2.—Diagramatic sketch of tree location at five spacings in 0.192-acre full plots and 16-milacre subplots. Outer circles represent average crown size 20 years after thinning where understory vegetation was controlled; inner circles where vegetation was allowed to develop naturally

Figure 3.—Plot thinned to 6.6-foot spacing, with understory vegetation controlled.

Figure 4.—Plot thinning to 13.2-foot spacing, with understory vegetation allowed to develop naturally. Manzanita brush in right foreground is 5 feet high.

Some understanding of tree distribution and crown closure for various spacings and vegetation treatment can be gained by comparing sketches in figure 2. Although trees left were sometimes not in the exact location for equal spacing, they were never closer than two-thirds the distance of treatment spacing. Crown closure 20 years after thinning varied from 86 percent where trees were 6.6 feet apart and vegetation was controlled to only 18 percent where trees were 26.4 feet apart and vegetation was not controlled.

Logging of overstory and thinning of saplings was started in the fall of 1957 and completed the fall of 1958. Thus, there was one growing season between thinning and initial measurement on some plots and up to two seasons on others. The one-year delay in completing logging and thinning affected all spacings and did not inadvertently bias growth measurements. All recent logging and thinning slash was removed from the plots and burned.

Diameters and heights of all trees were measured in the fall of 1959 and every four growing seasons for the next 20 years. Diameters were measured with a steel tape to the nearest one-tenth inch, and heights with a sectioned aluminum pole to the nearest one-tenth foot.

Tree volume for this report was computed using an improved volume equation for second-growth ponderosa pine recently developed by DeMars and Barrett.[3] The data base for this equation was obtained from north-central Washington and central and eastern Oregon. Therefore, volume estimates presented here will differ from those in previous publications on this study (Barrett 1970, 1973).

Percent cover of understory vegetation on 15 plots was measured by systematic sampling of 100 points per plot (Heady et al. 1959).

Figure 5.—A dominant tree on a plot thinned to 26.4-foot spacing. In 1959, just after thinning, this tree was 2 inches in diameter and 10 feet tall. Twenty years later it was 13.8 inches in diameter and 45 feet tall.

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[3] Donald J. DeMars and James W. Barrett. Unpublished data on file at Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Results and Discussion

Diameter Growth

Table 1—Results of analysis of variance

Variable	Spacing	Vegetation	Period		Lack of fit[3]	Spacing x period interaction	Vegetation x period interaction
			Linear[1]	Quadratic[2]			
Diameter increment	**	**	**	**	n.s.	**	**
Height increment	**	**	**	**	**	**	**
Volume increment	**	**	**	n.s.	**	**	**
Basal area increment	**	**	**	**	*	n.s.	**
Diameter	**	**	**	**	**	**	**
Height	**	**	**	**	**	**	**
Volume	**	**	**	**	n.s.	**	**
Basal area	**	**	**	**	**	**	**

n.s. = not significant; * = significant at 5-percent level of probability (significant); ** = significant at 1-percent level of probability (highly significant).

[1] The linear component of period isolates the variation accounted for if a straight line is fit through the data.
[2] The quadratic component of period isolates the variation accounted for if a second degree curve is fit through the data.
[3] Lack of fit isolates additional variation not accounted for by the linear and quadratic components.

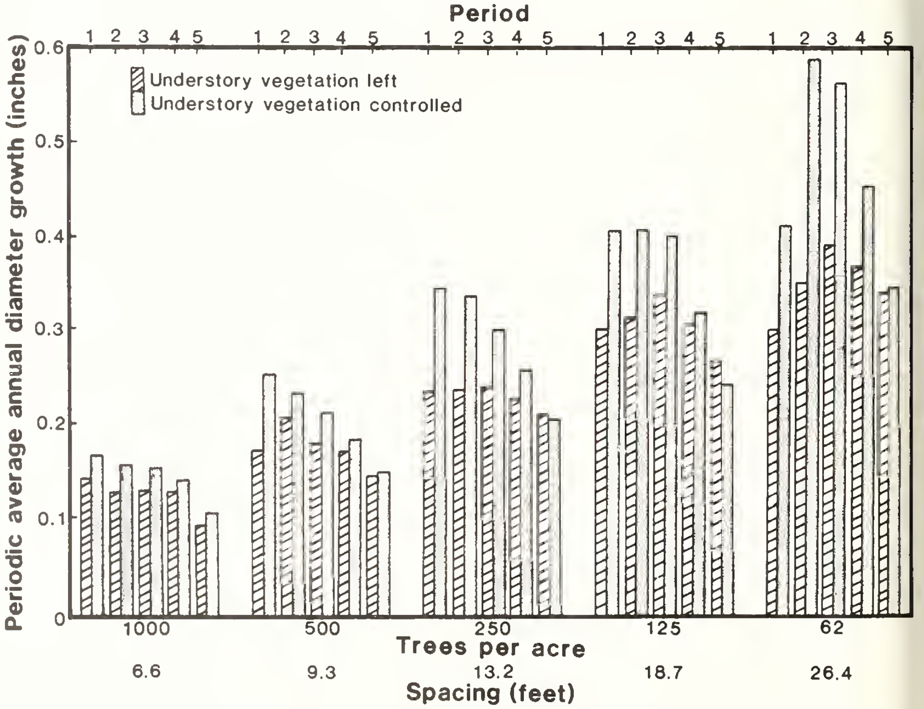

Figure 6.—Periodic annual diameter increment during five 4-year measurement periods. Increment is based on the average growth of individual trees living through each period.

Spacing and understory vegetation had highly significant effects on diameter growth (table 1). Widely spaced trees grew faster than narrowly spaced trees (fig. 6). During the 20 years of observation periodic annual diameter growth has averaged as follows:

Spacing	Trees per acre	Vegetation left	Vegetation controlled
Feet		*Inches*	
6.6	1000	0.13	0.15
9.3	500	.18	.21
13.2	250	.23	.29
18.7	125	.30	.35
26.4	62	.35	.47

Understory vegetation has had a pronounced deterrent effect on diameter growth especially at the wider spacings (fig. 6). This was most evident during the first three measurement periods and appears to have diminished in the last two. Severe drought during the last 4-year period may have influenced these relationships. Also, during this same period lack of snow cover and below freezing temperatures defoliated much of the ceanothus and some manzanita.

Although diameter growth at wider spacings increased during the first three periods, it has diminished since that time. This has been most evident and consistent during the last two periods of observation. A similar trend was observed in the Methow Valley study (Barrett 1981). This is probably due to increasing age and stand density (basal area).

Twenty years after thinning the effect of understory vegetation on average diameter is most evident at the wider spacings. For example, where 62 trees per acre were left, average diameter was 11.6 inches where the understory vegetation was controlled, compared to 9.1 inches where vegetation was allowed to develop naturally (fig. 7). Where 125 trees per acre were left, the comparison is 9.6 to 8.3 inches. If diameters are projected to 28 years after thinning, when trees may be merchantable, diameters are estimated to be:[4]

Spacing	Trees per acre	Vegetation left	Vegetation controlled
Feet		······· *Estimated d.b.h. (inches)*	········
6.6	1000	5.3	5.5
9.3	500	6.4	6.9
13.2	250	8.2	8.8
18.7	125	10.1	11.0
26.4	62	11.4	13.5

If we look at these results in terms of management goals and existing stock level guidelines (Barrett 1979) we find that 500 trees per acre probably exceeds the stocking level that will produce usable round wood 8 inches in diameter in 28 years (fig. 7). On the other hand, where 250 trees were left, average diameters have approached or exceeded maximum stocking at about 8 inches. Therefore, if supplying a round-wood market is the objective of the first commercial entry, it appears that no more than 250 trees per acre should be left (tables 2-6). Increment rates shown in figure 6 can be used to estimate the time needed for trees to grow to various diameters at the five stocking levels. Results of this study suggest that an acceptable initial number of trees to produce for a saw-log market on this site is between 125 and 250 trees per acre, although temporary losses in yield should be expected from a drastic reduction in the number of trees.

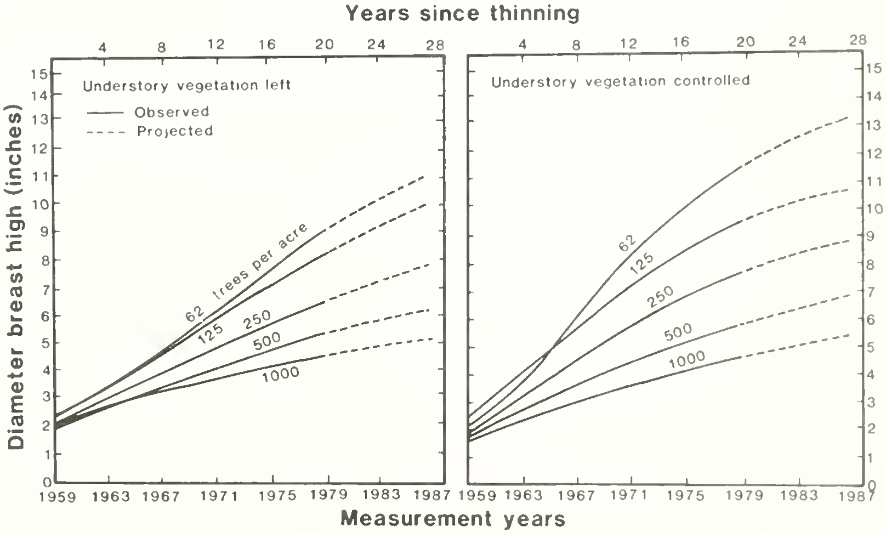

Figure 7.—Average stand diameter under five thinning treatments during 20 years of observation and estimates projected 8 years in the future, with vegetation left to develop naturally and vegetation controlled.

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[4] Projections of tree diameter and basal area beyond 20 years after thinning were made by equations fitted to the data and by examining trends of diameter and basal area growth. Unforeseen climatic changes during the next decade could influence these estimates.

Table 2—Number of ponderosa pine trees in each diameter class, by height and number per acre, in central Oregon in 1979, 20 years after thinning to 6.6-foot spacing (1,000 trees per acre), with and without understory vegetation control

	Vegetation left		Vegetation controlled	
Diameter Class	Trees per acre	Average height	Trees per acre	Average height
Inch		*Feet*		*Feet*
0.5	1	4.6	1	4.9
1	17	8.5	21	7.0
2	78	12.3	63	11.9
3	184	16.2	177	15.1
4	234	20.1	257	19.2
5	238	23.8	228	22.6
6	141	26.9	135	26.1
7	71	29.9	63	29.7
8	10	33.2	30	32.5
9			4	34.8
Total or average	974	21.3	979	20.5
		Inches		
Quadratic mean d.b.h.	4.7		4.7	
		Square feet per acre		
Basal area	115.5		120.7	

Table 3—Number of ponderosa pine trees in each diameter class, by height and number per acre, in central Oregon in 1979, 20 years after thinning to 9.3-foot spacing (500 trees per acre), with and without understory vegetation control

	Vegetation left		Vegetation controlled	
Diameter Class	Trees per acre	Average height	Trees per acre	Average height
Inch		*Feet*		*Feet*
1	1	8.2	1	7.2
2	10	11.5	3	9.8
3	51	14.5	24	13.1
4	101	17.7	80	18.7
5	129	20.6	108	21.2
6	111	24.7	132	24.3
7	61	26.8	101	28.2
8	24	31.3	43	32.1
9	7	37.6	4	33.7
10			2	42.0
Total or average	495	21.6	498	23.5
		Inches		
Quadratic mean d.b.h.	5.5		5.9	
		Square feet per acre		
Basal area	80.8		93.8	

4—Number of ponderosa pine trees in each diameter class, by height and er per acre, in central Oregon in 1979, 20 years after thinning to 13.6-foot ng (250 trees per acre), with and without understory vegetation control

	Vegetation left		Vegetation controlled	
eter	Trees per acre	Average height	Trees per acre	Average height
		Feet		*Feet*
	7	12.8		
	19	17.3	3	16.9
	48	20.2	14	22.0
	47	23.3	42	25.4
	57	27.4	67	28.7
	45	31.1	59	31.9
	19	32.3	36	35.5
	4	35.2	14	34.6
			2	34.8
			4	41.3
or age	246	25.2	241	29.8
		Inches		
ratic an h.	6.7		7.7	
		Square feet per acre		
area	60.1		78.5	

5—Number of ponderosa pine trees in each diameter class, by height and er per acre, in central Oregon in 1979, 20 years after thinning to 18.7-foot ng (125 trees per acre), with and without understory vegetation control

	Vegetation left		Vegetation controlled	
eter	Trees per acre	Average height	Trees per acre	Average height
		Feet		*Feet*
	1	12.5	2	15.5
	5	21.2	2	17.5
	35	27.7	10	28.2
	38	28.7	24	30.7
	29	33.7	26	35.2
	12	36.9	24	36.7
	3	40.9	26	40.3
	2	38.0	9	43.5
			2	31.9
or rage	125	30.4	125	32.2
		Inches		
ratic an .h.	8.3		9.0	
		Square feet per acre		
l area	47.2		62.6	

Table 6—Number of ponderosa pine trees in each diameter class, by height and number per acre, in central Oregon in 1979, 20 years after thinning to 26.4-foot spacing (62 trees per acre), with and without understory vegetation control

	Vegetation left		Vegetation controlled	
Diameter Class	Trees per acre	Average height	Trees per acre	Average height
Inch		*Feet*		*Feet*
6	5	18.3		
7	4	25.4	1	18.8
8	10	28.8	1	27.0
9	17	31.6	4	30.9
10	14	33.4	9	33.0
11	10	36.3	16	33.1
12	2	38.0	16	38.5
13			10	44.5
14			5	43.7
Total or average	62	31.2	62	36.9
			Inches	
Quadratic mean d.b.h.	9.2		11.7	
			Square feet per acre	
Basal area	28.5		45.9	

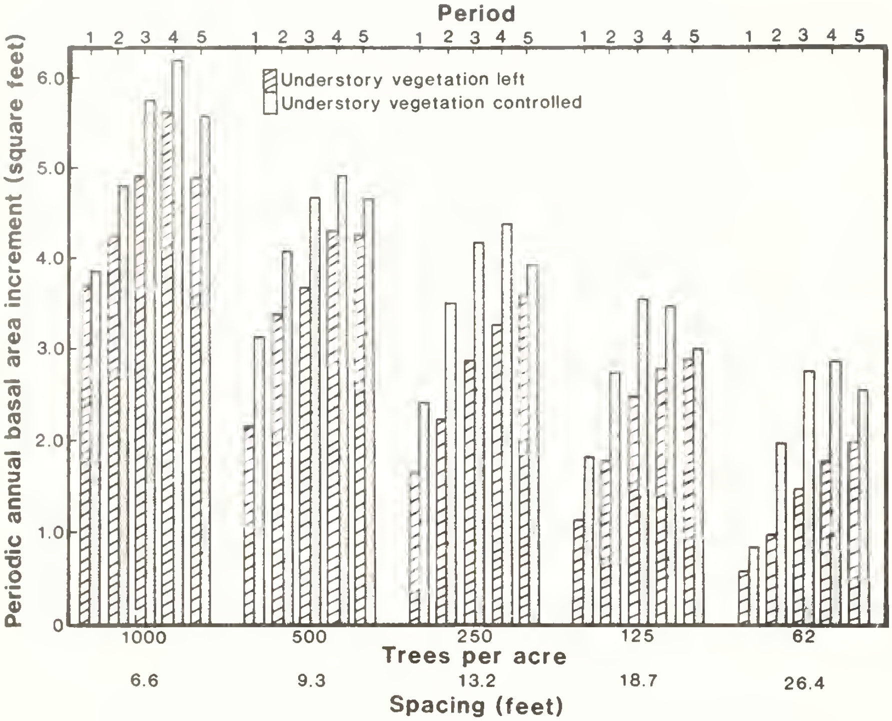

Figure 8.—Periodic annual basal area increment during five 4-year measurement periods.

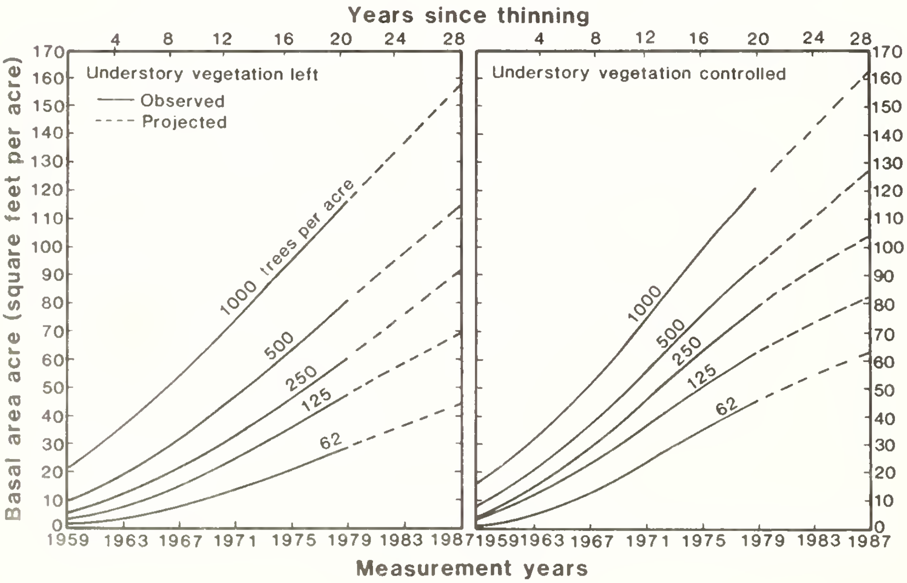

Figure 9.—Net basal area attained during 20 years after thinning and predicted 8 years in the future, with vegetation allowed to develop naturally and vegetation controlled.

Basal Area

Basal area was significantly and positively correlated with spacing (table 1). During the first four periods basal area increment increased steadily in all treatments where understory vegetation was controlled, with one exception (fig. 8), but during the last period increment declined in all treatments. Where understory vegetation was left to develop naturally periodic basal area increment increased at all spacings during the first four periods but declined in the fifth period at only the two narrowest spacings.

Periodic annual increment ranged from a high of 6.2 square feet per acre during the fourth period at the closest spacing to a low of 0.6 square foot at the widest spacing in the first period (fig. 8). The greater increments in basal area occurred where the initial basal area was greater. Understory vegetation consistently reduced basal area increment at all spacings. This effect was most pronounced at the wider spacings, where reductions of around 50 percent occurred during some periods.

Basal area at the closest spacing has accumulated more than 110 square feet during the 20 years after thinning, compared to only 25 square feet at the widest spacing where understory vegetation was left to develop naturally (fig. 9). In another 8 years (28 years after thinning) basal area at the closest spacing could be an estimated 160 square feet. This density could predispose the stand to a bark beetle infestation if trees attain the size for optimum insect development (Sartwell 1971).

Height Growth

Both stand density and understory vegetation had significant effects on height growth throughout the 20 years of observation (table 1). Trees at the widest spacing are growing about 1.5 feet per year where vegetation was controlled and only about 0.7 foot at the narrowest spacing (fig. 10). Understory vegetation is having the greatest effect at the wider spacings, reducing growth as much as 15 to 20 percent during some periods.

The reader should keep in mind that before thinning these trees were heavily suppressed by high density and overstory, and height growth was only a few inches per year. After thinning, roots needed time to grow and expand into space formerly occupied by those of cut trees. From figure 10 one might be tempted to conclude that trees in the two lowest densities (62 and 125 trees per acre) have reached maximum capacity for annual height growth. Reaching this growth rate capability apparently took about 12 years. Trees at higher densities may still be increasing in annual rate of growth, but additional time is needed to see if these denser spacings have reached maximum rate or will ever reach the rate attained by wider-spaced trees.

Because of the uneven pattern of past height growth (fig. 11), no attempt was made to project future height growth. Thus, volume growth could not be projected an additonal 8 years.

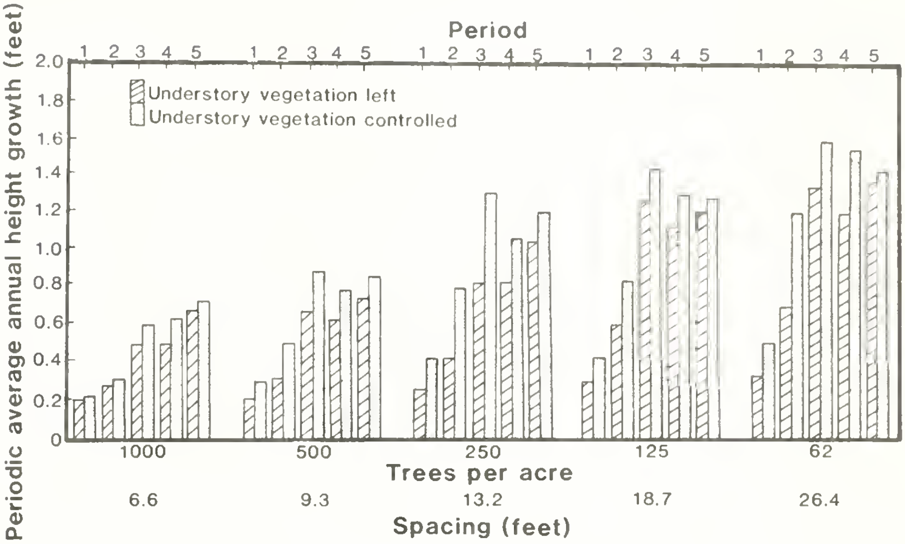

Figure 10.—Periodic average annual height growth during five 4-year measurement periods. Increment is based on the average growth of individual trees living through each period.

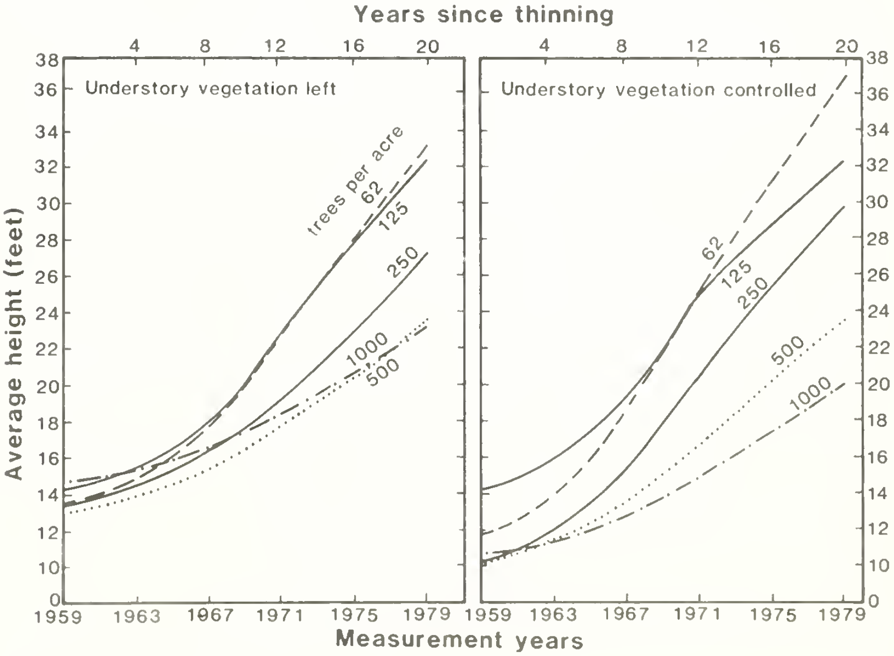

Figure 11.—Average tree heights during 20 years of observation. Averages are based on heights of trees living through each period, with vegetation left to develop naturally and vegetation controlled.

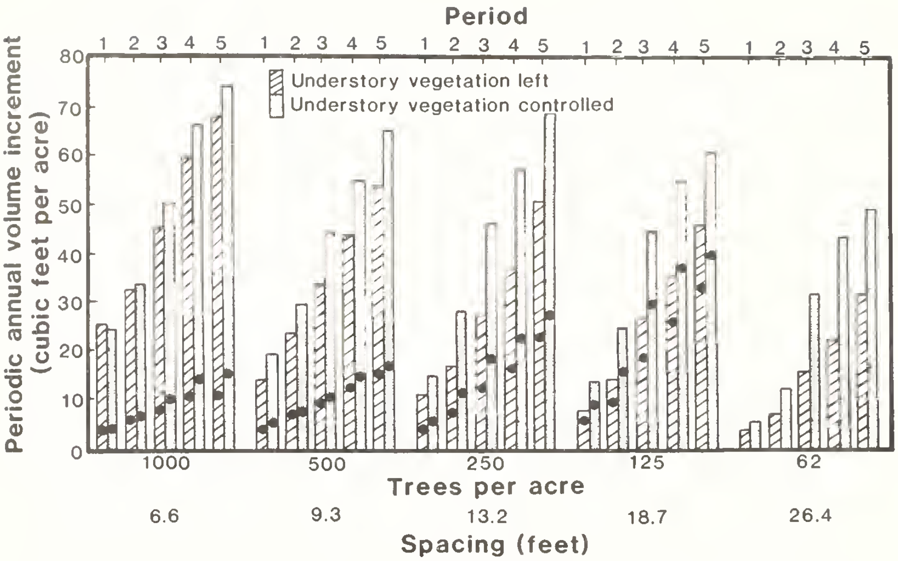

Figure 12.—Periodic annual net increment during five 4-year measurement periods. Bars show total increment for trees at each spacing. Points within bars show increment of the 62 largest well-distributed trees per acre within plots.

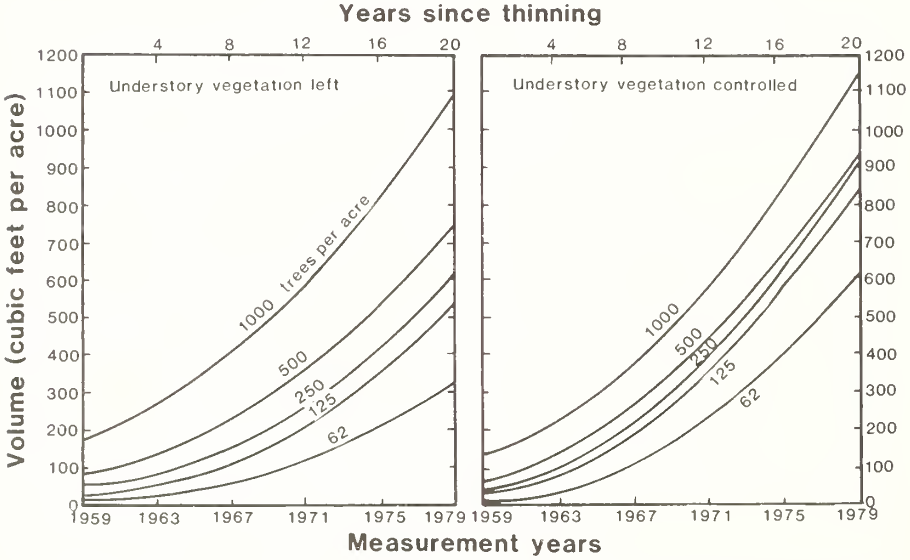

Figure 13.—Net yield of trees thinned to five stand densities, with vegetation allowed to develop naturally and vegetation controlled.

Mortality

There was no mortality at the widest spacings and it was minor at other spacings. Mortality ranged from 3.6 percent where 250 trees per acre were left to 0.4 percent where 500 trees per acre were left.

Since most of the trees that died were in the 1- and 2-inch diameter classes, the effect on gross volume increment was small. Since no mortality was observed during the first 4-year period and only two trees died during the last period, most of the mortality occurred between 1963 and 1975. The cause of tree deaths was unknown, although root rot (*Armillaria*) was suspected.

Volume Increment and Yield

The diameter at which ponderosa pine may be sawn into lumber differs with locale, but in central Oregon the lower limit is now about 9 inches at breast height. Since the majority of trees in this study are still below that size 20 years after thinning, yield and increment are examined here in cubic feet only.

Periodic annual increment (PAI)[5] has steadily increased over the 20 years of observation throughout all spacings tested (fig. 12). The highest annual increment measured during the last 4-year perod was about 75 cubic feet per acre per year at the 6.6 foot spacing where vegetation was controlled.

Although there was a consistent increase in PAI throughout the range of spacings it was most impressive at the wider spacings, where growth sometimes doubled from one period to the next. This was apparently due to rapid diameter and height growth where competition was low. Thus, increment rates on the low density plots are rapidly approaching those on the high density plots.

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[5] Volumes may differ from previous publications because improved volume equations were used in this report. See footnote 3.

As might be expected, spacing has had a highly significant effect on PAI throughout the 20 years (table 1), but it is also notable that where vegetation was controlled, PAI has been similar at three spacings (9.3, 13.2, and 18.7 feet) during each of the last three measurement periods (fig. 12). This suggests that if competition from understory vegetation could be controlled by chemicals or prescribed fire during the first decade after thinning the same amount of wood fiber might be produced over a wide range of spacings.

The growth-depressing effect of understory vegetation on PAI throughout the 20 years was highly significant (table 1). This effect was much more pronounced at the wider spacings, where PAI was sometimes reduced one third to one half.

The greatest yield of wood was produced where the highest number of trees were left (1,000 per acre) (fig. 13). This yield, however, was on trees having an average diameter of only 4.7 inches 20 years after thinning. Where 500 trees per acre were left, average diameters were from 5.5 to 5.9 inches.

One important need in ponderosa pine management is a stocking guide that is relatively independent of age and site. Stand density index (Reineke 1933) is one of several promising alternatives. The data on volume increment in relation to stand density index and basal area presented in figures 14 and 15 represent another contribution to guidelines for stocking. Some workers, however, believe these relationships are not as clearcut as presented in figures 14 and 15; they believe that pattern of stand development is independent of age and site but that rate of development may not be.

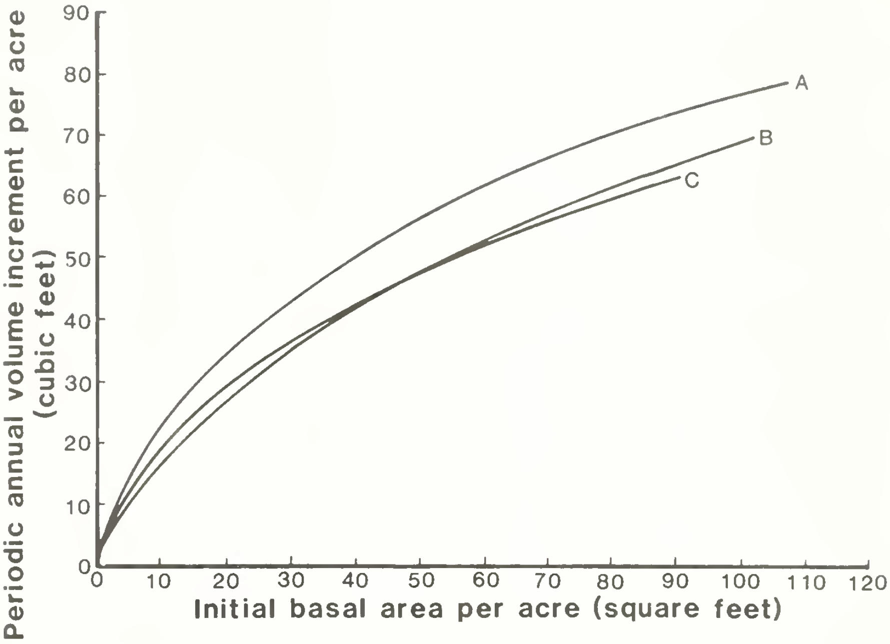

Figure 14.—Periodic annual volume increment in relation to basal area at the beginning of each growth period on two spacing studies.

A = Pringle Falls spacing study, understory vegetation removed $[y = 103.89007\ (1\text{-}e^{-0.0094292x})^{0.6269498}]$.

B = Pringle Falls spacing study, understory vegetation left $[y = 107.948063\ (1\text{-}e^{-0.0075134x})^{0.7096307}]$.

C = Methow study $[y = 97.8675\ (1\text{-}e^{-0.007255})^{0.6115}]$.

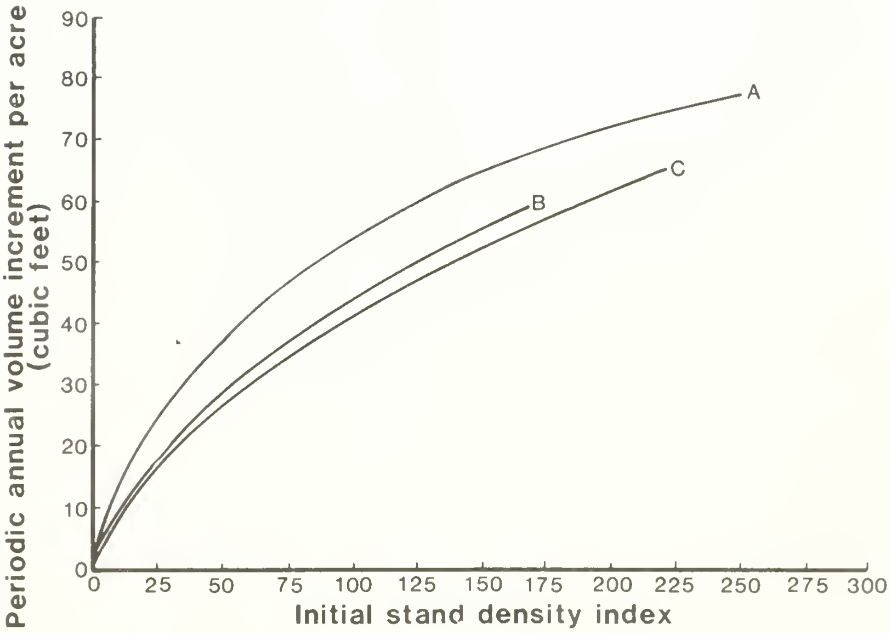

Figure 15.—Periodic annual volume increment in relation to stand density index (Reineke 1933) at the beginning of each growth period on two spacing studies.

A = Pringle Falls spacing study, understory vegetation removed $[y = 89.0077\ (1\text{-}e^{-0.0065674x})^{0.6836723}]$.

B = Pringle Falls spacing study, understory vegetation left $[y = 111.596877\ (1\text{-}e^{-0.0029654x})^{0.6885196}]$.

C = Methow spacing study $[y = 74.7556\ (1\text{-}e^{-0.007018x})^{0.6772}]$.

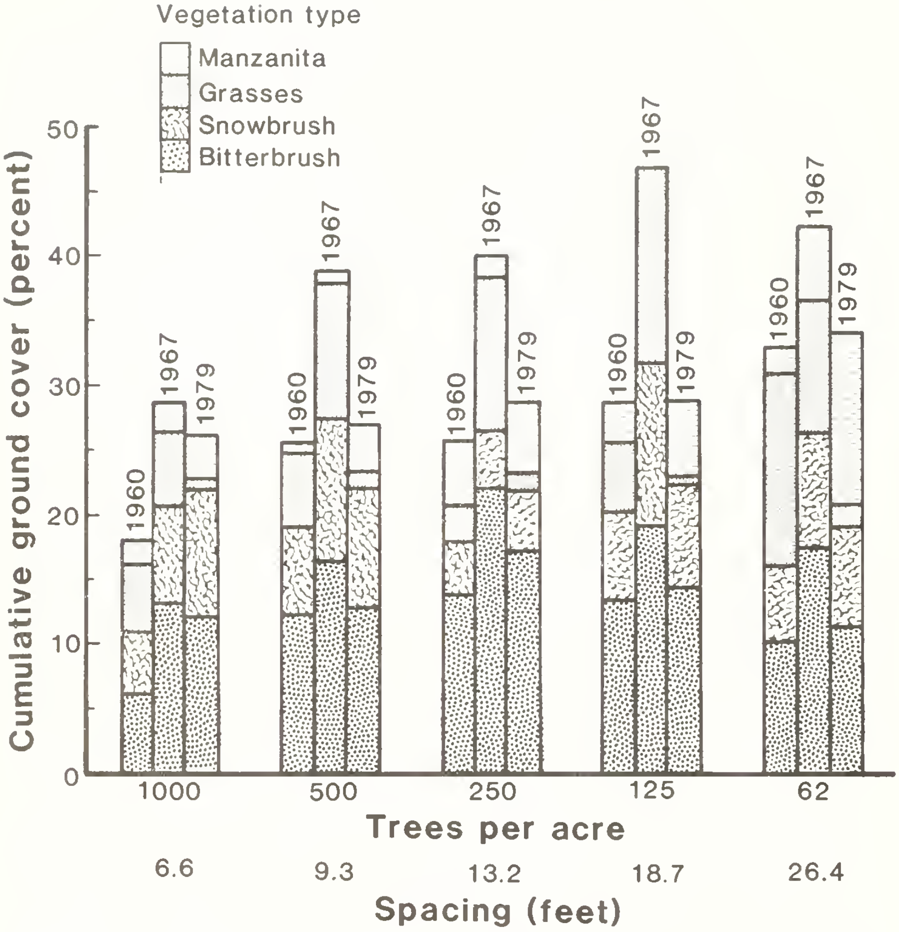

Figure 16.—Average percent of ground covered by understory vegetation in 1960, 1967, and 1979. Two growing seasons elapsed between overstory removal and thinning, and measurement of vegetation in 1960. Differences in the amount of vegetation cover among tree spacings may have developed before initial measurements were taken.

Effects on Understory Vegetation

Statistical tests showed that the amount of understory vegetation was affected by tree spacing (5 percent level of probability) only during 1967 (fig. 16). Cover percentages varied widely from plot to plot within treatments at the wide spacings, even in 1967, and were greater at other measurement dates. The first measurements of cover were not made until 1960. Figure 16 suggests that spacing was already having some effect on cover percentages, but this was not statistically significant.

Since controlling understory vegetation had a highly significant effect on diameter, height, and volume growth (table 1), and the spacing x vegetation interaction was highly significant, one might conclude that there must now be more vegetation present at the wider spacings than at narrow spacings. There may be, but our procedure for sampling understory vegetation apparently is not sensitive enough to detect existing differences in vegetative cover.

Results shown in figure 12 and table 7 suggest that trees sustained substantial losses in increment because of competition with understory vegetation. The growth-reducing effect is most evident at the wider spacings, where losses approach or exceed 50 percent (table 7). The lower losses of the last observation period could be the result of reductions in understory cover caused by climatic factors.

Oliver (1979) reported reductions in tree growth caused by brush competition in a similar experiment in a 12-year-old ponderosa pine plantation on a highly productive site in California. Where brush cover was near 100 percent, tree diameter was reduced by the equivalent of nearly 3 years of growth.

During the 1974-79 period two climatic extremes severely affected understory vegetation throughout central Oregon. During the winter of 1977-78 a drop in temperature to far below freezing, in the absence of snow cover, defoliated much of the manzanita and snowbrush. This cold period was followed by a severe drought the following summer which may have depressed cover percentages in 1979. Grasses also suffered; figure 16 shows a marked drop in grass cover in 1979. This depressing effect on growth of brush and grass species may have encouraged the growth of pine seedlings.

In 20 years, the pine reproduction that consisted of small seedlings at the time of thinning has also responded to additional growing space in the plots where understory vegetation was allowed to develop. Seedlings have increased in size and number and now constitute a notable part of the brush-grass competition. Numbers and sizes of small trees observed in 1979 were as follows:

	Excess trees per acre			
Spacing	Total	Below breast height	Above breast height	Average d.b.h. of trees above breast height
Feet				*Inch*
6.6	94	52	42	0.8
9.3	177	151	26	.9
13.2	698	656	42	.8
18.7	875	802	73	.8
26.4	1448	1141	307	.8

Whether the invasion of small trees in thinned stands becomes a problem in general practice depends largely on how the slash and understory vegetation are treated. Thinning slash is often mechanically crushed (Dell and Ward 1969) to reduce fire hazard. Young seedlings are often destroyed in this process or covered with slash. Also, prescribed burning or piling and burning destroys most unwanted seedlings.

Table 7—Losses of volume growth in suppressed sapling ponderosa pine thinned to five spacings and competing with understory vegetation, central Oregon

	Years after thinning				
Spacing	0-4	5-8	9-12	13-16	17-20
Feet			*Percent*		
6.6	0	4	10	11	9
9.3	27	20	24	21	17
13.2	27	40	41	35	26
18.7	45	44	41	36	25
26.4	33	56	52	50	37

Conclusions

Managers are frequently tempted to apply results from studies such as this to a broader geographic area than can be justified. This often happens because it is the only information available and some knowledge seems better than none. Studies such as this were not designed to predict growth and yield over a wide geographic area but to look at the relationship of tree spacing, understory vegetation, and growth and yield. It is not appropriate to use the information presented here, for example, to predict growth and yield in the Ochoco Mountains or on a low site in the Deschutes National Forest. Information on which to base such predictions would require intensive representative replication of this study, and funding to do this was not available when this study was installed. Thus, caution is advised in using these results to predict growth on other sites, initial stand sizes, and plant communities. Comparisons should be chosen carefully. A common error is to compare growth of recently thinned small pole stands to growth immediately after thinning in this study of saplings. Diameter growth in pole stands is usually much less than in sapling stands because density (basal area) is much higher and crown ratios frequently poorer. Another common mistake is to compare results of this study to a situation where four or five overstory trees per acre are left and the sapling understory is thinned. Even a few overstory trees per acre can be surprisingly effective in suppressing growth on thinned understory (Barrett 1969). On the other hand, as Bruce (1977) suggests, "The scientist should not hide behind the facile caveat 'under the conditions of this test these outcomes were observed.' His interpretation should include his best opinion about practical application." The discussion that follows is my best interpretation of application.

Results from this study may be used in several ways. First, they quantify the effects of spacing and understory vegetation on growth and give the manager some idea of gain from control of tree density and vegetation. Second, they provide an estimate of the time needed to grow trees to commercial sawlog size. And third, they provide an estimate of cubic volume yield 20 years after thinning. In addition, study results document the extent of mortality in this thinned stand. They also document the fact that severly suppressed trees will respond to release at 40 to 70 years of age and grow at rates observed in much younger trees. How long these growth rates continue is not known, but since ponderosa pine is a long-lived species we can assume that age will not be a serious deterrent to growth before trees at the wider spacings reach target diameters of 20 to 24 inches.

It is apparent from these results that the time required to reach a target diameter is affected by initial spacing and the amount of understory vegetation present. The lower the density of tree and understory vegetation the shorter the time needed to produce trees of specific sizes.

There appears to be a cost in yield if size is an objective. To produce larger trees in a given time, there must be fewer trees. Consequently growing stock is less and yield is reduced. Figure 17 shows this relationship for this study. Also strikingly evident in this. figure is the effect of understory vegetation on yield, although long-term yield will probably not be reduced in the same proportion as shown for the first 20 years after precommercial thinning. At the two widest spacings yield has been reduced 34 and 45 percent. Evidently, soil not occupied by tree roots was invaded by roots of understory vegetation. Observations in natural stands suggest that brush competition persists until crowns begin to close and trees become the superior competitors; the brush then dies or becomes less competitive. This observation suggests that brush control several years after thinning and again about 5 years later may enhance stand growth. On some sites, after trees reach 5 inches d.b.h., prescribed fire is a promising method of subduing competitive brush early in the rotation (Martin and Dell 1978).

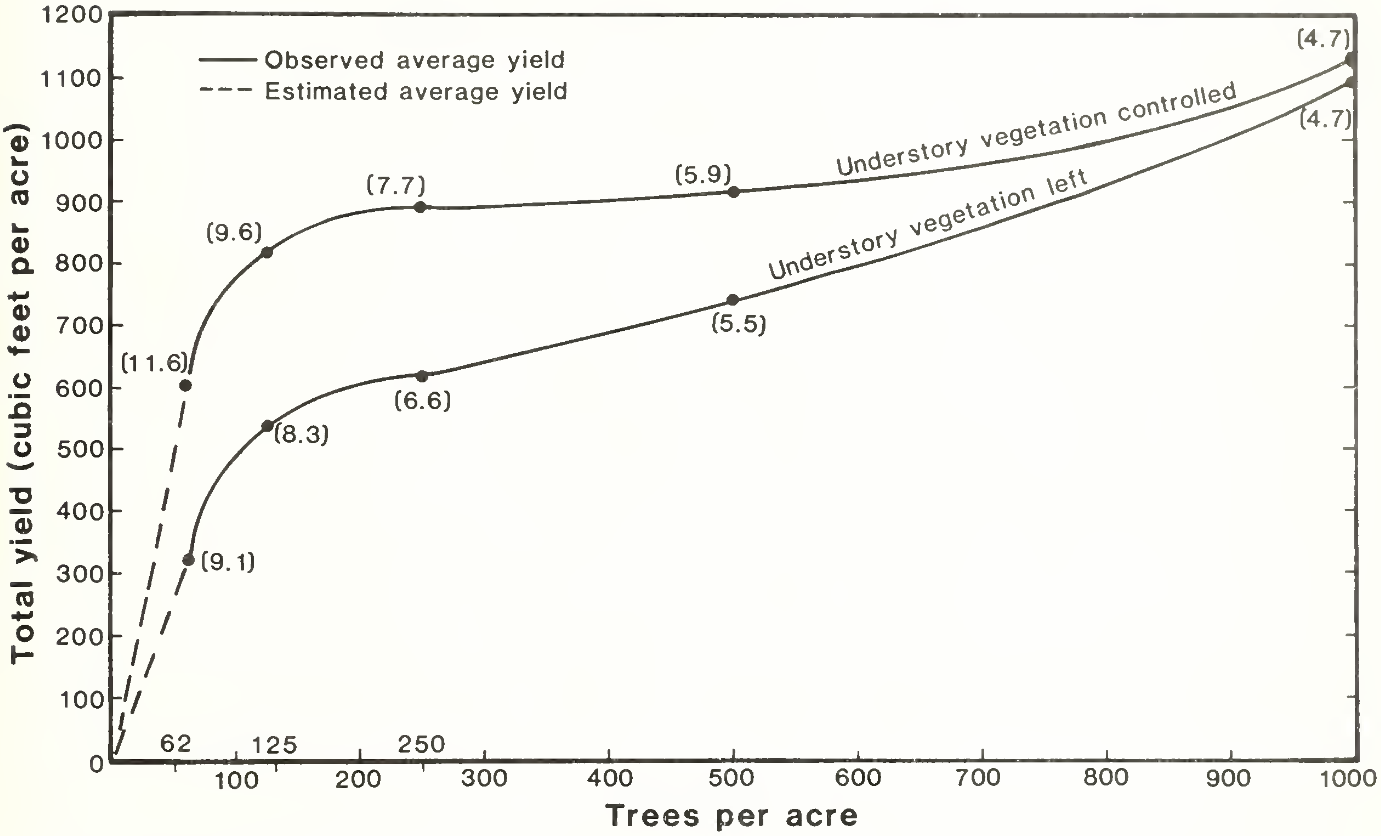

Figure 17.—Yield of suppressed ponderosa pine saplings 20 years after thinning to five densities, with vegetation allowed to develop naturally and vegetation controlled. Average diameters for each density (inches d.b.h.) shown in parentheses.

Metric Equivalents

1 inch = 2.54 centimeters
1 foot = 0.304 8 meter
1 acre = 0.404 7 hectare
1 square foot/acre = 0.229 6 square meter/hectare
1 cubic foot/acre = 0.069 97 cubic meter/hectare

Literature Cited

Barrett, James W. Dominant ponderosa pine do respond to thinning. Res. Note PNW-9. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1963. 8 p.

Barrett, James W. Spacing and understory vegetation affect growth of ponderosa pine saplings. Res. Note PNW-27. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1965. 8 p.

Barrett, James W. Response of ponderosa pine pole stands to thinning. Res. Note PNW-77. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1968. 11 p.

Barrett, James W. Crop-tree thinning of ponderosa pine in the Pacific Northwest. Res. Note PNW-100. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1969. 13 p.

Barrett, James W. Ponderosa pine saplings respond to control of spacing and understory vegetation. Res. Pap. PNW-106. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1970. 16 p.

Barrett, James W. Latest results from the Pringle Falls ponderosa pine spacing study. Res. Note PNW-209. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1973. 22 p.

Barrett, James W. Silviculture of ponderosa pine in the Pacific Northwest: The state of our knowledge. Gen. Tech. Rep. PNW-97. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1979. 106 p.

Barrett, James W. Twenty-year growth of thinned and unthinned ponderosa pine in the Methow Valley of northern Washington. Res. Pap. PNW-286. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1981. 13 p.

Bruce, David. Yield differences between research plots and managed forests. J. For. 75(1): 14-17; 1977.

Dell, John D.; Ward, Franklin R. Reducing fire hazard in ponderosa pine thinning slash by mechanical crushing. Res. Pap. PSW-57. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1969. 9 p.

Heady, Harold F.; Gibbens, Robert P.; Powell, Robert W. A comparison of the charting, line intercept, and line point methods of sampling shrub types of vegetation. J. Range Management 12: 180-188; 1959.

Martin, Robert E.; Dell John D. Planning for prescribed burning in the inland Northwest. Gen. Tech. Rep. PNW-76. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1978. 67 p.

Meyer, Walter H. Yield of even-aged stands of ponderosa pine. Tech. Bull. 630, rev. Washington, DC: U.S. Department of Agriculture; 1961. 59 p.

Mowat, Edwin L. Thinning ponderosa pine in the Pacific Northwest—a summary of present information. Res. Pap. 5. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1953. 24 p.

Mowat, Edwin L. Growth after partial cutting of ponderosa pine on permanent sample plots in eastern Oregon. Res. Pap. 44. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1961. 23 p.

Oliver, William W. Early response of ponderosa pine to spacing and brush: Observations on a 12-year-old plantation. Res. Note PSW-341. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1979. 7 p.

Reineke, L.H. Perfecting a stand density index for even-aged forests. J. Agric. Res. 46: 627-638; 1933.

Sartwell, Charles. Thinning ponderosa pine to prevent outbreaks of mountain pine beetle. In: Proceedings of precommercial thinning of coastal and intermountain forests in the Pacific Northwest symposium; 1971 February 3-4; Pullman, WA: Washington State Univ.; Coop. Ext. Serv. and Department Forest and Range Management; 1971: 41-52.

Volland, Leonard A. Plant communities of the central Oregon pumice zone. R-6 Area Guide 4-2. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region; 1976. 113 p.

Barrett James W. Twenty-year growth of ponderosa pine saplings thinned to five spacings in central Oregon. Res. Pap. PNW-301. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1982. 18 p.

Diameter, height, and volume growth and yield are given for plots thinned to 1000, 500, 250, 125, and 62 trees per acre in a 40- to 70-year-old stand of suppressed ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) saplings in central Oregon. Trees averaged about 1-inch in diameter and 8 feet in height at the time of thinning. Considerations for choosing tree spacing for precommercial thinning in this type of stand are discussed.

Keywords: Thinning effects, stand density, precommercial thinning, ponderosa pine, *Pinus ponderosa*.

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