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Effects of Leader Topping and Branch Pruning on Efficiency of Douglas-Fir Cone Harvesting With a Tree Shaker

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Abstract

In 1983, a study was conducted to evaluate the effects of leader topping and branch pruning on the efficiency of tree shaking to remove Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) cones. Removal efficiency for three topping and pruning treatments averaged 69 percent, whereas for the uncut control treatment it was 62 percent. The treatment combination that resulted in the greatest cone removal (70.8 percent) was cutting the last 2 years of growth from the leader but not pruning lateral branches. The pruning-topping effects were not additive, possibly because branch pruning several weeks prior to cone harvest resulted in premature removal of a portion of the most easily shaken cones.

Keywords: Cone collection, pruning, top pruning, pruning tools, Douglas-fir, tree shaker.

Harvesting conifer cones with mechanical tree shakers usually results in lower efficiency than is achieved with identical machines in harvesting deciduous nuts and fruits. Conifer cones are often attached to the branches with tough, woody stalks which necessitate a strong shake force to remove the cones. An attempt to induce abscission zone formation in the woody stalks by spraying abscission-inducing chemicals was tested in southern pine species, but the procedure was not successful (5). Similar abscission tests have not been reported for Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco).

Results from several field trials of harvesting cones of Douglas-fir with tree shakers have been reported (1, 2, 4, 11). In addition, two carefully controlled laboratory studies have been done to gather basic information on shaking characteristics of Douglas-fir. In the first study, detached cone-bearing limbs were shaken on a laboratory device that could vary both stroke length and frequency of shake (8); the second laboratory test simulated shaking two stems with different shapes (2).

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Results from tree shaking trials with Douglas-fir (2, 4, 11) and with other conifers (1, 10, 11) have been encouraging for use of this technique, but orchardists want more complete removal of cones. An average of 55 percent of Douglas-fir cones were removed when 7- to 9-m-tall seed orchard trees were shaken (4), and 52 to 70 percent were removed from larger forest-grown Douglas-fir (11). Attempts to evaluate the variables that influence the proportion of cones that can be removed indicate interactions of many factors: species (1, 2, 8, 11), clone (4, 10), stem diameter (3, 10, 11), tree height (1, 3, 4, 11), stem taper (1, 11), height to live crown (1, 3, 4, 11), physical characteristics of the wood (9), foliage density (1, 11), crown shape (11), branch size (2), branch angle (4), damage susceptibility (1, 10), cone distribution and size (1, 11), and cone maturity (1, 2). Sources of variation related to the tree-shaking machines themselves include factors such as length of shake stroke (7, 8, 11), number of shake cycles per minute (1, 4, 7, 8), amount of shake force or thrust applied to the bole (4, 11), type of thrust applied (4, 11), shake pattern (4, 7, 8), shaker head attachment height (1, 4, 10, 11), duration of shake (4, 7, 10, 11), and number of shakes (4, 8). The fact that many variables interact to influence cone removal is indicated by correlation coefficients (r^2) being less than 0.44 when cone removal is correlated with single variables, such as tree height, stem diameter, or height to live crown (1).

Results from the 1982 shaking test with Douglas-fir (4) suggest that crown shape and branch length can influence cone removal and crown damage. Cones could not be easily shaken from trees with long, pendent branches. Cones were most readily removed from short branches in the upper third of the crown. More shake energy appeared to be conducted to the ends of short, stiff branches. Cone removal was poorest from the lower third of the tree. The damping action of dense crowns on machine-induced vibrations and the propensity for excessive top breakage during shaking are both documented for Douglas-fir trees (1).

In 1983, I decided to test the effects of minor modifications of crown shape or structure of Douglas-fir on the shaking characteristics. The hypothesis was that trees with shorter, stiffer branches and less flexible tops would yield a greater percentage of cones and have less shaker-induced damage than untreated trees.

Objectives of the study were to determine (1) whether branch pruning and leader topping prior to tree shaking improves cone removal, and (2) whether topping results in less crown damage. A future objective is to evaluate harvest efficiency and tree vigor or health after the trees have been shaken in different crop years.

Methods

Sixty-eight trees growing in a Forest Service experimental plantation 24 kilometers north of Corvallis, Oregon, were chosen for study in 1983 because the planting closely approximated conditions in seed orchards. The trees all had normal crown form and foliage density and had good potential for cone production. Most trees had produced one or two cone crops during the preceding 4 years and 65 of the 68 trees were producing cones in 1983. The trees were in an area protected for research. Of the 68 study trees, 48 had been propagated as rooted cuttings in 1968 and had been planted in 1971; the other 20 trees were grafts made in 1973 on large, well-established rootstocks. Grafted trees were somewhat smaller in diameter and height than the cuttings (12.0 cm and 8.0 m vs. 15.8 cm and 8.9 m).

Leader topping and branch pruning were studied for their effect on cone removal efficiency and degree of top damage. Topping consisted of cutting off the top of each tree approximately 20 cm above the 1982 branch whorl. Pruning consisted of cutting off the distal end of major branches in each annual growth whorl. The amount cut from a branch varied according to branch age: all of the 1982 and 1983 increment was cut from the tip of branches 3 years and older; only the 1983 increment was cut from branches in the 1982 whorl.

The experiment was a 2 x 2 factorial of pruned vs. unpruned branches, and topped vs. untopped leaders in a randomized complete block design with 17 replications. Within each replication, each treatment was applied to one of four adjacent trees selected at random. Twelve replications consisted entirely of cuttings and five consisted of grafts. Pruning and topping were done in early August 1983; one worker on the ground used a pole pruner and another worker in the bucket of a lift truck used hand pruning shears.

Tree shaking was done the last week of August 1983 when the cones were mature. Cones had already begun to open on several trees. The Kilby Co.[1/] boom-type tree shaker described in the 1982 shaking study (4) was used. The same low energy, gentle shaking procedure developed in 1982 (4) was also used, except that clamping pressure of the shaker head was reduced from 750 to 500 lb/in^2 and the trees were shaken with the shaker in only one position rather than in two positions as in 1982. All 68 trees were shaken, including 3 trees that did not have cones. The 3 barren trees were given the same shaking treatment to collect crown damage information and to ensure that cumulative effects of shaking can be evaluated in future years on all 68 trees.

Each tree was shaken until it appeared that no more cones could be removed without increasing the shake energy to levels that would cause unacceptable upper crown breakage. The cones fell onto plastic tarps placed under each tree. The length of time each tree was shaken was recorded to the closest 5 seconds. Cones remaining attached to the trees after shaking were hand picked. Both the shaken and hand-picked cones were weighed with a spring scale immediately after collection. Tree measurements recorded included stem diameter, height before and after leader pruning, and height after shaking. Branch damage was recorded by noting the age of the oldest branch whorl on which broken tips occurred. Any external trunk damage to the bole was noted.

Data were analyzed for the 2 x 2 factorial by analysis of variance techniques. Percentage data were subjected to arcsin transformation prior to analysis. Cone removal data were analyzed for the 65 cone-bearing trees; and tree size, pruning length, and shaking data were evaluated for all 68 trees.

[1/] The use of company or brand names is for the convenience of the reader and does not constitute an endorsement by the U.S. Department of Agriculture.

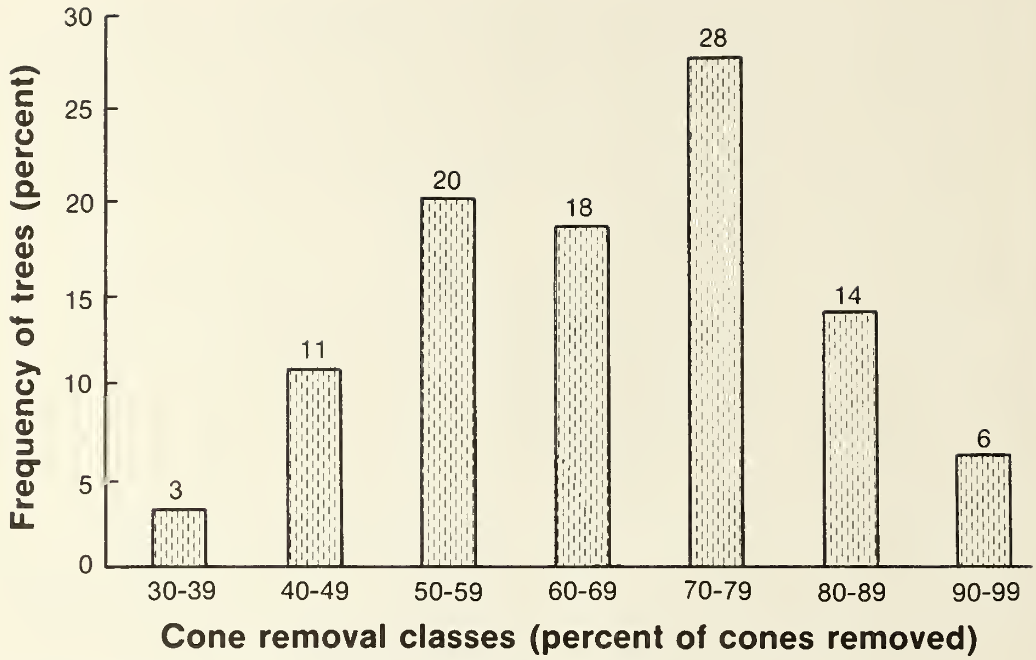

Figure 1.—Frequency distribution of study trees in various cone removal classes.

Results

Cone removal by shaking was successful with most trees: Only 14 percent of trees failed to drop at least 50 percent of their cones (fig. 1). Cone removal averaged 67 percent for all trees in the study (table 1). Trees subjected to topping or pruning treatments yielded more cones than did control trees. Controls averaged 61.5 percent, whereas pruned and/or topped trees averaged 68.7 percent. Analysis of variance tests showed neither pruning nor topping treatments to be significant at the 5-percent level, but the pruning-topping interaction was significant. The most effective treatment was topping without pruning; that treatment averaged 70.8-percent cone removal.

Effects of replication were significant at the 1-percent level for diameter, initial tree height, and total amount of height reduction because of the height and diameter size difference between grafts and cuttings (table 2). Randomization of treatments within replications was effective in that treatments were not significantly different for initial tree heights or stem diameters.

The two leader-topping treatments resulted in the mean removal of 1.4 and 1.7 meters from the upper crown of each tree. Total tree height reduction caused by topping and by shaker breakage averaged 0.5 meter more in topped trees than in untopped trees; the difference was significant at the 5-percent level. Leader breakage occurred in one-third of all leader-topped trees; that loss averaged 0.2 meter for all topped trees. The length of time the trees were shaken was not significant.

Damage to branches after shaking was confined to 1983 branch tips in the top one or two whorls. Fewer branches broke on pruned trees because the most fragile tips had already been removed. Leader topping did not appear to affect shaker damage to branches.

Table 1—Effect of leader topping and branch pruning treatments on weight and percentage of cones removed from Douglas-fir by shaking (means and standard errors), and analysis of variance

Branch and leader treatment	Number of trees	Average weight of cones per tree: Total	Average weight of cones per tree: Removed by shaking	Cones removed by shaking
		- - - - Kilograms	- - - -	Percent
Cone removal:				
Leader topping--				
Branch pruning	15	8.9 ± 0.8	5.9 ± 0.5	66.6 ± 3.5
No branch pruning	17	14.4 ± .9	9.5 ± .5	70.8 ± 3.3
Submeans		11.7	7.7	68.7
No leader topping--				
Branch pruning	17	9.8 ± .8	6.7 ± .6	68.8 ± 3.1
No branch pruning (control)	16	11.2 ± 1.0	6.6 ± .6	61.5 ± 4.5
Submeans		10.5	6.7	65.2
Means		11.1	7.3	67.0

	Degrees of freedom	Probability
Analysis of variance:		
Replications	16	.02
Leader topping (T)	1	.31
Branch pruning (B)	1	.73
T x B	1	.05
Experiment error	45	

Table 2—Tree parameters (means and standard errors) before and after shaking Douglas-fir, and analysis of variance

Branch and leader treatment	Number of trees	Time shaken	Diameter	Original height	Leader length cut off	Length of top broken by shaking	Total reduction in height
		Seconds	Centimeters	- - - - - -	- - - - - Meters	- - - - - -	- - - - - -
Tree parameters:							
Leader topping--							
Branch pruning	17	44 ± 2.6	15.0 ± 0.7	8.6 ± 0.3	1.4 ± 0.1	0.2 ± 0.1	1.6 ± 0.1
No branch pruning	17	54 ± 3.8	15.0 ± .8	8.7 ± .2	1.7 ± .1	.2 ± .1	1.9 ± .1
Submeans		49	15.0	8.7	1.6	.2	1.8
No leader topping--							
Branch pruning	17	47 ± 2.5	14.0 ± .8	8.5 ± .2	0 ± 0	1.3 ± .1	1.3 ± .1
No branch pruning (control)	17	49 ± 4.3	14.8 ± .7	8.5 ± .2	0 ± 0	1.2 ± .1	1.2 ± .1
Submeans		48	14.4	8.5	0	1.3	1.3
Means		48.5	14.7	8.6	--	--	1.5
	Degrees of freedom	- - - - - -	- - - - - -	- - - - - Probability	- - - - - -	- - - - - -	- - - - - -
Analysis of variance:							
Replications	16	.45	0	0	--	.17	0
Topping (T)	1	.59	.18	.49	--	0	0
Pruning (B)	1	.14	.45	.52	--	.46	.34
T x B	1	.28	.52	.61	--	.46	.21
Experimental error	48						

Little bole damage was detected where the shaker head was attached to each tree. Three trees experienced slight bole damage (bark slippage) when the shaker was accidentally operated with less than 400 lb/in² clamping pressure. Inadequate clamping pressure allowed undesirable movement between the pads of the shaker head and the bole. A clamping pressure of 500 lb/in² was adequate for proper transfer of shake energy to trees that averaged 8.6 m in height but was not so strong that clamping pressure damaged the cambial tissues beneath the pads.

Discussion and Conclusions

Cone harvest by shaking was more effective in 1983 than in 1982. Average cone removal increased from 55 percent in 1982 (4) to 67 percent in 1983. The most effective 1983 treatment was to leader-top the trees without pruning branch tips. The 6.5-percent increase in yield of cones of control trees in 1983 over yield in 1982 is attributed primarily to increased skill of the machine operator. The additional 5- to 10-percent increase in cone yield in 1983 probably resulted from the branch-pruning and leader-topping treatments.

The pruning and topping treatments were not done until 2 weeks before shaking; consequently, some cones were removed when the branch tips were pruned. Cones located on the tips of branches in the top one-third of the crown could have been easily removed by the shaker. The cone loss prior to shaking is evidenced by the lower average total weight of cones on branch-pruned trees than on trees that were not branch pruned. A more practical seed orchard procedure would be to limit pruning to the branches that were more difficult to shake in the lower two-thirds of the crown. Another technique that would enhance yield would be to prune only when there is no cone production; that would eliminate cone loss, yet still shorten and stiffen the most difficult-to-shake lower branches.

Both leader topping and branch pruning had greater influence on cone removal when done separately than when combined, but neither treatment effect was significant at 5 percent. The significant pruning-topping treatment interaction indicates that although the two treatments did affect cone removal, their effects were not additive when used together on the same trees. Removal of cones by clipping branch tips in the upper crown prior to shaking may be the most likely cause of the significant topping-pruning interaction. Large standard errors suggest that other uncontrolled variables also had considerable influence. As previously stated, many variables—both plant and machine—interact to determine the proportion of cones that can be removed by shaking (11).

Predicting the actual point where untopped trees will break during shaking is difficult. The top two or three internodes of Douglas-fir trees are slender and very subject to breakage when energy applied is sufficient to remove a majority of cones. Leader pruning prior to shaking allows orchardists to determine final tree height more accurately. Topping removes the most break-prone portion prior to shaking and may allow the machine operator to safely shake leader-pruned trees with slightly more force than trees whose leaders are not topped. On the average, topped trees had 0.5 m greater reduction in total height than did untopped trees, but this will not result in a meaningful difference in the size over the productive life of a seed orchard. Shaker-induced breakage of the main leader averaged 0.6 m and occurred in only about one-third of the leader-topped trees, whereas breakage in untopped trees averaged 1.25 m and occurred in all untopped trees.

Shaking these same trees when the next cone crop is produced will likely yield results somewhat different from those in 1983 because branch pruning is not planned for at least 2 years and then only during a noncrop year. Leader-topping may not be necessary if cone crops are frequent enough that top breakage induced by tree shaking keeps the upper crown in proper shape.

Observations and growth measurements will be made in future years on each of the 68 study trees. Trees will be examined for unseen or delayed symptoms of lower bole damage. I do not expect adverse effects from shaking on tree vigor or cone production since none were found in slash pine 4 years after shaking (6). Cumulative effects on crown structure will also be evaluated to determine if repeated shaking will gradually improve cone removal efficiency by allowing the shaker operator to use greater shake energy without causing unacceptable damage.

nglish Equivalents

1 centimeter (cm) = 0.3937 inch (in)
1 meter (m) = 3.2808 feet (ft)
1 kilogram (kg) = 2.2046 pounds (lb)
1 kilometer (km) = 0.6214 mile (mi)
0.0703 kilogram per square centimeter (kg/cm^2) = 1 pound per square inch (lb/in^2)

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A Dynamic Simulation Model for Analyzing the Importance of Forest Resources in Alaska

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Abstract

A dynamic simulation model has been adapted for use in Alaska. It provides a flexible tool for examining the economic consequences of alternative forest resource management policies. The model could be adapted for use elsewhere if an interindustry transaction table is available or can be developed. To demonstrate the model's usefulness, the contribution of the pulp and paper and tourism industries to Alaska's economy is analyzed. A $105 million increase in final demand for goods and services provided by the tourism industry would compensate for the loss of employment and earnings resulting from the closure of Alaska's two pulpmills. Most of the loss would be confined to higher paying technical jobs in two remote locations; the increase in jobs would involve lower paying jobs located throughout the State.

Keywords: Economic importance (forests), models, simulation, Alaska, management planning (forest).

Assessing Impacts

The livelihood of many Alaska residents is dependent on forest resources. Employees of the forest products industry are obviously dependent, but to varying degrees, employees in commercial salmon fishing, tourism, and some mineral-based industries are also influenced by forest resource management policies.

Any plan involving changes in National Forest management policies should include an analysis of socio-economic impacts. For example, the Alaska National Interest Lands Conservation Act (ANILCA) requires that the USDA Forest Service prepare periodic assessments of management for the Tongass National Forest. These assessments must include an analysis of how timber management policies affect the employment, income, and population of southeast Alaskans.

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To perform the economic impact analyses, a dynamic simulation model (IPASS) was adapted for use in Alaska. This paper describes how it can be used to evaluate forest resource management situations in Alaska.[1]

Analyzing Hypothetical Scenarios

IPASS can help to answer many of the questions facing policy analysts: Questions such as who would be affected by the closure of wood processing mills in Alaska? who would be affected by new investment in recreation and tourism facilities? and might the growth of the tourism industry counteract the decline in timber-based industries? The following discussion will show how IPASS can be used to analyze the economic significance of three resource-related scenarios.

Scenario 1: Alaska's Pulpwood Industry

The two pulpmills in southeast Alaska produce dissolving pulp. In 1977, production and export was roughly valued at $105 million. But increasing world-wide competition, depressed markets, and the high cost of installing pollution abatement equipment threatens the operation of these mills.

In this scenario, we assume the worst case—a complete shutdown of both mills with a permanent loss of $105 million in regional exports. Table 1 shows the impact of the mill shutdown on both employment and earnings, by year, in aggregated sectors of the economy.[2] The effect on the pulp and paper industry is immediate and, also, is greater than for any other industry. The two other wood products sectors, however, are also adversely affected because they provide logs and mill residues to the pulpmills. For years 2 through 5, the service industries show the indirect impacts of the loss of personal income, loss of population, and the overall reduction in economic activity caused by the mill closures.

Table 1 also shows how the various occupations were affected by the closure of the two pulpmills. Industrial technicians, who account for the largest proportion of the pulp and paper employees, experience the greatest and most lasting impact.

The pulpmills account for most of the basic jobs in the communities where they are located. Consequently, the mill closures would undoubtedly cause many individuals to move elsewhere—in the State or otherwise—because of the lack of reemployment opportunities. Pulpmill workers have traditionally received above-average wages; consequently, former pulpmill employees choosing to remain somewhere in Alaska would undoubtedly have to be retrained or accept lower wages.

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[1] A brief description of the IPASS model is provided in Appendix 1. For a more complete explanation of the IPASS system see, Olson, Doug; Schallau, Con; and Maki, Wilbur. IPASS: an interactive policy analysis simulation system. Gen. Tech. Rep. PNW-170 Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1984. 70 p.

[2] Appendix 3 provides a list of the 75 sectors in the Alaska model. Data for 75 sectors were derived and then were aggregated for the purpose of this paper.

Table 1—Impact on the Alaska economy[1] caused by closure of two pulpmills

Industry	Year of simulation 1	2	3	4	5
	JOBS LOST OR GAINED, BY SECTOR				
Agriculture, forestry, and fisheries	-11	-11	-12	-7	-8
Mining	-1	-3	-5	-4	-4
Construction	-14	-59	-82	-52	-42
Manufacturing:	-1,578	-1,646	-1,319	-1,068	-991
Logging	-460	-518	-342	-164	-138
Sawmills	-48	-56	-46	-41	-41
Pulp and paper mills	-1,065	-1,056	-917	-843	-793
Transportation, communications, and utilities	-91	-136	-156	-136	-123
Trade	-30	-153	-315	-331	-417
Finance, insurance, and real estate	-13	-69	-14	-77	-75
Services	-21	-102	-172	-156	-187
Government	-18	-30	-46	-59	-57
Total	-1,778	-2,208	-2,122	-1,891	-1,905
	EARNINGS LOST OR GAINED (THOUSAND DOLLARS)				
Agriculture, forestry, and fisheries	-241	-263	-223	-105	-138
Mining	-33	-112	-170	-155	-130
Construction	-501	-2,156	-3,000	-1,900	-1,526
Manufacturing:	-36,879	-38,440	-30,764	-24,900	-23,079
Logging	-10,753	12,111	-7,981	-3,826	-3,222
Sawmills	-1,025	-1,179	-965	-868	-867
Pulp and paper mills	-25,012	-24,817	-21,537	-19,805	-18,646
Transportation, communications, and utilities	-2,113	-3,170	-3,923	-3,268	-2,932
Trade	-605	-2,763	-4,805	-3,780	-5,545
Finance, insurance, and real estate	-196	-1,052	-205	-1,172	-1,129
Services	-495	-1,750	-2,681	-2,442	-2,815
Government	-244	-440	-654	-862	-848
Total	-41,305	-50,147	-46,426	-38,584	-38,143
	EMPLOYMENT, LOST OR GAINED BY OCCUPATION				
Managers	-78	-125	-128	-122	-130
Professional	-91	-121	-130	-121	-125
Technical	-18	-28	-42	-39	-42
Service	-81	-117	-173	-177	-195
Industrial technicians	-1,327	-1,494	-1,289	-1,050	-1,002
Clerical	-164	-269	-279	-298	-314
Sales	-17	-54	-77	-81	-95
Farm	-1	-1	-3	-3	-3

1/The impact is derived by subtracting the baseline data (that is, simulation of historical data) from the impact scenario data. A minus sign indicates a loss of employment or earnings.

Scenario 2: Changes in Tourism

In this scenario, we assume that promotion of Alaska tourism will increase the sale of goods and services produced in Alaska by $105 million.[3/] What impact will this have on employment and earnings? To answer this question we used[4/] national averages for tourism-related expenditures to derive estimates of tourism expenditures by industry. Table 2 shows that increased tourism would greatly stimulate employment and earnings in the service, trade, and transportation industries. All occupational categories would also grow.

Scenario 3: Will growth in tourism offset a decline in pulp production?

Scenario 3 is a combination of scenarios 1 and 2. This scenario examines the extent to which an increase in annual tourism expenditures of $105 million compensates for a coincidental decrease of $105 million in exports resulting from a closure of the two pulpmills.

Table 3 shows the impact of this scenario on employment, earnings, and employment by occupation. After the third year, an increase in tourism can more than compensate for the loss of total employment and earnings resulting from closure of the two pulpmills.

A $105 million increase in demand for goods and services provided by the tourism industry would eventually compensate for the loss of two pulpmills in terms of total employment and earnings. The employees losing work as a result of the mill closures would not, however, necessarily be people employed in the tourism industry. An examination of the changes, industry by industry, indicates that there are "gainers" and there are "losers." The wood products industry loses a large number of its employees and earnings, but the service and trade sectors gain. Employment by occupation also varies; for example, the employment for industrial technicians declined while service employment increased (fig. 1).

[3/] The value of expenditures by tourists would exceed the net economic contribution to Alaska's economy. Many of the items purchased by tourists, and the services provided, rely heavily on imports. Total tourism expenditures would consequently have to exceed $105 million.

[4/] The Research and Analysis section, Alaska Department of Labor, provided unpublished tourism survey data showing expenditures by nonresident tourists. These data were converted to expenditure classes in the Bureau of Economic Analysis' "National Income Product Account" (NIPA) that were identified as "tourism" related. The distribution of tourist dollars among Alaska industries was derived from the NIPA expenditure classes.

Table 2—Impact on the Alaska economy[1] of increased tourism expenditures

Industry	Year of simulation 1	2	3	4	5
	JOBS LOST OR GAINED, BY SECTOR				
Agriculture, forestry, and fisheries	3	22	23	28	25
Mining	0	23	25	26	24
Construction	3	213	82	76	36
Manufacturing	1	94	94	100	89
Logging	0	1	0	1	0
Sawmills	0	1	1	0	0
Pulp and paper mills	0	0	0	0	0
Transportation, communications, and utilities	652	970	945	928	893
Trade	101	540	920	845	982
Finance, insurance, and real estate	21	42	75	93	105
Services	121	770	753	884	858
Government	27	48	30	74	80
Total	929	2,722	2,947	3,056	3,090
	EARNINGS LOST OR GAINED (THOUSAND DOLLARS)				
Agriculture, forestry, and fisheries	58	347	358	412	370
Mining	0	894	934	990	903
Construction	100	7,848	3,003	2,809	1,283
Manufacturing	22	1,739	1,642	1,766	1,552
Logging	0	29	0	16	6
Sawmills	0	25	13	8	3
Pulp and paper mills	0	0	0	0	0
Transportation, communications, and utilities	13,072	19,532	19,304	18,627	17,796
Trade	1,406	7,267	11,477	8,220	10,911
Finance, insurance, and real estate	320	635	1,142	1,436	1,589
Services	2,310	9,240	8,936	10,533	10,053
Government	417	717	428	1,098	1,196
Total	17,700	48,220	47,223	45,891	45,654
	EMPLOYMENT, LOSS OR GAIN BY OCCUPATION				
Managers	115	271	296	295	308
Professional	29	114	126	151	150
Technical	15	88	91	105	104
Service	49	615	670	838	752
Industrial technicians	528	1,031	977	933	940
Clerical	154	496	590	599	637
Sales	41	103	194	127	191
Farm	0	4	5	8	7

[1]/The impact is derived by subtracting the baseline data (that is, simulation of historical data) from the impact scenario data. A minus sign indicates a loss of employment or earnings.

Table 3—Impact on the Alaska economy[1] caused by the coincidental closure of two pulpmills and increased tourism trade

Industry	Year of simulation 1	2	3	4	5
	JOBS LOST OR GAINED, BY SECTOR				
Agriculture, forestry, and fisheries	-8	10	12	21	16
Mining	-1	20	20	22	20
Construction	-11	150	-7	31	-5
Manufacturing:	-1,576	-1,552	-1,224	-969	-903
Logging	-460	-517	-341	-163	-138
Sawmills	-48	-54	-45	-40	-41
Pulp and paper mills	-1,065	-1,056	-917	-843	-794
Transportation, communications, and utilities	562	833	788	793	768
Trade	78	439	551	535	513
Finance, insurance, and real estate	8	2	2	24	28
Services	102	672	615	686	676
Government	17	9	-15	16	22
Total	-829	583	742	1,160	1,134
	EARNINGS LOST OR GAINED (THOUSAND DOLLARS)				
Agriculture, forestry, and fisheries	-180	73	144	306	224
Mining	-30	770	764	835	771
Construction	-381	5,526	260	1,153	-188
Manufacturing	-36,854	-36,701	-29,099	-23,153	-21,538
Logging	-10,752	-12,083	-7,965	-3,818	-3,222
Sawmills	-1,025	-1,155	-952	-860	-863
Pulp and paper mills	-25,012	-24,817	-21,537	-19,805	-18,646
Transportation, communications, and utilities	10,959	16,341	15,375	15,378	14,830
Trade	885	5,168	5,965	4,703	4,716
Finance, insurance, and real estate	128	26	35	375	419
Services	1,860	7,556	6,652	7,556	7,402
Government	283	157	-210	248	337
Total	-23,332	-1,083	-634	7,400	6,975
	EMPLOYMENT, LOSS OR GAIN BY OCCUPATION				
Managers	40	156	155	171	171
Professional	-60	-5	-1	23	23
Technical	-3	58	51	64	63
Service	-30	501	498	658	557
Industrial technicians	-793	-452	-329	-114	-75
Clerical	-7	256	267	300	309
Sales	26	65	100	52	82
Farm	-1	3	3	5	4

1/The impact is derived by subtracting the baseline data (that is, simulation of historical data) from the impact scenario data. A minus sign indicates a loss of employment or earnings.

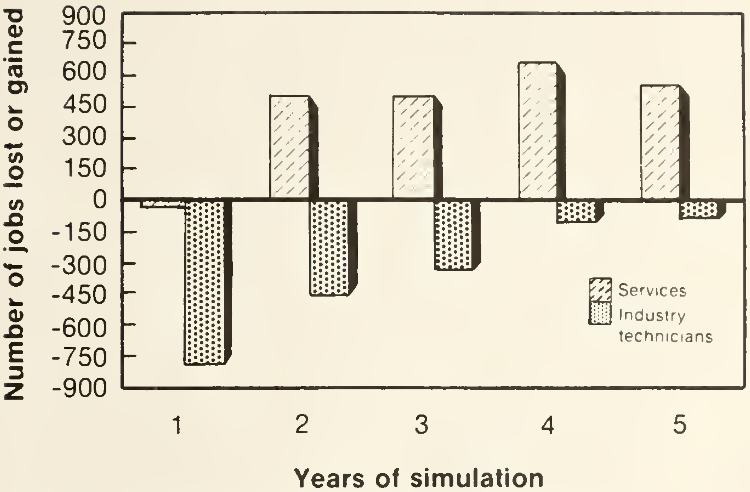

Figure 1.—Change in employment resulting from coincidental closure of two pulpmills and increased tourism expenditures does not affect all occupations equally.

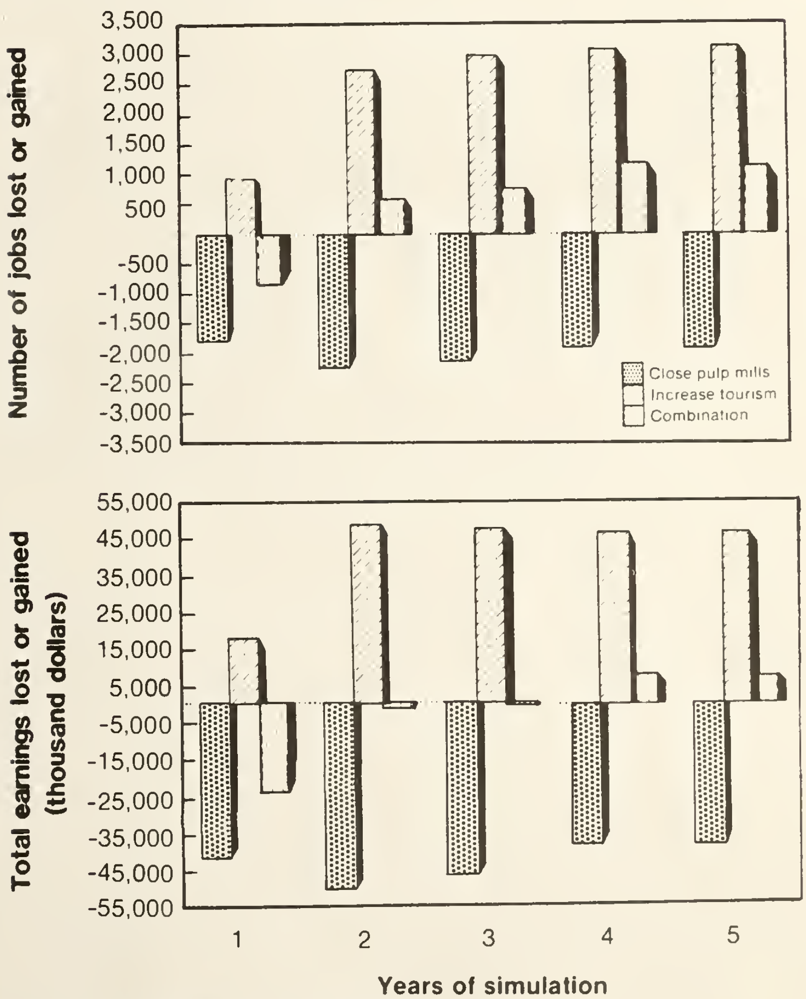

Figure 2.—Changes in total employment and earnings resulting from : (1) the closure of two pulpmills; (2) an increase in tourism expenditures; and (3) a combination of (1) and (2).

Summary

Figure 2 summarizes the change in employment and earnings associated with the three scenarios. The impact on employment and earnings caused by the closure of two pulpmills (scenario 1) is immediate and negative throughout the simulation. Most of the impact is felt by employees in the industry technician category, and most of the loss in jobs is likely to be limited to the towns in which the mills are located.

If tourism expenditures increase (scenario 2), the impact is immediate and positive throughout the simulation with service occupations making the major gains. These gains in employment would probably be spread throughout Alaska.

When the decrease in pulpmill activity coincides with increased sales by the tourism industry (scenario 3), the negative impact in loss of earnings resulting from the former is greater than the positive gains from the latter until the fourth year of the simulation, at which time the net impact is positive. In terms of employment, the impact of increased tourism is greater than the loss of pulpmill activity after the first year of the simulation. This apparent anomaly is explained by the fact that earnings per worker in pulp and paper is much higher than earnings per worker in tourism.

Although a $105 million increase in demand for goods and services provided by the tourism industry would compensate for the loss of employment and earnings resulting from the closure of Alaska's two pulpmills, worker displacement must be kept in mind. Most of the loss would be confined to higher paying, technical jobs in two remote locations, and the increase in jobs would involve lower paying jobs located throughout the State.

Appendix 1

A Brief Explanation of the IPASS Model

IPASS measures change over time.—The IPASS model provides analysts with a flexible, interactive technique for simulating how a particular economy will react to changes in both supply and demand associated with policy alternatives. The IPASS system is composed of eight basic elements or "modules" (fig. 3). Unlike the traditional interindustry model, IPASS introduces the element of time. The dotted lines indicate how each of the modules are linked recursively for use in measuring changes over several time periods.

The eight IPASS modules deal with both demand-side and supply-side factors that affect a region's growth and development. The investment module calculates the investment needed to expand capacity in order to produce more goods and services. This module is connected to the final demand module. The latter forecasts changes in final demand; for example, change in exports. The production module is a Leontief inverse that performs the conventional multiplier calculations of the individual industry impacts of changes in the demand for a region's industrial output. This module also responds to the production constraints emanating from the demand side via the final demand module and the supply side via the investment and labor force modules.

The employment module updates model parameters that influence labor productivity, while the labor force module calculates the supply of labor by occupation classes. The population module uses migration and cohort survival rates, as well as age-specific birth rates, to estimate year-to-year changes in a region's population. Components of value added, including personal income, are calculated by the primary inputs module.

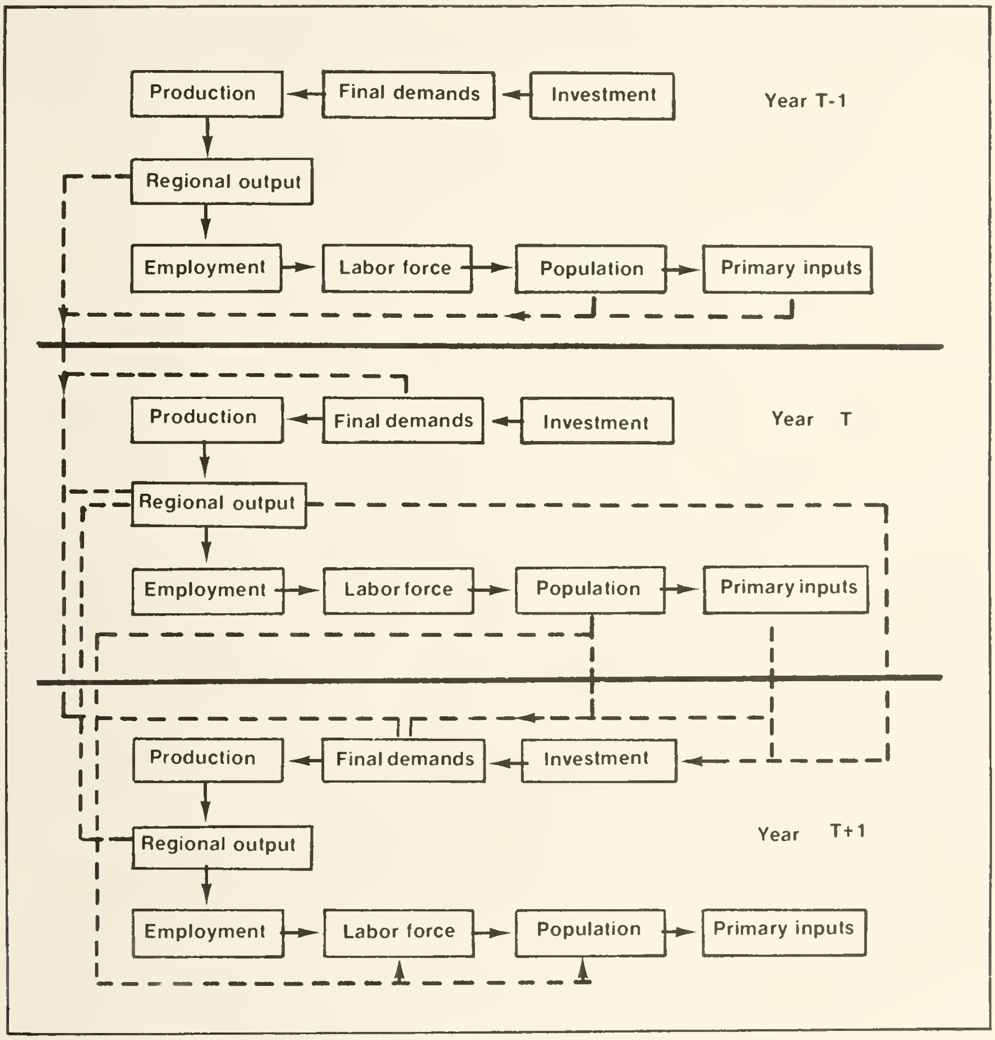

Figure 3.—IPASS is a dynamic, recursive system. Estimates for year T are influenced by transactions during the current as well as previous years. Investments for year T, for instance, are a function of regional output and primary inputs for year T-1.

Appendix 2

Assembling and Calibrating the Alaska IPASS Data Base

Ideally, all data for a particular IPASS model would be unique to the geographical area to be analyzed (see Appendix 3 for industry classification used for Alaska). For Alaska published data sources for some of the economic indicators and model parameters are lacking, however, and conducting a survey to obtain this information would be too costly and time consuming. For the Alaska model, we have, therefore, augmented Alaska published sources with data for the United States. Population and labor force participation, for example, are specifically for the State of Alaska. Capital-output ratios, however, are based on national ratios and trends. The USDA Forest Service software system, IMPLAN,[1/] was used to develop a synthetic input-output (I/O). Because the IMPLAN system uses direct coefficients from the national I/O model, coefficients for the Alaska IPASS model were modified to reflect Alaska's economy.

[1/] Unpublished report, 1982, "IMPLAN User's Manual," Land Management Planning, U.S. Department of Agriculture, Forest Service, Fort Collins, Colorado.

An important feature of the IPASS simulation system is the ease with which the user can examine the sensitivity of forecasts based, in part, on nonlocal sources. By introducing a range of values for a parameter, for example, the user can determine how much a particular economic indicator would be affected by a change in the underlying assumptions.

Calibrating the Alaska IPASS data base.—Parameters and rate-of-change variables were adjusted so that the 1977 to 1982 baseline simulation corresponded to historical trends of value added, employment, earnings, and population for Alaska. Economic impact analyses will be the principal uses of IPASS; consequently, the change of a particular indicator is a more important consideration than its absolute level. During calibration, we were mainly interested in simulating the historical levels for various indicators. The calibration can be viewed as an ongoing activity since the model can be easily recalibrated as new information becomes available.

Tables 4 and 5 compare the calibrated baseline simulation of selected employment and earning indicators with historical 1977-1982 data. With few exceptions, the IPASS estimates corresponded closely (that is, ± 10 percent) with the historical data. In general, the more annual fluctuations exhibited by an industry (for example, the construction and mining sectors), the larger the deviation between simulated baseline estimates and actual levels.

Table 4—Percentage of difference between the baseline simulation by IPASS and Alaska historical employment by industry

Industry	Year					
	1977	1978	1979	1980	1981	1982
	Percent					
Agriculture, forestry, and fisheries	2.24	-20.69	-8.72	-1.79	2.13	7.38
Mining	-5.41	13.05	25.64	15.74	-7.34	0.15
Construction	0.00	1.9	31.30	34.53	18.29	-4.29
Manufacturing	2.08	-5.67	-7.36	-11.84	-8.81	5.52
Transportation, communications, and utilities	2.23	-4.02	-5.17	-3.58	-5.74	-3.15
Trade	-0.88	4.72	6.50	12.81	7.58	2.82
Finance, insurance, and real estate	-0.15	-4.93	-2.27	4.64	3.69	-0.58
Services	-0.07	-0.97	-0.90	-3.11	-7.46	-11.69
Government	0.34	-4.03	-5.05	-1.04	.09	-0.30
All employment	0.22	-2.27	-0.21	2.33	0.04	-1.46

Table 5—Percentage of difference between baseline simulation by IPASS and Alaska historical earnings by industry

Industry	1977	1978	1979	1980	1981	1982
	Percent					
Agriculture, forestry, and fisheries	-15.63	-28.56	-14.42	-17.92	21.44	22.59
Mining	-6.01	17.34	37.58	22.54	-0.88	3.12
Construction	-14.67	18.40	64.55	61.57	35.17	6.41
Manufacturing	0.45	-5.52	-11.64	-14.98	-7.42	-0.55
Transportation, communications, and utilities	1.08	4.21	6.23	9.65	3.36	1.26
Trade	0.0	8.62	16.48	24.02	15.33	5.22
Finance, insurance, and real estate	0.0	-2.56	3.60	11.17	9.62	-5.59
Services	0.01	24.32	33.90	29.17	13.97	-0.94
Government	1.98	0.23	0.67	1.66	0.92	-3.94
All employment	-3.25	5.61	13.19	14.99	8.42	0.83

Appendix 3

Table 6—Comparison among IPASS, Bureau of Labor Statistics, and Bureau of Economic Analysis input-ouput model sectoring schemes and the Standard Industrial Classification code

IPASS sector number	Industry	Bureau of Labor Statistics (154 sectors)	Bureau of Economic Analysis (466 sectors)	Standard Industrial Classification (1972 edition)
1	Dairy and poultry	1	1,2	pt.01,pt.02
2	Meat animals	2	3	pt.01,pt.02
3	Feed, food grain	4	5	pt.01,pt.02
4	Other crops	3,5	4,6-10	pt.01,pt.02
5	Agricultural services	pt.7	pt.12	0254,07(exc.074)
6	Forest products and services	pt.6,pt.7	pt.11,pt.12	081-085
7	Fish products and services	pt.6,pt.7	pt.11,pt.12	091-092,097
8	Gold and silver mining	pt.10	17-18	1041,1044
9	Other metal ore mining	8,pt.10	13-16,19,21-23	10(exc.1031,1044,1081)
10	Metal mining services	pt.10	20	1081
11	Coal mining	11	24-25	111,pt.112,1211,pt.1214
12	Natural gas and petroleum	12	26-28	1311,1321,pt.138
13	Stone, gravel, and clay	13	29-43	141-145,pt.148,149
14	Chemicals and fertilizers	14	44-50	147
15	New construction	152	51	pt.15,pt.16,pt.17,pt.108,pt.1112,pt.1213 pt.138,pt.148
16	Maintenance and repair	15	52	pt.15,pt.16,pt.17,pt.138
17	Ordnance and related	16-17	53-58	348,3761,3795
18	Meat products	18	59-62	201
19	Dairy products	19	63-57	202
20	Canned, cured seafood	pt.27	68	2091
21	Fresh, frozen seafood	pt.27	73	2092
22	Other canned, preserved food	20	69-72,74	203
23	Bakery products	22	82-83	205
24	Beverages	25-26	88-92	208
25	Animal, marine fats, and oils	pt.27	97	2093
26	Other food and tobacco	21,23,24,pt27,28	75-81,84-87,93-96,98-106	204,206-207,209(exc.2091-2093),21
27	Textile goods	29-31	107-120	22(exc.225)
28	Apparel and fabrics	32-34	121-135	225,23(exc.239),39996
29	Logging	35	136	2411
30	Sawmills	36	137-139	2421,2422,2429
31	Other wood products	37-38	140-149,388	243-245,249
32	Furniture and fixtures	39-40	150-162	25
33	Pulp and paper mills	pt.41	163	261-262
34	Other paper and allied	pt.41-42	164-175	263-266
35	Printing and publishing	43-45	176-190	27
36	Chemical and allied	46-53	191-210	28(exc.28195)
37	Petroleum and refining	54	211-213	29
38	Rubber products	55-57	214-219	30
39	Leather products	58-59	220-228	31
40	Stone, clay, and glass	60-64	229-253	32
41	Primary metals	65-69	254-275	33
42	Fabricated metals	70-76	276-303	34
43	Nonelectrical machinery	77-87	304-345	35
44	Electrical machinery	88-96	346-375	36
45	Ship and boat	99	383-384	373
46	Other transportation	97,98,100-102	376-382,385-387,389	37(exc.373)
47	Scientific instruments	103-107	390-399	38
48	Miscellaneous manufacturing	108-110	400-419	39
49	Railroad	111	420	40,474,pt.4789
50	Local transit	112	421	pt.41
51	Truck transportation	113	422	42,pt.4789
52	Water transportation	114	423	44
53	Air transportation	115	424	45
54	Pipeline	116	425	46
55	Transportation services	117	426	47(exc.474,pt.4789)
56	Communications	118-119	427-428	48
57	Electrical utilities	120	429	pt.491,pt.493
58	Gas utilities	121	430	492,pt.493
59	Water and sanitation	122	431	494-497,pt.493
60	Wholesale trade	123	432	50,51(exc.Mfgrs. Sales Off.)
61	Retail trade	125	433	52-57,59,7396,8042
62	Finance and insurance	126-128	434-438	60-64(exc.pt.613),67
63	Real estate	129-130	439-440	65,66,pt.1531
64	Hotels and lodging	131	441	70(exc. Eating & Drinking)
65	Personal services	132-133	442-443	72,762-764,pt.7699
66	Business services	134-136	444-446	73(exc.7395),769(exc.7699),81,89(exc.8922)
67	Eating and drinking	124	447	58,pt.70
68	Auto repair	137	448	75
69	Motion pictures and recreation	138-139	449,450	78,79
70	Health services	140,pt.141	451-453,456-457	80(exc.8042),074
71	Education and nonprofit	pt.141-144	454-455	82-84,86,8922
72	Federal enterprises	145-146	458-461	4311,pt.491,pt.613
73	State and local enterprises	147-148	462-464	pt.41,pt.491
74	Scrap	151	466	
75	Administrative government			

United States Department of Agriculture

Forest Service

Pacific Northwest Forest and Range Experiment Station

Research Note PNW-433

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Occurrence of Insect and Disease Pests on Young-Growth Sitka Spruce and Western Hemlock in Southeastern Alaska

Susan M. Tait, Charles G. Shaw III, and Andris Eglitis

Abstract

Insects and diseases were surveyed in 16 even-aged, young-growth stands of Sitka spruce *(Picea sitchensis* (Bong.) Carr.) and western hemlock *(Tsuga heterophylla* (Raf.) Sarg.) in southeastern Alaska. Stand ages ranged from 17 to 27 years in nine thinned stands and from 12 to 22 years in seven unthinned stands. All stands appeared healthy. Although some organisms with damage potential were observed, no pests occurred at levels likely to cause damage. Insects recorded on spruce included a *Zeiraphera* sp. shoot moth (the first record of this insect in southeastern Alaska), a *Dioryctria* sp. moth, and a *Pineus* sp. aphid. Fungi that cause spruce diseases included *Lophodermium picea* (needle cast), *Chrysomyxa ledicola* (needle rust), and *Discocainia treleasei* and *Heliotium resinicola* in cankers. Insects on hemlock included *Pseudohylesinus tsugae* bark beetles, which occurred more frequently in thinned stands and on trees larger than 3 inches in diameter at breast height, and the adelgid, *Aldeges tsugae*. Diseases on hemlock included needle rust caused by *Pucciniastrum vaccinii* and dwarf mistletoe *(Arceuthobium tsugense)*. Sawflies *(Neodiprion spp.)*, geometrid moths (including *Melanolophia imitata),* blackheaded budworm *(Acleris gloverana),* and the shoot blight fungus, *Sirococcus strobilinus,* appeared on both spruce and hemlock. *Armillaria* sp. occurred in 39 percent of 165 hemlock stumps and 36 percent of 165 spruce stumps following thinning and was more common in hemlock stumps from stands thinned 5-6 years earlier than in those thinned 3-4 years earlier. *Fomes annosus* was found in only 2 percent of the spruce stumps and in no hemlock stumps.

Keywords: Insect surveys, diseases (plant), young-growth stands, Sitka spruce, western hemlock, Alaska (southeast).

Introduction

The mainland and islands of southeastern Alaska extend south from Yakutat to the Canadian border at Portland Canal (fig. 1). The area is heavily forested and contains some of the State's most valuable timber producing lands. Prior to 1953, timber harvest was limited (Harris and Farr 1974), and even now most areas are occupied predominantly by old-growth western hemlock *(Tsuga heterophylla* (Raf.) Sarg.) and Sitka spruce *(Picea sitchensis* (Bong.) Carr.).

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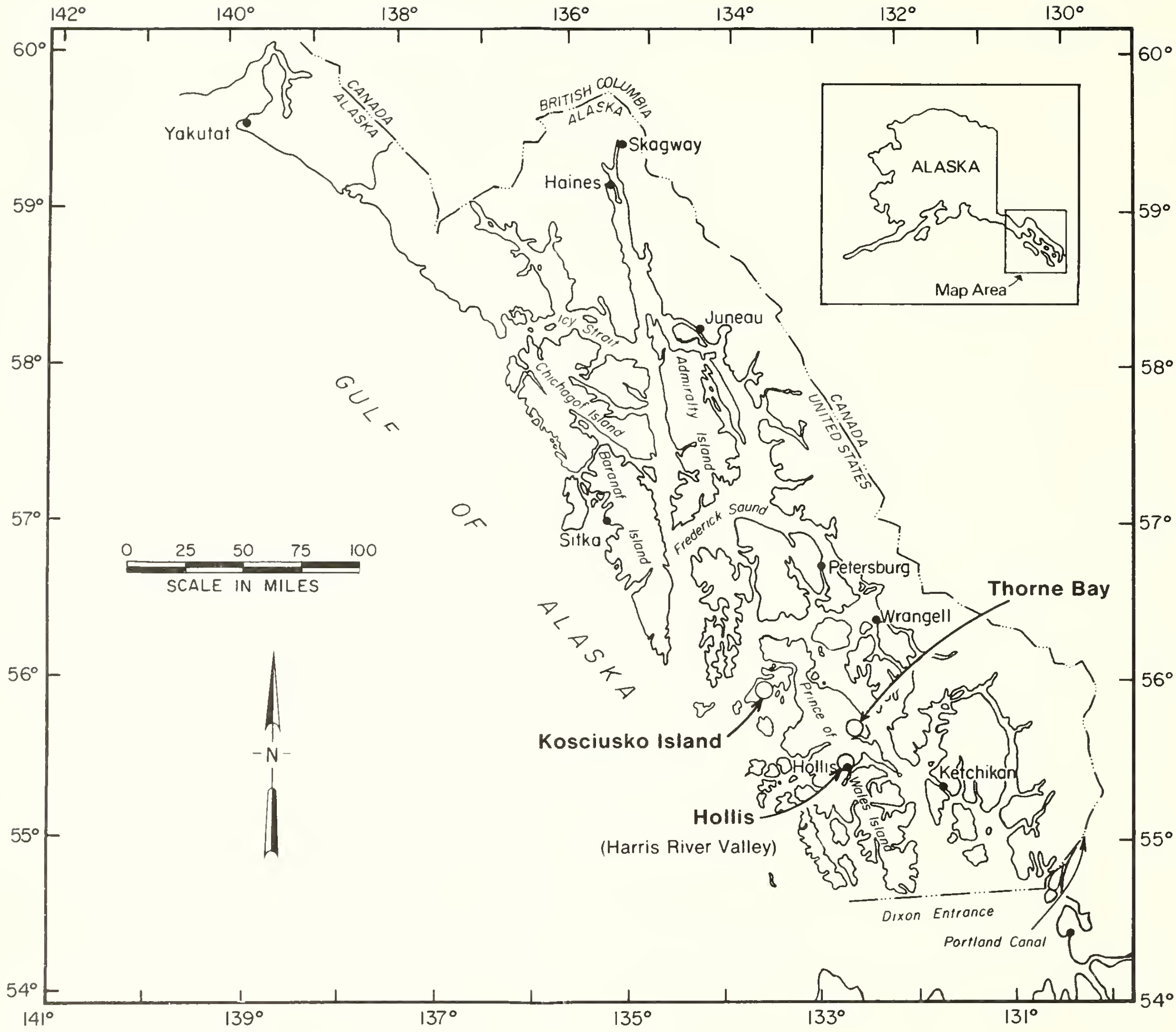

Figure 1.—Study sites in southeast Alaska.

These virgin forests have suffered periodic insect damage through epidemics of blackheaded budworm *(Acleris gloverana* (Wals.) (Lepidoptera: Tortricidae)) and hemlock sawfly *(Neodiprion tsugae* Midd. (Hymenoptera: Diprionidae)) (Hard 1974). The most serious pest-related loss has been wood decay caused primarily by *Fomes pinicola* (Schwartz ex Fr.) Cke. and *F. pini* (Thore) Lloyd in Sitka spruce, and *Armillaria mellea* (Vahl. ex Fr.) Cke., *F. pinicola,* and *F. annosus* (Fr.) Cke. in western hemlock (Farr and others 1976, Kimmy 1956, Laurent 1974). Dwarf mistletoe *(Arceuthobium tsugense* (Rosendall) G. N. Jones) is also common on western hemlock (Laurent 1974) and reduces growth and increases mortality of severely infected old-growth trees.

The relatively recent development of dense, naturally regenerated, even-aged stands over some 250,000 acres of land once occupied by uneven-aged, old-growth forest provides a setting for new pest problems. Stocking density, stem size, tree age, species composition, and stand microclimate differ from that in the old growth. Continued harvest of old growth is enlarging this young forest by 15,000 to 18,000 acres per year (Harris and Farr 1974). Management is intensifying on these lands as foresters initiate planting and thinning programs. This increased financial investment requires that forest managers have adequate knowledge of the occurrence and distribution of insects and diseases, and of the possibilities that damage may result from them.

Except for shoot blight caused by *Sirococcus strobilinus* Preuss, at Thomas Bay (Shaw and others 1981, Wicker and others 1978) foresters have reported no noticeable or serious pest problems in these young stands; however, there has been no ground monitoring of pest populations, nor has there been a thorough cataloging of the pest organisms present.

In this study we cataloged insects and diseases occurring in young stands, determined their relative abundance, and assessed their potential for causing damage.

Methods

Survey Procedures

Three locations with substantial areas occupied by young-growth forest (the Harris River valley and Thorne Bay on Prince of Wales Island, and Kosciusko Island, fig. 1) were sampled during summer 1982. Stands in each area were grouped by aspect, elevation, age, and year of thinning; 16 stands were selected for sampling.

In each stand three plots (5.5 feet wide) were sampled along a single, randomly located transect (fig. 2). The first plot was located a random 1 to 4 chains from the road, and the second and third plots were 2 or 3 chains beyond the origins of the preceding plot. Individual plots were oriented by randomly selecting an azimuth from 0 to 180 degrees when facing away from the road (fig. 2). Plot lengths were determined by extending each plot until six to eight crop trees, including at least two Sitka spruce and two western hemlock, were encountered (fig. 2). Crop trees were defined as those trees that should be left, on the basis of size and spacing, after thinning the stand to 300 stems per acre (12-foot by 12-foot spacing).

All trees over 4.5 feet tall were counted by species to determine stocking density, and crop trees were measured for diameter. Table 1 summarizes stand characteristics. Insects, stem wounds, cankers, distortions, offsets, and other damage were recorded. Leaders were rated as normal, distorted, short, dead, or missing. On hemlock, stem bases were examined for symmetry, indentations, or actual fluting in an attempt to identify incipient fluting (Harris and Farr 1974).

Pest organisms or damage were noted by height in the crown. One branch each from the lower, middle, and upper thirds of the crown was measured to determine the percentage of the branch containing foliage, percentage of green and discolored foliage present, and percentage of "needle cast" on spruce. Any pest organisms observed were also recorded. In addition, 0.5 inch of current, first-year, and second-year foliage at the distal end and midpoint of each branch was examined for organisms and damage.
A more general sampling for insects was also conducted three times on each tree by inserting densely foliated branches into a large net and vigorously shaking the branches. Insects found in the net were recorded by species or were collected for later identification.

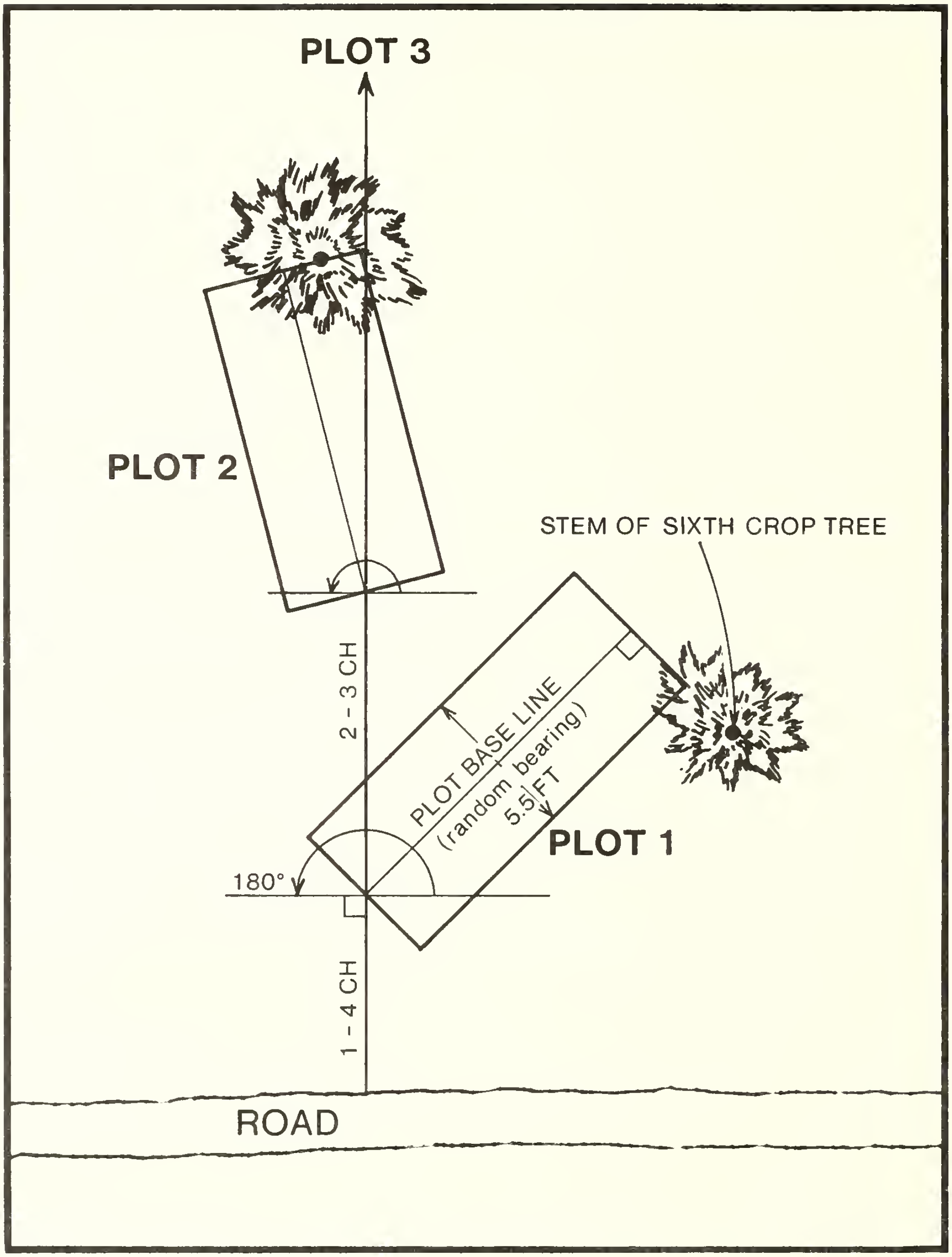

Figure 2.—Design for plot layout (not to scale).

Table 1—Stocking densities and distribution of crop trees in the 7 thinned and 9 unthinned stands sampled[1]

Tree species	Stand type: Unthinned	Stand type: Thinned	Total crop trees
Western hemlock:			
No. of crop trees sampled	75	84	159
Percent of all crop trees sampled	55	46	49
Stems per acre[2]	2856±547	404±100	--
Percent of total stocking[2]	76	53	--
Sitka spruce:			
No. of crop trees sampled	53	95	153
Percent of all crop trees sampled	43	52	49
Stems per acre	800±228	337±113	--
Percent of total stocking	21	44	--
Western redcedar:			
No. of crop trees sampled	3	2	5
Percent of all crop trees sampled	2	1	2
Stems per acre	95±43	26±22	
Percent of total stocking	3	3	--
Total:			
No. of crop trees sampled	136	181	317
Percent of all crop trees sampled	100	100	100
Stems per acre	3752±517	767±172	--
Percent of total stocking	100	100	--

[1]Stand ages appear in tables 4 and 5.

[2]Includes all trees over 4.5 feet tall.

Subsampling was done to quantify the occurrence of organisms or of damage that was abundant or of particular interest. For insects on shoots and buds of Sitka spruce, 10 current-year shoots were examined on each sample branch, 5 at the distal end and 5 at midbranch. Numbers of shoots with *Zeiraphera* sp., spider mites, and needle miner damage were counted. The same system was used to record damage from *S. strobilinus* or from other causes on western hemlock branches, except that shoots were used regardless of age. On all trees, the length of each sampled primary branch was measured and cankers counted.

To quantify the occurrence of *Pseudohylesinus tsugae* Swaine bark beetles on hemlock, feeding galleries were counted on 6-inch-long cylinders of stem bark centered at breast height. From this count and from each tree's diameter at breast height (d.b.h.), insect galleries per square foot of bark surface area were calculated. Three neighboring stands at Thorne Bay that had been thinned 1, 2, and 3 years previously were sampled in a separate survey to compare attack patterns in similarly situated stands. Eleven trees in each stand were selected on similar terrain and sampled for attacks by *P. tsugae* by counting old and new galleries on these cylinders of stem bark.

Another separate survey was conducted in stands thinned 3 (or more) years previously to determine levels of colonization by *F. annosus* and *Armillaria* sp. in stumps left after thinning. In each of 11 stands (6 in the Harris River valley, 2 at Thorne Bay, and 3 on Kosciusko Island), 15 western hemlock and 15 Sitka spruce stumps were inspected for *Armillaria* sp. The top 2-4 inches of each stump was cut off and a 0.5- to 1-0-inch-thick disc was removed. These discs were examined microscopically for *F. annosus* as described by Shaw (1981).

Data Analysis

The percentages of trees infected with various insect and disease pests were tallied on a stand basis, and differences in pest occurrence between thinned and unthinned stands were evaluated using the Student's "t" test. The same test was used to examine differences in attack intensity for *P. tsugae* in thinned and unthinned stands, the occurrence of *Zeiraphera* sp. on branches with less than or greater than 75 percent foliage retention or greenness, and the occurrence of *Armillaria* sp. in stumps of different ages left from thinning. The correlation coefficient between tree diameter and attack intensity of *P. tsugae* in thinned stands was also examined. A one-way analysis of variance was used to evaluate differences between stands in the symmetry of the base of hemlock crop trees. In all these analyses, differences were tested for significance at $P < 0.05$.

Results

Although various organisms were encountered (tables 2-8), their occurrence was low and all stands appeared healthy. No pests were found at levels likely to cause damage. As a further indication of health, the branches of both spruce and hemlock retained 85 percent of their foliage of which at least 95 percent was green.

The most notable of the organisms found were *Armillaria* sp. and *F. annosus* in stumps left from thinning; *Zeiraphera* in spruce buds; and *P. tsugae* in hemlock stems. Data obtained on these organisms are treated below; others are described in table 8 with their occurrences noted in tables 4-7.

***Armillaria* sp. and *F. annosus* in thinning stumps.**—*F. annosus* was found in only 2 percent of the spruce stumps examined and in none of the hemlock stumps (table 2). *Armillaria* sp. occurred in 39 percent and 36 percent of the hemlock and spruce stumps, respectively (table 2). Occurrence of *Armillaria* sp. was significantly higher in hemlock stumps from the seven stands thinned 5 to 6 years previously (11 ± 1 infected stumps per sample) than in those thinned 3 to 4 years previously (3 ± 1 infected stumps per sample). Levels of colonization by *Armillaria* in spruce stumps did not differ significantly by time since thinning. Spruce stumps from stands thinned 3 to 4 years earlier averaged 4 ± 1 infected stumps per sample, while stands thinned 5 to 6 years earlier averaged 7 ± 2 infected stumps per sample.

***Zeiraphera* sp. in spruce buds.**—After mid-June, larvae of *Zeiraphera* sp. *(Lepidoptera: Tortricidae)* were found on current-year spruce shoots at all three locations.[1] On affected buds the cap was webbed and remained in place longer than caps on neighboring, unaffected shoots. Beneath the bud cap, portions of the new needles were eaten and topped with a deposit of frass and webbing. Some feeding occurred further down the developing shoot later in summer, but most larvae evidently left the shoots before pupating. Six larvae from affected shoots were identified as *Zeiraphera* sp.—as was one adult reared from a larva and one reared from a pupa found in a shoot.[2]

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[1] Similar larvae were found in buds of 20-year-old Douglas-fir on Kosciusko Island.

[2] Another adult reared from a larva was identified as *Griselda radicana* Heinrich.

Table 2—Occurrence of *F. annosus* and *Armillaria* sp. in stumps left from thinning

Location	Years since thinning	Number of stands	Number of stumps		Infected by *F. annosus*		Infected by *Armillaria* sp.	
			Hemlock	Spruce	Hemlock	Spruce	Hemlock	Spruce
					Percent			
Hollis	5-6	1	15	15	0	0	67	13
Hollis	3-4	5	75	75	0	1	25	37
Kosciusko	5-6	3	45	45	0	7	75	55
Thorne Bay	3-4	2	30	30	0	2	3	20
Total or mean		11	165	165	0	2	39	36

Table 3—Occurrence of *Pseudohylesinus tsugae* feeding galleries by thinning year in 3 adjacent stands at Thorne Bay[1/]

Years since thinning	Tree d.b.h. (mean)	Galleries New	Galleries Old
	Inches	Number	
One	3.7±0.3	64	1
Two	2.7±0.3	13	101
Three	3.4±0.3	6	77

[1/]Galleries counted on a cylinder of stem 0.5 feet long that was centered 4.5 feet above the ground. Eleven trees sampled per stand.

Table 4—Occurrence of pest organisms on hemlock crop trees in thinned stands[1]

Location	Stand age	Number of trees	Rust	*Sirococcus strobilinus*	Cankers	Dead twigs	Erythraeids	Aphids and adelgids	Geo-metrids	Saw-flies	*Pseudohylesinus tsugae* 2/
Kosciusko	--	8	0	25	25	63	0	0	0	0	--
	17	6	67	67	50	71	0	29	14	71	--
	27	12	58	75	100	100	0	0	0	17	--
Thorne Bay	20	9	78	11	0	33	44	22	0	0	11
	19	11	63	8	9	100	9	18	0	0	91
	20	12	67	17	8	58	0	25	8	0	67
Hollis	20	6	33	17	50	83	17	33	17	0	50
	22	11	37	18	18	36	27	45	18	36	91
	23	8	50	38	0	75	0	0	0	0	63
Mean	21	9	50±8	32±8	29±11	69±8	11±5	19±5	6±3	14±8	62±12

-- = data missing.

1/ Data are percentage of trees affected in each stand.

2/ Data are only for stands in which both old and new galleries were counted.

Table 5—Occurrence of pest organisms on hemlock crop trees in unthinned stands[1]

Location	Stand age	Number of trees	Rust	*Sirococcus strobilinus*	Cankers	Dead twigs	Erythraeids	Aphids and adelgids	Geo-metrids	Saw-flies	*Pseudohylesinus tsugae* 2/
Kosciusko	15	9	78	78	0	78	0	0	0	11	--
	18	6	17	33	33	100	0	0	0	17	--
Thorne Bay	15	12	42	8	0	50	0	0	8	0	--
	12	17	35	18	12	88	12	18	0	35	35
Hollis	22	8	75	25	0	63	38	25	0	38	0
	21	13	23	23	31	100	0	0	8	0	15
	22	10	30	10	0	50	0	10	0	30	--
Mean	18	11	43±5	28±9	11±6	76±8	7±5	8±4	2±1	76±8	17±10

-- = missing data.

1/ Data are percent of trees affected in each stand.

2/ Data are only for stands in which both old and new galleries were counted.

Table 6—Occurrence of pest organisms on spruce crop trees in thinned stands[1]

Location	Number of trees	Rust	*Sirococcus strobilinus*	Needle cast	Cankers	Dead buds	Dead twigs
Kosciusko	13	0	0	92	62	0	28
	16	6	0	100	31	7	27
	8	0	[2]0	88	38	25	38
Thorne Bay	10	40	0	90	0	20	10
	9	44	11	100	0	56	11
	8	25	13	88	0	63	0
Hollis	14	71	0	93	38	7	7
	8	50	0	75	25	75	13
	10	40	10	100	40	20	10
Mean	11	31±8	4±2	92±3	26±7	30±9	16±4

Location	Erythraeids	*Zeiraphera*	Needle miners	Mites on shoots	Aphids	Geo-metrids	Saw-flies
Kosciusko	8	38	0	0	0	0	0
	0	88	0	0	7	7	7
	0	63	0	0	0	0	0
Thorne Bay	30	50	0	0	0	0	20
	11	44	0	0	0	11	0
	38	25	38	50	13	0	13
Hollis	29	36	14	36	0	0	14
	25	63	25	50	13	0	25
	0	40	30	0	0	0	10
Mean	16±5	50±6	12±5	15±8	4±2	2±1	10±3

[1] Data are percent of trees affected in each stand. Stands are listed in the same sequence as in table 4; stand ages are given there.

[2] Noted in this stand, but not on sampled trees.

Table 7—Occurrence of pest organisms on spruce crop trees in unthinned stands[1]

Location	Number of trees	Rust	*Sirococcus strobilinus*	Needle cast	Cankers	Dead buds	Dead twigs
Kosciusko	9	0	22	100	0	0	11
	13	0	0	100	23	8	31
Thorne Bay	7	14	14	86	0	0	14
	5	20	0	100	0	20	40
Hollis	10	0	0	100	10	30	10
	6	17	0	100	[2]0	33	17
	8	13	0	88	0	0	38
Mean	8	9±3	5±3	96±3	5±3	13±6	23±5

Location	Erythraeids	*Zeiraphera*	Needle miners	Mites on shoots	Aphids	Geometrids	Sawflies
Kosciusko	0	33	0	0	22	0	0
	0	69	8	0	0	0	8
Thorne Bay	0	43	0	0	0	0	29
	0	20	0	0	0	0	40
Hollis	50	50	60	10	0	0	40
	0	33	0	17	0	0	0
	0	13	0	0	0	0	[2]0
Mean	7±7	37±7	10±8	4±3	3±3	0	17±7

[1]Data are percent of trees affected in each stand. Stands are listed in the same sequence as in table 5; stand ages are given there.

[2]Noted in this stand, but not on sampled trees.

Table 8—Observations on the less common insects and diseases found in young-growth stands[1]

Host and pest	Remarks
Sitka spruce:	
Spider mites (Acari: Tetranychidae)	Mites inhabited bud surfaces and the bases of nearby needles. The limited webbing contained exuviae and other debris. Infested buds were not obvious to casual observation. Six percent of all sample branches were infested. The intensive subsample yielded 22 infested branches with 42 infested shoots--a mean of 1.9 shoots per 10-shoot sample on infested branches. Although species were not determined, a possible Oligonychus sp. was found in late August.
Needle miners	Microlepidoptera larvae mining needles at shoot tips, or the damage from these larvae, were observed in August and September. Twenty infested branches yielded 27 infested shoots. Five percent of all sample branches were infested.
Dioryctria (Lepidoptera: Pyralidae)	A single specimen of Dioryctria sp., possibly D. reniculelloides Mutuura & Munroe, was collected after it emerged from a bent spruce leader that had been incubated in a rearing cage for 28 days. The 0.75-inch-long larva had hollowed out the top 6 inches of the leader, causing it to shrivel. Although this was the only specimen collected, 10 percent of the spruce crop trees had abnormal leaders (6 slightly distorted, 9 very distorted, and 1 absent, out of 153). Leaders were often difficult to collect without felling the tree, so few of these leaders were examined; some of the distortions may have been caused by such insects.
Lepidoptera in cankers	Larvae were occasionally found in spruce cankers or wounds. Most larvae were damaged beyond recognition in cankers during location, but two were identified simply as Microlepidoptera; a third, reared to an adult, was identified as a Laspeyresia sp. (Lepidoptera: Olethreutidae). Some species in this genus mine in tree bark (Furniss and Carolin 1977).
Zeiraphera sp. in bark (Lepidoptera: Olethreutidae)	Blisters on spruce stems frequently appeared as if they had been bored by insects. Pupae were found in the bark of two crop trees and twice on nonsurvey trees. These four specimens, including one that was reared to an adult, were identified as Zeiraphera sp., probably Z. destitutana Walker.
Needle cast	Most spruce had some needle cast. No differences occurred between thinned and unthinned stands in the percentage of trees affected (see tables 6 and 7). Sampling by crown position showed that branches in the lower crown had 4.0 ± 0.7 percent needle cast, those in the midcrown had 0.9 ± 0.1 percent, and upper crown branches had 0.2 ± 0.04 percent. At each crown level, needle cast was greater in unthinned than in thinned stands, but the difference was significant only for lower crown branches. Lophodermium picea Fuckel is common on spruce in southeastern Alaska (Laurent 1974) and was likely present on many cast needles.
Needle rust	Significantly more trees were infected by Chrysomyxa ledicola Lagerh. in thinned stands (31 percent) than in unthinned stands (9 percent) (see tables 6 and 7). Differences among areas were not analyzed because on Kosciusko Island stands may have been examined too early for detection of rust. Some heavily infected small trees were observed near muskegs--sites likely to contain Labrador tea (Ledum groenlandicum Oeder), which is an alternate host for this rust (Ziller 1974).
Necrotic flecking	This needle symptom (Bega 1978) occurred frequently, but did not appear to cause any damage.
Sitka spruce:	
Cankers	Cankers were found on live and dead branches and on stems. On live trees, cankers were pitchy and eruptant and often had a cleft in the center, parallel to the branch or stem axis. A significantly greater percentage of spruce trees in thinned stands had cankers than did those in unthinned stands (see tables 6 and 7). Thinned stands at Thorne Bay differed strikingly from those in the Harris River valley and on Kosciusko Island in that no cankers were found on spruce at Thorne Bay, but 43 percent and 30 percent, respectively, of the spruce crop trees in thinned stands along the Harris River valley and on Kosciusko Island had cankers. There were 17 stem cankers on the 9 affected crop trees. Branch cankers occurred on 7 percent of the 146 lower crown branches sampled, 10 percent of the 131 middle crown branches, and on none of the 91 upper crown branches. On average, there were 2.4 ± 0.5 cankers per infected branch. Cankers were more common close to the stem, regardless of branch length. At least 2 fungi occurred on these cankers: Discocainia treleasei (Sacc.) J. Reid & Funk, a fungus known to cause serious damage on Sitka spruce in Canada (Funk 1981); and Heliotium resinicola Baranyay & Funk, a fungus that occurs on resin (Funk 1981) but apparently has not been tested for pathogenicity. Although not confirmed, black globular fruiting bodies present on small twig cankers from four spruce crop trees appear to be Botryosphaeria picea Funk.
Western hemlock:	
Microlepidoptera	These larvae were found webbed in a few needles on several trees at Thorne Bay and twice in the Harris River valley.
Acantholyda (Hymenoptera: Pamphiliidae)	Webspinning sawfly larvae were collected at least twice.
Cutworms (Lepidoptera: Noctuidae)	At least one larva of Panthea sp. was found.
Cankers	Cankers occurred on both live and dead branches. The most common were sunken and resinous and often encompassed the stub of a twig. Other cankers were resinous but not sunken and tended to occur on small-diameter branches. Only 1 crop tree had a stem canker. Fifteen percent of the 153 lower crown primary branches were cankered, 4 percent of the 150 middle crown branches, and none of the 107 upper crown branches. On average, there were 2.1 cankers per infected branch. Organisms causing these cankers have not been identified, but likely include: Discocainia treleasi, a fungus that occurred on spruce in this survey and also infects hemlock (Funk 1981); and Xenomeris abietis Barr (Funk 1981), a pathogen noted elsewhere on Prince of Wales Island.[2]

See footnotes at end of table.

Table 8—Observations on the less common insects and diseases found in young-growth stands[1] (continued)

Host and pest	Remarks
Needle rust	Pucciniastrum vaccinii (Wint.) Joerst occurred at low intensity in 15 of 16 stands and infected nearly 50 percent of the trees (see tables 4 and 5).
Dwarf mistletoe	Although hemlock residuals infected with A. tsugense occurred in the surveyed stands, dwarf mistletoe infections were found only twice on branches of young trees, neither of which was on a survey plot.
Fluting	No actual fluting was found; however, the analysis of variance indicated that there was a difference among stands in the basal symmetry of hemlock crop trees. If or how this difference relates to the potential for fluting to develop is unknown.
Sitka spruce and western hemlock:	
Sawflies	Levels of sawfly infestation were similar on spruce and hemlock and in thinned and unthinned stands (see tables 4-7). Sawflies were not recorded by species; however, Neodiprion tsugae (Hymenoptera: Diprionidae) and other Neodiprion sp. occurred on hemlock. A Neodiprion sp. and a possible Pikonema sp. (Hymenoptera: Tenthredinidae) were found on spruce.
Geometrids (Lepidoptera: Geometridae)	The green striped forest looper (Melanolophia imitata Wlk.), which can kill tops and, rarely, whole trees (Holsten 1980), occurred in low numbers (see table 4-7). A Hydriomena sp. and an Anthelia sp. (Columbia brindle looper) were also observed.
Aphids and adelgids (Homoptera: Adelgidae	These insects were recorded together (see table 4-7). A Pineus sp. was found on spruce and the hemlock woolly aphid, Adelges tsugae, on hemlock. Other, unidentified species were also present.
Erythraeids (Acari)	Predatory mites were collected from spruce and hemlock in the beating samples. The percent of trees with mites did not differ significantly between thinned and unthinned stands.
Sthereus sp. (Coleoptera: Curculionidae)	This weevil was found on only 6 hemlock and 8 spruce crop trees, although it is considered common in British Columbia and Alaska.[3]
Blackheaded budworm	Acleris gloverana Wals. (Lepidoptera: Tortricidae) was found only twice on hemlock and once on spruce.
Needle miners	Mined needles were found on 8 hemlock and 2 spruce.
Sirococcus shoot blight	The percent of hemlock trees infected with S. strobilinus did not differ significantly between thinned and unthinned stands (see tables 4 and 5). Even though the fungus occurred in all stands and about 30 percent of the hemlock crop trees were infected, intensity was low. Less than 6 percent of the sampled branches were infected and mean intensity of infection in affected subsamples was 1.7 out of 10 shoots. The fungus also occurred on spruce, in both thinned and unthinned stands, but to a very limited degree (see tables 6 and 7), which confirmed an earlier report that the fungus occurs on spruce in southeastern Alaska, but to a much lesser degree than on hemlock (Wicker and others 1978).
Injuries and distortions	Of the 317 crop trees examined, 15 had stem wounds, and 27 had slight and 4 had serious stem distortions. Of the 155 hemlock leaders observed, there were 5 slightly distorted and 2 dead. On 153 spruce there were 6 slightly distorted leaders, 9 very distorted, and 1 absent.
Western redcedar:	
Leaf blight	Didymascella thujina (Durand) Marie caused considerable browning of foliage on all 5 western redcedar crop trees.

[1]Tables 4-7 summarize occurrence for most of these pests by stand.

[2]Unpublished data (Shaw) on file, Forestry Sciences Laboratory, P.O. Box 909, Juneau, Alaska 99801.

[3]Personal communication, D. Evans, Canadian Forestry Service, Victoria; British Columbia, Canada.

Larvae were found in all 16 stands with no significant differences in occurrence between thinned and unthinned stands; however, there was a greater variation in attack intensity in unthinned stands (tables 5 and 6). Fifteen percent of the 367 samples either had larvae or had damage typical of these larvae; there was an average of 1.7 infected shoots per affected sample of 10 shoots.

Initial observations suggested that larvae were more frequent on vigorous shoots. The percentage of foliage retention and "green color" ratings were examined for correlation with occurrence of larvae or damage. Significantly more branches with over 75 percent foliage retention had attacks than those with less than 75 percent retention, but differences based on "foliage greenness" ratings were not significant—perhaps because only 17 of the 342 branches had less than 75 percent of their foliage classed as green. Buds on branches at all crown levels were attacked with no apparent preference for any crown height.

These collections are the first record of this insect in southeastern Alaska, although *Zeiraphera* sp. have caused serious damage to terminals of Sitka spruce trees in the Queen Charlotte Islands (Silver 1962, Unger and Humphreys 1984). The insect also occurs on white spruce *(Picea glauca* (Moench) Voss) and eastern larch *(Larix laricina* (Du Roi) K. Koch) in south-central and interior Alaska (Holsten and others 1980).

***Pseudohylesinus tsugae* (Coleoptera: Scolytidae) on hemlock.**—Short, vertical galleries, 0.25-0.5 inch long, occurred frequently on stems of western hemlock in thinned stands. Beetles identified as *P. tsugae* were often found in these galleries. In vigorous, live trees a few feeding galleries contained two beetles, but no egg galleries were found. Early in summer, only galleries with a beetle, fresh frass, or fresh clear resin were recognized and counted. Presumably these galleries were made during the current year. Later in summer, galleries with solidified opaque resin, and sometimes a scar scoring the sapwood under the bark, were also recognized. Actual age of these galleries was unclear.

Data on *P. tsugae* in tables 4 and 5 include only those stands in which both old and new galleries were recognized. The percentage of trees attacked was significantly greater in thinned stands than in unthinned stands—consistent with observations in coastal Oregon where *P. tsugae* attacked slash and leave trees after precommercial thinning (McGhehey and Nagel 1969). Our subsampling found from 0 to 47 feeding galleries per square foot of bark surface on the 92 hemlocks on which both old and new galleries were looked for. The number of galleries per square foot of bark surface area was significantly higher on hemlock trees in thinned stands (13) than on those in unthinned stands (0.4).

Feeding galleries of *P. tsugae* were more common on large trees, perhaps because the beetle preferred to enter under a bark flap and small trees had smoother bark. Attack intensity in thinned stands on trees with a d.b.h. of 3 inches or less (5 $\pm$ 2 galleries per square foot) was significantly lower than on trees with d.b.h. greater than 3 inches (21 $\pm$ 3 galleries per square foot). Also, the 0.69 correlation coefficient between total galleries per square foot and tree d.b.h. for the 54 hemlocks in thinned stands was significant.

The ratio of new to old galleries on trees in the separate survey at Thorne Bay suggests that *P. tsugae* breed in thinning slash and feed on residuals the year following thinning with few new feeding attacks occurring in succeeding years (table 3). In the main survey plots, however, there was no significant difference in intensity of new galleries by years since thinning. In two of the three stands thinned the previous year there were no new galleries. Possibly, these stands were thinned too late in the year for adults to lay eggs in the slash and produce attacking broods the following year. If only stands from the main survey that were attacked by *P. tsugae* are examined, then the temporal pattern of attack appears similar to that found in the separate survey.

Discussion

Even though this survey found only minimal pest damage, continued ground monitoring of insect and disease levels in young stands is justified because several organisms capable of causing significant damage were detected. Insects of concern include the blackheaded budworm and hemlock sawfly. The budworm is one of the area's most destructive insects and is of particular concern in young-growth stands (Hard 1974). Low populations of these and other defoliators are typical between outbreaks and their current absence does not imply that young stands are resistant to attack.

Results of this survey showed relatively low levels of stump colonization by *F. annosus* and, thus, confirm previous results (Shaw 1981); however, the potential for damage from this root disease is still of concern because the fungus frequently builds up after thinning (Morrison and Johnson 1978). Since current management plans call for several thousand acres of young-growth forest to be thinned before commercial harvest, sampling for *F. annosus* should continue. The relatively common occupancy of thinning stumps by *Armillaria* sp. also confirms earlier results (Shaw 1981) and emphasizes the need for pathogenicity testing and species determination for Alaska isolates of *Armillaria*.

Results of this survey also confirm previous work suggesting that neither *Sirococcus* shoot blight nor hemlock dwarf mistletoe will cause significant damage in managed young stands (Shaw and others 1981, Shaw 1982). It also appears unlikely that *Zeiraphera* sp. in spruce buds, *P. tsugae* on hemlock stems, or cankers on either spruce or hemlock will cause significant damage. Periodic monitoring, however, would reveal any unexpected population increases by these organisms or by others not observed in this survey.

A pest notable for its absence is the Sitka spruce weevil *(Pissodes strobi* Peck). This weevil has not been recorded in Alaska or the Queen Charlotte Islands, but has caused extensive damage elsewhere in coastal British Columbia, Washington, and Oregon (Hard 1974).

With thinning currently the main form of management in young stands, differences in occurrence of pests and levels of infestation between thinned and unthinned stands are of particular interest. Spacing, species selection, stand age, time of year when thinned, size and shape of thinning units, and time when adjacent units are thinned are all subject to manipulation that could influence development of pest populations. If pest damage were severe on particular stems, then thinning could reduce populations by removing these trees (for example, damaged leaders—such as the one we found killed by a *Dioryctria* sp.). At the low population levels we observed, however, it is unlikely that pests were a factor in many, if any, crop tree selections.

In our survey, comparison of pest levels among the three sampling areas was difficult because differences in time of year when stands were sampled might have affected results. Future surveys should be performed over a shorter time span (consistent from year to year) to allow for comparisons of data among different areas and stand types.

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Metric Equivalents

1 inch = 2.54 centimeters
1 foot = 30.48 centimeters
1 chain (66 feet) = 20.12 meters
1 acre = 0.4047 hectare

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Soil Compaction and Initial Height Growth of Planted Ponderosa Pine

P. H. Cochran and Terry Brock

Abstract

Early height growth of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) seedlings planted in clearcuts in central Oregon was negatively correlated with increasing soil bulk density. Change in bulk density accounted for less than half the total variation in height growth. Although many other factors affect the development of seedlings, compaction has reduced the rate of height growth.

Keywords: Soil compaction, soil bulk density, increment (height), ponderosa pine.

Introduction

Soil compaction during logging and related operations and subsequent reduction in tree growth is a continuing concern among land managers. Pertinent issues include the degree of compaction from use of certain types of equipment on different soil types under varying soil water contents, the length of time necessary for a compacted soil to return to the noncompacted condition, and the reduction in productivity related to the compaction.

This note reports rates of height growth for ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) seedlings planted in two clearcuts with varying degrees of compaction at individual planting sites. Cause of the compaction is not known.

The Study Area

The two small clearcuts (9.3 and 10.5 ha in size with closest edges between clearcuts about 67 m apart) were part of the Switchback Timber Sale administered by the Sisters Ranger District, Deschutes National Forest. They are located in sections 3 and 4, T12S, R9E, Willamette Principal Meridian. The topography slopes gently to the south; slopes exceed 3 percent in only 10 percent of the area. The mean annual precipitation is 100 cm, and the mean annual temperature is 6 °C. The soil is a deep, well-drained mountain soil formed from old Mount Jefferson ash 50 to 60 cm thick over residuum or colluvium from volcanic rocks. A soil survey of the area is underway, and this soil has been tentatively classified as a fine loamy mixed Andeptic Cryoboralf.

In creation of the clearcuts, Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), white fir (*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.), and ponderosa pine were first removed. Skidding and yarding was done between February and April 1974; slash was piled by use of tractors in late fall 1974. Incense-cedar (*Libocedrus decurrens* Torr.) and other stems infected by mistletoe were removed in 1977. Slash from this second entry was piled in the fall and winter of 1977, and 2-0 ponderosa pine seedlings were planted on a 2.4- by 2.4-m spacing in the spring of 1978. Seedlings were protected from animals

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by cages of rigid vexar placed around the seedlings in the fall of 1978. An examination of the plantation in March 1981 indicated that the vexar cages were in poor condition, and they were removed in the fall of 1981.

Methods

Maps of the two clearcuts were gridded, and 19 grid intersects (12 in clearcut 1 and 7 in clearcut 2) were randomly picked as starting points for a sampling transect. The direction of each transect was then established by randomly choosing an azimuth.

The selected grid intersects were located in the field by pacing, and a 30.5-m tape was laid out in the azimuth direction. All planted trees within a distance of 1.2 m perpendicular to the tape were measured for total height. None of the transects intersected, and no tree was measured twice. Length of the leaders for 1983 and internode lengths for 1982 were also measured. Damage from vexar cages distorting the main stem was also recorded as absent (1), low (4), moderate (7), or high (11); the numbers expressed the estimated degree of damage. A bulk density sample centered 15 cm from the base of the seedling toward the tape was taken from the 10- to 20-cm depth by use of a cylinder 10 cm in diameter and length. Samples were ovendried at 105 °C for at least 48 hours and were weighed with rocks and without.

Ten additional bulk density samples were taken at the 10- and 20-cm depth in undisturbed locations within 9 m of the borders of the clearcuts. Four samples were taken around clearcut 1 and six samples around clearcut 2; these samples were processed like the samples taken next to the seedlings.

An adjusted bulk density for each sample was determined by first calculating the volume of the rock in the sample from the weight of the rock and its particle density (2.64 g/cm^3). The adjusted bulk density is the dry weight of the soil without rocks divided by the cylinder volume minus the volume of rocks. Total heights, periodic annual height growth for 1982 and 1983, adjusted bulk density, and vexar damage were averaged for each transect. Multiple weighted regression techniques were then used to relate average height and average height growth for each transect to the average adjusted bulk density and the average vexar damage for that transect. Weighted regressions were used because each transect did not have the same number of trees because of mortality. Weights for each average transect value were the number of trees measured for that transect.

Results

No relationship was found between estimated damage caused by the vexar cages and either total height or height growth for the 1982 and 1983 growing seasons. Many of the stems were distorted in the first 30 cm of height by the vexar cages, and susceptibility to snow breakage in the future should be monitored.

Bulk density values for the 10 samples taken in undisturbed areas adjacent to the clearcuts ranged from 0.99 to 1.07 g/cm^3 and averaged 1.02 g/cm^3. When the sample values were adjusted for rock content, the range was 0.81 to 0.94 g/cm^3, and the average was 0.88 g/cm^3.

On the 19 transects in the clearcuts, 77 samples were taken next to seedlings that were measured for total height and height growth for 1982 and 1983. Detrimental compaction (Howes and others 1983) is here regarded as more than a 15-percent increase in soil bulk density. By this standard, unadjusted bulk densities greater than 1.17 g/cm^3 (1.02 g/cm^3 x 1.15) and adjusted bulk densities greater than 1.01 g/cm^3 (0.88 g/cm^3 x 1.15) are considered detrimental. Of the 77 unadjusted samples 34 (44.2 percent) were greater than 1.17 g/cm^3, and of the adjusted samples 29 (37.7 percent) were

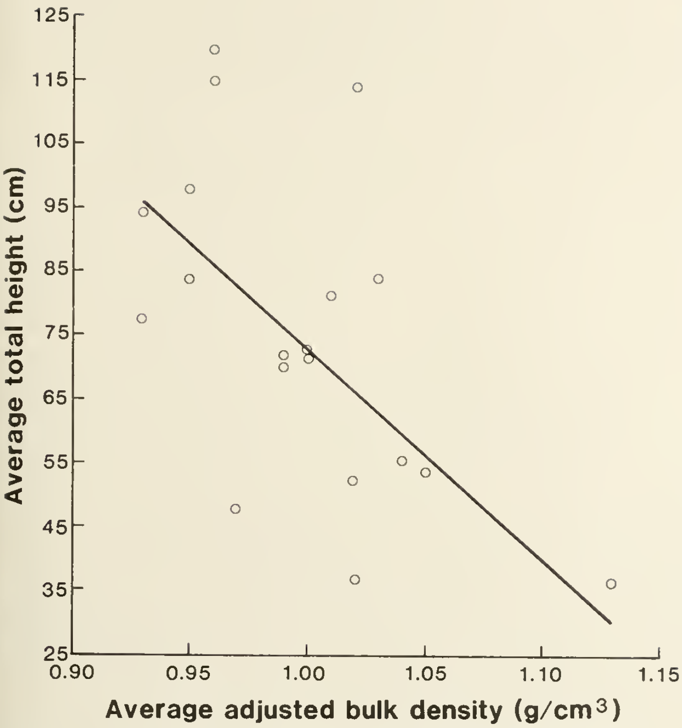

Figure 1.—Average total height vs. average adjusted bulk density for each of the 19 transects. Weighted regression techniques were used to calculate the regression.

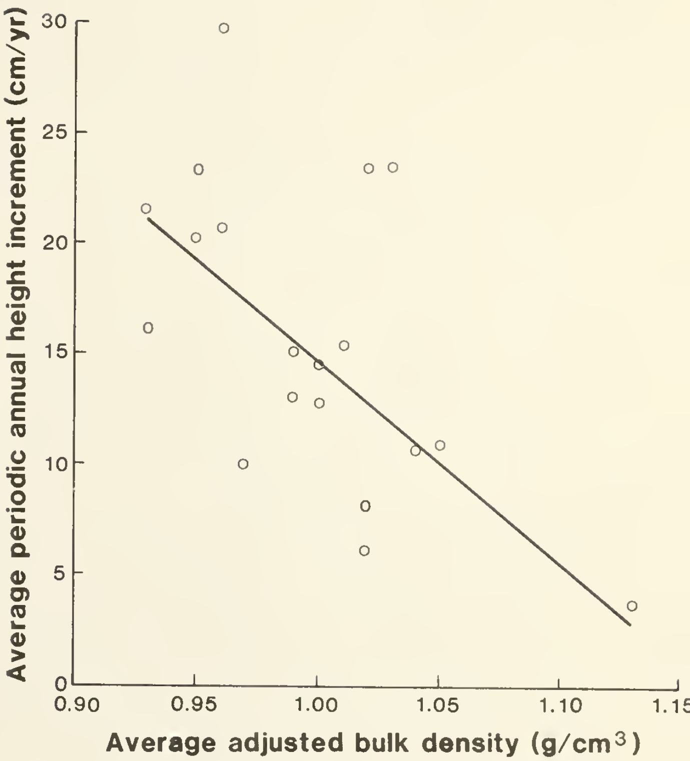

Figure 2.—Average periodic annual height increment during 1982 and 1983 vs. average adjusted bulk density for each of the 19 transects. Weighted regression techniques were used to calculate the regression.

greater than 1.01 g/cm³. Of the 19 transects 7 (36.8 percent) had average unadjusted bulk densities greater than 1.17 g/cm³ and average adjusted bulk densities greater than 1.01 g/cm³.

Total height and periodic annual height growth for 1982 and 1983 were negatively correlated with increasing values of adjusted bulk densities (figs. 1 and 2) and unadjusted bulk densities. All the regressions expressing these correlations are statistically significant at the 5-percent level of probability even though the r^2 values are 0.5 or less (table 1). The low r^2 values for these regressions indicate that other factors influenced total height and height growth besides bulk density. The nature of these factors and their influence on height growth are subject to speculation; however, the significance of the regressions shows that soil compaction has reduced the height growth of the trees.

Table 1—Equations expressing average total height in centimeters (y_1) or average periodic annual height increment for 1982 and 1983 in centimeters (y_2) as functions of average unadjusted bulk density (x_1) and average adjusted bulk density (x_2) for the 19 transects

Equation	r^2	Standard error
		Centimeters
$y_1 = 441.6 - 321.96\, x_1$	0.50	32.57
$y_1 = 401.5 - 328.80\, x_2$	.43	35.04
$y_2 = 107.8 - 81.17\, x_1$	.46	8.93
$y_2 = 105.7 - 90.98\, x_2$	.47	8.86

Conclusion

Compaction, measured by changes in soil bulk density, reduced height growth for the 5-year period after planting. The scatter of the data points caused by the influence of unmeasured variables tends to mask the influence of compaction, but the negative influence of compaction is real. How long the negative influence will continue is unknown. An additional study, planned to test the effect of tillage of compacted areas on growth rates, will also attempt to determine the length of time growth rates are reduced on compacted areas that are not tilled.

Metric and English Units of Measure

When you know:	Multiply by:	To find:
Centimeters (cm)	0.394	Inches
Grams per cubic centimeter (g/cm^3)	62.4	Pounds per cubic foot
Hectares (ha)	2.469	Acres
Celsius (°C)	1.8 then add 32	Fahrenheit (°F)

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A Stockability Equation for Forest Land in Siskiyou County, California

Neil McKay

Abstract

An equation is presented that estimates the relative stocking capacity of forest land in Siskiyou County, California, from the amount of precipitation and the presence of significant indicator plants. The equation is a tool for identifying sites incapable of supporting normal stocking. Estimated relative stocking capacity may be used to discount normal yields to levels that these sites can produce.

Keywords: Stocking capacity, indicator plants, yield (forest), California, forest productivity.

Introduction

The prediction of potential timber yields requires an evaluation of stocking and productivity. Normal yield tables often are the only tools available. Where shallow soils, moisture stress, soil toxicity, or other limitations on stocking capacity are present, many sites are unable to support normal stocking and yields. For such areas, normal yield tables may overestimate stocking capacity and productivity.

MacLean and Bolsinger (1973) describe a procedure for estimating relative stocking capacity from equations based on site index and geographical and environmental variables, and from the presence of indicator plants. These estimates are used to identify sites incapable of supporting normal stocking and to discount normal yields given these limitations.

This paper presents an equation to estimate relative stocking capacity on forest land in Siskiyou County, northern California. The equation incorporates the assumptions and techniques developed by MacLean and Bolsinger.

Background

In 1969, the Forest Inventory and Analysis work unit of the Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, began to develop a technique to determine quantitatively the productive potential of forest land incapable of supporting normal yield table levels of stocking.[1] At that time, no documented technique was available to make such evaluations.

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[1] Unpublished study plan, 1969, "Study Plan for the Development of a Method for Estimating the Stocking Capacity of Forest Lands," by Robert B. Pope. On file at the U.S. Department of Agriculture, Forest Service, Forestry Sciences Laboratory, Forest Inventory and Analysis, P.O. Box 3890, Portland, Oregon 97208.

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Griffin (1967), in a study in northern California, developed a vegetative drought index relating soil moisture to the presence or absence of 172 indicator plants. Building on Griffin's work, MacLean and Bolsinger (1973) speculated that, because stand density is related to soil moisture, indicator plants also would be useful in estimating stocking capacity. In their study, stocking capacity is expressed by stand density index—an expression of relative stand density that permits direct comparison among stands in different stages of development (Reineke 1933).

MacLean and Bolsinger made three assumptions for their study. First, they accepted an assertion by Daubenmire and Daubenmire (1968) that plant species on a site tend to persist even after disturbance. Second, they accepted the advice of Waring and Majo (1964) to limit use of plant indicators to presence or absence, as plant coverage is likely to be influenced by disturbance. Finally, they assumed a one-to-one relationship between stocking capacity and yield capability for a given site index.

Equations for estimating stocking capacity in Shasta and Trinity Counties in California were published in 1973 (MacLean and Bolsinger 1973). An additional report (MacLea and Bolsinger 1974) presents equations for several other regions in California. Neithe publication provides an equation for Siskiyou County.

In 1981, the Forest Inventory and Analysis work unit began to develop an equation fo Siskiyou County based on the work of MacLean and Bolsinger (1973). The work unit needed this tool to identify stocking limitations on its permanent plots within the count in order to improve periodic inventory estimates. The equation presented in this pape is the result.

The Equation

The equation for Siskiyou County estimates the stocking capacity of a site expressed as a proportion of that for sites described in normal yield tables. For areas without stocking limitations, the equation estimates a relative stocking capacity that is within ±20 percen of "normal." This implies that a limitation on stocking exists whenever relative stockin capacity is less than 0.8 of normal. For such areas, normal yield predictions are discounted by the estimated relative stocking capacity. If, for example, the estimated relative stocking capacity of a Douglas-fir site is 0.5, then the normal yield table predictions of basal area, number of trees, and yield should be multiplied by 0.5.

The generalized form of the equation is:

$$\text{Relative stocking capacity} = f\,(\text{NSDI}, X_i).$$

Where: Relative stocking capacity is expressed as a proportion of normal yield stockin
NSDI = normal stand density index, and
X_i = precipitation or indicator plant variables.

The equation for Siskiyou County is:

$$\text{Relative stocking capacity} = \frac{1}{\text{NSDI}}(356 + 81X_1 + 0.0283X_2 - 80X_3 - 71X_4 - 53X_5 - 246X_6 - 80X_7 - 131X_8 - 76X_9 + 84X_{10} - 98X_{11} - 64X_{12} - 118X_{13} - 54X_{14}).$$

When: NSDI = normal stand density index from an appropriate yield table

X_1 = *Abies magnifica, Adenocaulon bicolor,* or *Smilacina* spp.[2]

X_2 = (annual precipitation)^2

X_3 = *Chrysothamnus* spp.

X_4 = *Quercus garryana*

X_5 = *Festuca* spp.

X_6 = *Pinus contorta* on a dry flat

X_7 = *Agropyron spicatum*

X_8 = *Lomatium nudicaule*

X_9 = *Arctostaphylos viscida*

X_{10} = *Salix* spp., except along streambeds and in low, wet areas

X_{11} = *Castilleja* spp.

X_{12} = *Juniperus occidentalis*

X_{13} = *Rhus trilobata*

X_{14} = *Artemisia tridentata*

The geographic area to which this equation applies is all of Siskiyou County except the area west of R. 11 W. (Mount Diablo Meridian) and the area of the Klamath Mountain north of the Siskiyou-Trinity County line and east of R. 12 W. (Mount Diablo Meridian) For this latter area, use the stockability equation for Shasta and Trinity Counties developed by MacLean and Bolsinger (1974).

Application

To use the equation, select a normal stand density index from a normal yield table tha is appropriate for the site and species. Normal stand density indices (NSDIs) for yield tables commonly used in California are:

Species and source	NSDI
Ponderosa pine (Meyer 1961)	365
Douglas-fir (McArdle and others 1961)	370
Douglas-fir (Schumacher 1930)	400
Lodgepole pine (Dahms 1964)	460
Mixed conifer (Dunning and Reineke 1933)	479
White fir (Schumacher 1926)	565
California red fir (Schumacher 1928)	725

All other independent variables except annual precipitation have a value of one, if present, or zero, if absent. Annual precipitation is entered to the nearest inch.

The independent variable labeled "*Pinus contorta* on a dry flat" (variable X_6) should mee all of the following criteria to have a value of one:

1. Lodgepole pine is the only tree species present.
2. The stand occurs on a dry flat; pumice soil is usually present.
3. Topographic slope is 5 percent or less.

In Siskiyou County this combination is most common above 5,000 feet (1524 m) near Mount Shasta.

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[2] Scientific and common names of plants are given on page 5.

Several guidelines apply when determining which indicator plants are present. Search thoroughly to find plants that are typically scattered. Ignore plants growing within small areas that differ from the surrounding study area; examples are rock outcrops, springs, or skid roads. Elsewhere, tally all indicators even if scarce. Record the presence of indicator species that were obliterated by disturbance if this is known. The plant grouping of *Abies magnifica, Adenocaulon bicolor,* and *Smilacina* spp. (variable X_1) is recorded as present if any species within the group is found.

An Example

Can a hypothetical ponderosa pine site in Siskiyou County support normal stocking? If not, how is normal yield discounted to account for stockability problems?

Careful inspection of the site reveals the presence of four indicator plants: *Adenocaulon bicolor* (X_1), *Chrysothamnus* (X_3), *Festuca* (X_5), and *Agropyron spicatum* (X_7). *A. bicolor* is found at a spring and, because this locaiton is much wetter than the rest of the area, the presence of this plant is ignored. Also, a precipitation map indicates that the site annually receives 20 inches of water.

The appropriate values to insert into the equation are:

NSDI for ponderosa pine = 365;
annual precipitation = 20;
X_3, X_5, and X_7, = 1; and
all other plant indicators = 0.

Therefore:

$$\text{Relative stocking capacity} = \frac{1}{356}(356 + 0.0283(X_2)^2 - 80(X_3) - 53(X_5) - 80(X_7))$$

Entering values for NDSI, X_2, X_3, X_5, and X_7:

$$\text{Relative stocking capacity} = \frac{1}{356}(356 + 0.0283(20)^2 - 80(1) - 53(1) - 80(1)) = 0.42$$

Because the estimated relative stocking capacity is 0.42, the site is incapable of supporting a normal yield of ponderosa pine (relative stocking capacity is less than 0.8). To estimate the yield that the site can support at full stocking, multiply the normal yield for desired stand age by 0.42. Had the relative stocking capacity exceeded 0.8, the site would have been judged capable of supporting normal stocking and yield.

Reliability of the Equation

The relative stocking capacity is estimated by a ratio estimator. The numerator of this estimator is a linear equation that estimates the stand density index that the site will support. The denominator, an estimate of normal stand density index for the site, is selected from the appropriate normal yield table. The sampling error associated with the denominator is assumed to be zero (that is, the normal stand density index is assumed to be a constant). Descriptive statistics are presented only for the numerator.

The equation accounts for 83 percent of the variation (R^2) in stand density index capacity. The standard error of the estimate is 72 stand density index points. The equation was fitted by stepwise regression using the data from 70 plots within the study area.

Because stepwise regression analysis of large numbers of empirically selected variables may underestimate variance and overestimate the amount of explained variation when the number of observations is low, the equation was tested against the field data from 26 plots within the study area. This validation set was randomly selected from the entire set of study plots prior to the analysis. The validation plots were not used for model building. The standard deviation of the residuals computed for the validation set is 95 stand density index points. The difference between estimated and actual mean stand density indices is +7 stand density index points. This small amount of positive bias is probably an accident of sampling. This compares favorably with the range of bias, +6 to +21 stand density index points, observed by MacLean and Bolsinger (1973) while validating stocking equations for five other areas in California.

Plant Names

Scientific names	Common names
Abies concolor (Gord. & Glend.) Lindl. ex Hildebr.	white fir
Abies magnifica A. Murr.	California red fir
Adenocaulon bicolor Hook.	trail plant
Agropyron spicatum (Pursh) Scribn. & Sm.	wheatgrass
Arctostaphylos viscida Parry.	whiteleaf manzanitia
Artemsia tridentata Nutt.	big sagebrush
Castilleja spp. Mutis.	Indian paint-brush
Chrysothamnus spp. Nutt.	rabbitbrush
Festuca spp.	annual fescue
Juniperus occidentalis Hook.	western juniper
Lomatium nudicaule (Pursh) Coult. & Rose.	hog fennel
Pinus contorta Dougl. ex Loud.	lodgepole pine
Pinus ponderosa (Dougl. ex Laws.)	ponderosa pine
Pseudotsuga menziesii (Mirb.) Franco	Douglas-fir
Quercus garryana Dougl. ex Hook.	Oregon white oak
Rhus trilobata Nutt. ex T. & G.	squaw bush
Salix spp. L.	willow
Smilacina spp. De sf.	false solomon's seal

Names of trees are according to Little (1979); scientific names of grasses, herbs, and shrubs are according to Munz and Keck (1970).

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Are Seed and Cone Pathogens Causing Significant Losses in Pacific Northwest Seed Orchards?

E.E. Nelson, W.G. Thies, and C.Y. Li

Abstract

Cones systematically collected in 1983 from eight Douglas-fir seed orchards in western Washington and Oregon yielded large numbers of common molds. Fungi isolated from apparently healthy, developing cones were similar to those from necrotic cones. Necrosis in cones aborted in early stages of development was apparently not associated with pathogenic fungi or bacteria. Environmental factors appeared to account for early cone abortions, although on-site temperatures were not recorded, nor were those fungi isolated from aborted cones tested for pathogenicity. Necrotic areas in cones collected during the summer were associated with insect activity. Good crops of healthy cones were produced when fertilization and partial girdling had been used to stimulate cone production and insecticides used to control cone insects.

Keywords: Diseases (cone), diseases (seed), orchards (seed), Pacific Northwest, Douglas-fir.

Introduction

Western Oregon and Washington seed orchards now provide much of the seed required for regeneration of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) in the Pacific Northwest. Because of the high value of seed produced in orchards, cultural practices that encourage high yields of quality seed become increasingly important. Destruction of developing seed and cones by insects and disease must be minimized.

Seed and cone insects have long been known to reduce Douglas-fir seed production. Loss in productivity from fungi or other pathogens, however, has not been measured, nor is it generally accepted that significant losses from diseases occur in developing cones (Hunt 1975). Nearly all documented losses from fungi occur in stored cones and seed (Shea 1960, Bloomberg 1966). Seed viability in stored cones decreases with time, but loss can be reduced by proper handling and storage of cones and seed in controlled environments and by use of fungicides (Shea 1960, Gordon 1967, Harvey and Carpenter 1975).

In 1983, we examined cones collected periodically from Douglas-fir seed orchards to determine if diseases of seeds and cones caused significant losses in western Washington and Oregon.

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Materials and Methods

Sampling Procedure

Eight seed orchards (table 1) were sampled biweekly from onset of flowering to June, then monthly until cones were ready to be picked. Initially, six cones (two from each 120° sector) were selected from the upper crown and six from the lower crown of each of four trees representing early, late, and intermediate flowering families. Thus, 12 trees were sampled from each orchard on each date, and 12 cones were collected from each tree where cone production allowed. Because cone crops were poor in 1983, we collected only six cones from each tree as the season progressed. Aborted cones were sampled only if they appeared to have aborted since the last sampling period; such cones were not difficult to identify during those periods of rapid, early cone development.

Table 1—Seed orchards sampled for cone and seed diseases in 1983

No.	Orchard	Location	Ownership
1.	Captain Moses	Darrington, WA	USDA Forest Service
2.	Dennie Ahl	Shelton, WA	USDA Forest Service
3.	Dee Flat	Parkdale, OR	USDA Forest Service
4.	Walter H. Horning	Colton, OR	USDI Bureau of Land Management
5.	Turner	Turner, OR	Weyerhaeuser Co.
6.	Beaver Creek	Corvallis, OR	USDA Forest Service
7.	David T. Mason	Sweet Home, OR	Barringer and Associates
8.	Row River	Cottage Grove, OR	Georgia Pacific Corporation[1/]

[1/] Since acquired by Weyerhaeuser Co.

Laboratory Procedures

Procedures were modified as cones developed over the course of the growing season. Initially, female flowers were sectioned lengthwise, surface sterilized, and plated onto potato dextrose agar (PDA). As cones developed, scales were excised and similarly treated. When seed development became obvious, only the seed and that area of the ovuliferous scale cradling the seed were plated. As seeds began to approach maturity, they were carefully removed from the scales and plated onto both PDA and one of two media selective for *Fusarium* spp. (Nash and Snyder 1962, Komada 1976). The internal condition of each dissected cone was recorded. Sample tissues were surface sterilized in a stainless steel wire basket suspended for 1 minute in a beaker of 1-percent sodium hypochlorite resting in water in an ultrasonic cleaner, followed by two rinses with sterile, distilled water. Ultrasonic vibrations reduced air bubbles clinging to cones, increasing contact of tissues with the hypochlorite. These procedures were intended to sample for fungi within tissues, excluding those on the surface, even though some of the surface fungi may have become destructive before seed was extracted.

Results and Discussion

Over the season, 4,564 cones were examined. From these, 7,293 fungi were isolated, but only a few of the fungi were identified. Most of the isolates appeared to be common molds normally classified as saprophytes or facultative parasites. Many of these isolates, especially from earliest samples, may include fungi that escaped surface sterilization in spite of attempts to eliminate air bubbles on the cone surface. Shea (1960) and Gordon (1967) also found molds dominating their isolations.

PDA supports the growth of many but not all fungi; thus, fungi other than those isolated may have been present. No attempt was made to isolate potential pathogens other than fungi.

We recovered one isolate of *Fusarium* sp. from *Fusarium*-selective media, but no tests were made to determine if it was pathogenic. We consider recovery of only a single isolate notable, however, because we sampled a broad range of families on a broad range of sites over an entire growing season. Finding only one isolate does not mean that spores of the fungus could not have been on tissue surfaces. If *Fusarium* spp. gain access to nursery beds through infested seed, our results would suggest that invasion of seed tissues occurs after cone harvest and not while cones are developing on the tree.

Cones aborted in large numbers at early stages of development in most orchards. Although a pathogenic cause for at least some of these abortions cannot be ruled out, they appeared more likely to be caused directly by unfavorable environment because: the abortions seemed to occur simultaneously; they were concentrated in certain families or locations within an orchard; they occurred generally in one orchard experiencing low temperatures; and they did not seem to be associated with any one fungus or small group of fungi.

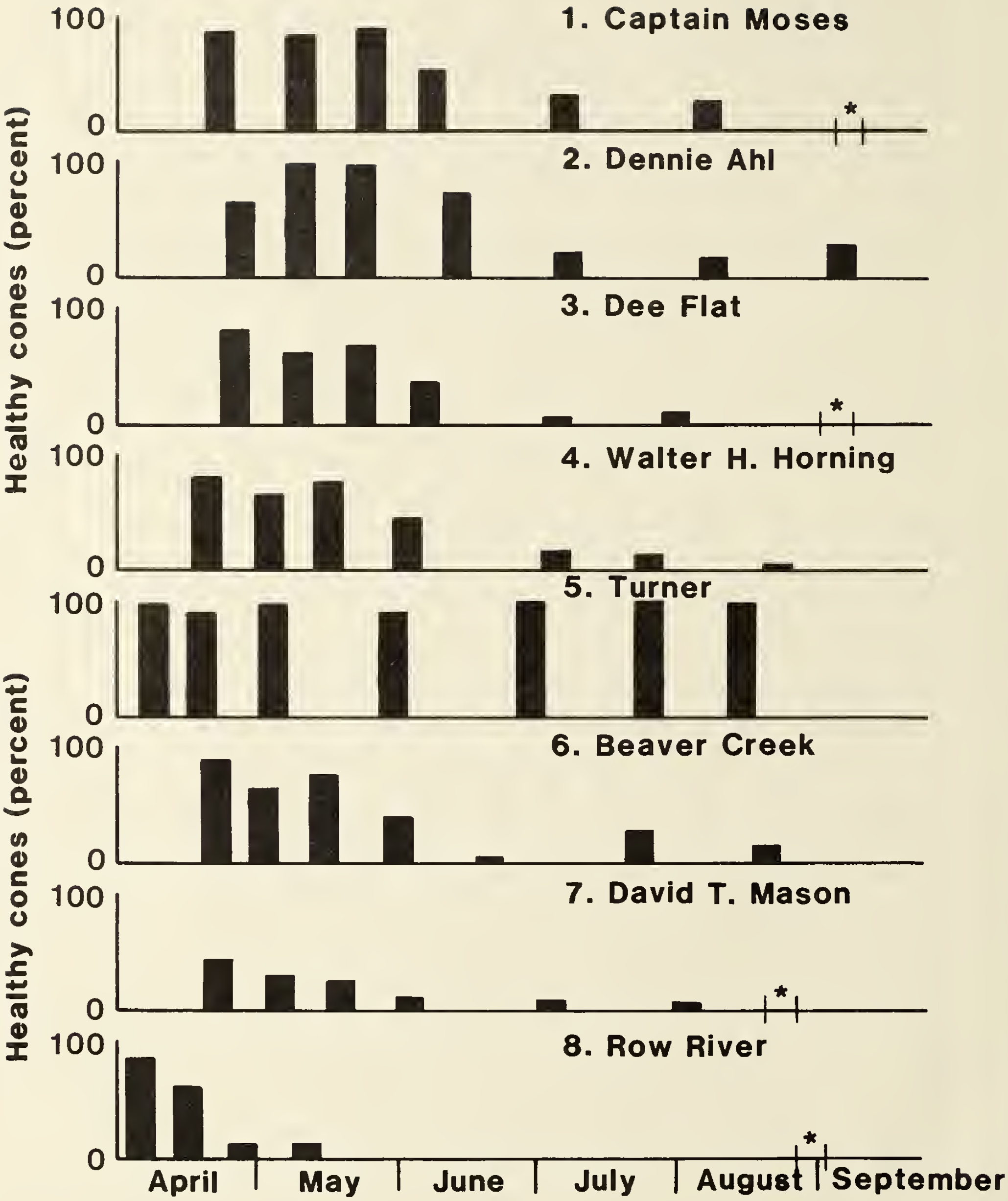
As the season progressed beyond the first 4 weeks, necrotic cones or necrotic areas in cones were associated with insect mining.[1/]

The large proportion of common molds and, more importantly, the isolation of similar kinds and numbers of fungi from necrotic and apparently healthy cone tissues leads us to believe that many of these fungi may have been merely "resting" in cones and not colonizing living tissues as primary pathogens. All isolates were classified into broad taxonomic groups, but only a few were identified to species; none were tested for pathogenicity. Thus, we have analyzed only those data on appearance of cones at the time they were dissected.

Considerable variation in numbers of healthy-appearing cones occurred among the eight orchards sampled. Cone production in 1983 was generally poor, and insect populations built up from the heavy 1982 cone crop contributed substantially to even poorer yields in orchards where insecticides were not used. In some orchards (especially 7 and 8), the poor cone crop, early abortions, and insect damage combined to limit collections to fewer cones than planned or to no cones on some dates. A combination of partial girdling and fertilizing in the previous year, and applying insecticide at orchard 5 apparently resulted in comparatively large numbers of healthy cones throughout the sampling period.

Even though previously aborted cones were not included in successive samples, percentage of healthy cones dwindled progressively with time (fig. 1). The most significant drop occurred at the end of May with the appearance of cone insects. Losses from insects in June, July, and August were heavy in all but orchard 5 where insecticides were used. Losses from aborted cones in April were considerable in some orchards (especially 7) and in some families (especially early flowering families) in several orchards. Even though we cannot rule out bacteria or fungi in these early abortions, environmental factors were more likely responsible. Gordon (1967) found immature Douglas-fir cones heavily contaminated with fungi and bacteria. We saw no obvious qualitative or quantitative differences between fungi from immature aborted cones and apparently healthy ones.

[1/]Insects and samples of insect-infested cones were sent to Timothy D. Schowalter, Department of Entomology, Oregon State University, to supplement his study of damage caused by cone insects.



* Indicates no healthy cones were found

Figure 1.—Percentage of healthy cones in samples collected from eight seed orchards, April-September 1983.

We consistently found darkened (water-soaked in appearance) areas of fleshy cone tissues associated with cone-mining insects. By the end of August or early September, nearly all insect-infested cones had nearly 100 percent of the tissues in some stage of decay. Although we did not test these cones, viable seed produced by them would likely be lacking in quantity and perhaps quality as well. Cones not mined by insects appeared normal.

Losses in seed production from cone abortion during early stages of development are sometimes considerable. We believe that seed and cone pathogens do not cause significant losses in Pacific Northwest seed orchards, but additional study of the pathology of cones in early stages of development is needed. Our study was conducted over only one season; conditions—hence diseases—in other years could differ greatly from those in 1983.

Acknowledgments

We appreciate the excellent cooperation of all seed orchardists in this study, and the many tedious hours spent by Harlan Fay, Maggie De La Rosa, Joe McNeill, John Chamard, and others in processing cones and culturing fungi.

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January 1986

Inventory and Value of Old-Growth in the Douglas-Fir Region

Richard W. Haynes

Abstract

Timber inventory data for all owners in western Washington and western Oregon were summarized by age classes to provide an estimate of the remaining amount of old growth timber. The data suggest that roughly 30 percent of the timberlands in the Douglas-fir region contain essentially mature timber (stands whose age is in excess of culmination of mean annual increment). Available information on value of old growth is scanty but does suggest that old-growth Douglas-fir is some 56 percent more valuable than second-growth Douglas-fir.

Keywords: Old-growth stands, stumpage prices, stumpage evaluation, timber supply.

Background

About half of the softwood timber inventory for the United States is on public lands in the West. Much of this timber is in stands commonly called old growth. The term "old growth" lends itself to an array of interpretations, but most definitions in the Pacific Northwest include age. Policies regarding the management and eventual harvest of old-growth timber are controversial because, without an explicit definition, basic management information is lacking. During the early 1980's, there was a concern that anticipated increases in USDA Forest Service harvest would engender controversy. In an attempt to provide background information for this controversy, the Society of American Foresters, in April 1982, chartered a task force to study issues associated with scheduling the harvest of old-growth timber. The task force was to develop a definition of old growth, assess the amount of remaining old growth, and review current old growth timber harvesting policies. This paper presents the background material prepared for that task force on two issues: (1) the question of how much old growth is still left in the Douglas-fir region and (2) whether old growth commands a higher stumpage price than does second growth.

Work on the first issue involved compiling available inventory statistics for the Douglas-fir region in a manner that would facilitate a discussion of old growth. Because all definitions have some age or size criteria, I assembled the available information for each owner group by stand age, area, and cubic volume. I also replicated the presentation of the data for the other public owners because I had two sources of data for these owners.

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Work on the second issue involved reviewing available stumpage price data to determine if old growth commanded higher stumpage prices than second growth. Higher values for old growth could reflect higher qualities (for example, less knots or more rings per inch) unique to old growth. These values could then be used as justification for retaining and managing older stands.

Following publication of the task force report (Society of American Foresters 1984), the Society of American Foresters adopted a position calling for an ecological definition of old growth, improved inventories, and harvest scheduling based on balancing economic, social, and environmental values.

Timber Inventory Statistics for the Douglas-Fir Region

Timber inventory volumes in cubic feet were compiled from two sources. The primary source was data collected by the Forest Inventory and Analysis unit, USDA Forest Service, Pacific Northwest Research Station, Forestry Sciences Laboratory, Portland, Oregon. These data are described for western Washington by Bassett and Oswald (1981a, 1981b, 1982) and for western Oregon by Jacobs (1978), Bassett (1979), and Mei (1979). These data cover three owner groups: other public, forest industry, and other private (terms are defined in the appendix). The second source of data is the various inventories of public lands conducted by the responsible agencies. For public owners other than the Forest Service and the BLM (Bureau of Land Management, U.S. Department of the Interior), the inventory information collected by the Forest Inventory Analysis unit duplicated the data. The inventories were conducted in the mid-1970's for western Oregon and the late 1970's for western Washington. The National Forest inventories came from Timber Management, Pacific Northwest Region, and represent inventories made, for the most part, in the early 1970's; they are, however, the most recent available.

The spatial detail for the private timberlands and for some public timberlands is limited to multicounty subregions (fig. 1). Forest Service inventory information is available for each National Forest. Age class representations are presented for each owner. Timberland administered by the NPS (National Park Service) is not included in the other public owner group, but the available information is presented in a separate section.

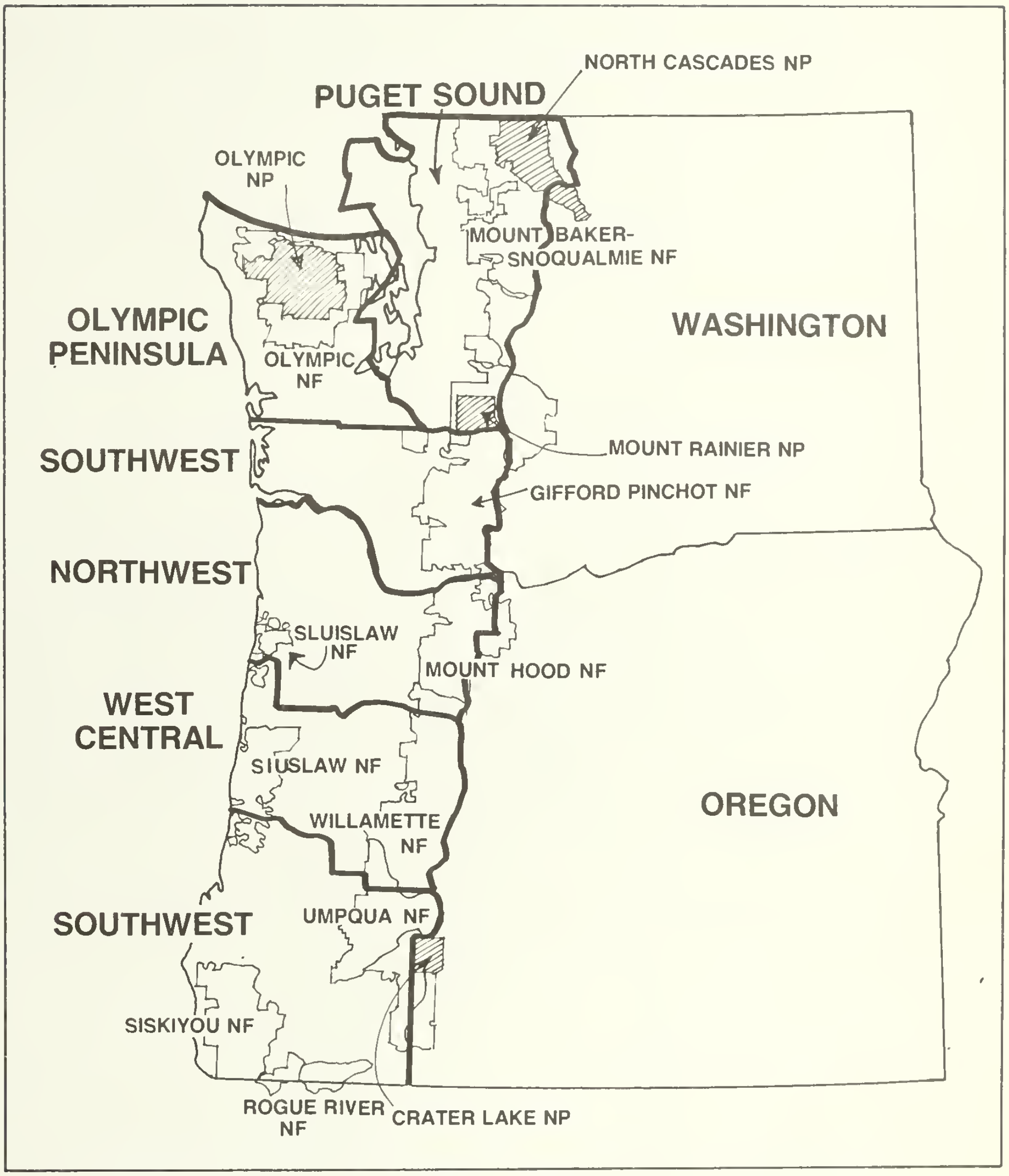

Figure 1.—Inventory units in the Douglas-fir region.

imberland Area and ubic Volume by Stand ge and Owner Group

Definitions of each subregion and the location of each west-side National Forest are shown in figure 1. Timberland area and softwood inventory volumes by stand age (in 10-year age classes) for each of the west-side National Forests and various subregional owner groups are given in tables 1 through 5. Uneven-aged stands are presented separately and are split between those less than 100 years old and those over 100 years. The data for other public owners in the State of Washington include small amounts of timberland administered by the BLM. The data for Oregon, however, recognizes timberlands administered by the BLM as a separate ownership.

Table 1—Timberland area and volume for National Forests in western Washington, by stand age

	Mount Baker-Snoqualmie		Olympic		Gifford Pinchot	
Stand age	Acres	Volume	Acres	Volume	Acres	Volume
Years	Thousand	Million cubic feet	Thousand	Million cubic feet	Thousand	Million cubic feet
5	17	7	48	3	95	22
15	25	5	25	5	27	14
25	16	10	22	30	11	9
35	17	24	3	5	23	49
45	42	108	37	94	40	140
55	31	64	1	4	51	210
65	42	117	20	82	40	196
75	23	100	4	18	25	146
85	33	156	9	45	15	122
95	23	151	2	15	17	111
105	30	193	10	66	27	202
115	18	112	2	17	15	108
125	26	161	6	40	15	142
135	4	33			15	142
145	55	334	17	152	17	155
155	11	68			6	58
165	4	48			4	24
175	6	49	21	210	13	143
185	64	454			8	94
195	4	27			2	13
250	242	1,962	42	427	78	737
300+	191	1,934	163	1,980	154	1,679
Uneven-aged:						
Under 100	23	68			101	455
Over 100	162	1,143	83	695	223	1,890
Nonstocked	15		21		63	

Table 2—Timberland area and volume for National Forests in western Oregon, by stand age

Stand age	Mount Hood		Willamette		Siuslaw		Umpqua		Rogue River		Siskiyou	
	Acres	Volume	Acres	Volume	Acres	Volume	Acres	Volume	Acres	Volume	Acres	Volume
Years	Thousands	Million cubic feet	Thousands	Million cubic feet	Thousands	Million cubic feet	Thousands	Million cubic feet	Thousands	Million cubic feet	Thousands	Million cubic feet
5	11	11	4	13	26	0	56	7	45	--	43	16
15	17	34	7	11	7	0	14	4	2	--	22	22
25	20	37	4	6	23	61	13	11	8	3	17	22
35	18	49	9	24	6	18	7	17	25	3	15	23
45	28	78	18	58	41	189	9	22	22	8	24	56
55	37	166	24	92	23	100	4	15	25	34	28	57
65	37	159	38	228	75	458	18	90	1	1	17	43
75	31	190	44	284	31	212	18	92	22	20	20	81
85	11	59	36	228	73	673	9	59	5	15	7	30
95	18	154	27	218	19	207	5	31	23	32	11	49
105	2	18	34	276	77	886	18	100	13	35	4	15
115	7	65	38	332	6	47	7	50	17	71	2	9
125	2	9	11	95	8	80	9	48	24	67	2	21
135	4	25	11	108		--	4	34	48	66		--
145	4	33	29	289		--	4	31	30	143	4	23
155	4	30	20	166	3	30	4	19	16	48	2	16
165	5	48	11	82	2	23	4	5	11	49	4	28
175	4	43	5	69	1	6	5	43	13	100	4	11
185	5	66	13	116	5	44	4	35	5	19	2	7
195		--	7	63		--	7	70	63	462	7	42
250	179	1,939	104	1,066	5	52	79	744	19	218	102	661
300+	39	482	234	2,664	5	98	140	1,470	31	226	69	607
Uneven-aged:												
Under 100	41	217	107	590	3	5	95	397			130	390
Over 100	96	777	218	1,790	77	720	304	2,306	577	3,390	190	997
Nonstocked			5		19		38				19	

-- = Less than 1 million cubic feet.

Table 3—Timberland area and volume for other public owners,[1] by inventory unit and stand age

Stand age	Puget Sound		Olympic Peninsula		Southwest Washington		Northwest Oregon		West-central Oregon		Southwest Oregon	
	Acres	Volume	Acres	Volume	Acres	Volume	Acres	Volume	Acres	Volume	Acres	Volume
Years	Thousands	Million cubic feet	Thousands	Million cubic feet	Thousands	Million cubic feet	Thousands	Million cubic feet	Thousands	Million cubic feet	Thousands	Million cubic feet
5	81	7	80	1	53	10	108	10			17	1
15	37	18	86	97	42	46	97	71			13	--
25	42	47	76	71	69	122	128	166			12	14
35	103	240	184	285	87	229	82	173	27	60		
45	99	387	127	554	64	331	50	209	9	40	18	79
55	119	831	101	761	5	37	8	29	28	97	15	18
65	27	94	44	527	6	43			9	3	25	11
75	13	104	13	94	19	130	11	115	3	27	19	191
85	5	38					13	174	18	102	2	5
95											10	47
105					19	186						
115	3	48			19	231						
125	10	97							3	56		
135					6	103			3	26		
145												
155												
165			7	84								
175												
185												
195												
250			39	42							1	8
300+	5	25									2	10
Uneven-aged:												
Under 100	22	122	48	226	19	105	49	87			23	70
Over 100	60	435	44	482			17	164	9	87	4	59
Nonstocked			19	1								

[1] Excluding BLM lands in western Oregon.

-- = Less than 1 million cubic feet.

Table 4—Timberland area and volume for forest industry owners, by inventory unit and stand age

Stand age	Puget Sound		Olympic Peninsula		Southwest Washington		Northwest Oregon		West-central Oregon		Southwest Oregon	
	Acres	Volume	Acres	Volume	Acres	Volume	Acres	Volume	Acres	Volume	Acres	Volume
Years	Thousands	Million cubic feet	Thousands	Million cubic feet	Thousands	Million cubic feet	Thousands	Million cubic feet	Thousands	Million cubic feet	Thousands	Million cubic feet
5	203	37	184	31	348	24	204	55	248	105	279	16
15	92	39	81	50	184	111	72	19	174	104	185	55
25	100	176	144	200	201	266	155	260	172	354	156	172
35	133	323	194	588	263	873	254	892	106	337	69	186
45	132	572	191	742	118	516	165	652	67	215	19	19
55	114	602	130	1,040	123	705	39	180			46	275
65	13	78	78	547	16	78	44	225	32	166	24	85
75	14	113	71	661	9	123	32	229				
85	8	17	9	117	16	198			16	165	44	82
95	17	33	8	121	14	128	13	130	6	38	10	64
105	17	101			9	149			20	199		
115			9	102	9	56			11	163		
125	6	61	7	100	16	203						
135												
145					5	49						
155												
165												
175												
185												
195	8	73										
250	28	242			5	15			31	260	135	1147
300+	21	172			24	306			33	365	94	668
Uneven-aged:												
Under 100	49	236	66	480	77	411	46	54	86	148	273	670
Over 100	36	210	23	217	12	85			18	82	92	402
Nonstocked	6	--	21	--	45	--						

-- = Less than 1 million cubic feet.

Table 5—Area and volume for other private owners, by inventory unit and stand age

Stand age	Puget Sound		Olympic Peninsula		Southwest Washington		Northwest Oregon		West-central Oregon		Southwest Oregon	
	Acres	Volume	Acres	Volume	Acres	Volume	Acres	Volume	Acres	Volume	Acres	Volume
Years	Thousands	Million cubic feet	Thousands	Million cubic feet	Thousands	Million cubic feet	Thousands	Million cubic feet	Thousands	Million cubic feet	Thousands	Million cubic feet
5	51	12	104	36	75	11	48	18	70	34	50	25
15	42	41	48	19	80	63	47	22	39	15	94	27
25	100	100	22	1	76	80	122	158	134	189	114	105
35	133	193	76	126	68	108	84	158	64	121	78	108
45	173	410	86	155	98	390	87	273	66	145	35	120
55	137	410	74	249	52	157	54	164	44	141	31	31
65	66	310	39	172	34	162	22	52	27	33	20	31
75	42	236	12	55	37	83	15	34	5	20	5	6
85	23	144	19	130			6	68	11	69	12	40
95	8	29									34	40
105	16	102									31	117
115									5	15		
125									9	27		
135												
145												
155												
165												
175												
185												
195												
250												
300+									12	207	7	93
Uneven-aged:												
Under 100	139	334	50	170	39	92	148	340	105	203	190	289
Over 100	17	77	14	72	30	279	4	26			31	77
Nonstocked	54	5	37	20	61	15						

Growth and Mortality Information

Old-growth stands have frequently been called decadent. The implication is that these stands are slowly deteriorating while still containing a large component of salvable as well as nonsalvable trees. The inventory information for ownerships other than Forest Service (this information is not available for Forest Service lands) contains information on growth and mortality by stand age that demonstrates little factual basis for this supposition. Summaries of this information are shown in table 6. In all cases, net growth of older age classes is positive. The growth volumes in table 6 are for gross growth.

Table 6—Growth and mortality for all private ownerships, by State and stand age

Stand age	Western Washington		Western Oregon	
	Growth	Mortality	Growth	Mortality
Years	- - - - - - Million cubic feet - - - - -			
5	8	--	7	2
15	66	2	28	1
25	117	3	120	2
35	206	8	127	3
45	200	10	77	3
55	166	11	28	3
65	56	4	13	4
75	37	3	12	1
85	12	1	7	4
95	5	1	1	5
105	8	1	4	--
115	5	1	1	1
125	5	1	1	--
135	1	--	--	--
145	--	--		
155				
165	1	--		
175				
185				
195	--	--		
250	4	1		
300+	1	1	8	4
Uneven-aged:				
Under 100	66	5	1	8
Over 100	21	4	53	7
Nonstocked	1	--		

-- = Less than 1 million cubic feet.

Other Public Inventory Information

There are several other sources for estimates of old-growth volumes in National Forests and on other public lands. The first is a compilation of Pacific Northwest west-side National Forest lands containing old-growth habitat. This compilation is shown in table 7 and was part of a talk given by the Regional Forester at a conference on old-growth forests (Sirmon 1982). In general this old-growth habitat was timberlands with timber 250 years old or older that have been relatively undisturbed (less than 10-percent entry). The data were taken from inventory statistics collected by Timber Management, Pacific Northwest Region. More complete than this definition of old growth is the one used by the Region that includes stands of 10 acres or more generally containing the following characteristics:

1. Mature and overmature trees in the overstory.
2. Multilayered canopy and trees of several age classes.
3. Standing dead trees and down material are present.
4. Evidence of human activities may be present but such activities have not significantly altered the other characteristics and would be subordinate factors in a description of a stand.

Table 7—Acreage of National Forests and of old-growth habitat, by Forest

National Forest	Old-growth habitat[1]	Total forest	Old-growth as a percentage of total
	- - Thousand	acres - -	Percent
Mount Baker-Snoqualmie	643	1,716	37.5
Olympic	152	651	23.3
Gifford Pinchot	431	1,331	32.4
Mount Hood	259	1,060	24.4
Willamette	385	1,667	23.1
Siuslaw	24	625	3.8
Umpqua	207	988	20.9
Rogue River	71	638	11.1
Siskiyou	230	1,093	21.0

[1]Stands of at least 10 acres, older than 250 years, with less than 10 percent entry.

Inventory information was provided by the three largest other public agencies[1] (table 8). The information gives only acres by age class and supplements the material given in table 3 except the figures given there for western Oregon do not include BLM timberlands. An exact reconciliation of the information in tables 3 and 8 should not be attempted. The data for these tables came from different inventories conducted at different times and with different standards. For owners other than the BLM, the information in table 3 should be considered more definitive as the same inventory standards and definitions were applied to the lands managed by each agency.

[1] DNR (Washington Department of Natural Resources), BLM, and The Oregon Department of Forestry.

Table 8—Acreage administered by the BLM, Washington DNR, and Oregon Department of Forestry, by age class

BLM		Washington DNR		Oregon Department of Forestry	
Age class	Acres	Age class	Acres	Age class	Acres
Years	Thousands	Years	Thousands	Years	Thousands
Nonstocked	76				
1-5	111	0	251	1-5	3
10	171	10	81	10	156
20	142	20	69	20	130
30	120	30	84	30	129
40	94	40	130	40	120
50	51	50	164	50	75
60	51	60	96	60	20
70	51	70	43	70	17
80	73	80	32	80	31
90	75	90	17	90	20
100	67	100-150	43	100	12
110	66			110	3
120	70			120-150	11
130-150	108				
160-200	132	160+	90	160+	3
210-250	128				
250-300	196				
310+	109				

National Park Service

The National Park Service estimated that there are approximately 660,000 acres of old growth in the national parks in the Douglas-fir region.[2/] These are stands in excess of 200 years with a relatively heavy accumulation of downed logs on the forest floor. This figure does not include North Cascades National Park where vegetation mapping is just starting.

Value of Old Growth

The other issue besides the inventory statistics is the supposition that old-growth timber is inherently more valuable than smaller or second-growth timber. The empirical evidence that supports this position has been scanty because reported Forest Service stumpage prices are volume-weighted averages of all species and sizes. The Washington DNR (Department of Natural Resources), however, has compiled their stumpage price data for second- and old-growth timber. This data for western hemlock/white fir (*Tsuga heterophylla* (Raf.) Sarg./*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.) and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco.)

[2/] Personal letter, June 13, 1983, from Jim Larson, NPS, Seattle, Washington.

Table 9—Stumpage prices for second growth[1] and old-growth[2] western hemlock/white fir and Douglas-fir, by calendar year

Calendar year	Western hemlock/white fir		Douglas-fir	
	Second growth	Old growth	Second growth	Old growth
	$/MBF, Scribner scale			
1970	$ 33.68	$ 48.18	$ 36.60	$ 86.06
1971	21.63	42.99	45.78	75.17
1972	14.09	76.64	54.13	110.41
1973	112.39	213.14	188.38	249.17
1974	108.48	208.22	163.56	253.11
1975	83.10	134.14	139.72	199.58
1976	93.00	169.15	126.76	212.32
1977	104.79	155.47	152.24	224.04
1978	130.39	189.89	152.79	297.23
1979	152.43	324.28	261.81	475.13
1980	282.19	315.69	295.63	482.31
1981	136.53	208.94	262.92	258.78
1982	108.39	144.52	160.70	228.00
1983	77.76	86.33	151.22	134.55
1984	65.64	76.68	133.39	207.64

[1]Second growth = timber aged 0 to 99 years.

[2]Old growth = timber aged 160 years or older.

Source: Unpublished data on file at the Washington Department of National Resources, Olympia, Washington.

are shown in table 9. Statistically the differences between second growth and old growth are significant[3] for both species groups; that is, old-growth stumpage is more valuable than second-growth stumpage. In 1984 dollars, the average differences were $98 for western hemlock/white fir and $125 for Douglas-fir. The trend in the differences between old growth and second growth has been flat, however, during the past two decades; that is, old growth has not become progressively more valuable than second growth.

[3]Significance was tested at the 5-percent level using an unpaired t-test for comparison of means. The price data was first deflated using the wholesale price index (1967=100).

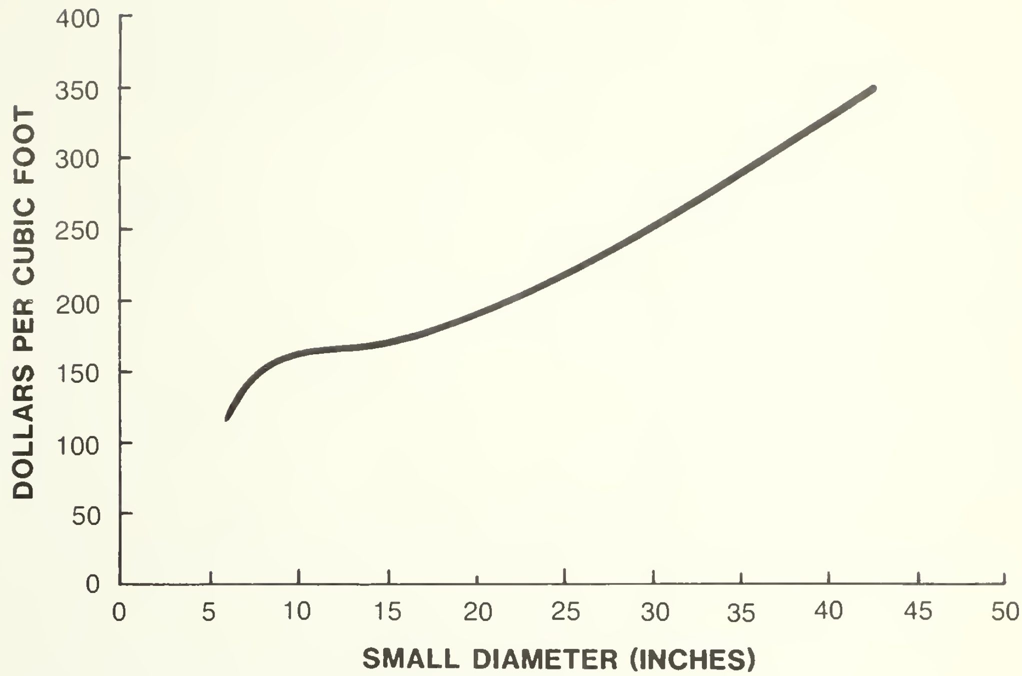

Figure 2.—Value of lumber recovery by log diameter.

Another way to judge value is product recovery. Although it is difficult to judge whether old growth has an inherently higher stumpage value, the relationship between log diameter and cubic recovery is well documented (Snellgrove and others 1985). These relationships expressed on a dollar-per-cubic-foot basis are shown in figures 2 and 3 for lumber and veneer, respectively. The curve for lumber reflects a combination of data from cutting and dimension mills. The curve rises fastest for small diameters as the basic problem of cutting square or rectangular boards from round logs becomes less of a factor, then continues to rise at decreasing rates as higher grade lumber is recovered from larger logs.

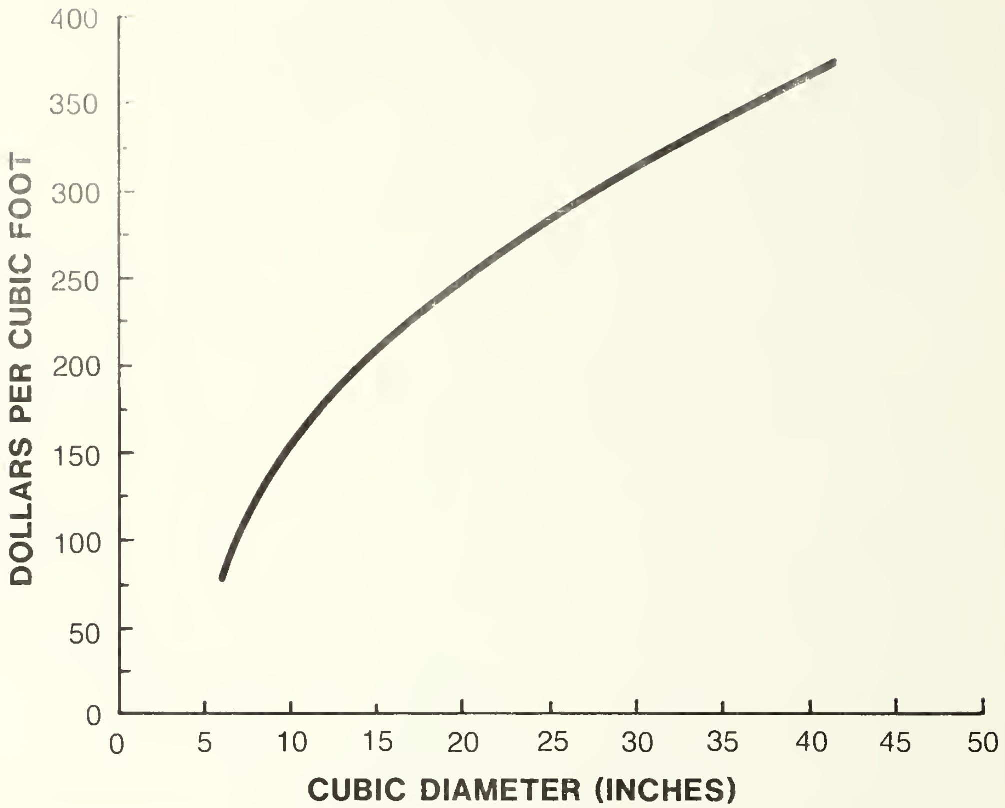

Figure 3.—Value of plywood recovery by log diameter.

Figures 2 and 3 show that the dollar recovery from logs varies directly with log diameter. The inference then is that larger logs having a higher value should have higher stumpage prices. The two figures are not directly comparable though, as different prices were used for each product and production costs were ignored.

Discussion

The available inventory information is at best only suggestive of the volumes and areas of old growth left in the Douglas-fir region. The information available from tables 1-5 and table 8 is summarized as follows:

Age class	Forest Service	Other public			Forest industry	Other private	Total
		NPS	BLM	Other			
	(Million acres)						
100+	4,861	660	876	251	769	169	7,586
160+	2,189	660	565	54	379	19	3,866
250+	1,876	660	305	47	371	19	3,278

Each line in the tabulation contains all acres that fall into that and all older age classes. The data were summarized for these three age classes because 100+ represents roughly the culmination of mean annual increment in the Douglas-fir region, 160+ is the Washington DNR definition of old growth, and 250+ is the Forest Service definition of old growth.

These estimates suggest that in the Douglas-fir region there are 3.3 million acres meeting the Forest Service age definition and probably another 0.6 million acres that are potential candidates for old-growth status in the next several decades. The data for the 100+ category include 2.3 million acres that are uneven-aged stands over 100 years old. There probably is an indeterminate amount of these stands that also meets either the Washington DNR or Forest Service definition of old growth. Nevertheless, the estimates of total old growth suggest that at the time of the inventories roughly 30 percent of the timberlands in the Douglas-fir region contain essentially mature (in excess of culmination of mean annual increment) timber.

The numbers are deceptive. First there is a necessary caution that age of existing stands (ignoring problems of measurement) is by itself a poor measure of old growth. Another caution is that the inventory data do not address the necessary stand characteristics that are integral parts of any old-growth definition. They do not, for example, include data on stand structure and composition. A third caution is the age of the inventory statistics—particularly those from the Forest Service. Most of these inventories are at least 10 years old and cutting activity during that time has probably taken place disproportionally in older stands.

The value information demonstrates, in part, the scarcity of old growth. In an economic sense, higher prices for old-growth stumpage represent a higher payment for both a relatively scarce resource and the potential for greater product recovery. These higher prices are also consistent with the perception that the volumes of old growth are declining. Lastly, high value provides some justification for retaining and managing older stands.

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Metric Equivalents

1 inch = 2.54 centimeters
1 foot = 0.3048 meter
1 cubic foot = 0.03 cubic meters
1 acre = 2.47 hectares

Appendix 1

Terminology

Age class—A classification of stands for trees based on the midpoint of 10-year intervals.

Diameter class—A classification of trees based on diameter outside the bark measured at breast height, 4-1/2 feet (1.37 m) above the ground. D.b.h. is the common abbreviation for "diameter at breast height."

Dominant trees—Live trees with crowns extending above the general level of the crown canopy and receiving full light from above and partly from the side; larger than the average trees in the stand and with crowns dense, comparatively wide and long, but somewhat crowded on the sides.

Forest industry lands—Lands owned by companies or individuals operating wood-using plants.

Forest land—Land at least 10 percent stocked by live trees or land formerly having such tree cover and not currently developed for nonforest use.

Growing stock trees—All live trees with the exception of cull trees.

Growing stock volume—Net volume in cubic feet of live sawtimber and poletimber growing stock trees from stump to a minimum 4-inch (10-cm) top (of central stem) outside the bark. Net volume equals gross volume less deduction for rot and missing bole sections. Growing stock trees are subdivided into poletimber and sawtimber trees.

Land area—Area reported as land by the Bureau of the Census. Total land area includes dry land and land temporarily or partially covered by water, such as marshes, swamps, and river flood plains; streams, sloughs, and canals less than one-eighth mile (200 m) wide; and lakes, reservoirs, and ponds less than 40 acres (16 ha) in area.

Mean annual increment—A measure of the productivity of forest land in terms of the average increase in cubic-foot volume per acre per year. For a given species and site index the average is based on the number of years needed for the mean annual increment to culminate in fully stocked stands.

Mortality—Volume of sound wood in trees dying from natural causes during a specified period.

National Forest lands—Federal lands that have been designated by Executive order or statute as National Forest or purchase units and other lands under the administration of the Forest Service, including experimental areas and Bankhead-Jones Title III lands.

Net annual growth—The net increase in volume of trees during a specified year. Components of net annual growth of trees: (a) the increment in net volume of trees alive at the beginning of the specified year and surviving to the year's end, plus (b) the net volume of trees reaching sawtimber or poletimber size during the year, minus (c) the net volume of trees that died during the year.

Nonstocked areas—Timberland less than 10 percent stocked with growing stock trees.

Other private lands—All privately owned lands except those classed as forest industry lands.

Other public lands—Lands administered by public agencies other than the Forest Service.

Poletimber stands—Stands with a mean diameter (weighted by basal area) from 5.0 to 9.0 inches (12.5 to 22.5 cm) if softwood and from 5.0 to 11.0 inches (12.5 to 27.5 cm) if hardwood.

Poletimber trees—Live trees of commercial species at least 5.0 inches (12.5 cm) in d.b.h. but smaller than sawtimber size, and of good form and vigor.

Roundwood—Logs, bolts, or other round sections cut from trees.

Salvable dead trees—Standing or down trees of commercial species, at least 9.0 inches (22.5 cm) in d.b.h. for softwoods and at least 11.0 inches (27.5 cm) in d.b.h. for hardwoods, containing 25 percent or more sound wood volume and at least one merchantable 12-foot (3.8-m) log if softwood or one merchantable 8-foot (2.5-m) log if hardwood.

Sapling and seedling stands—Stands with a mean diameter (weighted by basal area) less than 5.0 inches (12.5 cm).

Timber harvest—Volume of roundwood removed from forest land for products.

Timber volume—Includes the net volume in cubic feet of poletimber and sawtimber trees and salvable dead sawtimber trees of all species, the net volume in cubic feet of cull trees of commercial species, and gross volume of noncommercial species. Volume is measured from stump to a minimum 4-inch (10-cm) top outside the bark.

Timberland—Forest land capable of producing 20 cubic feet or more per acre (1.4 m^3/ha) per year, and not withdrawn from timber utilization.

Uneven aged—Stands in which less than 70 percent of the growing stock volumes are in three adjoining age classes.

Uneven aged over 100—An unevenaged stand where the main stand is over 100 years of age.

Uneven aged under 100—An unevenaged stand where the main stand is under 100 years of age.

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Research Note PNW-438

April 1986

Effect of Jellyrolling and Acclimatization on Survival and Height Growth of Conifer Seedlings

W. Lopushinsky

Abstract

Field tests with control (C), root-dipped (D), jellyrolled (J), and jellyrolled and acclimatized (J + A) bare-root seedlings were conducted at 14 sites in Oregon and Washington in 1984. Nine tests were conducted with ponderosa pine, four with Douglas-fir, and one with lodgepole pine. A separate test with ponderosa pine and Douglas-fir was conducted in Washington in 1983.

In the 1984 test, average values of survival for ponderosa pine for the C, D, J, and J + A treatments were 82, 86, 85, and 87 percent, respectively. The increases in height were 16, 18, 17, and 15 percent, respectively. Survival of the J + A seedlings was significantly higher than that of C seedlings, but other differences among treatments for survival or growth were not significant. For Douglas-fir, average values of survival for the C, D, J and J + A treatments were 77, 72, 74, and 70 percent, respectively; height growth was 18, 19, 17, and 18 percent, respectively, with no significant differences. Survival of lodgepole pine was 99 percent for all treatments, and height growth ranged from 28 to 34 percent.

In the 1983 test in Washington, survival of ponderosa pine ranged from 70 percent for C seedlings to 80 percent for J + A seedlings, but results were not consistent among the three sites and therefore not conclusive. Height growth in pine ranged from 34 (J) to 41 (D) percent. Survival of fir seedlings ranged from 97 to 100 percent, and growth from 21 to 23 percent.

Seedling moisture stresses prior to planting were significantly higher in J + A fir and pine seedlings than in C, D, or J seedlings in two cases, and higher than D or J seedlings in another. Control seedlings developed significantly higher moisture stresses in a planting bag than did D, J, or J + A seedlings that developed similar stresses. Collectively, the results indicated that there is no advantage in survival, height growth, or moisture stress from jellyrolling or acclimatizing seedlings as compared to root dipping the seedlings.

Keywords: Seedling survival, increments (height), seedling growth, bare root nursery stock.

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Introduction

Exposure of roots of bareroot conifer seedlings to drying conditions during planting decreases survival (Feret and others 1985; Hermann 1962, 1967), and regeneration guides recommend that exposure of roots be kept to a minimum (Cleary and others 1978, Dahlgreen 1976). Attempts to minimize root desiccation have included dipping roots in water (Mullin 1971), in sodium alginate solutions (Owston and Stein 1972), in vermiculite slurries,[1] and in clay slurries (Dierauf and Marler 1969, Owston and Stein 1972). More recently, jellyrolling has been recommended (Dahlgreen 1976). Jellyrolling is a preplanting treatment that involves dipping roots of seedlings in a vermiculite-water slurry and wrapping the roots in wet burlap to form a roll. Usually the seedlings are wrapped 50 to a bundle 1 or 2 days prior to outplanting. With increased emphasis on obtaining better survival and growth in planted seedlings, jellyrolling is increasingly common in the Pacific Northwest. The technique is described in a recent publication on regeneration (Lotan and Perry 1983) and in USDA Forest Service planting specifications. A recent Extension Service bulletin (Cleary and DeYoe 1982) suggests that jellyrolling is a good option when seedlings are planted in extremely hot and dry conditions. One large forest nursery offers jellyrolling as a service at the nursery prior to shipping seedlings.

Dahlgreen (1976) proposed that seedlings be both jellyrolled and acclimatized. The objective of jellyrolling is to keep seedlings wet during handling and planting, and to minimize damage to roots caused by handling during planting. An additional benefit is that flecks of vermiculite adhering to roots aid in distinguishing seedling roots from other woody roots when root orientation is checked during planting operations. Some foresters feel that the whole jellyrolling procedure results in more careful handling and planting of seedlings. Acclimatization involves keeping jellyrolled seedlings in a shelter, such as a tent or shed, for 24 to 48 hours to allow temperature adjustment to the field environment.

Currently, foresters jellyroll seedlings in one of two ways. In some cases, seedlings are jellyrolled and then kept in cold storage until they are planted 1 or 2 days later. In other cases, after jellyrolling, seedlings are acclimatized for 1 or 2 days in a tent or shed located in the field or near the seedling storage facility.

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[1] Unpublished report, 1975, "Preplanting Root Dip," by R.A. Ryker, on file at U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, 324-25th Street, Ogden, UT 84401.

Few data are available on the effects of jellyrolling or acclimatization on survival or growth of conifer seedlings. I know of only two field tests. One involved plantings of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) and lodgepole pine (*Pinus contorta* Dougl. ex Loud.) seedlings in eastern Oregon. Jellyrolling did not increase survival, but did increase height growth of ponderosa pine by 15 percent.[2/] The other study—done in Idaho and involving nearly 110,000 seedlings—consisted of four field trials with Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and one with ponderosa pine.[3/] The test included jellyrolling and root dipping in water. None of the treatments increased survival or growth significantly; however, conditions were cool and moist during planting and this may not have provided appropriate conditions for testing the technique.

Even less is known about effects of acclimatization. Changes in physiological functioning of seedlings following removal from cold storage have not been extensively studied, so there is little physiological basis on which to judge the value of acclimatization. In an administrative study conducted in the Boise National Forest in Idaho in 1979[4/] there was little difference in first-year survival or growth of ponderosa pine seedlings acclimatized for 1 to 5 days, but survival and growth decreased drastically after a 10-day treatment.

Dipping roots of bareroot seedlings in a peat moss-water mixture at the planting site just prior to planting to keep roots wet is common during many planting operations. In a review of factors affecting performance of planted seedlings, Chavasse (1980) states that moistening roots of coniferous stock before planting improves survival and growth. Also, Mullin (1971) found dipping roots in water to be beneficial, but in that study seedlings were root-dipped immediately after lifting in the nursery. In a recent study with jack pine (*Pinus banksiana* Lamb.) seedlings in Michigan (Belli and Dickman 1985), seedlings were sprayed with water, sealed in plastic-lined bags, and stored for 39 hours at 4.5 °C. The roots of both sprayed and unsprayed (control) seedlings then were soaked for 30 minutes in tapwater immediately before planting. Neither the spray nor soak treatment had any significant effect on seedling water stress following planting or on the root-to-shoot ratio of the seedlings after one growing season.

Despite limited information on effects of the treatment, jellyrolling is being practiced by many foresters. The objective of the present study was to determine the effects of jellyrolling and acclimatization on first-year survival and height growth of ponderosa pine and Douglas-fir seedlings planted on a wide variety of sites in eastern Oregon and Washington. It is hoped this information will aid foresters in evaluating techniques to increase survival and growth of bare-root conifer planting stock.

[2/] Unpublished report, 1982, "Seedling Handling Technique Improves Growth of 3/0 Ponderosa Pine," by J.L. Dunbar, on file at U.S. Department of Agriculture, Forest Service, Pacific Northwest Region, P.O. Box 3623, Portland, OR 97208.

[3/] Research study 232/19, 1979, "Bare-Root Seedling Handling and Planting Practices," by D.L. Miller, Potlatch Corporation, Lewiston, ID 83501.

[4/] Personal communication, W.R. Terrill, P.O. Box 466, Tonasket, WA 98855.

Methods

1984 Tests

Field tests were conducted at eleven sites in Oregon and three in Washington in 1984, and at one site in Washington in 1983 (fig. 1). During 1984, nine tests were conducted with ponderosa pine, four with Douglas-fir, and one with lodgepole pine for a total of 11,200 seedlings. All tests were conducted with 2-year-old, bare-root, nursery-grown seedlings. All but one of the tests were conducted on clearcut harvested areas; the tests covered a wide range of site conditions (table 1). Elevations ranged from 1250 to 2020 m, and slopes from 0 to 55 percent. Several aspects were represented, but most units faced south or east. Average annual precipitation ranged from 15 to 177 cm, and mean annual temperature from 2.8 to 16.7 °C. Eleven of the units were harvested from 1980 to 1983, one unit was cut in 1972 and another in the 1930's, and one was an old burn. On most units, residue was broadcast burned or piled and burned. Soil depths ranged up to 208 cm, and water-holding capacity was considered good.

Figure 1.—Location of National Forest Ranger Districts in Washington and Oregon where control and treated ponderosa pine, Douglas-fir, and lodgepole pine seedlings were planted in spring 1984. The Chelan site was planted in May 1983.

Table 1—Planting site characteristics and environmental conditions at time of planting test sites, 1984

										Conditions during planting			
National Forest and Ranger District	Elevation	Slope	Aspect	Annual precipitation	Mean annual temperature	Date of harvest	Residue treatment, site preparation[1]	Planting method	Soil depth	Air temperature	Relative humidity	Soil water tension	Soil temperature
	meters	percent		cm	°C				cm	°C	percent	bars	°C
Colville:													
Colville	1460	25-30	E	64	7.8	1983	P	Auger	30	10.5	47	—	5.5
Wenatchee:													
Naches	1280	25	NE	177	5.6	1983	BB	Hoe	30-90	20.7	42	0.20	7.8
Entiat	1250	20	S-SW	35	9.4	1982	BB	Hoe	180	11.6	82	.13	8.0
Malheur:													
Long Creek	1620	55	NW	63	5.2	1980	BB	Auger	41	12.5	54	.10	10.0
Deschutes:													
Bend	1370	0-3	E	49	7.7	1981	PB	Auger	60-90	6.6	50	—	10.0
Fort Rock	1420	0	Flat	38	7.6	1930's	*	Machine	90 +	14.4	42	—	10.6
Sisters	1250	0-5	SE	76	12.8	1982	PB	Auger	5-208	6.1	93	.10	10.0
Winema:													
Chemult	1475	0-20	SW	63	8.9	1981	MPB	Shovel	50-150	12.8	35	.48	5.6
Chiloquin	1340	5-10	W	33	16.7	Old burn	D	Auger	50-100	12.2	77	.18	12.8
Klamath	1540	0-5	W	63	8.3	1981	MPB	Hoe	30	3.9	60	.00	4.4
Fremont:													
Lakeview	2020	10	N-NW	37	7.8	1981	BB	Hoe	63-122	10.0	72	.00	10.0
Silver Lake	1900	32	S	38	2.8	1980	PB	Auger	50-100	11.6	68	.10	8.7
Umpqua:													
Diamond Lake	1430	40	E-SE	152	7.8	1972	CS	Hoe	60-240	18.0	54	.10	13.3
Siskiyou:													
Illinois Valley	1280	25	SE	154	11.9	1982	BB	Hoe	Up to 91	11.1	41	.20	7.2

* = no residue treatment, Whitfield "V" blade used to make furrows 91 cm wide; – indicates no measurement made.

[1] Treatments include pile (P), pile and burn (PB), broadcast burn (BB), chemical spray (CS), machine pile and burn (MPB), and disked (D).

After seedlings were obtained from the nursery, they were kept in cold storage at 1 to 2 °C for periods ranging from 2 to 21 weeks prior to the tests. Seedlings within a given test were graded to obtain uniform top size and root mass. For all tests, top height of ponderosa pine seedlings ranged from 16.3 to 22.7 cm, stem diameter from 5.4 to 6.3 mm, seedling fresh weight from 20.3 to 27.8 gm, and shoot-to-root ratio (ovendry weight) from 1.8 to 2.7. Comparable values for Douglas-fir were 18.9 to 34.7 cm, 4.4 to 6.5 mm, 13.0 to 27.3 gm, and 1.2 to 2.0. Seedlings were divided into four groups by treatment. Seedlings designated as controls (C) did not receive additional moistening. Roots of seedlings designated as dipped (D) were immersed for several seconds in a peat moss-water slurry at the planting site before being planted. Seedlings designated as jellyrolled (J) were root-pruned to 30.5 cm. Roots were then dipped in a thick vermiculite-water slurry and were wrapped in wet burlap in bundles of 25 seedlings each. Seedlings were jellyrolled 1 day before planting and were kept in cold storage at 1 to 2 °C. Seedlings designated as jellyrolled and acclimatized (J + A) were jellyrolled 1 day before planting and then were placed in a tent or shed at ambient temperature for about 24 hours. For the Entiat site (see fig. 1), seedlings were acclimatized in a growth chamber at 10 °C, 90 percent RH (relative humidity), and a light intensity during a 16-hour light period of about 3.5 W/m^2 (300 fc).

Seedlings were planted by USDA Forest Service crews from March to June 1984. During planting, crews were rotated systematically among treatments to reduce bias. At each test site, seedlings were planted in eight plots, each containing 100 seedlings, for a total of 800 seedlings. Each plot consisted of four rows of seedlings, each row of 25 seedlings representing one treatment, with rows randomized within plots. Most seedlings were planted with a tree planting hoe or auger. Air temperature during planting ranged from 3.9 to 20.7 °C, soil temperature (20.3 cm depth) from 5.5 to 13.3 °C, and relative humidity from 35 to 93 percent (table 1). Soil water tensions ranged from 0 to 0.48 bar, but most values were 0.20 bar or less. Estimated wind speeds ranged from 0 to 32 km/h, and cloud cover from clear to overcast. At the Entiat site, seedlings were planted during intermittent showers. After planting, heights of seedlings were measured. In autumn, survival was tallied and heights were remeasured.

1983 Test

In a separate test, 1,200 2-0 bare-root seedlings each of ponderosa pine and Douglas-fir were planted on three sites in the Chelan Ranger District (Wenatchee National Forest) in north-central Washington in May 1983 (fig. 1.) Elevation of the sites is 1300 m, average annual precipitation is 80 cm per year, and mean annual temperature is 6 °C; aspects were east, south, and west. Slope ranged from 20 to 70 percent. Burned by a severe forest fire in 1970, the area contained few trees, despite earlier attempts at reforestation.

Average top height for graded pines was 17.2 cm, stem diameter 5.8 mm, fresh weight 20.2 gm, and shoot-to-root ratio 2.9. Values for fir were 19.0 cm, 4.9 mm, 12.0 gm, and 1.3. Treatments were identical to those in the 1984 test except that the seedlings were acclimatized for 48 hours in a tent (temperature 8.5 to 20.0 °C; relative humidity 45 to 98 percent) near the planting site.

Four plots each of fir and pine were planted on each of the three sites, with treatments in rows as before. Seedlings were planted with a hoe-type tool. Temperature during planting ranged from 16.5 to 24.5 °C, and relative humidity from 24 to 37 percent; it was clear and sunny. Soil moisture tension ranged from 0.08 to 0.47 bar.

Seedling Moisture Stress

During planting at the Chelan site, moisture stress of 10 seedlings from each treatment was determined with a pressure chamber (Waring and Cleary 1967) to characterize moisture stresses of seedlings delivered to the planting site. Moisture stress was similarly determined for fir seedlings at the Entiat site in 1984.

The main benefit of jellyrolling is thought to be prevention of desiccation of seedlings during handling and while they are being carried in planting bags. To test this, control, dipped, and jellyrolled seedlings were placed in planting bags with the tops of the seedlings exposed; the bags were placed outdoors on a warm sunny day. Temperature ranged from 27.0 to 32.5 °C and relative humidity from 18 to 32 percent, which created a considerably higher evaporative demand than would normally be encountered during planting. The moisture stress experiment was a completely randomized design. Moisture stress of whole shoots was determined immediately prior to exposure to obtain initial stress values, and twice again during an exposure period of approximately 2½ hours. Twelve seedlings from each treatment were measured each time. Root systems of the pine seedlings appeared visibly drier than those of the fir seedlings and, indeed, initial moisture stresses for control and dipped pine seedlings were somewhat higher than those for the fir.

The planting experiments were designed as randomized complete block designs with each site used as a block. Douglas-fir and ponderosa pine were separate experiments. Differences among the four treatments in survival and height growth were determined by analysis of variance and Tukey's multiple comparison procedure with $p \leq 0.05$.

Results

1984 Tests

Survival of ponderosa pine for all sites and treatments during the 1984 test ranged from 39 to 98 percent; height growth ranged from 7 to 28 percent (table 2). Average values of survival for pine for the C, D, J, and J + A treatments were 82, 86, 85, and 87 percent, respectively, and for height growth 16, 18, 17 and 15 percent, respectively. Survival of jellyrolled and acclimatized seedlings (J + A) was significantly higher ($p \leq 0.05$) than the survival of control seedlings, but no other differences among treatments for survival or growth were significant.

Survival of Douglas-fir for all sites and treatments ranged from 55 to 87 percent; height growth ranged from 14 to 22 percent. Average values of survival for the C, D, J, and J + A treatments were 77, 72, 74, and 70 percent, respectively, and for height growth 18, 19, 17, and 18 percent, respectively, with no significant differences among treatments. In the one test with lodgepole pine, survival was 99 percent for all treatments, and height growth ranged from 28 to 34 percent. Variability in survival among treatments was somewhat less in ponderosa pine, 2 to 13 percent, compared to 5 to 16 percent in the fir. Variability in height growth among treatments, on the other hand, was less in the fir, 0 to 3 percent, as compared to 2 to 12 percent for ponderosa pine.

1983 Test

In the 1983 Chelan test, survival of pine on three sites ranged from 54 to 94 percent, and height growth from 29 to 45 percent. Average values of survival in pine for the C, D, J, and J + A treatments were 70, 74, 70, and 80 percent, respectively, and height growth 38, 41, 34, and 37 percent, respectively. The high average value of survival for the J + A treatment was the result of high survival of J + A seedlings on one of the three sites. Survival of fir seedlings ranged from 97 to 100 percent; height growth ranged from 20 to 26 percent. Average survival of fir for three sites was high for all treatments, 98 to 99 percent, and values for growth ranged from 21 to 23 percent.

Table 2—First-year survival and height growth of ponderosa pine, Douglas-fir, and lodgepole pine seedlings following root dipping and jellyrolling, 1984

National Forest and Ranger District	Species	Survival[1] C	D	J	J+A	Height Growth[1] [2] C	D	J	J+A
		-Percent-							
Colville:									
Colville	PP	95	97	94	94	28	26	19	16
Wenatchee:									
Naches	PP	79	90	91	87	24	28	26	25
Malheur:									
Long Creek	PP	87	91	90	93	9	10	12	11
Deschutes:									
Bend	PP	80	87	93	88	9	17	19	15
Fort Rock	PP	90	88	92	92	17	19	18	15
Winema:									
Chemult	PP	94	96	95	95	24	21	22	22
Chiloquin	PP	75	80	74	83	16	20	19	15
Klamath	PP	42	44	39	50	7	9	7	7
Fremont:									
Lakeview	PP	95	97	98	98	13	14	12	12
Average[3]		82a	86ab	85ab	87b	16c	18c	17c	15c
Wenatchee:									
Entiat	DF	82	56	70	65	19	18	16	16
Deschutes:									
Sisters	DF	59	61	59	55	22	22	22	22
Umpqua:									
Diamond Lake	DF	82	86	80	76	15	18	16	16
Siskiyou:									
Illinois Valley	DF	86	86	87	82	15	16	14	17
Average[3]		77d	72d	74d	70d	18e	19e	17e	18e
Fremont:									
Silver Lake	LP	99	99	99	99	29	32	28	34

[1] Treatments were control (C), dipped (D), jellyrolled (J), and jellyrolled and acclimatized (J+A).
[2] Height growth equals the increase in height divided by the initial height, multiplied by 100.
[3] Treatment means followed by the same letter were not significantly different at the 0.05 level.

Seedling Moisture Stress

Moisture stresses in fir and pine seedlings for the Chelan test prior to planting were significantly higher ($p \leq 0.05$) in the J + A seedlings (5.0 to 9.5 bars) than moisture stresses in the C, D, or J seedlings (2.5 to 5.5 bars) (table 3). Within species, no other differences among treatments were significant. At the Entiat site, moisture stresses in fir seedlings were significantly higher ($p \leq 0.05$) in the C and J + A seedlings (3.2 to 4.4 bars) than stresses in D or J seedlings (1.7 to 2.4 bars). Other differences among treatments were not significant. In fir, J seedlings generally exhibited the lowest moisture stress, but values were not significantly lower. Values for pine are not directly comparable to those for fir because the tops of the pine seedlings were kept exposed during the period of measurement, whereas the fir was kept enclosed.

Initial moisture stresses (time zero) in fir seedlings in a planting bag ranged from 1.4 to 4.1 bars (fig. 2). Moisture stresses for all treatments increased with time, and at 147 minutes, stresses ranged from 7.3 bars for jellyrolled seedlings to 16.0 bars for control seedlings. At time zero, all means were significantly different ($p \leq 0.05$) except for C versus D, and D versus J. At 66 and 147 minutes, the mean value for C was significantly higher ($p \leq 0.05$) than for D, J, or J + A; the latter three treatments were not significantly different from each other. In the case of ponderosa pine, initial stresses ranged from 4.2 to 7.2 bars. Moisture stress increased with time and at 125 minutes, values ranged from 15.3 bars for jellyrolled seedlings to 22.7 bars for the controls. At time zero, moisture stresses in both C and D seedlings were significantly higher ($p \leq 0.05$) than were stresses in J seedlings. At 63 minutes, the mean value for C was significantly higher ($p \leq 0.05$) than that for D but not J; at 125 minutes, the value for C was significantly higher ($p \leq 0.05$) than that for both D and J.

Table 3—Moisture stresses in control, root-dipped, and jellyrolled Douglas-fir and ponderosa pine seedlings prior to planting, Chelan and Entiat Ranger Districts[1/]

	Chelan				Entiat			
Species	C	D	J	J + A	C	D	J	J + A
	bars							
Douglas-fir[2/]	3.5a	3.5a	2.5a	5.0b	3.2ab	2.4a	1.7a	4.4b
Ponderosa pine[3/]	4.3a	3.8a	5.5a	9.5b	—	—	—	—

— indicates no measurement made.
[1/] Treatments were controls (C), dipped (D), jellyrolled (J), and jellyrolled and acclimatized (J + A). Treatment means for a species followed by the same letter were not significantly different at the 0.05 level of probability.
[2/] Seedlings were kept in a closed box during measurements.
[3/] Seedlings were kept in an open box with seedling tops exposed.

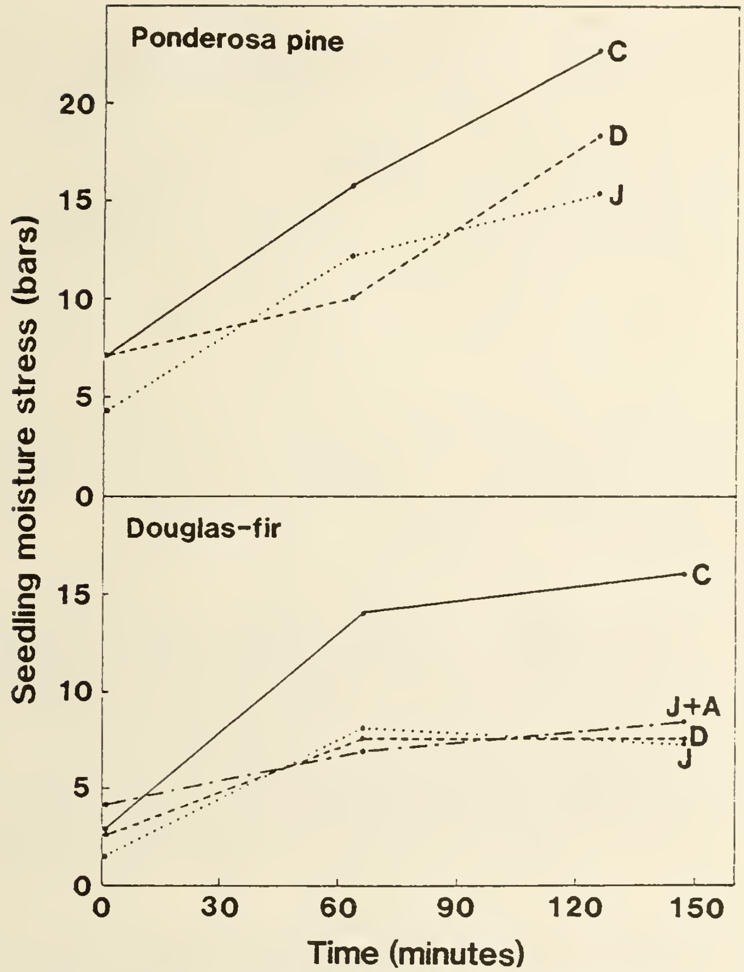

Figure 2.—Moisture stress in control (C), root-dipped (D), jellyrolled (J), and jellyrolled and acclimatized (J + A) ponderosa pine and Douglas-fir seedlings in a planting bag with the tops exposed on a warm sunny day.

Discussion

In the 1984 field tests, jellyrolling of seedlings did not increase survival significantly over survival of control or dipped seedlings. Although survival of pine seedlings that had been both jellyrolled and acclimatized was significantly higher than that of untreated seedlings, the increase in survival was only 5 percent, which may not be sufficient to justify the added cost of jellyrolling and acclimatization. More importantly, survival of jellyrolled and acclimatized seedlings was not significantly higher than that of slurry-dipped seedlings. There also was no effect from jellyrolling or acclimatization on seedling height growth. Survival results for Douglas-fir were just the opposite; that is, survival was lowest in the jellyrolled and acclimatized seedlings and was highest in the controls with no significant differences among treatments. In the Chelan test, the average value for survival of jellyrolled plus acclimatized pine seedlings was higher than that for the other treatments only because of higher survival on one of the three test sites. That, plus the very high and equal survival of the fir seedlings for all treatments, made the Chelan results inconclusive. Collectively, the results indicated that there were no significant beneficial effects of jellyrolling or acclimatization on survival or height growth of ponderosa pine and Douglas-fir seedlings compared to simply dipping seedlings prior to planting.

From a physiological standpoint, there is little to support jellyrolling. The small amount of water absorbed by jellyrolled seedlings would be transpired in a short time following outplanting. Maintenance of root tissue hydration undoubtedly is important for efficient water absorption, but it is doubtful whether properly stored seedlings with damp root systems would benefit much from additional moistening. Seedlings that have dried considerably during storage obviously should be remoistened, but that can be accomplished without jellyrolling. In the present study, moisture stresses of nontreated controls measured prior to planting ranged from 3.2 to 4.3 bars (table 3)—stress levels typical of moist, cold-stored seedlings and too low to affect performance.

There is little evidence that allowing cold-stored seedlings to warm up briefly prior to planting is beneficial. It should be noted, however, that there were no indications in the present tests, or in previously cited studies, that exposure of seedlings to moderate temperatures for 1 or 2 days prior to planting is detrimental to survival or growth. It is tempting to speculate that coniferous seedlings subjected to prolonged cold and dark storage may require gradual exposure to warmer temperatures and perhaps increased light to begin normal functioning—particularly stomatal control of water loss—and that the response varies with species. The positive effects of acclimatization with pine in the present study could be taken to support this; however, information in this area is very limited. McCracken (1978) did find that cold storage reduced the rate of recovery of CO_2 uptake in seedlings of *Pinus mugo* Turra and *Pinus radiata* D. Don., and speculates that adjustment to light may be necessary following prolonged cold and dark storage. Recently Grossnickle and Blake (1985), working with seedlings of jack pine and white spruce (*Picea glauca* (Moench) Voss), found that stomatal conductance increased and seedling resistance to water flow decreased during the 18-20 days following removal of the seedlings from cold storage. No changes were observed after only 2 days, the amount of time often used to acclimatize jellyrolled seedlings.

In the present study, exposure of the tops of the seedlings during acclimatization did result in slightly elevated moisture stresses; the stress levels of 4.4 to 5.0 bars in fir seedlings (table 3) are, however, not excessive for planting stock (Cleary and others 1978). The higher value of 9.5 bars in pine undoubtedly was the result of shoot exposure in those seedlings during measurements on the planting site. Apparently, survival of those seedlings was not adversely affected by this level of stress. Perhaps a greater concern with acclimatization is that it requires more careful scheduling of planting operations once acclimatization is started, and field acclimatization at higher elevations risks freezing seedlings. Another consideration is cost. Costs of jellyrolling vary somewhat, but once the procedure is operational, costs are reported to average around $10 per thousand seedlings.

Results in the present test may have been influenced by several factors. The cool and moist conditions that occurred during the 1984 planting season may not have provided sufficiently stressful conditions for the test. The 1983 Chelan test, however, was conducted under ideal conditions. Another factor is the potential for seedlings drying out while in planters' bags. Planters may carry seedlings for several hours, which would provide greater opportunity for seedling desiccation than occurred during test plantings when seedlings were planted in groups of 25. Measurement of seedling moisture stresses in a planting bag with the seedling tops exposed showed that unmoistened seedlings developed considerably higher stresses than dipped or jellyrolled seedlings, which generally exhibited lower and generally similar stresses.

In conclusion, there appears to be no advantage, in terms of survival, height growth, or stress reduction, from jellyrolling or acclimatizing bare-root conifer seedlings as compared to simply root-dipping them in peat moss-water or vermiculite-water slurries at the planting site.

Acknowledgments

The author gratefully acknowledges the assistance of B.K. Van Hoven in coordinating the study, R.S. Schellhaas in locating field sites, A.K. Dahlgreen (deceased) for assisting with the Chelan test, and other Forest Service personnel for planting seedlings and monitoring field performance.

English Equivalents

1 meter (m) = 39.37 inches or 3.28 feet
1 centimeter (cm) = 0.3937 inch
1 millimeter (mm) = 0.03937 inch
1 gram (gm) = 0.03527 ounce or 0.0022 pound
degrees Celsius (°C) = (degrees Fahrenheit–32)/1.8
kilometers per hour (km/h) = 0.6214 miles per hour
1 bar = 14.504 pounds per square inch

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Research Note
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Use of Curlleaf Mountain-Mahogany by Mule Deer on a Transition Range

J. Edward Dealy, Paul J. Edgerton, and
Wayne G. Williams

Abstract

Using the pellet-group sampling method, we concluded that migrating mule deer showed no preference in use between two ratios of curlleaf-mountain-mahogany cover and openings on a northern California transition range. Where there is a need to develop forage openings in transition habitats dominated by dense thickets of curlleaf mountain-mahogany, manipulation of cover levels within the extremes tested in this study should provide sound management options.

Keywords: Wildlife habitat, deer (mule), curlleaf mountain-mahogany.

Introduction

Curlleaf mountain-mahogany (*Cercocarpus ledifolius* Nutt.) is a small hardwood tree that is valuable in the western United States as a forage and cover species for mule deer and other ungulates and as cover and nesting habitat for many smaller species of wildlife (Dealy 1971, 1975; Leckenby and others 1982; Thomas and Maser 1979). Land managers and biologists are interested in developing intensive management prescriptions to enhance the habitat value of plant communities where curlleaf mountain-mahogany is the primary overstory component. Many stands of curlleaf mountain-mahogany are too tall and dense to provide significant forage for mule deer. Land managers often consider the use of logging in large thickets to improve the balance of forage and cover but question the effect that reduced cover will have on use by deer.

The study reported here tested the hypothesis that on a winter migration route, habitat combining 30-m-wide cover and 30-m-wide cleared strips will be used at a different intensity by deer than habitat combining 91-m-wide cover and 30-m-wide cleared strips.

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Study Area and Methods

Study Area

The study area is located near Alturas, California, in the Devil's Garden District of the Modoc National Forest, on and around Mowitz Butte (fig. 1). Topography is slightly rolling with occasional low hills and lava outcroppings present. Elevation is approximately 1300 m. Vegetation is a mosaic of ponderosa pine (*Pinus ponderosa* Dougl. ex Loud.), western juniper (*Juniperus occidentalis* Hook.), and curlleaf mountain-mahogany in the overstory, and antelope bitterbrush (*Purshia tridentata* (Pursh) D.C.), big sagebrush (*Artemisia tridentata* Nutt.), serviceberry (*Amalanchier alnifolia* Nutt.), and green rabbit-brush (*Chrysothamnus viscidiflorus* (Hook.) Nutt.) in the shrub layer. Idaho fescue (*Festuca idahoensis* Elmer) is the primary grass species. Soils are primarily well-drained Turnquist loams of medium depth. There is some pumice influence in this area. Frequent basalt outcroppings occur throughout the study area.

The area provides important transitory range for the migratory herd of Devil's Garden mule deer. A few resident mule deer also use the area during the summer, but most use occurs in late autumn as deer migrate to lower elevation wintering areas and in tne spring as they return to higher summer range (fig. 1).

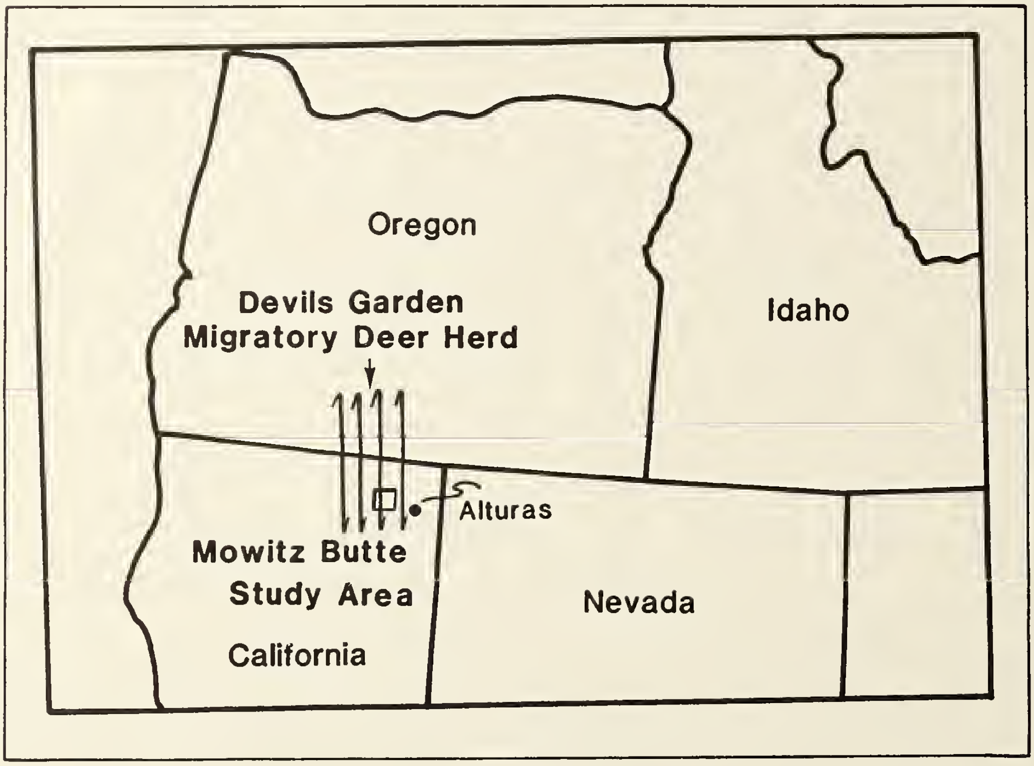

Figure 1.—Location of the Mowitz Butte study area and the migration route of the Devil's Garden deer herd.

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Results

Before-treatment means for the 30- and 91-m leave strips were 16 and 15 pellet groups per transect, respectively. After-treatment means for 30- and 91-m leave strips were 14 and 15 per transect, respectively. The test showed no significant difference at a 95-percent confidence interval between treatments or between pretreatment and posttreatment periods.

Blocks 1 through 5 had mean numbers of pellet groups of 12, 19, 19, 19, and 6, respectively. The test for block differences was highly significant.

Discussion and Conclusions

There is controversy among researchers concerning whether or not pellet group distribution accurately represents animal distribution (see Neff 1968 for a review of literature). Collins and Urness (1981) did not get a good correlation between pellet group distribution and actual use of habitat subunits by deer. Their habitat subunits appeared to be limited to only a portion of the habitat needed for day-to-day living. Deer moving among subunits produced a disproportionate distribution of pellet groups in relation to actual use. Leckenby (1968) also found poor correlation between distribution of deer pellet groups and actual observed use of habitats. These habitats had similar characteristics to those of Collins and Urness (1981) in that deer needed more than one type of habitat to fulfill their requirements. Conversely, White (1960), working in western Montana, found good correlation between distribution of mule deer pellet groups and observed subhabitat use; Bennett and others (1940), sampling white-tailed deer pellet groups in several forest types of Pennsylvania, showed good agreement between pellet group distribution and population observations.

In our study we expected that deer would use two habitats of different cover-to-opening ratios at different intensities. The difference in our treatment areas, compared to those of Collins and Urness (1981) and Leckenby (1968), was that each of our areas contained portions of cover and openings representative of the entire migration route in that locale. There was, therefore, no apparent necessity for animals to move between treatments except to change ratios of cover and openings. Because there was no difference in numbers of pellet groups among the different ratios of cover and openings, and with the assumption that pellet group distribution was a true indicator of animal distribution, we concluded that deer showed no preference between treatments.

Where there is a need to develop forage openings in transition habitats dominated by dense thickets of curlleaf mountain-mahogany, manipulation of cover levels within the extremes tested in this study should provide sound management options.

English Equivalents

1 meter (m) = 3.28 feet
1 square meter (m^2) = 10.764 square feet
1 kilometer (km) = 0.62 mile

Methods

The basic plot layout is a randomized block design, each block consisting of a 0.4- x 0.8-km rectangle. Five sites with the most abundant curlleaf mountain-mahogany were selected for the blocks. Tree crown closure averaged 55 percent and varied among blocks from 52 to 59 percent. Each block was separated into two 0.4- x 0.4-km treatment sites. Two treatments were imposed on each block: 30-m-wide cover strips, and 91-m-wide cover strips (fig. 2).

Treatments were installed in 1972 by clearing 30-m-wide strips of all tree cover every 30 m on one treatment and clearing 30-m-wide strips every 91 m on the other treatment. Selection of treatments for position in each block was done randomly.

Deer pellet groups were sampled to determine pretreatment and posttreatment differences and differences between treatments. On each 0.4- x 0.4-km treatment site, 20 transects were installed, each with 20 randomly placed 9-m^2 circular plots for a total of 400 plots per treatment per block. Pellet group data were combined for logged corridors and cover areas within each treatment in each block. Pellet groups were aged as plots were read, and only current year groups were counted and recorded. Deer pellet groups were sampled for 2 years before treatment and for 5 years afterwards.

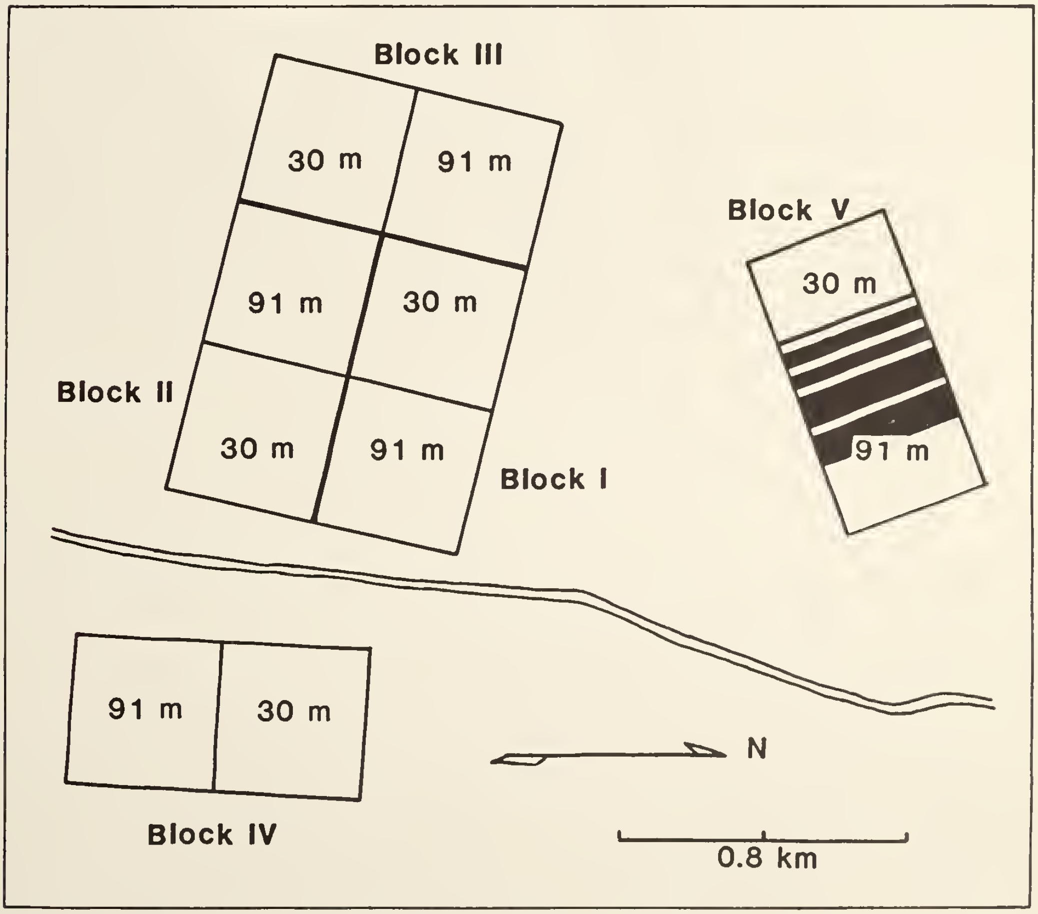

Figure 2.—Distribution of blocks and treatment locations in the study area.

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Research Note
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April 1986

Growth Of White Fir After Douglas-Fir Tussock Moth Outbreaks: Long-Term Records in the Sierra Nevada

Boyd E. Wickman

Abstract

Radial growth of white fir trees, *Abies concolor* (Gord. and Glend.) Lindl. ex Hildebr., defoliated almost 30 years ago by Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough), in the central Sierra Nevada was compared with 22 years of growth prior to the outbreak. There was little difference in growth between the two periods indicating that enhanced growth of defoliated trees after the outbreak did not occur as reported for two other California outbreaks. Increment cores also revealed for the first time an even older outbreak, which occurred on the same site in 1906-8.

Keywords: Increment (radial), insect outbreaks, Douglas-fir tussock moth, white fir, California (Sierra Nevada), Sierra Nevada—California.

Introduction

The long-term effects of a Douglas-fir tussock moth (DFTM) outbreak on growth of white fir (*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.) in California were recently reported (Wickman 1980). This type of information is rare because tree and stand records from past outbreaks are practically nonexistent. Forest management activities have also drastically altered most old outbreak areas. One old outbreak near Mammoth Lakes in the Inyo National Forest, California, was relocated and sampled in 1977. Growth measurements taken of severely defoliated trees on a study plot established in 1938 indicated that radial growth of white fir was greatly enhanced for 36 years after the outbreak collapsed. Growth of defoliated trees was significantly greater than growth of nearby nondefoliated hosts during the entire postoutbreak period, although preoutbreak growth was similar for both stands (Wickman 1980). This outbreak suffered 30 percent tree mortality on the study plot, and increased growth rate of survivors was attributed to increased availability of water, nutrients, and sunlight. In other words, the tree mortality had a thinning effect that proved beneficial to survivors. Similar responses after DFTM defoliation were noted in white fir 10 years after an outbreak in northeastern California (Wickman 1978a). Questions often posed are does this accelerated growth compensate for growth loss and perhaps some of the mortality during an outbreak? and is this a common stand response after severe DFTM outbreaks? Both questions are difficult to answer because of the paucity of records on old outbreaks and the changes imposed on many of these areas by human activities during the intervening years. My approach to this problem is to reexamine old outbreak sites where tree defoliation and stand damage information are available. Then I use these sites for case studies by using dendrochronological techniques to reconstruct preoutbreak and postoutbreak growth rates as related to defoliation history.

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There are currently only three old outbreak areas in California that have defoliation and tree damage records. The two already mentioned are still being measured periodically. A third area is located on the west slope of the central Sierra Nevada in the Stanislaus National Forest. This outbreak occurred in 1954-56 and tree damage was studied on permanent plots for 5 years after the outbreak was treated with DDT (Wickman 1963). In the most severely defoliated stands at Hell's Mountain, white fir mortality amounted to 20 percent of the stand volume, and radial growth reductions from 1955 to 1957 averaged 74 percent.

A remeasurement of plot trees on this severely damaged area was scheduled for 1981 to record 22-year postoutbreak growth response. Unfortunately, in 1976 a large, intense forest fire burned from Cherry Valley northward through the plots. The fireline extended through or adjacent to the entire 1956 study area and very few study trees survived the fire or subsequent salvage logging. Increment cores taken during a reconnaissance of the area in June 1980 showed depressed growth patterns in 1956 and 1957 in trees immediately east of the fireline and the old study area. This, combined with mapped defoliation, indicates that tussock moth defoliation extended into the adjacent stand. In September 1981, trees in the old Hell's Mountain DFTM outbreak area were sampled for radial growth. This paper reports the 22-year postoutbreak growth patterns found in the area and records for the first time an even older outbreak that occurred in the same area.

Study Site and Methods

The study site is about 19.3 km east of Long Barn, California, in the Stanislaus National Forest. Elevation varies from 1951 to 2073 m. The original mixed conifer stand was composed of about 75 percent white fir, 15 percent red fir (*Abies magnifica* A. Murr.), 5 percent Jeffrey pine (*Pinus jeffreyi* Grev. & Balf.), and 5 percent sugar pine (*Pinus lambertiana* Dougl.). Green stand volume of true fir prior to the outbreak was 133,380 board feet per ha. Pine volume was not recorded because the stand was logged for old-growth pine in 1955. Many old-growth fir were killed by secondary insects after the DFTM infestation. Five years after severe defoliation 27,170 board feet per ha had been killed (Wickman 1963). Defoliation was mapped as heavy throughout the Hell's Mountain area in 1956,[1] but heaviest defoliation was patchy and was located mostly on the ridgetop; individual tree defoliation estimates were made only on the study plots that were later burned.

Twenty white fir, which by evidence from growth patterns and mapping were defoliated in 1956, were cored at breast height adjacent to the fireline on an east-west transect approximately 400 m long near the ridgetop. The aim was to duplicate the layout of the old 1956 plots, but at a location 45-60 m north of the fireline.

[1]Mimeographed report, 1957, "Control of an Infestation of the Douglas-Fir Tussock Moth With DDT Aerial Spray: Calaveras and Tuolumne Counties, California," by R.E. Stevens, U.S. Department of Agriculture, Forest Service, California Forest and Range Experiment Station. Report on file, Pacific Southwest Forest and Range Experiment Station, P.O. Box 245, Berkeley, California 94701.

There were no known comparable fir stands nearby that escaped defoliation in 1955-56. An area that suffered light defoliation in 1956 was located instead at Jawbone Pass 800 m west at 1951 m elevation. This area had about 10 percent more white fir in the stand and very little red fir, but basal area (based on a 16-point sample) and stand age were similar to the heavily defoliated plot. There was no tree mortality due to defoliation in this area and, consequently, no "thinning effect" was expected in this stand.

Dominant and codominant sample trees were selected from each of three classes as follows: 20 heavily defoliated white fir, 10 nonhost pine in the same area, and 10 lightly defoliated white fir nearby. A tabulation of diameter and age distributions for each tree class follows:

	Heavy defoliation (*n* = *20*)	*Nonhost* (*pine*) (*n* = *10*)	*Light defoliation* (*n* = *10*)
Diameter (in centimeters):			
$\bar{x}$	60.96	60.96	76.2
range	33-109.2	45.7-114.3	38.1-111.8
Age (in years):			
$\bar{x}$	99	103	107
range	61-235	69-230	70-164

Two increment cores were taken from each tree at breast height, 90 degrees from each other (usually from the north and west quadrants), and to the center of the tree. Cores were mounted on wood blocks and measured on a Bannister incremental measuring machine that was interfaced with an Apple-II desktop computer for recording, tabulating, and exhibiting data.[2] Annual measurements on cores were averaged for each tree class and 22-year preoutbreak rates were compared with 22-year postoutbreak growth rates.

[2]Use of a trade name does not imply endorsement or approval of any product by the USDA Forest Service to the exclusion of others that may be suitable.

Results and Discussion

Average annual preoutbreak and postoutbreak growth rates did not differ for any of the three classes (table 1). Lightly defoliated trees were faster growing than the other two classes from immediately after the outbreak until 1973 when all three classes were growing at about the same rate. This growth pattern continued through 1981 (fig. 1). These results are different from those reported for the Mammoth Lakes site 36 years after an outbreak. There, 36 years of postoutbreak growth of defoliated trees was significantly greater than 36 years of postoutbreak growth of nearby nondefoliated hosts (Wickman 1980). This enhanced growth of defoliated fir probably compensated for individual tree growth lost during the 5-year outbreak and immediate postoutbreak period at Mammoth Lakes.

Table 1—Average white fir and pine growth before, during, and after a Douglas-fir tussock moth outbreak, Stanislaus National Forest

			Radial increment in mm per year	
Period	Years	Tree class	x̄	±S.E.
1933-54	22	H.D. 1/	3.018	± 0.09
		L.D. 2/	3.665	± 0.10
		Pine	2.703	± 0.06
1955-59	5	H.D.	1.478	± 0.32
(DFTM effects)		L.D.	2.758	± 0.44
		Pine	2.208	± 0.18
1960-81	22	H.D.	2.977	± 0.10
		L.D.	3.625	± 0.18
		Pine	2.823	± 0.07

1/ H.D. = heavy defoliation

2/ L.D. = light defoliation

Figure 1.—Average annual radial growth of white fir and pine at Hell's Mountain Douglas-fir tussock outbreak area, 1930 to 1981.

There was no similar pattern of postoutbreak accelerated growth at Hell's Mountain for heavily defoliated trees, but lightly defoliated trees did exhibit a 7-year period of enhanced growth following the outbreak. There was also no increased pine growth during the first 20-year postoutbreak period as noted at Mammoth Lakes (Wickman 1980).

These results are important because they indicate that a "thinning effect" may not occur on all sites and stands after severe DFTM outbreaks. Results from this case study should be interpreted, however, with caution. The actual defoliation history of the sample trees used for the heavy defoliation class was unknown. Sample trees were adjacent to an area of known heavy defoliation, but DFTM population centers and severe tree damage usually occur in clumps. Individual tree defoliation of 50 percent or less rarely results in significant mortality but does cause measurable growth reductions (Koerber and Wickman 1970; Wickman 1963, 1978b; Wickman and others 1980). There were only a few snags or downed dead trees in the sample area so defoliation could have been moderate rather than heavy, based on the 50-percent radial growth reduction found in the sample trees (table 1). Moderate defoliation would result in light subsequent tree mortality and, perhaps, little stand thinning.

Another difference between the Mammoth Lakes and Hell's Mountain case studies relates to growing site. The stands at Mammoth Lakes are on dry sites, with lower fir volumes, and they receive on the average about 50 cm less annual precipitation than do those at Hell's Mountain (Wickman 1963). The only other area where long-term studies indicate increasing radial growth of white fir after a severe outbreak is also on a dry site in northern California (Wickman 1978a). Except for the very ridgetop, the site index at Hell's Mountain is mostly class II. The "thinning effect" that enhances growth response may only occur on poor, dry sites. On good growing sites neither growth reduction nor recovery may be as extreme because the competition for nutrients and moisture is not as keen. Evidence of an older outbreak in the Hell's Mountain area may shed further light on this difference.

Eleven white fir were old enough to show patterns of tree growth between 1906 and 1912 that are very similar to growth patterns of the 1954-56 outbreak (fig. 2).

Figure 2.—Average annual radial growth of white fir and pine at Hell's Mountain Douglas-fir tussock moth area, 1880 to 1929.

A characteristic tree ring pattern has been noted for all other DFTM outbreaks studied (Brubaker 1978; Brubaker and Greene 1978; Koerber and Wickman 1970; Wickman 1963, 1978a, 1980; Wickman and others 1980). Furthermore, pine growth during 1907-9 was higher than fir growth and increasing rather than decreasing as one would expect from moisture deficiencies. Lending additional credence to a 1906-8 outbreak is the fact that in 1906 the first recorded California outbreak was underway at Fish Camp, California, about 72 km south (Eaton and Struble 1957). Precipitation and pine growth in northern California were above normal during this period (Keen 1937), and precipitation and tree growth at Mammoth Lakes were also on an upward trend (Wickman 1980); the growth reduction of white fir was apparently not the result of environmental factors but of a DFTM outbreak.

I have examined cores from mature white fir at the sites of old and recent DFTM infestations in the Inyo, Stanislaus, Eldorado, and Modoc National Forests without finding evidence of infestations other than those recorded by entomologists since 1936. This is not unusual because severe defoliation would have occurred on small acreages, or even within clumps of trees, and the probability of sampling those small units at a later date is slight. Brubaker (1978) reports from Idaho studies that breast height increment cores can identify severe DFTM infestations, but growth effects of moderate defoliation could not be reliably confirmed by dendrochronology techniques thus making it difficult to identify old outbreaks. Moderate and sometimes light defoliation were readily identified from increment cores taken after infestations in California and Oregon (Wickman 1963, Wickman and others 1980). This new evidence points to the 1906-8 outbreak as the earliest one detected from dendrochronologies in California.

The study site was most likely the locale of two DFTM outbreaks in a 50-year span. Because noticeable outbreaks (20 percent or greater tree defoliation) have not recurred on the same areas since 1936 (other than three at Iron Mountain in the Eldorado National Forest (Mason and others 1983)), the two outbreaks at Hell's Mountain in this century are unique. The stand dynamics at Hell's Mountain have also been influenced by the two DFTM defoliation episodes. Age distribution and site quality of mixed conifer stands on the west side of the Sierra Nevada are complex, highly variable, and often the result of past disturbances (Dolph and Amidon 1979). Two defoliation episodes probably increased nutrient cycling immediately after both outbreaks (Klock and Wickman 1978). This in turn may have had some longer term effects on site quality.

Age distribution is also affected by DFTM outbreaks. During the 1956 infestation, for example, there was heavier mortality in small understory white fir. Over 50 percent of the saplings and small poles were killed, mostly as a result of defoliation alone at the Hell's Mountain site (Wickman 1963). The growth patterns reported here do not, however, show a competitive advantage for pine growth after either outbreak as reported after the Mammoth Lakes outbreak (Wickman 1980), or as predicted from a simulation model of DFTM and stand dynamics in Idaho by Moore and Hatch (1981).

The effects of pest outbreaks, especially defoliators, may be subtle, but they are an important consideration when determining site quality classifications and predicting tree growth (Mattson and Addy 1975). Dendrochronologies of old outbreaks can have considerable value for estimating growth loss due to pests in future stand prognosis models. The data base for such measurements is small, unfortunately, and the case studies reported to date show considerable variation in growth response after defoliation. Some of this variation may be the result of poor historical data or it may be caused by variation of site index and age distribution in individual areas (Dolph and Amidon 1979).

A concerted effort therefore should be made to protect the few remaining study areas that contain good historical records of past DFTM defoliation and tree damage. Determining long-term effects of defoliation on stand dynamics in these areas is the only way to document growth loss caused by forest pests, to validate stand prognosis models, and to compute benefit-cost analyses of proposed management practices.

English Equivalents

1 centimeter (cm) = 0.39 inch
1 meter (m) = 3.28 feet
1 kilometer (km) = 0.6214 mile
1 hectare (ha) = 2.47 acres

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New and Modified Techniques for Studying Nitrogen-Fixing Bacteria in Small Mammal Droppings

C.Y. Li and Chris Maser

Abstract

Nitrogen-fixing bacteria in small mammal droppings are potentially important to forest productivity. As we study this phenomenon, however, we continually find unknowns, such as bacteria that we cannot isolate and purify because we do not know which techniques to use. For example, we have recently observed acetylene reduction in the droppings of the tundra vole (*Microtus oeconomus*) from St. Lawrence Island, Alaska, but we have failed three times to isolate the responsible bacterium. We hope this note will help stimulate parallel research on use of techniques under various circumstances.

Keywords: Laboratory methods, nitrogen-fixing bacteria, mammals (land).

Collecting Fecal Samples

We devised four alternative methods for collecting fecal samples—methods that ensured as much sterility as possible.

1. Catch the animal in a trap that keeps it alive and unharmed. Remove it from the trap and place it into a clean, sterilized cloth bag. Leave the animal in the bag for three to five minutes to defecate then release it. Pick up the deposited fecal pellets with sterile forceps and place the pellets in a sterile vial or petri dish.

2. Catch the animal in a live trap. Remove it from the trap and, while holding it upside down, gently remove any exposed fecal pellets with sterile forceps and place the pellets in a sterile vial or petri dish.

3. Catch the animal in a killing trap, excise the terminal fecal pellets, and place them into sterile receptacles with sterile forceps.

4. Catch the animal and put it into a thoroughly clean and, if possible, sterilized cage. Collect the fecal pellets with sterile forceps as the animal deposits them.

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Laboratory Techniques

We used the fecal pellets of three small mammals: (1) California red-backed vole (*Clethrionomys californicus*), (2) northern flying squirrel (*Glaucomys sabrinus*), and (3) deer mouse (*Peromyscus maniculatus*). To test for the presence of nitrogen-fixing bacteria, as measured by the acetylene reduction assay, Döbereiner nitrogen-free liquid medium (Döbereiner and Day 1976) was used for feces of the California red-backed vole and the northern flying squirrel. It worked well for these rodents because the nitrogen-fixing bacterium turned out to be *Azospirillum* sp. This medium did not work for the deer mouse pellets, however, so we tried Burk's nitrogen-free liquid medium (Burk 1930). Burk's medium worked well because the nitrogen-fixing bacterium in the deer mouse feces was *Clostridium butyricum*.

One or two fecal pellets were placed in 20 mL of nitrogen-free liquid medium in a 60-mL capacity serum bottle. Bottles were capped and flushed for 5 min with nitrogen gas containing less than 10 p/m oxygen. The liquid medium became turbid after incubation for 2 days at 30 °C. Acetylene was then injected into each bottle to 10 percent (v/v); the bottles were gently swirled immediately after addition of acetylene and left to stand at 30 °C. Bottles without acetylene injection served as controls. After 18 hr, 0.1-mL gaseous samples from each bottle were removed and analyzed for ethylene and acetylene with a Hewlett-Packard 5830A gas chromatograph[1/] fitted with a 2-m × 2.1-mm, 80-100 mesh, Porapak R column. Oven temperature was adjusted to 70 °C. Injection and flame ionization detector temperatures were each adjusted to 100 °C. Nitrogen carrier gas flow rate was adjusted to 40 $mL^{-1} \cdot min^{-1}$.

Bacterial cultures that reduced acetylene were isolated in two ways: (1) by repeatedly streaking the cultures in the bottles on Döbereiner agar medium containing 0.002 percent yeast extract, and (2) by streaking and incubating the Döbereiner and Burk agar media at 30 °C in an anaerobic chamber in which generator-released hydrogen gas combined with atmospheric oxygen in the presence of a catalyst to form water. The result was an anaerobic atmosphere in the chamber that contained approximately 5-9 percent carbon dioxide throughout the incubation period. (The anaerobic system we used is produced by: BBL Microbiology Systems, Becton Dickinson and Co., Cockeysville, MD USA.)

Clostridium butyricum, isolated from the feces of the deer mouse, was tested for its ability to reduce acetylene to ethylene by a method slightly modified from the Pankhurst tubes as described by Campbell and Evans (1969). The two H-tube arms (63 mL total volume) were identical in size and attached to each other by a connecting tube fitted with a ground glass joint and a clamp. One arm of each H-tube contained 10 mL of Burk's liquid medium supplemented with 0.002 percent yeast extract. After sterilization of the tubes with the medium in one arm and non-absorbant cotton in each connecting tube, sterile stoppers were inserted into each arm and the tubes flushed with sterile nitrogen gas. Alkaline Pyrogallol (2.0 mL) was injected into the arm not containing the liquid medium. Bacterial suspension (0.01 mL) was inoculated into the medium with a sterile syringe and needle. Control tubes were inoculated with sterile distilled water.

[1/]Use of a trade name does not imply endorsement or approval of any product by the USDA Forest Service to the exclusion of others that may be suitable.

For *Azospirillum* sp., isolated from the feces of the red-backed vole and the flying squirrel, a suspension (0.01 mL) in sterile distilled water was added to serum bottles that contained 20 mL Döbereiner's nitrogen-free liquid medium supplemented with 0.002 percent yeast extract. The bottles were capped with sterile serum stopper closures and flushed with nitrogen for 5 min. Oxygen was added to 1 percent of the gas volume. Cultures in the H-tubes and serum bottles were incubated at 30 °C for 3 days. Acetylene was injected into each H-tube and bottle, and the aforementioned procedure of ethylene determination followed.

To express the nitrogenase activity per unit of bacterial protein, bacterial cells were harvested and washed with cold 5 percent trichloroacetic acid. Protein was solubilized in 0.5 N sodium hydroxide in boiling water for 10 min (Agarwal and Keister 1983) and measured by the modified Lowry method (Markwell et al. 1978).

Yeast populations in feces were determined by the dilution plate method on sodium albumenate agar (Waksman and Fred 1922).

Conclusion

The best method for excising rodent fecal samples is under sterile conditions from a freshly killed animal. This does necessitate killing, however, which is probably not essential except under particularly stringent laboratory research design. We found holding animals in sterile cloth bags until they defecated to be preferable under most conditions. Further, a particular individual can be sampled repeatedly.

Nitrogen-free liquid media can be used to test for the presence of nitrogen-fixing bacteria in the feces of forest rodents. Place one or two fecal pellets in the liquid medium, flush for 5 min with nitrogen gas containing less than 10 p/m oxygen, and incubate at 30 °C. The resulting turbid liquid can be tested for nitrogenase activity by its ability to reduce acetylene to ethylene.

Döbereiner nitrogen-free medium, supplemented with yeast extract, is effective for *Azospirillum* sp. *Azospirillum* sp. can be isolated by repeatedly streaking the cultures on Döbereiner medium followed by incubation under anaerobic and aerobic conditions.

Clostridium butyricum can be isolated by incubating the streaking cultures on Burk's nitrogen-free medium, supplemented with yeast extract, under anaerobic conditions. This system is selective for *Clostridium butyricum*.

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English Equivalents

1 millimeter (mm) = 0.0394 inch
1 meter (m) = 39.37 inches
1 milliliter (mL) = 0.034 fluid ounces
°C = (°F −32)/1.8

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A Method for Estimating the Preharvest Potential for Seedling Height Growth on Cutover Forest Land in Southwestern Oregon

Don Minore

Abstract

Diameter growth of young trees as measured on Douglas-fir stumps of the previous stand was related to height of 5-year-old Douglas-fir seedlings on 16 cable-yarded, broadcast-burned progeny test plantations in southwestern Oregon. The resulting regression can be used to estimate the preharvest potential for seedling height growth on cutover land.

Keywords: Seedling growth, increment (height), site class (-increment, progeny tests.

Introduction

The site quality of forest land can be readily determined when that land supports mature trees, but it is difficult to determine the original site quality after those mature trees have been harvested. Information about the preharvest potential of a cutover area for postharvest seedling growth is often needed, but seldom available.

The potential of a cutover area for seedling growth is important. Seedlings that eventually become crop trees usually overcome brush competition and escape browsing while they are young. Rate of young seedling growth determines the time required to attain the height necessary to escape brush and animals, and that rate varies with site quality. Young plantations and other cutover areas unfortunately lack trees that are suitable for the conventional determination of site quality. Suitable site trees can sometimes be found in adjacent uncut stands if those stands occupy the same slopes, aspects, and soils; but no local site index curves are available for stands in southwestern Oregon. The age-height relationships used elsewhere are difficult to apply because of the common occurrence of suppression periods in the growth of southwestern Oregon trees, and most site index curves provide little information about tree height during the first few years of plantation growth.

Postharvest seedling height growth may not reflect preharvest site quality of the land on which those seedlings grow because site quality can be changed: soil compaction, soil removal, erosion, and the effects of fire may significantly alter a site. If estimates of preharvest potential for growth are needed (for example, to assess the effects of site preparation on site quality), they should be obtained by using preharvest variables, not postharvest seedlings.

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Radial growth measured on stumps of the previous stand is a suitable preharvest variable, and Schmidt (1954) used it to estimate the site quality of cutover land on Vancouver Island, British Columbia. He selected five of the largest Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) stumps available on each of his 0.4-hectare (1 acre) cutover plots but excluded abnormally large stumps. Schmidt then measured growth along three radii and calculated the average diameter of each stump at age 100. These stump diameters were averaged for each plot, and the plot averages were used to construct freehand curves that related stump diameters to the site indexes determined by measuring heights and ages of trees in adjacent uncut stands. His results varied with the site index involved, but Schmidt's stump estimates and the age-height measurements were similar on 73 percent of his plots. He measured 100 years of stump growth to minimize the effects of variations in stand density that are characteristic of young stands.

It is important to minimize the effects of stand density when using tree diameter as an indicator of site quality. This can be done by using the largest trees available. A second strategem may be effective—measurement of diameter when the trees are young and not yet competing with adjacent trees.

Duvall (1983) found that the diameter growth of young seedlings was unrelated to spacing in the plantations that he studied. Site quality, not spacing, influenced their diameter growth. This initial free growth was followed by a transition period in which spacing began to affect growth. Duration of the initial period of free growth was variable and difficult to determine, but Duvall suggested that the influence of site quality would continue to be discernible until competition became severe.

Drew and Flewelling (1979) assumed that individual tree growth is not related to stand density before crown closure occurs. If that assumption is valid, the influence of site quality on diameter growth will be discernible until crown closure wherever competition from other vegetation is not severe. Unfortunately, other vegetation is often abundant in young stands, and seedling growth is often reduced by shrub and grass competition.

The method described here was designed to minimize the effect of vegetative competition and stand density variation while maximizing the effect of preharvest site quality on the radial growth measured on Douglas-fir stumps. My objective was to relate stump measurements to seedling heights in a regression that could be used on cutover land to estimate its preharvest potential for seedling height growth.

Methods

Field data were collected on 16 progeny test plantations administered by the Forest Service, U.S. Department of Agriculture, and the Bureau of Land Management, U.S. Department of the Interior, in southwestern Oregon. Eight of the plantations were in Curry County, and eight were in Douglas County. All had been cable yarded and broadcast burned, and all were fenced to keep out browsing mammals. Brush competition, if present, had been controlled. The site quality of these minimally disturbed, carefully maintained progeny test plantations was assumed to be unaffected by logging and to be representative of the preharvest site conditions. The plantations were 4 to 5 hectares (10 to 12 acres) in size. Each contained several thousand carefully planted, individually tagged Douglas-fir seedlings of known parentage. When the seedlings were 5 years old from seed, their heights were measured by Forest Service or Bureau of Land Management personnel. I obtained the average 5-year seedling height for each plantation from records stored at the Forest Service, Forestry Sciences Laboratory, in Corvallis, Oregon.

Twenty Douglas-fir stumps were measured on each of the 16 plantations in 1984. In selecting the stumps to be measured, I assumed that growth potential would be best expressed by the best growing stumps. There were three other assumptions: (1) when the trees were very young (the stump centers), brush competition or browsing may have reduced both height and diameter growth; (2) when the trees were pole size or larger (peripheral portions of the stumps), intertree competition probably reduced growth; and (3) a sapling 10 centimeters (3.9 in) in diameter would be large enough to escape browsing and serious brush competition but small enough to be relatively unaffected by the intertree competition that occurs after crown closure. Annual ring width at 5 to 15 centimeters (2 to 6 in) from the pith was the criterion used in selecting 20 well-growing stumps. Stump sizes and heights varied, but neither size nor height was considered in choosing the stumps to be measured.

Beginning at a distance of 5 centimeters (2 in) from the pith, the distance occupied by 10 annual rings was measured along four radii on each of the 20 stumps selected on each plantation. The radii were oriented at right angles, in north, south, east, and west directions (fig. 1). The 10-ring distances were measured to the nearest millimeter (0.0394 in). A paint scraper was useful in removing pitch, and I used dissecting needles to mark the inner and outer boundaries of the 10-ring distance to be measured (fig. 2).

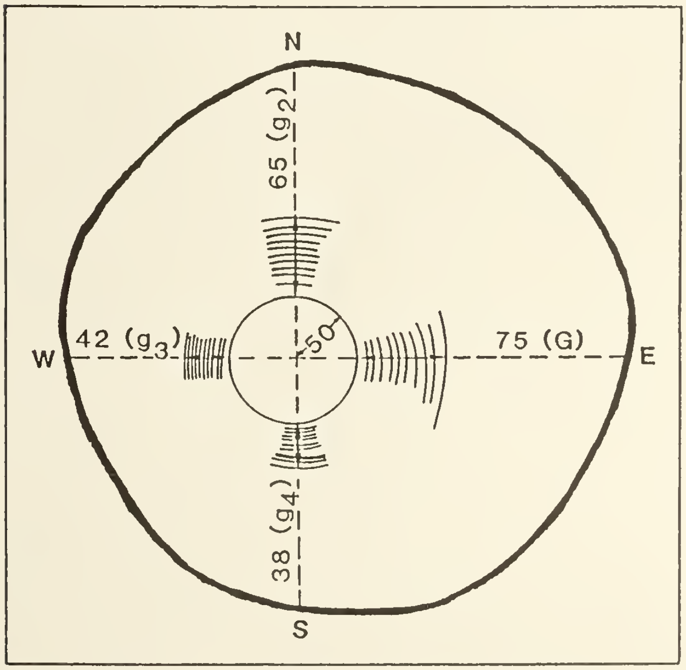

Figure 1.—The four radial growth measurements obtained for each stump in the sample. Ten annual rings are included in each measurement. Distances shown are in millimeters.

Figure 2.—Radial growth measurement in the field. Dissecting needles mark the 10 annual rings to be measured along a single radius.

Stump measurements and seedling heights were compared in several ways to obtain the best possible relation of preharvest stump growth to postharvest seedling height on the 16 plantations. I began with the following assumptions:

1. Postharvest seedling height growth can be related to radial growth measured on stumps of the previous stand where minimal disturbance occurred during harvest and site preparation. That relationship is often obscured, however, by extreme sample variation; high preharvest stand densities; and laterally unequal influences on growth, such as slope, unequal vegetative competition, and early injury.

2. Extreme sample variation can be reduced by discarding the two extremes in each 20-stump sample—the stump with the best growth and the stump with the poorest growth. This trimmed-mean technique is appropriate when the sampled distribution has long tails.

3. Radial growth reductions caused by high preharvest stand densities can be minimized by ranking the stumps on each plantation in order of growth and using a subsample of the same number of similarly ranked, well-growing stumps from each plantation.

4. Laterally unequal influences on growth produce asymmetric stumps and may be associated with reduced seedling height. Stump symmetry therefore should be considered when relating stump measurements to seedling height.

Regression analyses were used to relate 5-year seedling height and several expressions of stump growth.

Results and Discussion

Growth varied among radii on the same stump, among stumps in the same plantation, and among stumps in different plantations. The variation among radii and among stumps in the same plantation tended to obscure variation among plantations (appendix, table 2). Nevertheless, average 10-year radial growth of the stumps was significantly ($P<0.01$) related to average 5-year seedling height on the plantations when the four growth measurements from each stump were averaged and all the stumps were used. Less than half of the among-plantation variation in seedling height was associated with radial growth when this was done, however; and the regression was not strong enough to be useful in predicting seedling height.

Growth variation among radii on the same stump could be eliminated by using only the largest growth measurement obtained for that stump—the maximum radial growth (R). Unfortunately, this did not improve the stump growth-seedling height correlation, and it did not reduce the variation among stumps in the same plantation (appendix, table 3). The maximum radial growth value was convenient for comparing stumps, however; and I found it to be useful in ranking stump growth.

Growth variation among stumps in the same plantation was most evident when the best growing stump was compared with other stumps in that plantation (appendix, table 3). The high-growth ends of the sample distributions were long tailed, and the trimmed-mean technique was used to reduce sample variation. The two stumps with extreme R-values (stumps 1 and 20) were deleted, which left data for 18 stumps in each plantation. Of these 18 stumps, the five with largest maximum radial growth were judged to be least influenced by stand density. These five stumps were used in all subsequent calculations (appendix, table 3).

Radial growth and symmetry were both important in relating stump measurements to seedling heights on the 16 plantations, and I weighted the maximum radial growth of each stump by that stump's symmetry. The simplest and most effective weighting factor reduced the maximum growth measurement (R) by an amount equal to the sum of the differences between R and the three other growth measurements:

$$R - \Sigma (R - r_i) \; ;$$

where: R = the largest radial growth measured on the stump, and
r_i = the three other radial growth measurements.

For example, if R is 16 and the r_i's are 15, 13, and 12 then

$$[R - \Sigma (R - r_i)] = 8.$$

This growth-symmetry factor (GSF) was calculated for each of the five stumps with the largest R-values in each plantation. The plantation averages (table 1) were then related to 5-year seedling height averages in a regression (fig. 3):

$$SH = 44.32 + 1.79(\text{average GSF}) ;$$

where: SH = average 5-year seedling height in centimeters, and
GSF = average growth-symmetry factor.
R^2 = 0.692
$s_{y \cdot x}$ = 20.55
n = 16

This regression can be used to predict the height of unbrowsed 5-year-old seedlings on cable-yarded, broadcast-burned clearcuts in southwestern Oregon. It should be most helpful, however, when it is used to estimate preharvest growth potential on cutover land where site quality has been affected by logging or by site preparation treatments. Only measurements of stumps are required, and those measurements reflect the undisturbed conditions present when the stumps were saplings with diameters of 10 centimeters (3.9 in).

Estimates obtained from the stump measurement-seedling height regression express growth potential in terms of average unbrowsed 5-year seedling height rather than mature tree height, and they do not indicate relative volume production at the end of a rotation. Nevertheless, the potential for seedling growth is important information whenever the effects of harvesting methods or site preparation treatments are compared, and it is a value that should be considered in managing cutover land.

Summary of Method

The following steps should be followed to estimate the preharvest growth potential of a cutover area:

1. Locate on the area at least 10 stumps that show no evidence of suppression between 5 and 15 centimeters (2 and 6 in) from the pith. Choose stumps with the widest annual rings that can be found between 5 and 15 centimeters (2 and 6 in).

2. On each stump, beginning 5 centimeters (2 in) from the pith, measure the distance (mm) occupied by 10 annual rings on north, south, east, and west radii.

3. After all the stumps have been measured, use the maximum radial growth measurement (R) on each stump to rank the stumps from best growing (stump 1) to poorest growing.

4. Calculate growth-symmetery factors for stumps 2, 3, 4, 5, and 6:

$$R - [(R - r_2) + (R - r_3) + (R - r_4)] \text{ or } R - \Sigma(R - r_i)$$

where: R = the maximum growth measurement, and
r_2, r_3, and r_4 (or r_i) = the other three growth measurements.

5. Average the five growth-symmetry factors and use that average in the regression equation:

Average 5-year seedling height = 44.32 + 1.79(average growth-symmetry factor).

Table 1—Average maximum 10-year radial growth (R), growth-symmetry factor [R-Σ(R-r_i)], and 5-year seedling height, by plantation

Plantation	Average R, 20 stumps	Average R, 18 stumps 1/	Average R, 5 stumps 2/	Average R- (R-r), 5 stumps 3/	Average 5-year seedling height 4/
	mm 5/	mm 5/	mm 5/	mm 5/	cm 6/
A	18.8	18.1	21.8	11.2	69.0
B	39.0	36.3	52.6	28.2	98.6
C	30.4	29.3	39.6	16.0	98.9
D	31.0	29.7	40.8	16.0	91.6
E	35.4	35.2	45.6	25.4	76.0
F	29.4	29.2	38.2	8.2	56.4
G	39.6	39.8	48.8	12.2	57.3
H	74.3	74.7	90.2	66.8	144.9
I	55.4	54.8	64.6	38.0	111.7
J	51.9	50.3	64.0	47.0	180.0
K	72.0	71.8	86.6	51.4	136.2
L	56.1	56.4	69.2	42.2	99.1
M	41.6	41.4	53.4	16.2	50.4
N	57.4	56.8	70.6	30.4	106.1
O	44.7	43.4	56.2	20.8	58.1
P	42.4	40.3	57.0	27.6	95.0

1/ The stumps with largest and smallest R-values were deleted to reduce within-plantation variation.
2/ The 5 stumps with largest R-values remaining after deleting the 2 extreme values.
3/ The 5 largest R-values are here reduced in proportion to the asymmetry of the stump on which they were measured.
4/ Average height of all seedlings in the plantation.
5/ To convert to inches, multiply by 0.03937.
6/ To convert to inches, multiply by 0.3937.

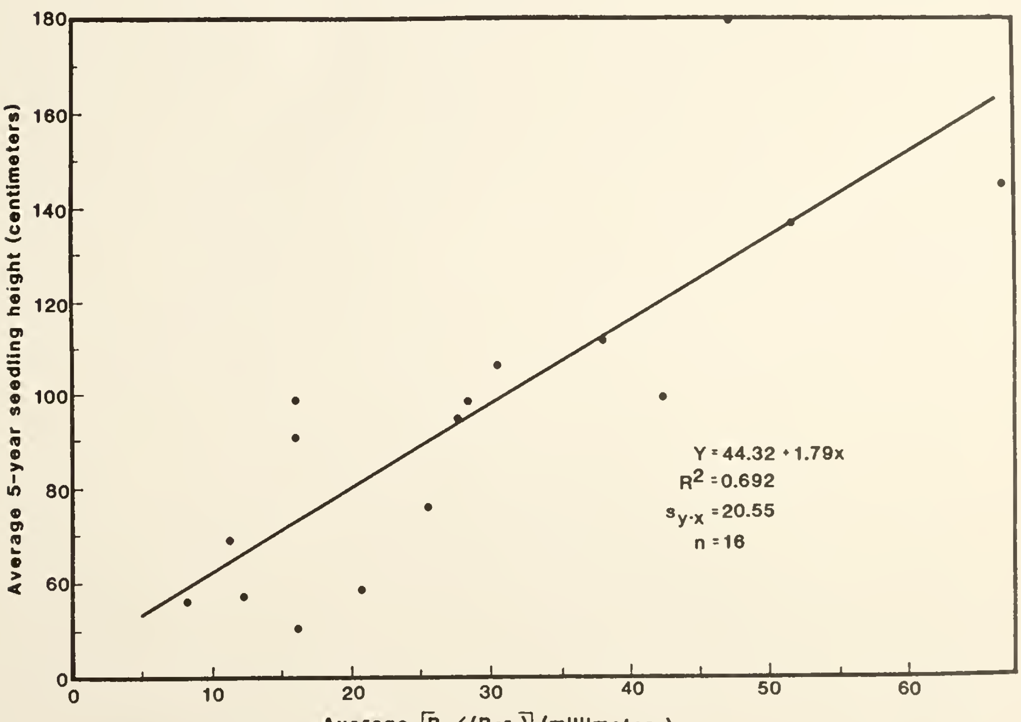

Figure 3.—Relation of the growth-symmetry factor [R-Σ(R-r_i)] to 5-year seedling height.

Acknowledgments

Financial support for this research was provided by the U.S. Department of the Interior, Bureau of Land Management, and U.S. Department of Agriculture, Forest Service, under the auspices of the Southwest Oregon Forestry Intensified Research (FIR) Program.

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Appendix

Table 2—Average 10-year radial growth [1/] for each of the 20 stumps measured on each plantation, ranked from best growth (stump 1) to poorest growth (stump 20), and average 5-year seedling height on each plantation

Plantation	Stump 1	Stump 2	Stump 3	Stump 4	Stump 5	Stump 6	Stump 7	Stump 8	Stump 9	Stump 10	Stump 11	Stump 12	Stump 13	Stump 14	Stump 15	Stump 16	Stump 17	Stump 18	Stump 19	Stump 20	Average, all stumps	Average 5-year seedling height 2/
	10-year radial growth in millimeters 3/																					cm 4/
A	32.5	19.5	19.5	19.2	18.8	18.8	17.8	17.8	17.5	16.8	16.5	14.8	14.0	14.0	13.8	13.5	11.2	10.5	8.8	8.5	16.2	69.0
B	104.5	57.5	56.0	47.0	39.0	37.8	35.5	34.8	34.0	33.0	30.5	26.2	24.5	22.8	22.2	20.0	17.5	16.8	15.2	15.2	34.5	98.6
C	40.5	39.0	38.5	34.5	29.0	27.0	26.0	25.5	24.8	24.2	23.2	21.8	21.0	21.0	19.8	19.5	19.5	19.5	18.2	17.2	25.5	98.9
D	55.8	40.8	38.8	34.5	33.5	30.5	29.5	27.2	25.5	23.5	23.5	21.5	21.5	21.2	20.0	19.8	18.8	18.0	17.8	15.2	26.8	91.6
E	47.0	46.5	42.2	40.0	38.8	35.2	34.5	34.0	30.2	29.8	28.8	28.5	28.0	26.5	26.0	25.2	22.8	22.2	20.8	19.0	31.3	76.0
F	42.5	36.2	32.5	32.2	29.8	28.5	27.2	25.5	25.0	25.0	24.5	24.0	22.2	20.5	18.8	18.0	14.8	14.5	14.2	11.2	24.4	56.4
G	45.0	42.0	42.0	40.8	39.2	38.0	36.2	35.5	35.2	35.0	34.8	34.0	33.8	33.5	32.0	31.0	30.5	24.5	21.5	21.2	34.3	57.3
H	89.8	88.2	87.8	85.2	81.0	79.5	79.2	79.0	78.8	77.2	72.5	64.0	63.2	60.5	58.8	53.5	52.5	49.0	45.8	43.0	69.4	144.9
I	71.0	62.8	61.8	59.5	56.0	54.0	53.8	52.5	51.8	50.5	48.8	48.8	46.0	44.0	43.0	41.5	39.5	39.0	38.5	36.2	50.0	111.7
J	81.0	67.2	65.2	59.8	55.8	51.2	50.8	48.8	48.2	45.2	45.0	42.2	39.5	38.5	37.5	36.8	35.8	33.8	33.0	27.5	47.1	180.0
K	90.5	89.2	77.0	76.2	75.8	72.8	70.8	69.5	66.5	66.5	64.5	63.0	59.0	58.0	57.8	55.2	53.5	51.0	48.0	47.8	65.6	136.2
L	68.5	65.5	65.0	61.8	59.0	58.8	57.8	54.8	53.0	51.8	48.2	46.0	44.2	41.8	40.2	38.8	36.8	34.8	29.8	29.0	49.3	99.1
M	56.5	49.8	49.8	43.0	41.5	39.8	39.5	36.5	35.8	35.5	33.8	34.8	33.2	33.2	30.8	30.2	27.5	27.5	27.0	18.8	36.2	50.4
N	81.5	69.8	61.5	59.8	59.0	57.5	56.2	55.5	51.8	51.2	50.8	49.8	41.5	41.5	40.5	38.8	38.0	37.5	36.2	34.2	50.6	106.1
O	77.5	56.5	48.5	47.2	42.5	42.0	40.8	38.0	38.0	36.5	36.2	35.2	34.0	33.5	33.0	32.2	30.2	30.2	25.8	24.0	39.1	58.1
P	80.0	79.2	54.8	45.2	37.8	36.8	36.5	35.0	34.8	31.5	29.5	27.8	27.5	27.2	24.8	24.2	24.0	21.2	18.8	15.5	35.6	95.0

1/ Growth was measured along north, south, east, and west radii, then averaged for each stump.
2/ Average height of all seedlings in the plantation.
3/ To convert to inches, multiply by 0.03937.
4/ To convert to inches, multiply by 0.3937.

Table 3—Maximum 10-year radial growth (R) and growth-symmetry factor [$R-\Sigma(R-r_i)$] for each of the 20 stumps measured on each plantation, ranked from best to poorest maximum growth[1/]

Plantation	Stump 1		Stump 2 3/		Stump 3 3/		Stump 4 3/		Stump 5 3/		Stump 6 3/		Stump 7		Stump 8		Stump 9		Stump 10	
	R 2/	$R-\Sigma(R-r_i)$	R	$R-\Sigma(R-r_i)$	R	$R-\Sigma(R-r_i)$	R	$R-\Sigma(R-r_i)$	R	$R-\Sigma(R-r_i)$	R	$R-\Sigma(R-r_i)$	R	$R-\Sigma(R-r_i)$	R	$R-\Sigma(R-r_i)$	R	$R-\Sigma(R-r_i)$	R	$R-\Sigma(R-r_i)$
	10-year radial growth in millimeters 5/																			
A	40	10	25	3	22	12	21	14	21	12	20	15	20	11	20	10	20	7	20	6
B	110	88	61	47	61	41	51	35	45	21	45	-3	42	25	42	10	40	22	39	22
C	59	-23	46	24	43	27	37	27	37	-9	35	11	30	18	30	14	30	7	29	12
D	66	25	47	22	45	20	39	21	37	-9	36	26	34	20	31	25	30	19	29	7
E	52	87	51	16	49	39	43	31	43	12	42	29	39	21	36	28	35	10	33	22
F	48	26	41	22	39	-21	38	16	37	3	36	21	35	14	32	4	32	4	30	12
G	53	9	51	27	51	-13	49	21	47	22	46	4	42	31	40	19	44	20	40	25
H	95	74	93	74	92	75	92	65	89	51	85	69	85	60	85	54	82	71	82	70
I	80	44	70	37	68	47	63	27	62	52	60	27	59	33	57 -	53	55	50	53	43
J	102	18	70	51	69	62	66	41	59	46	56	35	55	40	50	45	50	31	50	30
K	96	74	96	20	92	81	84	51	81	62	80	43	79	54	78	32	77	47	70	56
L	75	35	74	40	73	55	68	31	66	49	65	36	62	50	60	32	59	30	57	48
M	62	40	62	13	60	-14	54	37	46	34	45	11	44	27	43	10	41	35	41	10
N	85	71	81	36	70	36	70	12	69	32	63	36	62	50	61	47	61	22	60	23
O	84	58	64	34	60	9	55	29	55	5	47	27	45	17	44	31	42	26	42	20
P	105	2	88	56	61	36	49	34	44	-6	43	18	43	11	41	28	40	26	38	25

Plantation	Stump 11		Stump 12		Stump 13		Stump 14		Stump 15		Stump 16		Stump 17		Stump 18		Stump 19		Stump 20	
	R	$R-\Sigma(R-r_i)$	R	$R-\Sigma(R-r_i)$	R	$R-\Sigma(R-r_i)$	R	$R-\Sigma(R-r_i)$	R	$R-\Sigma(R-r_i)$	R	$R-\Sigma(R-r_i)$	R	$R-\Sigma(R-r_i)$	R	$R-\Sigma(R-r_i)$	R	$R-\Sigma(R-r_i)$	R 4/	$R-\Sigma(R-r_i)$
	10-year radial growth in millimeters 5/																			
A	18	17	18	2	16	8	16	-6	15	14	15	10	15	9	12	9	12	-2	11	2
B	33	23	33	6	30	1	27	17	26	11	24	8	20	10	19	10	16	13	16	13
C	26	15	25	9	25	4	23	18	23	15	23	0	22	12	22	12	22	12	22	7
D	28	10	26	7	23	17	23	17	23	10	22	6	21	17	20	11	20	1	19	18
E	33	13	32	23	30	24	30	16	30	11	28	7	27	23	26	11	26	5	22	10
F	29	22	27	17	26	11	25	-3	23	13	23	6	18	5	18	3	17	-6	15	13
G	39	24	39	17	37	25	36	16	35	30	35	23	34	20	27	17	24	14	24	13
H	79	68	69	46	68	52	67	41	61	52	60	34	56	42	50	46	49	36	47	31
I	53	17	53	-5	51	42	50	45	50	34	50	22	46	28	44	24	43	29	40	25
J	49	46	45	34	43	25	43	18	43	14	42	32	41	27	40	15	34	30	31	17
K	70	48	67	51	65	37	65	26	62	50	62	45	56	36	55	49	54	29	51	39
L	55	19	55	2	53	34	50	5	50	-3	49	14	46	39	40	19	33	20	32	20
M	39	25	38	29	38	19	37	24	34	8	32	25	31	30	30	20	30	18	24	3
N	57	36	52	43	48	22	46	28	45	27	45	20	44	20	44	13	44	5	41	27
O	41	13	39	28	39	15	37	30	36	26	36	21	36	13	35	16	29	16	28	12
P	37	-26	34	9	34	8	34	7	32	22	30	9	30	6	28	13	20	15	18	8

1/ Growth was measured along north, south, east, and west radii on each stump. R = largest measurement. r_i = the other 3 measurements.
2/ The largest R measured on each plantation.
3/ Stumps used in the stump growth-seedling height correlation.
4/ The smallest R measured on each plantation.
5/ To convert to inches, multiply by 0.03937.

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Research Note
PNW-443
May 1986

Invertebrates of the H.J. Andrews Experimental Forest, Western Cascades, Oregon: III. The Orthoptera (Grasshoppers and Crickets)

David C. Lightfoot

Abstract

An inventory of Orthoptera (grasshoppers and crickets) at the H.J. Andrews Experimental Forest, near Blue River, Oregon, was conducted to determine the species present and ecological relationships. A key for identification and an annotated list are presented. From qualitative assessments of successional habitat relationships, generalized species associations of forest Orthoptera are proposed, and their responses to forest succession are predicted.

Keywords: Invertebrata, keys (invertebrata), checklists (invertebrata), Oregon (H.J. Andrews Exp. For.).

Introduction

Orthoptera are important primary consumers in many terrestrial ecosystems (Odum and others 1962, Rodell 1977, Uvarov 1977). In temperate regions they are especially prevalent in grassland and scrub formations (Barnum 1964, Campbell and others 1974, Otte 1976). Relatively few Orthoptera occur in temperate forests of the Pacific Northwest and little is known about species composition or about orthopteran community patterns or processes.

This study was conducted to inventory the Orthoptera of the H.J. Andrews Experimental Forest (HJA) (a long-term ecological research site of the National Science Foundation), Willamette National Forest, near Blue River, Oregon, and to provide information about and identify those species that occur there. Analysis of long-term ecological trends is of primary concern at the HJA. To determine how orthopteran communities change over time, patterns of habitat associations were qualitatively assessed for a series of sites at different stages of vegetational succession. Consistent species assemblages were found associated with generalized habitat types representing early and late seral plant communities. Predictions can be made from these findings as to how populations and species composition should respond to environmental changes resulting from natural and anthropogenic disturbances and to subsequent vegetational succession.

At the time the research was done, DAVID C. LIGHTFOOT was a graduate student at the Systematic Entomology Laboratory, Department of Entomology, Oregon State University, Corvallis, Oregon 97331. He is currently a graduate student at the Department of Biology, New Mexico State University, Las Cruces, New Mexico 88003.

The H.J. Andrews Experimental Forest is managed cooperatively by the Pacific Northwest Research Station and the College of Forestry, Oregon State University. This paper is one of a continuing series that report on scientific studies in the Forest.

Methods

The HJA is located east of Eugene, Oregon, in the Willamette National Forest on the west slope of the Cascade Range. A detailed description of the site may be found in Franklin and Dyrness (1971). Franklin and Dyrness (1973) describe several elevational forest zones in the coniferous forests of western Oregon and Washington, two of which are represented at the HJA and will be referred to in this paper. The temperate Western Hemlock Zone is found from 150 to 1 000 m elevation and covers most of the study area. Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) are the dominant canopy species. There are few natural canopy openings in the zone. The cool-temperate Pacific Silver Fir Zone is found on ridges and peaks from 1 000 to 1 500 m. The dominant canopy species are Pacific silver fir (*Abies amabilis* Dougl. ex Forbes), noble fir (*Abies procera* Rehd.), Douglas-fir, and western hemlock. Meadows and other natural openings are common.

Sampling was conducted in 1978, 1979, and 1980, primarily during late summer and autumn when most species were in the adult stage. Sample sites were chosen to represent a variety of habitat and successional vegetation types distributed throughout the HJA. Orthopteran species composition and habitat characteristics at sample sites were recorded. Voucher specimens were deposited in the H.J. Andrews Experimental Forest special insect collection in the Systematic Entomology Laboratory at Oregon State University, Corvallis.

Results

Most species of Orthoptera occurring at the HJA were probably accounted for in this study. A key to identification and an annotated list of the Orthoptera follows. The key is for adult insects, and males and females will key together except as noted. Figures 1 through 3 are provided to illustrate the locations of some morphological characters used in the key.

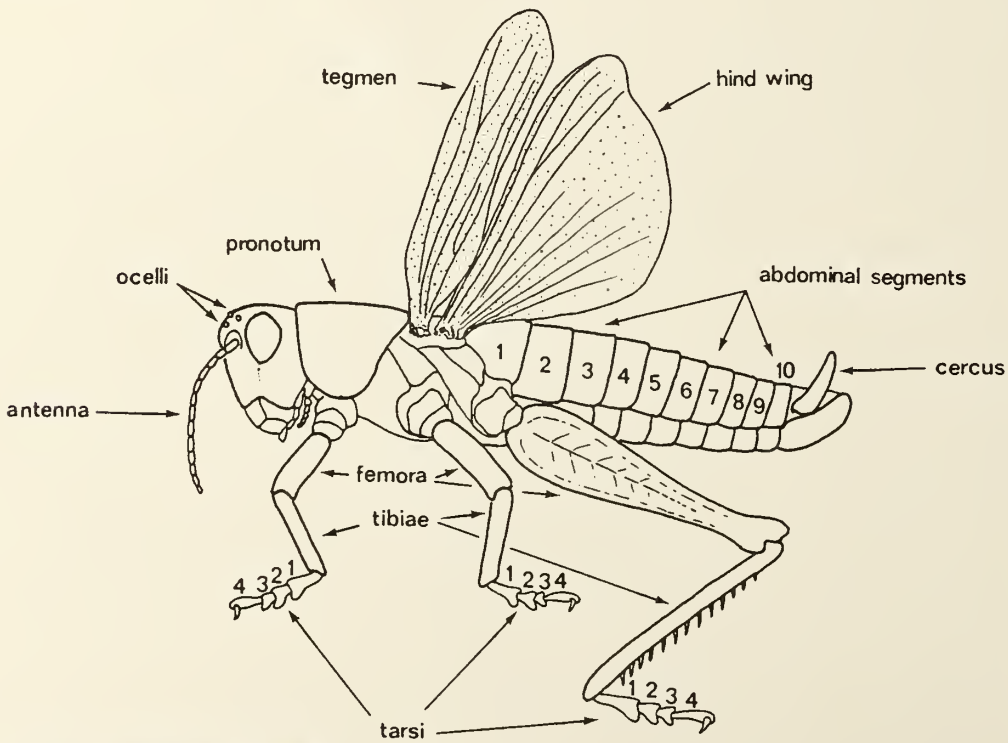

Figure 1.—Generalized orthopteran external morphology.

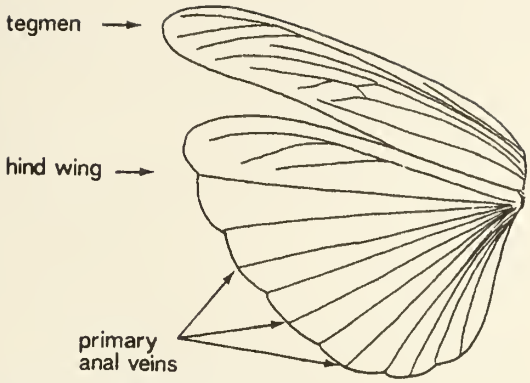

Figure 2.—Grasshopper wings.

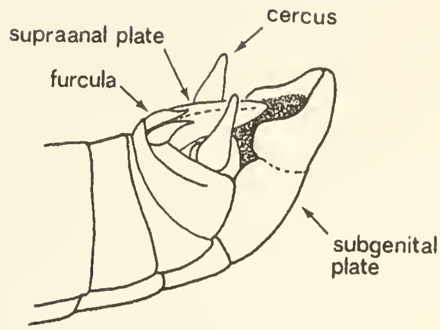

Figure 3.—Apex of a male grasshopper abdomen.

Key to the Orthoptera of the H.J. Andrews Experimental Forest

1a. Hind tarsi have three or four segments (figs. 4, 5); if three segments, auditory organ present on front tibiae (fig. 6). Antennae with more than 30 segments. (Suborder Ensifera.) -- 13

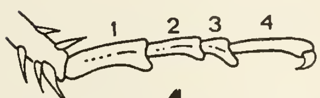

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Figure 4.—Four tarsal segments.

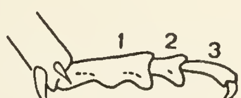

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Figure 5.—Three tarsal segments.

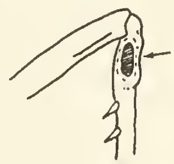
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Figure 6.—Auditory organ on front tibia.

1b. Hind tarsi have three segments, no auditory organ on front tibiae; auditory organ on first abdominal segments (fig. 7). Antennae with less than 30 segments. (Suborder Caelifera.) -- 2

2a. Pronotum greatly extended posteriorly, often to apex of abdomen (fig. 8). Tegmina much smaller than hind wings. Front and middle tarsi have two segments, hind tarsi have three segments, arolium (lobe) absent between tarsal claws (not as in fig. 10). Black to various shades of brown and gray. Very small, length 5 to 10 mm. (Pygmy locusts; family Tetrigidae; subfamily Tetriginae.) ------------------ *Tetrix subulata* (Linnaeus)

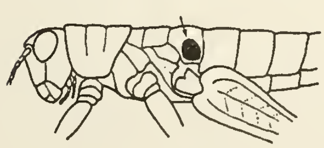
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Figure 7.—Auditory organ on first abdominal segment.


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Figure 8.—Posteriorly extended pronotum of a tetrigid grasshopper.

2b. Pronotum not greatly extended posteriorly (fig. 9). Tegmina equal to or longer than hind wings. All tarsi have three segments, arolium present (fig. 10). Size medium to large, length 20 to 45 mm. (Short-horned grasshoppers; family Acrididae.) ---------- 3

3a. Prosternum with median spine or tubercle (fig. 11). Wings long, at least to tip of abdomen, short, or absent; when present, hind wings clear. (Spur-throated grasshoppers; subfamily Melanoplinae.) ---------------------------------- 5

3b. Prosternum without median spine or tubercle. Wings present and long, hind wings colored or clear. Antennal segments round or flattened. ----------------- 4

4a. Face rounded, median ridge of pronotum elevated and cut by one or more transverse grooves on prozona (fig. 12). Posterior margin of metazona produced to a point at intersection of median ridge, prozona shorter in length than metazona (fig. 13). Wings long, hind wing disc yellowish or red with a black band, tegmina often mottled. Antennal segments round. (Band-winged grasshoppers; subfamily Oedipodinae.) --- 10

4b. Face slanted back ventrally, median ridge of pronotum low and cut by one transverse groove, prozona greater in length than metazona (fig. 14), posterior margin of metazona not produced to a point (fig. 15). Antennal segments flattened, especially those at base. Wings variable, often reaching apex of abdomen in males, short of apex in females. Hind femora surpassing apex of abdomen and wings. Hind wings clear, body brown to olive green, lateral ridges of pronotum lightly marked, forming a faint "X" when viewed from above. Length 14 to 25 mm. (Slant-faced grasshoppers; subfamily Gomphocerinae.) --------------------- *Chorthippus curtipennis* (Harris)

5a. Wings present, either fully developed or reduced to small tegminal pads (figs. 16, 17). -- 6

5b. Wings absent. Male cerci as in figure 18. Brownish to olive green, two dark lateral bands running the length of the body, ventral surface yellow. Hind tibiae reddish brown. Length 19 to 24 mm. ----------------- *Boonacris alticola* Rehn and Randell

6a. Wings long or reduced to small pads. If reduced, tegminal pads nearly oval in shape, touching dorsally, or separated by a distance less than half the width of one pad. -- 8

6b. Wings never long, reduced to small tegminal pads. Wing pads elongate and widely separated by at least a distance equal to half the width of one pad (fig. 19). ---- 7

7a. Tegminal pads very narrow (fig. 20). Posterior margin of metazona slightly notched at intersection of median ridge (fig. 21). Make cerci as in figure 22. Brownish or olive green and brown, broad yellowish dorsal band running the length of the abdomen bordered by dark lateral bands, ventral surface yellow, hind tibiae yellowish brown. Length 16 to 24 mm. -------------------------- *Prumnacris rainierensis* Caudell

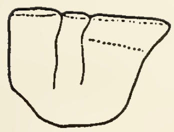

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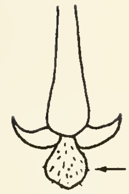
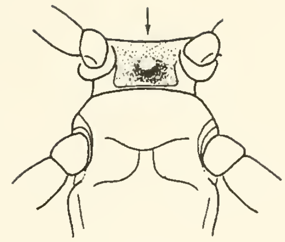
Figure 9.—Typical grasshopper pronotum.



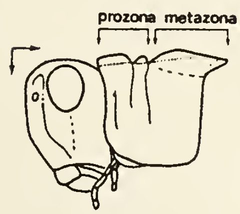
10

Figure 10.—Arolium present between tarsal claws.



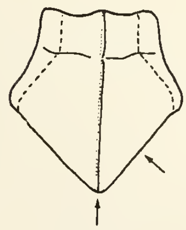
11

Figure 11.—Prosternal process of a spur-throated grasshopper.



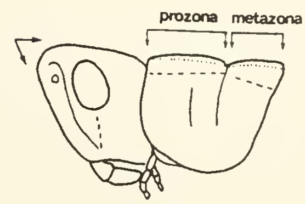
12

Figure 12.—Head and pronotum of a band-winged grasshopper.



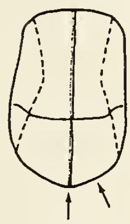
13

Figure 13.—Dorsal view of a band-winged grasshopper pronotum.



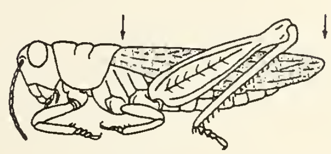
14

Figure 14.—Head and pronotum of a slant-faced grasshopper.



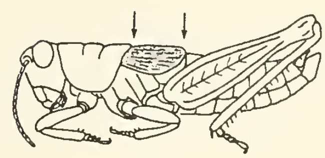
15

Figure 15.—Dorsal view of a slant-faced grasshopper pronotum.



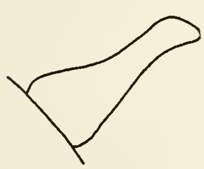
16

Figure 16.—Long-winged, spur-throated grasshopper.



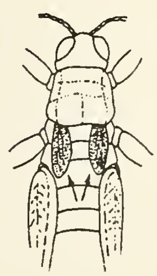
17

Figure 17.—Short-winged, spur-throated grasshopper.



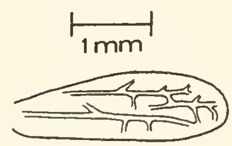
18

Figure 18.—Male cercus of *Boonacris alticola*



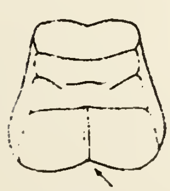
19

Figure 19.—Wing pads of a short-winged, spur-throated grasshopper



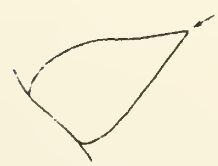
20

Figure 20.—Tegminal pad of *Prumnacris rainierensis*.



21

Figure 21.—Pronotum of *Prumnacris rainierensis*



22

Figure 22.—Male cercus of *Prumnacris rainierensis*

7b. Tegminal pads almost oval (fig. 23). Posterior margin of metazona straight across at intersection of median ridge (fig. 24). Male cerci as in figure 25. Same general color as *P. rainierensis* except that dorsal surface of abdomen is greenish rather than yellow. Length 18 to 25 mm. ---------------------- *Podisma hesperus* (Hebard)

8a. Wings reduced to small, oval tegminal pads (fig. 26). Male cerci as in figure 27. General color dark brown, hind tibiae red. Length 20 to 26 mm. ------------------------------- *Melanoplus validus* Scudder

8b. Wings fully developed, reaching or surpassing the apex of the abdomen. --- 9

9a. Apex of male subgenital plate slightly notched (fig. 28) (also refer to fig. 3). Male supraanal plate broad at base, becoming narrow at apex (fig. 29). Male cerci as in figure 30. Brownish to yellowish with dark spots on tegmina, hind tibiae red to bluish gray. Length 20 to 24 mm. ------------------- *Melanoplus sanguinipes* (Fab.)

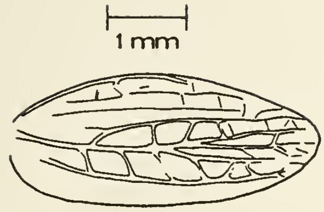
9b. Apex of male subgenital plate broadly notched (fig. 31). Male supraanal plate constricted midway to apex (fig. 32). Male cerci as in figure 33. Brownish, yellowish, or reddish, hind tibiae red. Length 18 to 24 mm. --- *Melanoplus femurrubrum* (DeGeer)

10a. Hind wing disc yellow or greenish yellow with black band. Median ridge of pronotum elevated more so on prozona than metazona, and cut by two grooves on prozona (fig. 34). ------------------------------------ 11

10b. Hind wing disc red with black band (fig. 35). Median ridge of pronotum well elevated throughout and cut by one groove approximately midway (fig. 36). Gray to brownish gray, hind tibiae blue. Length 24 to 28 mm. --- *Arphia conspersa* Scudder

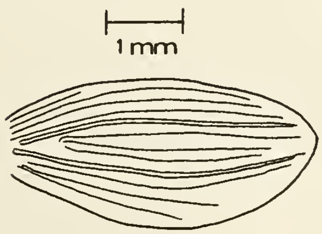
11a. Primary anal veins one, two, and three of hind wings slightly enlarged and thickened (see fig. 2 for position of wing veins), wing disc yellow, black band indistinct and broken (fig. 37). Tegmina mottled, no distinct bands. Light gray, mottled with dark and light spots, hind tibiae blue. Length 30 to 36 mm. ----------- *Circotettix shastanus* Bruner

11b. Anal veins of hind wing all equal in size, wing disc yellow to greenish yellow, black band of hind wing disc entire. ------------------------------ 12



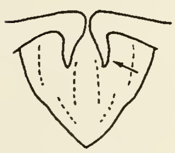
23

Figure 23.—Tegminal pad of *Podisma hesperus*.



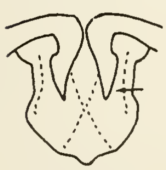
26

Figure 26.—Tegminal pad of *Melanoplus validus*.



29

Figure 29.—Male supraanal plate of *Melanoplus sanguinipes*.

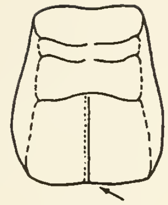


32

Figure 32.—Male supraanal plate of *Melanoplus femurrubrum*.

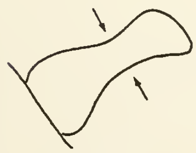
35

Figure 35.—Left wings of *Arphia conspersa*.



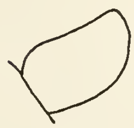
24

Figure 24.—Pronotum of *Podisma hesperus*.



27

Figure 27.—Male cercus of *Melanoplus validus*.

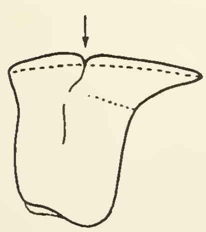


30

Figure 30.—Male cercus of *Melanoplus sanguinipes*.

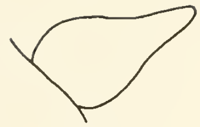
33

Figure 33.—Male cercus of *Melanoplus femurrubrum*.



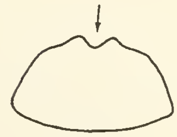
36

Figure 36.—Pronotal crest cut by one groove.



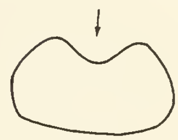
25

Figure 25.—Male cercus of *Podisma hesperus*.



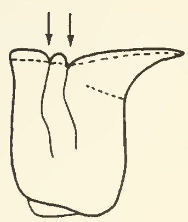
28

Figure 28.—Male subgenital plate of *Melanoplus sanguinipes*.



31

Figure 31.—Male subgenital plate of *Melanoplus femurrubrum*.



34

Figure 34.—Pronotal crest cut by two grooves.

37

Figure 37.—Left wings of *Circotettix shastanus*.

12a. Tegmen banded with three dark bands. Hind wing disc greenish yellow, black band narrow and faint, spur short (fig. 38). Dark brown or gray, mottled darker, hind tibiae blue. Length 20 to 34 mm. ---------------- *Trimerotropis fontana* Thomas

12b. Tegmen not banded. Hind wing disc yellow, black band broad, and suffuse to apex of wing, spur long (fig. 39). Dark gray, mottled darker. Hind tibiae blue. Length 28 to 38 mm. ------------------------ *Trimerotropis suffusa* Scudder

13a. Tarsi have four segments, ovipositor flattened, swordlike (fig. 40). Wings present or absent. -- 14

13b. Tarsi have three segments, second segment very small, ovipositor cylindrical, not flattened. Wings present. (Crickets; family Gryllidae.) ---------------- 15

14a. Auditory organ located at base of front tibiae (fig. 41). Wings present, as small pads, or they are long. ------------------------------------- 21

14b. No auditory organ present. Wings absent. Body rounded or humped dorsally, pronotum indistinct, not extending posteriorly over mesonotum. (Camel crickets; family Gryllacriddidae; subfamily Raphidiophorinae.) ---------------------- 18

15a. Ocelli absent. Hind tibiae armed with minute teeth between spines (fig. 42). Pronotum usually longer than wide. Head small, barely deeper than pronotum when viewed laterally (fig. 43). Wings long, usually extending past apex of abdomen. Form slender, color green or yellowish. (Tree crickets; subfamily Oecanthinae.) ---- 17

15b. Ocelli present (fig. 44). Hind tibiae without small teeth between spines. Head large, much deeper than pronotum when viewed from side (fig. 44). Wings short or long. Form robust, color black or dark brown. -------------------------- 16

16a. Spines of hind tibiae long and movable (fig. 45). Dark brown, wing length variable (specimens from the HJA have long wings extending past the apex of the abdomen). Small, less than 15 mm long. (Ground crickets; subfamily Nemobiinae.) ----------------------- *Eunemobius carolinus neomexicanus* Scudder

16b. Spines of hind tibiae short and immovable (fig. 46). Black, wings reduced. Size medium, over 15 mm long. (Field crickets; subfamily Gryllinae.) --------------------------- *Gryllus veletis* (Alexander and Bigelow)

17a. First and second basal antennal segments marked with two linear black marks as in figure 47, or unmarked. Yellowish brown. Length 16 to 24 mm. --------------------------------- *Oecanthus californicus* Sauss

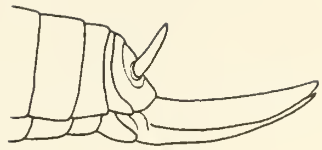
17b. First and second basal antennal segments marked with two black spots as in figure 48. Pale green. Length 16 to 22 mm. --------- *Oecanthus fultoni* Walker

38

Figure 38.—Left wings of *Trimerotropis fontana*.

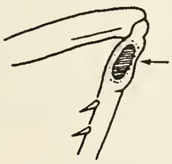
39

Figure 39.—Left wings of *Trimerotropis suffusa*.



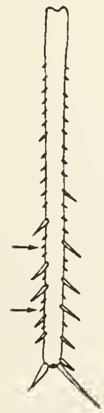
40

Figure 40.—Laterally flattened ovipositor.



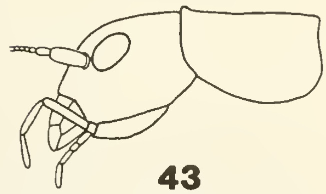
41

Figure 41.—Auditory organ on front tibia.



42

Figure 42.—Hind tibia of a tree cricket.

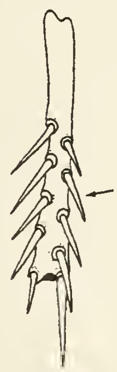


43

Figure 43.—Head and pronotum of a tree cricket.

44

Figure 44.—Head and pronotum of a field or ground cricket.



45

Figure 45.—Hind tibia of a ground cricket.

46

Figure 46.—Hind tibia of a field cricket.

47

Figure 47.—Basal antennal segments of *Oecanthus californicus*.

48

Figure 48.—Basal antennal segments of *Oecanthus fultoni*.

18a. All tibiae square in cross-section, ridges of all four angles armed with rows of small overlapping spines running the length of the tibiae. Appendages very long in proportion to body, combined length of front tibia and tarsi longer than length of body. Uniform dark reddish brown. Body length 15 to 30 mm, maximum size with appendages spread, over 200 mm. ------------------------ *Tropidischia xanthostoma* (Scudder)

18b. Tibiae rounded below with a row of spurs dorsally on each side. Appendages not excessively long in proportion to body, combined length of front tibia and tarsi much less than length of body. Various shades of gray and brown. ------------ 19

19a. Male cerci evenly incurved from base, with long, segmented, apical appendage (fig. 49). Ovipositor as in figure 50, apical portion of lower valve with more than nine crenulations on ventral surface. Dorsal surface of male abdomen armed with low, blunt tubercles. Light gray brown, lightly mottled darker with indistinct light band on dorsal surface. Length 12 to 17 mm. ----------- *Pristoceuthophilus celatus* Scudder

19b. Male cerci elongate, almost straight to apex, then incurved, with short, segmented, apical appendage (fig. 51). Ovipositor as in figure 52, apical portion of lower valve with nine or fewer crenulations on ventral surface. -------------- 20

20a. Dorsal abdominal segments of male armed with numerous blunt tubercles and long, conical spines, segment five bearing a large sclerotized structure (Hubbell's organ) extending over segments three through six. Dark brown, light cream-yellow central band on dorsal surface distinct. Length 12 to 15 mm. – *Pristoceuthophilus sargentae* Gurney

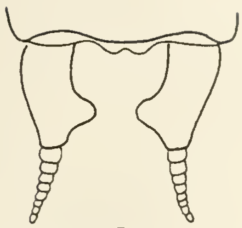
20b. Dorsal abdominal segments one through eight of male almost smooth, or with very low, blunt tubercles; Hubbell's organ absent. Coloration as above. Length 12 to 17 mm. ------------------------------ *Pristoceuthophilus cercalis* Caudell

21a. Hind legs stout, not more than 1.2 times longer than middle or fore legs. Hind tibiae armed with eight or fewer spines in each of two dorsal rows. Lateral ridges of pronotum indistinct. Tegmina of male enlarged and rugose, extending half the distance to the apex of the abdomen. Female wings and ovipositor much reduced. Gray, mottled with black, brown, and pink. Length 28 to 40 mm. (Hump-winged crickets; family Prophalangopsidae.) ------------------------------ *Cyphoderris monstrosa* Uhler

21b. Hind legs slender, hind tibia at least two times longer than middle or fore tibiae. Hind tibiae armed with more than eight spines in each of two dorsal rows. Lateral ridges of pronotum distinct. Wings reduced to tegminal pads or fully developed, reaching well past apex of abdomen. Green, brown, or gray. (Long-horned grasshoppers; family Tettigoniidae.) ------------------------------------- 22

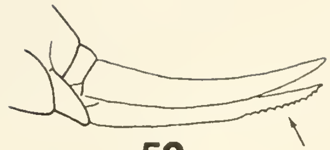
22a. Lateral groove present on first two tarsal segments (fig. 53). Ovipositor long and swordlike. -- 23

22b. First two tarsal segments smooth, not grooved laterally (fig. 54). Ovipositor short, strongly curving upward. Fully winged and leaflike, usually green. Length 38 to 42 mm. (Bush katydids; subfamily Phaneropterinae.) -------- *Scudderia furcata* Brunner



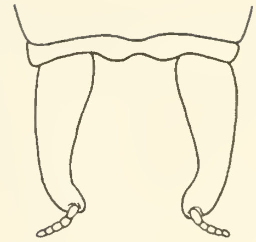
49

Figure 49.—Male cerci of *Pristoceuthophilus celatus*.



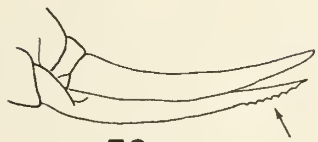
50

Figure 50.—Ovipositor of *Pristoceuthophilus celatus*.



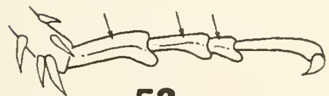
51

Figure 51.—Male cerci of *Pristoceuthophilus cercalis* or *P. sargentae*.



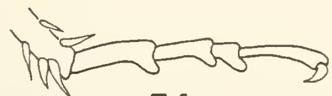
52

Figure 52.—Ovipositor of *Pristoceuthophilus cercalis* or *P. sargentae*.



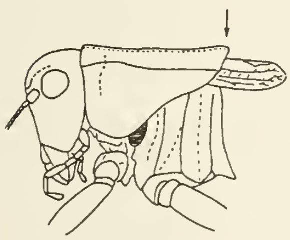
53

Figure 53.—Lateral grooves on tarsal segments.



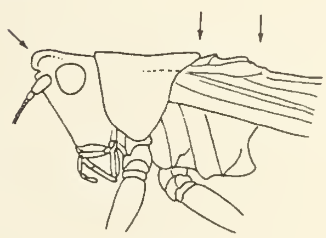
54

Figure 54.—No lateral grooves on tarsal segments.



55

Figure 55.—Lateral view of a shield-backed katydid.

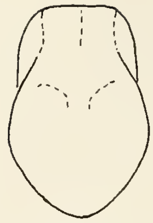


56

Figure 56.—Lateral view of a meadow katydid.

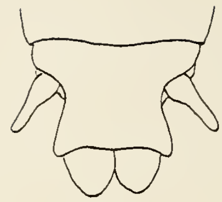
23a. One or more spines present on dorsal surface of front tibiae. Anterior vertex of head not produced forward, pronotum usually extended posteriorly over entire thorax (fig. 55). Wings reduced to small pads, partially covered by pronotum. All legs conspicuously spined. (Shield-backed katydids; subfamily Tettigoniinae.) – – – – – 24

23b. No spines present on dorsal surface of fore tibiae. Anterior vertex of head produced forward to rounded point, pronotum not extended posteriorly over entire thorax (fig. 56). Green with a black stripe running from the vertex of the head to the posterior margin of the pronotum. Wings long (a brownish, short-winged form is known from western Oregon, but has not been found at the HJA). Length 18 to 22 mm. (Meadow katydids; subfamily Conocephalinae.) – – – *Conocephalus fasciatus vicinus* (Morse)



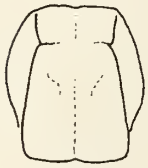
57

Figure 57.—Pronotum of *Neduba convexa*.



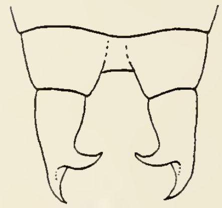
58

Figure 58.—Male cerci and pseudocerci of *Neduba convexa*.



59

Figure 59.—Pronotum of *Steiroxys strepens*.



60

Figure 60.—Male cerci of *Steiroxys strepens*.

24a. Pronotum much larger posteriorly than anteriorly when viewed from above (fig. 57). Male cerci conical with no teeth, pseudocerci present (fig. 58). Female ovipositor with teeth near apex. Brown, gray, reddish, or yellowish, never green. Length 20 to 26 mm. ------------------------ *Neduba convexa* Caudell

24b. Pronotum uniform throughout when viewed from above (fig. 59). Male cerci curved inward at apex with a large internal tooth (fig. 60). Female ovipositor without teeth. Green, brown, or gray, often with dorsal yellow stripes. Length 22 to 24 mm. ------------------------------- *Steiroxys strepens* (Fulton)

Annotated List

ORDER Orthoptera
SUBORDER Caelifera
SUPERFAMILY Acridoidea
FAMILY Tetrigidae
SUBFAMILY Tetriginae (pygmy locusts)

Tetrix subulata **(Linnaeus)**

1837. *Gryllus subulatus* Linneaus, Fauna Boreali-Americana, 4:251.

Distribution: Throughout most of the Neartic and Palearctic regions.

Habitat: Primarily riparian or occurring in low, damp areas. At the HJA: seeps and along streambanks in the Western Hemlock Zone.

References: Rehn and Grant (1961), Strohecker and others (1968).

FAMILY Acrididae
SUBFAMILY Melanoplinae (spur-throated grasshoppers)

Boonacris alticola **Rehn and Randell**

1962. *Boonacris alticola* Rehn and Randell, Transactions of the American Entomological Society, 88: 152.

Distribution: Cascade Range and Coast Range of Oregon.

Habitat: Low, herbaceous growth in meadows, forest margins, and in open woodland areas. At the HJA: mostly in the Silver Fir Zone, often in association with western brackenfern (*Pteridium aquilinum* (L.) Kuhn).

References: Rehn and Randell (1962).

Melanoplus femurrubrum **(DeGeer)**

1773. *Acrydium femurrubrum* DeGeer, Mémoires Pour Servir a la Histoire Des Insects, 3: 493.

Distribution: Throughout the United States and across southern Canada.

Habitat: Grasses in meadows, along roads, and in open woods. At the HJA: uncommon throughout the area at all elevations.

References: Helfer (1963), Strohecker and others (1968).

Melanoplus sanguinipes **(Fabricius)**

1798. *Gryllus sanguinipes* Fabricius, Supplementum Entomologiae Systamaticae, p. 195.

Distribution: Throughout the United States and across southern Canada.

Habitat: Grasses in meadows, along roads, and in open woods. At the HJA: throughout the area, especially in the Western Hemlock Zone.

References: Helfer (1963), Strohecker and others (1968).

***Melanoplus validus* Scudder**

1879. *Melanoplus validus* Scudder, Proceedings of the Davenport Academy of Natural Sciences, 7: 197.

Distribution: Cascade Range and Sierra Nevada, from Washington to northern California.

Habitat: Grasses in subalpine meadows. At the HJA: meadows and open woods in the Silver Fir Zone.

References: Gurney and Buxton (1968).

***Podisma hesperus* (Hebard)**

1936. *Dendrotettix hesperus* Hebard, Transactions of the American Entomological Society, 62: 182.

Distribution: Known to occur only in the Cascade Range of central Oregon.

Habitat: Low, herbaceous growth in meadows, forest margins, and open woodlands. At the HJA: meadows and open woodlands in the Silver Fir Zone.

References: Rehn and Randell (1963).

Note: Rehn and Rehn (1939) transferred the species from *Dendrotettix* to *Podisma* and noted close affinities to *Podisma sapporensis* Shiraka, which has since been placed in the genus *Parapodisma*. It now appears that *Podisma hesperus* may also belong to the genus *Parapodisma* (Rehn and Randell 1963). Also see Fontana and Vickery (1976).

***Prumnacris rainierensis* Caudell**

1907. *Prumnacris rainierensis* Caudell, Proceedings of the Entomological Society of Washington, 8: 134.

Distribution: Cascade Range of Washington and northern Oregon.

Habitat: Meadows, sparsely vegetated slopes, and open forests at high elevations. At the HJA: open woodlands in the Silver Fir Zone.

References: Helfer (1963).

Subfamily Gomophocerinae (slant-faced grasshoppers)

***Chorthippus curtipennis* (Harris)**

1841. *Chorthippus curtipennis* Harris, Report on the Insects of Massachusetts Injurious to Vegetation, p. 149.

Distribution: Throughout the United States and southern Canada.

Habitat: Grasses in meadows, along roads, and in open woods. At the HJA: throughout the area at all elevations.

References: Otte (1981), Strohecker and others (1968).

SUBFAMILY Oedipodinae (band-winged grasshoppers)

Arphia conspersa **Scudder**

1874. *Arphia conspersa* Scudder, Proceedings of the Boston Society of Natural History, 17: 514.

Distribution: Western North America from Alaska to Mexico, east to the Rocky Mountains.

Habitat: Bare soil in fields and along roads. At the HJA: along dirt roads and in recent clearcuts in the Western Hemlock Zone.

References: Otte (1984), Strohecker and others (1968).

Circotettix shastanus **Bruner**

1890. *Circotettix shastanus* Bruner, Proceedings of the U.S. National Museum, 12: 76.

Distribution: Cascade Range, Sierra Nevada, and Siskiyou Mountains of southern Oregon and northern California.

Habitat: Bare, rocky ridges at high elevations. At the HJA: rock outcroppings and talus slopes in the Silver Fir Zone.

References: Helfer (1963), Otte (1984), Strohecker and others (1968).

Trimerotropis fontana **Thomas**

1876. *Trimerotropis fontana* Thomas, Proceedings of the Davenport Academy of Sciences, 1: 255.

Distribution: Western North America from British Columbia to northern Baja California, east to the Rocky Mountains.

Habitat: Bare soil in fields, open woodlands, and rocky hillsides. At the HJA: along dirt roads and in recent clearcuts and bare spots in meadows, at all elevations throughout the area.

References: Helfer (1963), Otte (1984), Strohecker and others (1968).

Trimeroptropis suffusa **Scudder**

1876. *Trimeroptropis suffusa* Scudder, Bulletin of the U.S. Geological Territorial Survey, 2: 265.

Distribution: Western North America from British Columbia to northern Arizona, New Mexico, and California, east to the Rocky Mountains.

Habitat: Bare soil in open woodlands. At the HJA: along dirt roads, in recent clearcuts, and in open areas in the forest at all elevations.

References: Helfer (1963), Otte (1984), Strohecker and others (1968).

SUBORDER Ensifera
SUPERFAMILY Tettigonioidea
FAMILY Prophalangopsidae (hump-winged crickets)

***Cyphoderris monstrosa* Uhler**

1864. *Cyphoderris monstrosa* Uhler, Proceedings of the Entomological Society of Philadelphia, 2: 552.

Distribution: Western North America, Rocky Mountains from Colorado to Alberta, west to British Columbia and south through Cascade Range to southern Oregon.

Habitat: High-elevation coniferous forests.

References: Helfer (1963).

Note: Cyphoderris has not been found at the HJA, but is common at high elevations in the Cascade Range in Oregon. These katydids are likely to occur in the Silver Fir Zone at the HJA.

FAMILY Tettigoniidae
SUBFAMILY Phaneropterinae (bush katydids)

***Scudderia furcata* Brunner**

1878. *Scudderia furcata* Brunner, Monographien der Phaneropteriden, p. 239.

Distribution: Throughout the United States and southern Canada.

Habitat: Shrubs and small deciduous trees. At the HJA: shrubs along roads, in clearcut areas, and in open woods in the Western Hemlock Zone.

References: Helfer (1963).

SUBFAMILY Conocephalinae (meadow katydids)

***Conocephalus fasciata vicinus* (Morse)**

1901. *Xiphidium vicinum* Morse, Canadian Entomologist, 33: 203.

Distribution: Western North America from British Columbia to California, and east to the Rocky Mountains.

Habitat: Grasses in fields and meadows. At the HJA: clearcuts and other open, grassy areas in the Western Hemlock Zone.

References: Helfer (1963).

SUBFAMILY Tettigoniinae (shield-backed katydids)

***Neduba convexa* Caudell**

1907. *Neduba carniata* variety *convexa* Caudell, Proceedings of the U.S. National Museum, 32: 300.

Distribution: Western North America from western Washington south through western Oregon and into northwestern California.

Habitat: Forest floor and understory vegetation in deciduous and coniferous forests. At the HJA: understory vegetation particularly in second-growth forests in the Western Hemlock Zone.

References: Rentz and Birchim (1968).

***Steiroxys strepens* Fulton**

1930. *Steiroxys strepens* Fulton, Annals of the Entomological Society of America, 23: 611-641.

Distribution: Central Coast and Cascade Ranges of Oregon.

Habitat: Open, grassy areas in subalpine meadows. At the HJA: natural meadows in the Silver Fir Zone.

References: Fulton (1930), Rentz and Birchim (1968).

FAMILY Gryllacrididae

SUBFAMILY Rhaphidophorinae (camel crickets)

***Pristoceuthophilus celatus* (Scudder)**

1894. *Ceuthophilus celatus* Scudder, Proceedings of the American Academy of Science and Arts, 30: 97.

Distribution: Western North America from British Columbia to northern California west of the Cascade Range.

Habitat: Moist, dark areas, usually on the forest floor of woodland areas. At the HJA: under bark and objects on the ground in old-growth forests, mainly in the Western Hemlock Zone.

References: Helfer (1963).

***Pristoceuthophilus cercalis* Caudell**

1916. *Pristoceuthophilus cercalis* Caudell, Proceedings of the U.S. National Museum, 49: 673.

Distribution: Western Oregon and Washington, east to the Rocky Mountains.

Habitat: Moist, dark sites, usually on the forest floor of woodland areas. At the HJA: under bark and objects on the ground in old-growth forests in both zones.

References: Helfer (1963).

***Pristoceuthophilus sargentae* Gurney**

1947. *Pristoceuthophilus sargentae* Gurney, Journal of the Washington Academy of Sciences, 37(12): 430.

Distribution: Known only to occur in the Three Sisters-McKenzie Pass area of the Cascade Range in central Oregon.

Habitat: Usually under loose bark of trees or under objects on the ground in old-growth forests above 1 200 m elevation. At the HJA: old-growth forests in the Silver Fir Zone. Specimens have been found more than 35 m above ground level on the trunks of conifers.

References: Gurney (1947), Helfer (1963).

***Tropidischia xanthostoma* (Scudder)**

1861. *Rhaphidophora xanthostoma* Scudder, Proceedings of the Boston Society of Natural History, 8: 12.

Distribution: Coastal mountains and west side of the Cascade Range, from central California to British Columbia.

Habitat: Dark, moist sites, such as under logs and in riparian areas in old-growth forests. At the HJA: near streams in old-growth forests in the Western Hemlock Zone.

References: Helfer (1963).

Family Gryllidae

Subfamily Gryllinae (field crickets)

***Gryllus veletis* (Alexander and Bigelow)**

1960. *Acheta veletis* Alexander and Bigelow, Evolution, 14: 335.

Distribution: Throughout much of North America, in the West from Washington to central California.

Habitat: Holes and cracks in the ground in open fields, along roads, or other similar sites. At the HJA: on the ground in recent clearcuts and along roadsides in the Western Hemlock Zone.

References: Weissman and others (1980).

Subfamily Nemobiinae (ground crickets)

***Eunemobius carolinus neomexicanus* Scudder**

1896. *Nemobius carolinus neomexicanus* Scudder, Journal of the New York Entomological Society, 4(3): 99.

Distribution: Western United States from southern Washington to Mexico.

Habitat: Grasses in fields and meadows. At the HJA: open, grassy areas, mainly in the Western Hemlock Zone.

References: Helfer (1963), Vickery and Johnstone (1973).

Subfamily Oecanthinae (tree crickets)

***Oecanthus californicus* Saussure**

1874. *Oecanthus californicus* Saussure, Imprimere Imperriale:Paris, 3: 293.

Distribution: Western United States, east to the western Great Plains.

Habitat: Brush thickets in grasslands and open forests. At the HJA: in clearcuts and along roads in the Western Hemlock Zone.

References: Walker (1962, 1963).

***Oecanthus fultoni* Walker**

1962. *Oecanthus fultoni* Walker, Annals of the Entomological Society of America, 55(3): 309.

Distribution: Throughout much of the United States and southern Canada.

Habitat: Usually on deciduous trees, occasionally on smaller shrubs. At the HJA: on deciduous trees in the Western Hemlock Zone.

References: Walker (1962, 1963).

Discussion

The Orthoptera of the HJA were found to occupy a variety of plant communities or habitats of three generalized types based on vegetational structure and successional status. Of the 25 species of Orthoptera from the HJA, 12 were found primarily in early seral sites, 7 in natural meadows or on associated rock outcroppings, and 5 in late seral or mature forests. On the basis of these generalized relationships to habitats and to each other, the Orthoptera of the HJA may be classified into three major forest orthopteran species associations: early seral, meadow, and forest associates (table 1). Species

Table 1—Major forest orthopteran species associations at the H.J. Andrews Experimental Forest

Early seral associates	Meadow associates	Forest associates
Arphia conspersa	*Boonacris alticola*	*Cyphoderris monstrosa*
Conocephalus fasciatus vicinus	*Chorthippus curtipennis*	*Neduba convexa*[1]
Gryllus veletis	*Circotettix shastanus*[2]	*Pristoceuthophilus celatus*
Melanoplus femurrubrum	*Melanoplus validus*	*Pristoceuthophilus cercalis*
Eunemobius carolinus neomexicanus	*Podisma hesperus*	*Pristoceuthophilus sargentae*
Oecanthus californicus	*Prumnacris rainierensis*	*Tropidischia xanthostoma*
Oecanthus fultoni	*Steiroxys strepens*	
Scudderia furcata		
Tetrix subulata[3]		
Trimerotropis fontana		
Trimerotropis suffusa		

[1] Forest margins.
[2] Rock outcroppings.
[3] Temporary pools, seeps, and riparian areas.

within each of these three assemblages may be assumed to share similar ecological attributes because they consistently occur together under similar environmental conditions. These associations are generalized concepts. Individual species are not necessarily limited to a particular association or habitat type but predominate in one of the three.

Early seral associates comprise the largest assemblage of Orthoptera and occur in sites characterized by plant communities in early seral stages of forest succession. Such communities are found in clearcuts or along roadsides and are dominated by low, herbaceous vegetation. Early seral associates probably occur in such habitats because of the physical characteristics of the environment, the availability of palatable food plants, and the dispersal capabilities of the insects.

Structural attributes of vegetation may influence the distribution and abundance of grasshoppers by modifying abiotic environmental conditions (Anderson 1964, Joern 1982, Scoggan and Brusven 1973). Vegetational structure of early seral sites at the HJA may provide appropriate temperature and moisture conditions as a result of higher levels of insolation than can be found under the forest canopy. Relatively warm, dry conditions are important for the development of many temperate grasshoppers (Uvarov 1977). Plant species composition may influence the distribution of early seral associates as food resources. Several of these grasshoppers are known to be diet generalists (Banfill and Brusven 1973, Mulkern and others 1964). Diet generalist herbivores should theoretically be associated with unpredictable plants of early seral communities (Cates and Orians 1975, Rhoades and Cates 1976).

Early seral associates are mobile insects readily capable of dispersing to new locations. These species have broad distributions; all range across western North America and five range across the entire continent, thereby encompassing a wide spectrum of environmental conditions and food resources. As mobile generalists, these species are probably well adapted to dispersing rapidly and colonizing temporary habitats, such as the early seral plant communities at the HJA. Scoggan and Brusven (1973) conclude that environmental alterations, such as logging, increase the distribution and abundance of ecologically equivalent species in Idaho forests. As succession proceeds and vegetation cover increases at any given site, populations of early seral associates should decline.

Meadow associates occur at the HJA primarily in natural mesic and subalpine meadows in the Pacific Silver Fir Zone (Franklin and Dyrness 1973) but are seldom found in early seral plant communities. Like early seral associates, meadow associates occur in plant communities that are characterized by low, herbaceous vegetation and by high levels of insolation. Meadow associates, however, occur in plant communities with relatively stable plant species compositions. Meadow associates may have more specialized diets for predictable host plants that utilize different antiherbivore defenses than do unpredictable plants of early seral communities (Rhoades and Cates 1976).

Most meadow associates are flightless and limited in distribution to the coastal and Cascade-Sierra Nevada mountain ranges. At the HJA and throughout the western Oregon Cascades, meadow associates are generally restricted to widely scattered meadow communities, which results in patchy distribution patterns. Limited dispersal capabilities and possible host-plant interactions may restrict meadow associates from colonizing temporarily disturbed sites.

Only a few species of Orthoptera actually occur within the forest at the HJA. Forest associates, unlike early seral and meadow associates, are represented by nocturnal species that apparently do not require high levels of insolation. These species are probably omnivores and are not associated with any particular host plants but are associated with structural characteristics of forest communities. Forest associates are flightless, have low dispersal potential, and are limited in distribution to forests of the Pacific Northwest that are west of the Cascade Range. With the exception of those species restricted to the Pacific Silver Fir Zone, forest associates appear to be widespread throughout the forested areas of the HJA. Like meadow associates, these species occur in a relatively stable habitat where populations should remain stable until the habitat is altered.

Conclusion

The Orthoptera of the HJA exhibit close relationships to successional plant communities. Consideration of species associations or ecological groups, rather than individual species, may be more practical for making generalizations about ecological characteristics for these insects. At the HJA, the Orthoptera can be classified into the following major associations on the basis of distributional relationships to each other and to generalized successional plant communities: early seral, meadow, and mature forest associates. From a knowledge of the successional patterns of these plant communities, the following predictions for associated Orthoptera can be made: early seral associates colonize disturbed sites, but populations decline as forest succession proceeds; and meadow and forest associates form relatively stable populations over long periods of time in their respective habitats until catastrophic disturbances change those environments.

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English Equivalents

1 meter (m) = 3.3 feet
1 millimeter (mm) = 0.04 inches

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Resource Partitioning Among Woodpeckers in Northeastern Oregon

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Abstract

Eight species of woodpeckers coexist in conifer forests in northeastern Oregon: northern flicker (*Colaptes auratus*); yellow-bellied (*Sphyrapicus varius*) and Williamson's (*S. thyroideus*) sapsuckers; and pileated (*Dryocopus pileatus*), hairy (*Picoides villosus*), white-headed (*P. albolarvatus*), three-toed (*P. tridactylus*), and black-backed (*P. arcticus*) woodpeckers. Tree diameter was the most important factor considered in selection of nest trees by northern flickers, Williamson's sapsuckers, and pileated and hairy woodpeckers. These species partitioned the nest habitat by occupying different forest stands or conditions of nest trees. Pileated woodpeckers occurred in grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.) stands and nested in snags dead 10 or more years. The same stands were used by Williamson's sapsuckers which nested in live or recently dead trees. Northern flickers and hairy woodpeckers nested in ponderosa pine (*Pinus ponderosa* Doug. ex Laws.) forests but flickers used larger snags.

Foraging habitat and strategies differed. Only the pileated woodpecker excavated extensively in dead wood—particularly in downed wood and in grand fir forests. Northern flickers fed on the ground in open forests or grasslands. Live trees were used by Williamson's sapsuckers and white-headed woodpeckers. Sapsuckers drilled sapwells in Douglas-fir (*Pseudotsuga menzeisii* (Mirb.) Franco) and the white-headed woodpecker gleaned on ponderosa pine trunks and ate seeds. The remaining three species foraged by scaling, but the three-toed woodpecker fed exclusively in lodgepole pine (*Pinus contorta* Dougl. ex Loud.) stands. The hairy and black-backed woodpeckers scaled on similar trees in ponderosa pine stands. Hairy woodpeckers occasionally foraged on limbs and cones; black-backed woodpeckers used neither.

Theoretically, nesting should have occurred when maximum food was available; however, hairy and black-backed woodpeckers, species most similar in their feeding habitat and strategies, fledged their young the earliest and the latest, respectively. This temporal separation could reduce competition.

Keywords: Woodpeckers, birds, wildlife habitat.

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Introduction

Eight species of woodpeckers coexist in the coniferous forests of the Blue Mountains of northeastern Oregon. Because these woodpeckers are insectivorous and excavate nest cavities in dead trees, a potential for competition exists. Theoretically, two species cannot coexist over time using the limited resources in identical ways because one eventually replaces the other (Schoener 1974). Through coevolution, the environment can be partitioned so each species occupies a separate niche and competition is avoided (Darlington 1972). Partitioning occurs if the species use: (1) different resources; (2) the same resource in different places; or (3) the same resource at different times (MacArthur 1958). The objectives of the study were to compare nesting habitat, foraging, and breeding phenology among eight woodpecker species.

Study Area

The study was conducted in the 11,400-ha Starkey Experimental Forest, Wallowa-Whitman National Forest, an area representative of the central Blue Mountains. Located 35 km southwest of La Grande, Oregon, Starkey Experimental Forest is characterized by undulating uplands dissected by moderately to steeply walled drainages and elevations of 1070-1525 m. Annual precipitation averages 50 cm, of which nearly half is snow. Snow is on the ground from November through March.

Strickler (1966) describes the soils and vegetation. Soils originated from basalt and pumicite. Vegetation is closely associated with soil type and depth, and habitats have developed in a mosaic. Three habitats—open forest, dense forest, and grassland—are described by Edgerton and Smith (1971). Burr's (1960) classification was used to identify forest types at Starkey as: (1) open ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.), (2) ponderosa pine-Douglas-fir (*Pseudotsuga menzeisii* (Mirb.) Franco), (3) Douglas-fir-grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.)-ponderosa pine, and (4) grand fir-Douglas-fir-western larch (*Larix occidentalis* Nutt.).

Fire suppression and selective timber harvesting in the 1930's resulted in stand structure unlike that of even-aged stands. Multilayered canopies with some much larger trees characterize most stands. As these large trees die or are cut, favorable conditions allow new tree establishment. Over time, this has created multilayered stands with numerous patches of young, even-aged trees and a few large, overmature trees.

In the 1970's an outbreak of mountain pine beetle (*Dendroctonus ponderosae)* occurred that infested over 200,000 ha in the Blue Mountains (Crookston and others 1977). The outbreak peaked in 1977 in the Starkey Experimental Forest killing thousands of lodgepole and ponderosa pines. These dead trees were present throughout the study.

Methods

Nesting

We searched for nests of eight woodpecker species: northern flicker (*Colaptes auratus*); yellow-bellied (*Sphyrapicus varius*) and Williamson's (*S. thyroideus*) sapsuckers; and pileated (*Dryocopus pileatus*), hairy (*Picoides villosus*), white-headed (*P. albolarvatus*), three-toed (*P. tridactylus*), and black-backed (*P. arcticus*) woodpeckers between 15 April and 15 July 1976, 1977, and 1978 by hiking or riding horseback along routes of travel some 0.5 km apart. Travel was in proportion to the area occupied by each forest type. Nests containing an incubating adult or nestlings were considered active. Characteristics of the nest tree and habitat in 0.1-ha plots surrounding the nest were recorded. Nest tree characteristics included: nest height; exposure; amount and direction of tree lean; species; condition (live or dead); diameter at breast height (d.b.h.); height; and percent of the branches, bark, needles, and top remaining. Habitat characteristics included: density of the live stems, dead trees, and stumps; basal area; percent of canopy closure and number of canopy layers and heights; ground cover height, type, and coverage; slope gradient and aspect; distance to a clearing and to water; average size and percent of cover of dead and downed material (logs); forest type; and landform (slope, ridge, or draw).

Snag used for nesting

In June and July 1978 we checked nests each week for eggs, nestlings, fledged young, or nest failures. We considered young to be fledged if the cavity was vacant and the nestlings had been within a week of fledging age at the last observation.

To characterize the habitat available to woodpeckers, we sampled forest areas along 48 transects, each 805 m long and containing 10 sample points at 70-m intervals. Transects were located using an 805-m grid placed on a map of the study area. Starting points were selected from a random numbers table, and cardinal directions assigned systematically for each transect. At each sample point we recorded habitat characteristics described earlier for nest tree location in a 0.1-ha plot. The same characteristics measured at nest trees were measured at sample points.

Chi-square analysis($P \leq 0.05$) was used to compare nesting habitat characteristics to the general forest condition. We made comparisons only for those woodpecker species for which 10 or more nests were located in dead trees.

A stepwise discriminant function analysis was used (Klecka 1975) to determine habitat characteristics that best discriminated between use and nonuse for nesting by four species. This analysis was used only for a species with at least 50 nests in dead trees. Only woodpecker nests located prior to 1979 were used in the analysis. For three of these four woodpecker species, less than 8 percent of the nests were in live trees. Therefore we limited our analysis to nests in dead trees. Characteristics that emerged from the analysis with significant F-values ($P \leq 0.01$) were considered good discriminators. This same analysis was used by Conner and Adkisson (1976) to distinguish nesting habitat among woodpecker species.

Foraging

We observed woodpecker feeding activities on eight 50-ha plots once each month from September 1976 to September 1977. Each 3-hour observation period took place within 6 hours of sunrise in order to include periods of intense feeding activity. Individual woodpeckers were observed for a maximum of 15 minutes to prevent sampling bias (Williams 1975). A new feeding site was recorded each time a woodpecker under observation moved between trees or more than 1 m on the same tree. Foraging behavior and habitat characteristics were recorded at each feeding site along a 2000-m circular route through the plot. Recorded characteristics included: forest type; landform (ridge, slope, or draw); tree species; tree condition (alive or dead), height of trees, length of logs; percent of bark, branches, and needles on tree; feeding location (trunk, branch, or ground); and height at which the bird was feeding. To obtain a sample of available habitat, we measured habitat characteristics using the point-center quarter method (Cottam and Curtis 1956) at 80 points (for trees and snags) and 40 points (for logs and stumps) spaced equidistance along the circular route.

Feeding activity was classified as: scaling—prying off layers of bark to get at insects in the superficial bark; excavation—digging into the wood; gleaning—searching over the trunk and limb surfaces; flycatching—pursuit of insects during flight; sapsucking—eating sap or cambium; ground foraging—feeding on the ground or digging in the soil for insects; and seed harvesting—extraction of seeds from cones (Jackman 1975).

Discriminant function analysis was used to distinguish feeding habitat among seven woodpecker species, and to compare characteristics at feeding sites with the available habitat. Minimum sample size was 25; significant F-values were originally $P \leq 0.05$ but were reduced to $P \leq 0.01$ when nearly all the variables considered showed significance. Analyses were done by condition class (dead trees, live trees, or logs). Chi-square analysis was used to compare feeding habitat variables with available habitat ($P \leq 0.01$ and a minimum of 10 observations).

Results and Discussion

Nesting

Pileated woodpecker.—Pileated woodpeckers nested almost exclusively in dead ponderosa pine and western larch, although one nest was found in a live grand fir. They selected the largest dead trees available to nest in (fig. 1, table 1); 58 percent of the nest trees had broken tops. Less than 25 percent of the original limbs and bark remained in 76 percent and 58 percent of the nest trees, respectively, which suggested that the trees had been dead at least 10 years.

We tested characteristics of 63 nests in available dead trees and compared these with nests of other woodpeckers (table 1). The characteristics of nest trees were significantly different ($P \leq 0.01$) than random choice would indicate. Diameter at breast height and percent of bark, broken tops, and branches were the best discriminators ($P \leq 0.01$) between dead trees used and those not used for nesting.

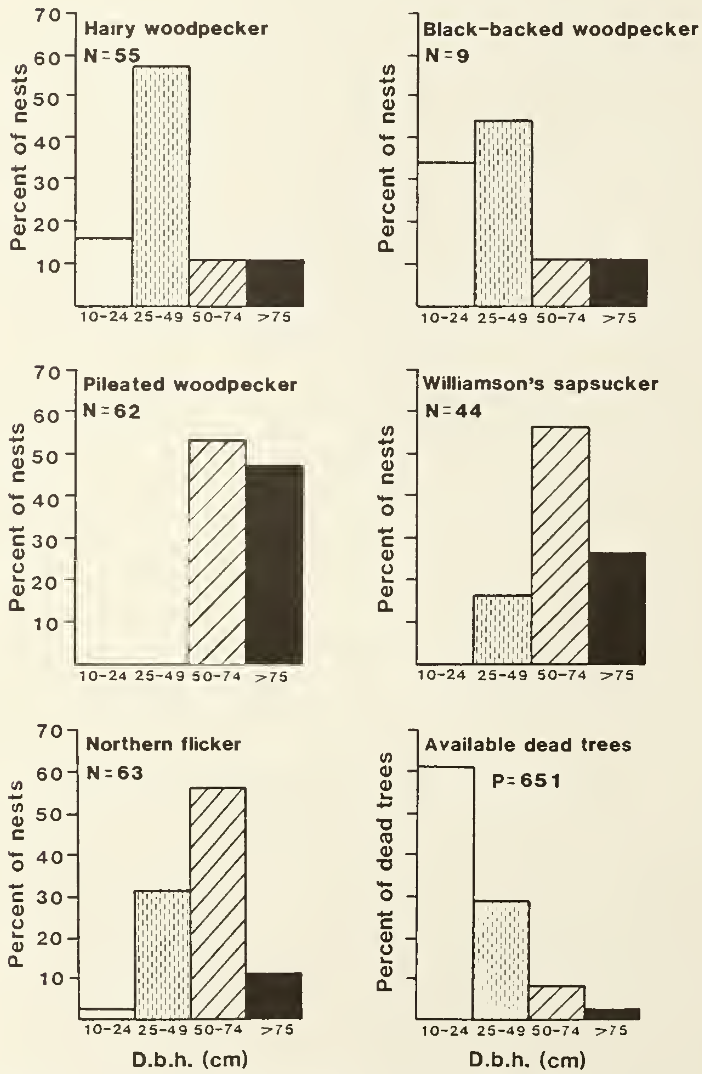


Figure 1.—Diameter at breast height (d.b.h.) of dead trees used for nesting by five woodpecker species and of a sample of available dead trees. N is the number of nest trees and P is the number of dead trees.

Table 1—Frequency and mean (standard deviation) of measurements of nest tree characteristics for 5 woodpecker species

Characteristic	Pileated woodpecker	Hairy woodpecker	Northern flicker	Williamson's sapsucker	Black-backed woodpecker	Available snags
Tree species: 1/	* 2/	*	*	*		
Ponderosa pine	60	68	81	40	67	48
Lodgepole pine	0	17	3	0	27	24
Western larch	39	10	3	41	6	9
Douglas-fir	0	5	13	10		16
Grand fir	1	0	0	9	0	3
Diameter at breast height (cm)	76 (13.3)*	42 (21.6)*	56 (17.1)*	70 (26.4)*	37 (21.1)	27 (16.9)
Tree diameter at nest (cm)	57 (12.7)	26 (11.3)	46 (16.8)	43 (19.5)	30 (6.9)	--
Height (m)	28 (9.1)*	15 (9.8)*	15 (9.2)*	24 (10.1)*	19 (9.9)*	14 (6.8)
Hole height (m)	15 (5.6)	8 (6.0)	8 (6.2)	15 (7.1)	5 (6.2)	--
Percent bark	34 (33.9)*	84 (29.2)*	66 (39.7)*	87 (21.0)	97 (6.7)	91 (23.7)
Percent branches	25 (29.0)*	59 (35.5)*	34 (36.7)*	61 (35.6)*	85 (27.9)	68 (36.0)
Percent needles	4 (17.8)	10 (27.2)	10 (28.7)	42 (45.1)	43 (48.5)	6 (19.6)
Percent top broken	12 (16.2)*	20 (26.5)*	33 (29.5)*	14 (21.1)*	0.3 (1.3)	9 (22.4)
Lean	7 (7.0)*	6 (8.0)	9 (8.4)	6 (7.6)	6 (9.0)	5 (6.6)
Sample size	63	59	68	86	15	652

1/ Percent of nest trees by tree species; remaining characteristics are averages.

2/ Asterisks identify variables used in significantly different frequencies ($P \leq 0.01$) from available dead trees.

Table 2—Average (standard deviation) measurements at nest sites for 5 woodpecker species

Measurement	Pileated woodpecker	Hairy woodpecker	Northern flicker	Williamson's sapsucker	Black-backed woodpecker	Available habitat
Live stem density (number/0.1 ha)	38 (16.4)* 1/	13 (10.5)*	15 (12.3)	22 (15.0)*	17 (16.5)*	19 (12.8)
Dead stem density (number/0.1 ha)	7 (6.5)*	11 (11.5)*	5 (5.8)	6 (6.1)*	18 (18.9)*	5 (8.6)
Basal area (m^2/ha)	30 (15.6)*	18 (10.3)*	14 (8.7)*	19 (10.2)*	20 (11.9)*	45 (19.4)
Percent canopy	74 (22.4)	39 (26.1)	35 (23.5)	60 (26.2)	46 (25.5)	64 (26.8)
Lower canopy height (m)	14 (4.2)	11 (4.5)	11 (4.3)	13 (4.5)	10 (3.2)	10 (4.0)
Upper canopy height (m)	28 (5.3)*	22 (8.3)*	25 (7.0)	27 (6.3)*	22 (8.1)	24 (6.0)
Percent ground cover	46 (27.2)*	57 (25.0)*	59 (27.2)*	54 (28.2)*	58 (31.1)	36 (23.6)
Distance to water (m)	514 (429.1)*	638 (580.6)*	489 (473.0)*	330 (449.0)*	609 (417.2)	317 (207.3)
Distance to clearing (m)	38 (64.7)	11 (21.1)	12 (21.6)	20 (34.7)	9 (10.8)	26 (35.6)
Number of stumps (number/0.1 ha)	1 (2.2)*	3 (5.2)*	3 (3.8)*	3 (3.0)*	2 (2.7)*	8 (10.0)
Percent logs	13 (12.0)	9 (11.8)*	7 (5.3)*	10 (9.0)	6 (6.1)*	13 (11.3)
Size logs (cm)	24 (13.6)	24 (11.6)	33 (15.0)*	31 (14.9)*	23 (7.0)	21 (11.1)
Slope gradient	20 (11.3)	10 (10.5)*	14 (14.3)*	17 (14.6)	12 (10.1)	20 (15.6)
Sample size	63	59	68	86	15	367

1/ Asterisks identify variables used in significantly different frequencies ($P \leq 0.01$) from available habitat.

Many habitat characteristics in the 0.1-ha plot surrounding a tree occurred in significantly different frequencies than if selected at random from available habitat (table 2). Five variables (stem density, upper canopy height, ground cover type, basal area, and stump density) best discriminated between nest sites and systematically sampled plots throughout the habitat. Eighty-three percent of the nests occurred in grand fir forest types (fig. 2), and 95 percent were in stands with at least two canopy levels. Two-thirds of the nest sites contained more than 75 percent canopy closure. Grass or forb vegetation predominated (92 percent) at nest sites. More dead trees and live trees over 30 cm d.b.h. (diameter at breast height) occurred at nest sites than at sample plots in grand fir types. Fewer than five stumps occurred in 95 percent of the nest habitats.

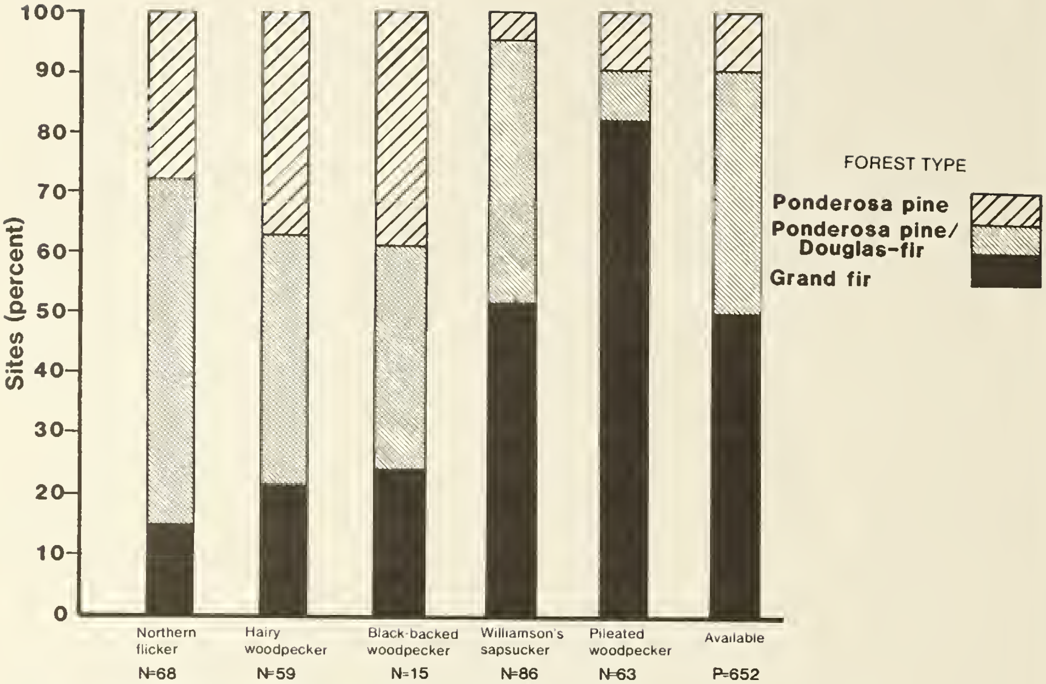


Figure 2.—Percentage of nest sites for five woodpecker species and of available habitat by forest type. N is the number of nest sites and P is the number of sample sites.

Hairy woodpecker.—Ninety-three percent of 59 hairy woodpecker nests were located in dead trees. Ponderosa pine made up the greatest percentage of nest trees, although all tree species except grand fir were used (table 1). D.b.h. and the percent of top broken off were the best discriminators between dead trees used and those not used. Raphael and White (1984) report similar findings. Snags 25 to 50 cm d.b.h. were preferred (fig. 1). Fifty-one percent of the nest trees had broken tops. The mean amount of bark and limbs remaining were 84 and 59 percent, respectively, which suggested that nest trees had been dead less than 5 years.

Characteristics of the habitat around nest trees were significantly different than those of available habitat (table 2). Basal area was the best discriminator between used and available habitat. Seventy-eight percent of the nests occurred in the ponderosa pine forest types (fig. 2). Ridges, low slope gradients, and southerly exposures were preferred. Hairy woodpeckers nested in relatively open stands with low basal areas ($\bar{x}$ = 17 m^2/ha), low stem densities ($\bar{x}$ = 13 per 0.1 ha), and open canopies (table 2). Densities of dead trees at nest sites were higher than densities at sampled plots in the ponderosa pine-associated forest types. About three-fourths of the nest sites contained more than five dead trees per 0.1 ha, less than five stumps per 0.1 ha, and very little dead and downed woody material. Although we observed hairy woodpeckers excavating nests at a later date than most other species (fig. 3), their young fledged the earliest (fig. 4). Forty-seven percent of the nests had young fledge during the week of 22 June.

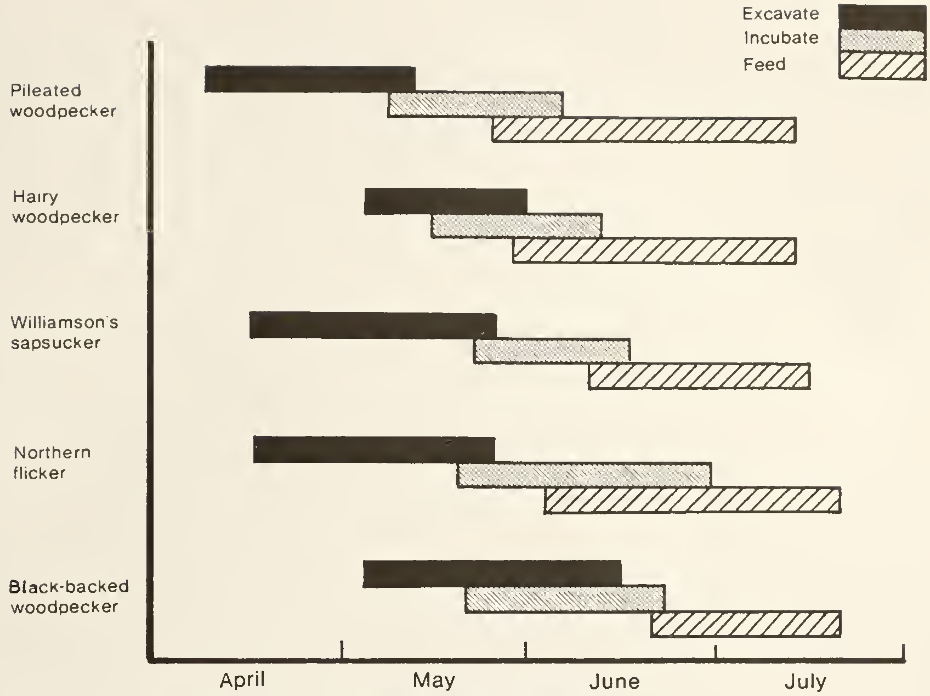


Figure 3.—The dates five woodpecker species were observed excavating, incubating, and feeding nestlings.

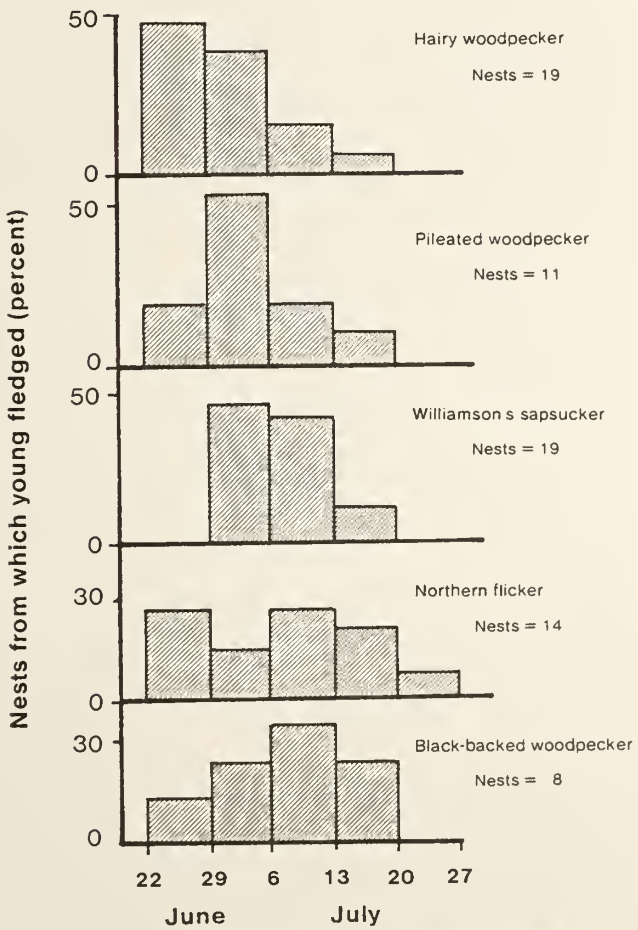
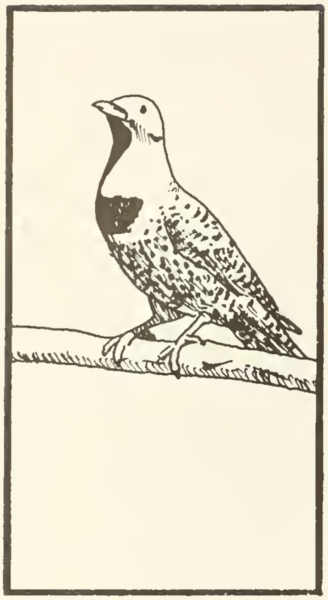


Figure 4.—The dates when young woodpecker species fledged.



Northern flicker

Northern flicker.—Ninety-five percent of 68 northern flicker nests occurred in dead trees. All the nest tree characteristics measured (except percent of needles) were significantly different from the characteristics of available dead trees (table 1). D.b.h. was the best discriminator between dead trees used and those not used.

Northern flickers frequently (79 percent) nested in ponderosa pine (table 1) and preferred snags greater than 50 cm d.b.h. (fig. 1). Seventy-one percent of the nest trees had broken tops, 72 percent had less than half their original limbs, and 68 percent had more than half the bark. Most nest trees had been dead more than 5 years.

Eighty-five percent of the nest trees were in ponderosa pine types (fig. 2). Ridgetops, slope gradients less than 10 percent, and southerly aspects were preferred. Basal areas was the best discriminator between used and unused habitat. Basal areas of less than 34 m^2/ha occurred at 67 of the 68 nest sites. Stem densities of less than 25 trees per hectare were selected. The low stem density and basal area influenced the high amount of herbaceous ground cover (59 percent) and low rate of canopy closure (35 percent). We believe ponderosa pine types provided open stands for nest sites adjacent to grasslands where the birds foraged.

Northern flickers had the greatest span in nesting and fledging dates of the woodpeckers (figs. 3 and 4).

Williamson's sapsucker.—Of 86 nests located for the Williamson's sapsucker, 51 percent occurred in dead trees and 49 percent in live trees. Western larch comprised the majority (62 percent) of the live trees with nests, although dead western larch, ponderosa pine, Douglas-fir, and grand fir were also used. All the measured characteristics of dead trees used for nesting, except percent of needles and amount of lean, were significantly different than those characteristics of available snags (table 1). D.b.h. was the best discriminator between dead trees used and dead trees available but unused.

Nest trees averaged 70 cm d.b.h., and 64 percent had broken tops. Most nest trees (73 percent) retained three-fourths of the original bark, and an average of 61 percent of the branches remained. Of the nests in dead trees, a d.b.h. greater than 50 cm was preferred (fig. 1). These conditions suggested that nest trees were alive or had been dead less than 3 years. Because the Williamson's sapsucker is a poor excavator (Spring 1965), it nests in live or recently dead trees with advanced decay in the heartwood (Erskine and McLaren 1972, Miller and others 1979, Shigo and Kilham 1968).

Although all forest types contained sapsuckers, 53 percent of the nests occurred in the grand fir types (fig. 2). Basal area was the best discriminator between used and unused habitat. This species preferred stands with less than 75 percent canopy closure, basal areas less than 34 m^2/ha, two or three canopy layers, and more than one dead tree per 0.1 ha. The surrounding habitat contained less than five stumps per 0.1 ha, shrub vegetation, and logs larger than 25 cm in diameter.

We suspect that most nests occurred in grand fir forest types because these stands provide large, decayed, and deteriorating western larch and ponderosa pine suitable for nest sites. Live Douglas-fir trees were also abundant here and provided a source of sap. Williamson's sapsuckers nested at a later date than some of the woodpeckers (fig. 3) and fledged young primarily in July (fig. 4).

Black-backed woodpecker.—Sixty percent of the 15 black-backed woodpecker nests were in dead trees. Ponderosa pine, lodgepole pine, and western larch were used (table 1). Nests usually occurred in small-diameter (< 50-cm d.b.h.), tall (>15 m), recently dead (<5 years) trees. Ponderosa pine forest types contained 73 percent of the nest sites (fig. 2). Nests occurred in stands with a mean canopy closure of 46 percent and basal area of 20 m^2/ha. More than three-fourths of the nest sites contained less than five stumps per 0.1 ha, less than 10 percent log cover, and more than five dead trees per 0.1 ha.

The preference for small-diameter (<50 cm d.b.h.) (fig. 1) trees was unusual as most woodpeckers nested in larger dead trees (Mannan 1977, McClelland and others 1979, Raphael and White 1978, Scott 1978). Short (1974) states that the smaller woodpeckers reduce competition for their nests if they drill their cavities in trees too narrow for expansion by larger woodpeckers. McClelland and others (1979) think three-toed woodpeckers avoid drilling through the thick sapwood of large trees to get to the decayed heartwood. In most conifers, sapwood decays more rapidly than heartwood and should be more suitable for excavation. We believe the black-backed woodpecker prefers dead pines because pines have a thicker layer of sapwood than do other tree species of the same size. We also believe trees less than 50 cm d.b.h. are preferred because they contain a higher percentage of sapwood than do trees greater than 50 cm d.b.h., and this species often excavates nests in sapwood.

Black-backed woodpeckers nested and fledged young at a later date than the other four species. Young fledged from nests after 6 July at 63 percent of the nests.

Resource partitioning.—Although yellow-bellied sapsuckers and white-headed and three-toed woodpeckers nested in the study area, less than 10 nests were located and they are not discussed. Black-backed woodpeckers were not included in the discriminant analysis because we located too few nests.

Pileated and hairy woodpeckers, northern flickers, and Williamson's sapsuckers nested in dead trees averaging more than 40 cm d.b.h. and selected dead broken-topped ponderosa pines for their nests. There were, however, variations in tree condition, forest type, and other characteristics, which separated the habitat of each species.

The analysis correctly classified 67 percent of the nests in the appropriate species category. Forest type was the variable that best discriminated among nest sites of the four species. Use of forest type separated pileated woodpeckers and Williamson's sapsuckers (both used the grand fir types) from northern flickers and hairy woodpeckers (both used the open ponderosa pine types). Bark condition was the second-best discriminating variable and, in combination with forest type, distinguished among nest sites of all species. Pileated woodpeckers nested in dead trees with less bark than those used by Williamson's sapsuckers. Northern flickers nested in dead trees that had less bark than trees used by hairy woodpeckers. Including percent of needles, stem density, and d.b.h. also resulted in significant F-values.

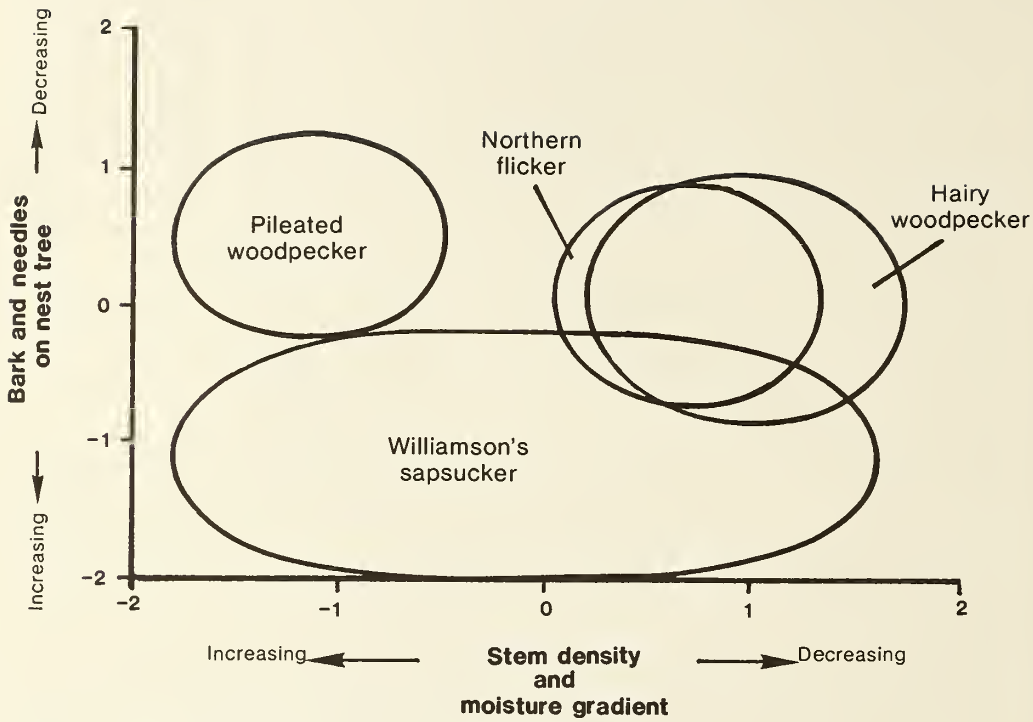


Figure 5.—Overlap in characteristics of the nest snag and habitat surrounding nests for four woodpecker species. The ellipses are described by the mean ± one standard deviation of the first (X-axis) and second (Y-axis) discriminant function scores of each species.

Each species' respective nesting niche was calculated with the mean and one standard deviation of the first and second discriminant function scores (fig. 5). Pileated woodpeckers nested in trees with less bark and needles and the area around nests had a higher moisture gradient and stem density than the trees and areas used by other woodpeckers. The moisture gradient was lowest in the ponderosa pine forest types, moderate in the Douglas-fir forest types, and highest in the grand fir forest types. Williamson's sapsuckers nested in stands with a wide range of moisture gradients and stem densities but nested in live or recently dead trees that retained a large portion of bark and needles. Nest trees of pileated woodpeckers and Williamson's sapsuckers could not be distinguished 6 to 7 percent of the time.

The greatest overlap in niche existed between hairy woodpeckers and northern flickers. Both nested in trees that retained little bark and needles and in stands with a lower moisture gradient (ponderosa pine forest type) and lower stem density than stands used by other species. Hairy woodpeckers had a larger niche and used slightly drier forest types than those used by northern flickers. Nest trees of these two species could not be distinguished 13 to 29 percent of the time. We believe these four species partitioned the habitat by using different forest types or by nesting in different types of trees in the same forest types.

Foraging

Pileated woodpecker.—During this study, pileated woodpeckers fed by excavating two-thirds of the time and by scaling the remainder of the time (fig. 6). This species foraged in logs, live trees, and dead trees 36, 35, and 29 percent of the time, respectively (fig. 7). The grand fir forest types were preferred and contained 64 percent of the feeding sites.

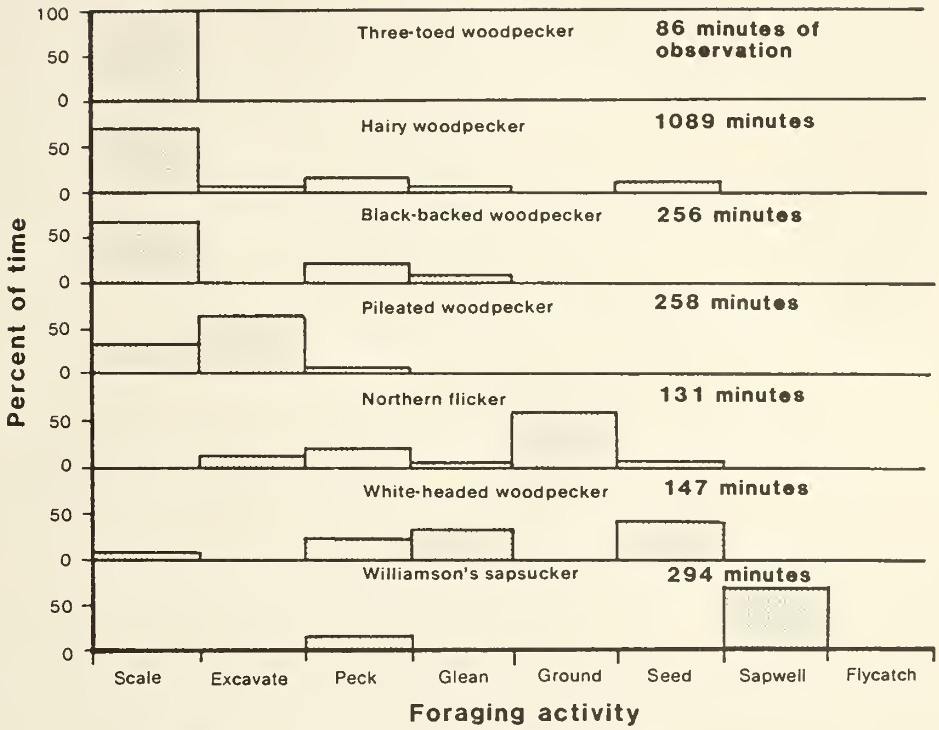


Figure 6.—Percentage of time seven woodpecker species engaged in foraging activities. Observations on any bird were limited to 15 minutes.

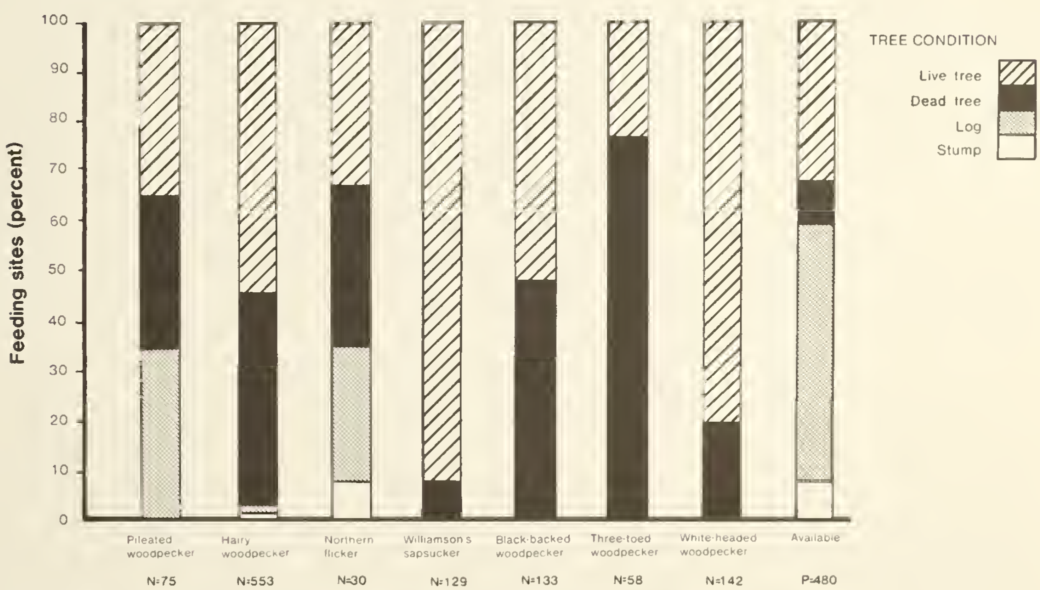
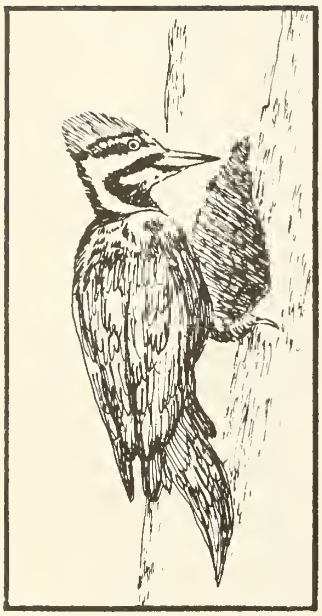


Figure 7.—Percentage of foraging sites of seven woodpecker species that occurred in four condition classes. N is the number of foraging sites and P is the number of sample sites.

Dead and downed material used as feeding sites were significantly different from available dead and downed material in d.b.h., length, and tree species. The discriminant analysis entered two variables (d.b.h. and forest type) that distinguished sites used for foraging from available sites. Pileated woodpeckers used Douglas-fir and western larch logs of large diameter (>25 cm) and long length (>15 m) disproportionately more than random selection would account for. Seventy-eight percent of the downed material used for foraging had less than one-fourth of the bark, branches, and needles remaining.

The amount of bark and branches remaining and the d.b.h. of dead trees used for feeding versus available dead trees were significantly different. D.b.h. and forest type distinguished between used and available dead trees. Dead trees greater than 50 cm d.b.h. with at least three-fourths of their bark but less than three-fourths of their branches characterized most of the feeding sites (75 percent) in dead trees. Dead trees retained an average of 12 percent of the needles. These conditions suggested that trees dead only long enough to lose some limbs but not much bark were preferred feeding sites. The approximate time span since death was 5 years. Mannan (1977) also reports foraging by this species on large-diameter snags.


Pileated woodpecker

Live trees used as feeding sites were significantly different from available live trees in d.b.h. and height. Large trees were preferred; 46 percent of the trees used for feeding were greater than 50 cm d.b.h., and 77 percent of the trees were taller than 15 m. Percent of bark was the best discriminator between trees used for feeding sites and available trees because portions of the bark had been removed as a result of the foraging activity.

Pileated woodpeckers fed extensively on carpenter ants (*Camponotus* sp.). Sanders (1970) found that carpenter ants nest only in logs, stumps, and dead trees greater than 30 cm in diameter and in live trees greater than 20 cm d.b.h. The ants use larger diameter material because the smaller diameter material lacks permanence, decays faster, and forces the ants to move more often. We suspect that pileated woodpeckers selected woody material greater than 25 cm in diameter because ants were more abundant there. In addition, larger diameter dead wood generally contains higher densities of woodborers because of additional surface area and moisture retention.[1/]

A third of the foraging by pileated woodpeckers consisted of scaling for bark beetles in and under the bark of live trees. We presume this woodpecker favored the larger diameter trees because these trees have higher densities of beetle larvae (Parker and Stevens 1979).

Although an analysis of pileated woodpecker fecal material collected at the Starkey Experimental Forest showed 95 percent of the diet consisted of carpenter ants in 1980-81 (Beckwith and Bull, 1985), a portion of the diet must have consisted of bark beetles in 1976-77 because pileated woodpeckers were observed scaling about a third of the time. The discrepancy was caused by a change in prey availability from 1976 to 1981. The mountain pine beetle population was at a peak in 1977, but by 1981 was at a low level. We believe the woodpeckers preyed on the bark beetles when the beetles were abundant but changed to other prey when the beetles declined.

[1/]Personal communication, B.E. Wickman, Forestry and Range Sciences Laboratory, Route 2, Box 2315, La Grande, Oregon 97850.

Black-backed woodpecker.—Black-backed woodpeckers scaled 72 percent of the time and pecked and gleaned the remainder of the time (fig. 6). All forest types were used and 97 percent of the foraging occurred on ridges. Live and dead trees were used in approximately equal proportions (fig. 7). Live lodgepole pine was preferred for foraging and was used 54 percent of the time. Tree species was the best discriminator between live trees used and those not used.

D.b.h., height, and percent of needles were significantly different for dead trees used for feeding from those of available dead trees. Percent of needles was the best discriminator between used and available dead trees. This species fed in trees that averaged 34 cm d.b.h. and 19 m tall, and retained 41 percent of their needles. The retention of needles suggested that the trees had been dead less than 2 years.

The larvae of wood-boring beetles make up three-quarters of the black-backed woodpecker's diet (Bent 1964). Wickman (1965) and Baldwin (1960) report this species feeding on woodborers (*Monochamus oregonensis*) and Engelmann spruce beetles (*Dendroctonus engelmanni*).

Three-toed woodpecker.—Three-toed woodpeckers acquired food exclusively by scaling (fig. 6), and 78 percent of the feeding sites were in dead trees (fig. 7). All characteristics of foraging sites except bark condition were significantly different than if the sites had been selected at random from available dead trees. Forest type and percent of needles remaining were the best discriminators between habitat used and not used. Three-toed woodpeckers scaled dead trees that averaged 24 cm d.b.h. and 18 m tall, and that retained most of their bark (93 percent), limbs (76 percent), and a portion of the needles (21 percent). These conditions describe trees that had been dead less than 3 yr. Koplin (1969) also observed this species feeding on insects in the bark of freshly killed trees. All feeding occurred on the trunk at an average height of 7 m (table 3). This species used grand fir types 69 percent of the time. All feeding activity took place on lodgepole pine trees and on flat terrain. Birds occurred only in grand fir forest types that contained lodgepole pine.

Table 3—Frequency and mean values (standard deviation) of tree characteristics used for foraging by 7 woodpecker species, condition classes combined

Characteristic	Pileated woodpecker	Black-backed woodpecker	Three-toed woodpecker	Hairy woodpecker	White-headed woodpecker	Williamson's sapsucker	Northern flicker
Tree species: 1/							
Ponderosa pine	27	37	--	51	100	30	40
Lodgepole pine	8	41	100	33	--	9	3
Western larch	18	10	--	5	--	14	7
Douglas-fir	39	10	--	5	--	47	50
Grand fir	8	2	--	5	--	--	--
D.b.h. (cm)	51 (26.1)	31 (16.0)	24 (6.7)	30 (15.1)	44 (14.8)	41 (18.6)	56 (11.8)
Height (m)	20 (12.1)	18 (8.6)	19 (4.5)	16 (7.2)	20 (5.9)	21 (8.1)	20 (10.0)
Percent bark	64 (42.6)	97 (7.1)	94 (6.0)	97 (9.8)	100 (1.1)	98 (9.9)	58 (47.4)
Percent branches	52 (44.8)	89 (23.9)	81 (20.2)	92 (18.7)	98 (5.3)	94 (19.4)	35 (37.0)
Percent needles	37 (47.2)	72 (40.6)	38 (43.5)	72 (38.8)	90 (27.5)	91 (25.4)	13 (26.0)
Foraging height	9 (7.9)	10 (6.8)	7 (3.5)	8 (5.9)	7 (5.0)	10 (6.2)	14 (8.9)
Sample size (number of trees)	75	133	58	553	142	129	30

1/ Percent of all foraging sites that occurred, by tree species. For other variables, means and standard deviations are presented.

White-headed woodpecker.—White-headed woodpeckers spent 41 percent of their time extracting seeds from pine cones (fig. 6). We assumed they were feeding on seeds although they could have been taking insects from the cones. As 80 percent of the foraging took place on live trees, we only analyzed feeding sites on live trees.

Forest type, d.b.h., and tree species at foraging sites were significantly different than if those sites had been selected at random from available habitat. Forest type was the best discriminator between used and available trees. Only ponderosa pine (table 3) and ponderosa pine forest types were used. The birds preferred trees greater than 25 cm d.b.h., and foraged on the lower 4 m of the trunk more than three-fourths of the time.

We suspect ponderosa pine was used because the layered bark provides crevices sheltering numerous insects. Larger trees (and areas lower down on the trunk) have greater surface area and deeper cracks, which presumably provide refuge for insects. In addition, trees over 25 cm d.b.h. are the best seed producers (Fowells and Schubert 1956).

Northern flicker.—Northern flickers spent 65 percent of their foraging time (fig. 6) on the ground and lesser amounts of time excavating, pecking, gleaning, and seed harvesting in live and dead trees, downed material, and stumps (fig. 7). This variety of strategies and condition classes portrays the versatile and opportunistic nature of this species.

In areas used for ground foraging, the vegetative ground cover and bare area averaged 52 and 40 percent, respectively; rock and downed material made up the remainder. Mean height of vegetation was 10 cm. Percent of low ground cover and height of ground vegetation may have enhanced the accessibility of prey species. Grasses, generally fescue (*Festuca* spp.) or pinegrass (*Calamagrostis rubescens*), dominated most (81 percent) of the feeding sites. Fifty-nine percent of these feeding sites occurred in ponderosa pine types. Lawrence (1967), Stallcup (1968), and Jackman (1975) also report that northern flickers feed extensively on the ground, primarily to search for ants.

Williamson's sapsucker.—Both the Williamson's and yellow-bellied sapsuckers occurred in the study area, but we never observed the latter species foraging, so our comments are restricted to the Williamson's sapsucker. Sapsuckers fed at sap wells three-fourths of the time and pecked or gleaned the rest of the time (fig. 6). Tate (1973), Jackman (1975), and McClelland (1977) report extensive use of sap; Stallcup (1968) observed this species gathering ants on trunks and eating phloem.

We analyzed only feeding sites in live trees because 93 percent of the foraging occurred there. Tree species, d.b.h., and height were significantly different at foraging sites than if sites had been selected at random from available live trees. D.b.h. was the best discriminator of the three variables that distinguished between feeding sites and available habitat. Douglas-fir and western larch trees were preferred for feeding and were used 46 and 14 percent of the time, respectively. Trees had a mean d.b.h. and feeding height of 21 cm and 10 m, respectively (table 3). Grand fir forest types contained half the foraging sites. The high foraging height enabled the birds to reach the phloem through a thin layer of bark even though the trees were larger and thick barked at the base (Oliver 1970). Both Stallcup (1968) and Oliver (1970) report sapsuckers using ponderosa pine trees extensively; their study areas were, however, stands solely of ponderosa pine.

Hairy woodpecker.—Scaling was the predominant feeding activity (75 percent) of hairy woodpeckers; pecking, seed harvesting, and gleaning comprised the remainder (fig. 6). The two ponderosa pine forest types contained 59 percent of the feeding sites, although the grand fir forest types were used in a greater proportion than their occurrence at Starkey. Ridges were also used in greater frequency than expected. Live and dead trees were used, respectively, 55 and 42 percent of the time as feeding sites (fig. 7).

Hairy woodpeckers preferred to feed in live lodgepole pine and western larch and used ponderosa pine in proportion to its occurrence. Tree species was the best discriminator between used and unused trees. The hairy woodpecker showed a preference for trees greater than 25 cm d.b.h. Of the feeding sites recorded in dead trees, 67 percent occurred in ponderosa pine. Dead trees greater than 25 cm d.b.h. and 15 m tall were preferred. Dead trees retaining more than three-fourths of their bark and limbs were used most of the time (82 percent). Dead trees used for foraging retained an average of 47 percent of the needles, which suggested that these trees had been dead 1-3 years.

Resource partitioning.—During this study we detected four ways that woodpeckers partition resources: (1) they use different substrates, (2) they occupy different forest types, (3) they use different foraging techniques, and (4) they use resources at different times (young fledged at different times).

We included nine habitat variables in the discriminant function analysis to determine which variables could distinguish the foraging habitats among the seven woodpecker species. The analysis correctly classified 42 percent of the feeding sites according to species. Eight of the nine variables had significant F-values ($P \leq 0.01$). Percent of bark was selected as the best discriminator. This variable alone, however, could not separate feeding sites of pileated woodpeckers and northern flickers or of those species that fed on live trees or recently dead trees.

When d.b.h., the second-best discriminator, was considered, feeding sites of white-headed woodpeckers could be distinguished from those of all other species except Williamson's sapsuckers. By including tree condition in the analysis, feeding sites of pileated woodpeckers and northern flickers could be distinguished because the former species fed in dead and downed woody material. When forest type was included, Williamson's sapsuckers were separated from the white-headed woodpeckers; the former preferred grand fir forest types and the latter fed exclusively in ponderosa pine forest types. Even when land form and tree species were considered, significant differences ($P \leq 0.01$) were not detected between hairy and black-backed woodpeckers.

The foraging niche of each species was calculated using the mean and one standard deviation of the first two discriminant functions (fig. 8). Considerable overlap occurred among most species and particularly between the hairy and black-backed woodpeckers. This analysis did not include, however, foraging activities or locations on trunk or limb as variables, both of which can separate species ecologically.

Different foraging activities presumably result in the acquisition of different prey (Williams 1975). Foraging activities were significantly different among all woodpecker species except the hairy and black-backed woodpeckers. In Illinois, Williams (1975) found the foraging activities of four woodpecker species to be significantly different and felt this allowed coexistence by reducing competition for food. Differentiation of foraging behavior was the major factor that permitted different woodpecker species to coexist in ponderosa pine forests in Colorado (Stallcup 1968). In California, Raphael (1980) and Raphael and White (1984) found that foraging methods, rather than differences in microhabitat, are responsible for the foraging segregation of a group of cavity nesters.

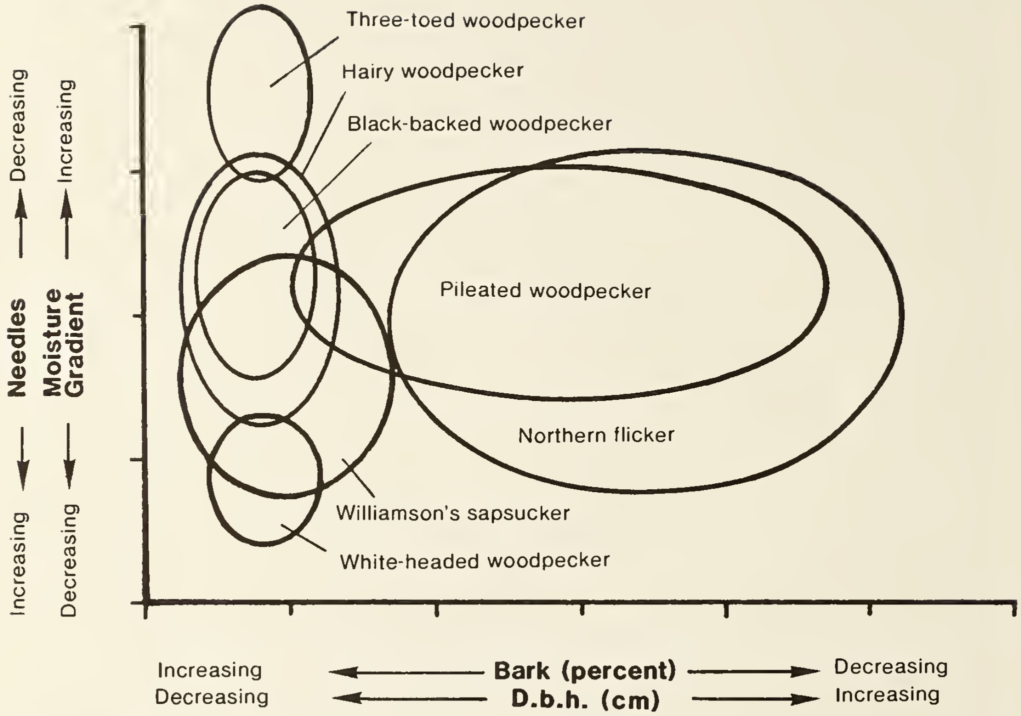


Figure 8.—Niche overlap in woodpecker use of live, dead standing, and downed trees for feeding. Ellipses are described by the mean ± one standard deviation of the first (X-axis) and second (Y-axis) discriminant function scores of each species.

The hairy and black-backed woodpeckers used similar habitats and foraging activities during our study. Feeding location was the primary habitat difference between hairy and black-backed woodpeckers as the latter species foraged only on trunks. The hairy woodpecker scaled and pecked on branches 27 percent of the time.

Another means of partitioning is temporal separation of resource utilization. Hairy woodpeckers fledged young the earliest and black-backed woodpeckers fledged young the latest of the woodpecker species. This temporal difference in breeding phenology may augment the demand for food at different times by these two species.

Habitat partitioning and foraging strategies acted to separate the feeding habitat of seven species. Hairy and black-backed woodpeckers showed the most overlap as both fed in the same habitat with the same strategies. We suspect some competition could exist between these two species if resources were limited.

Implications for Management

Managers of public forest land in the United States have begun to pay attention to maintaining population levels of cavity nesting birds in managed forests (Davis and others 1983). Most management action has been predicated on simple management models that involve the species, size, numbers, and distribution of snags (see Thomas and others 1979 as an example). The information from this study indicates how the primary excavators (woodpeckers) partition and exploit habitat. Those insights reveal the attributes of habitat, beyond snags, that are important to the individual species.

Most currently used models, such as those of Thomas and others (1979) and Davis and others (1983), assume that if snags are available in appropriate sizes, numbers, and distribution, then the natural succession or the guided growth of the managed forest will produce adequate habitat conditions for the woodpeckers and the secondary cavity nesters that use the abandoned cavities. This assumption is probably correct. If adequate habitat is not provided, however, for all the sympatric species of woodpeckers, more specific habitat models can be derived from such information as presented here.

Acknowledgments

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English Equivalents

1 centimeter (cm) = 0.39 inch
1 meter (m) = 39.37 inches or 3.28 feet
1 kilometer (km) = 0.62 mile
1 hectare (ha) = 2.47 acres
1 square meter per hectare (m^2/ha) = 4.33560 square feet per acre

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Research Note PNW-445

July 1986

Effect of Operational Fertilization on Foliar Nutrient Content and Growth of Young Douglas-Fir and Pacific Silver Fir

P.H. Cochran, W. Lopushinsky, and P.D. McColley

Abstract

Nitrogen concentration in current year needles of Pacific silver fir (*Abies amabilis* Dougl. ex Forbes) showed a significant ($P \leqslant 0.05$) 1.9-fold increase after fertilization with sulfated urea (40-0-0-6), compared with a nonsignificant 1.3-fold increase in Douglas-fir (*Pseudotsuga menziesii* (Mirbel) Franco) and a significant ($P \leqslant 0.05$) 2.5-fold increase in bracken fern (*Pteridium aquilinum* (L.) Kuhn.). Nitrogen concentration in needles of unfertilized Pacific silver fir (0.99 percent) indicated a deficiency of nitrogen, whereas the concentration in Douglas-fir (1.35 percent) was above threshold levels. Total sulfur concentration in needles ranged from 0.05 to 0.09 percent for both species, with no significant effect of fertilization. Fertilization resulted in increased needle surface area for Pacific silver fir.

Diameter growth of the trees, stand basal area growth, and volume growth were all increased by fertilization. More trees on the fertilized plots had broken tops, and rates of height growth for undamaged trees were greater for the fertilized plots; but the difference attributed to fertilization was not quite significant at the 5-percent level of probability.

Keywords: Foliar analysis, nitrogen fertilizer response, increment, Pacific silver fir, Douglas-fir.

Introduction

Most of the Wenatchee National Forest near Cle Elum, Washington, is in alternate sections interspersed with privately owned land, much of which has been clearcut. The effects of very large clearcuts on runoff, erosion, timing of peak streamflow, and fish and wildlife habitat, although largely undocumented, are thought to be substantial. A management objective for National Forests in this area is to accelerate the growth of newly established stands and reduce possible adverse post-harvest effects on the land and associated resources. Published literature (Miller and Fight 1979, Regional Forest Nutrition Research Project 1979) suggests that fertilization is one way to increase tree growth, but there has been little experience with fertilization in these particular Forests. In 1979 and 1980, a nitrogen-sulfur fertilizer was applied to about 2,000 acres of conifer stands in the Wenatchee National Forest west of Cle Elum. Sulfur was included in the formulation along with

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nitrogen because previous studies have shown a positive response to sulfur in eastern Washington and Oregon (Geist 1971, Klock and others 1971). The fertilization program was conducted by personnel of the Wenatchee National Forest. This study was done to determine if the nitrogen-sulfur fertilization increased tree growth.

Methods

The study areas are in the Wenatchee National Forest west of Cle Elum and southeast of Snoqualmie Pass in the Cascade Range in Washington. Elevation ranges from 2,400 to 3,500 feet. All aspects were represented. Slopes vary from 0 to 70 percent, but most slopes are 45 percent or less. Annual precipitation ranges from 60 to 95 inches per year, of which about 50 percent occurs as snow. Mean annual temperature is 39 °F; mean temperature is 24 °F in January and 57 °F in July. Soils in the study area are deep sandy loams or loamy sands formed in glacial till materials and are classified as medial-skeletal Typic Cryorthods.[1] Study areas with these soil types were selected because they are relatively productive and are typical of forest soils in the fertilized area, and in the Cle Elum area in general.

Areas selected for fertilization were well-stocked clearcuts 50 to 60 acres in size, which had been planted with Douglas-fir (*Pseudotsuga menziesii* (Mirbel) Franco).[2] Other naturally occurring tree species included Pacific silver fir (*Abies amabilis* (Dougl.) Forbes), western redcedar (*Thuja plicata* Donn), western white pine (*Pinus monticola* Dougl. ex D. Don), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), and black cottonwood (*Populus trichocarpa* T. & T. ex Hook.). Most areas had been precommercially thinned, which left trees of sapling to small pole size. Understory vegetation consisted of vine maple (*Acer circinatum* Pursh), snowbrush (*Ceanothus velutinus* var. *velutinus* Dougl. ex Hook.), huckleberry (*Vaccinium* spp.), and bracken fern (*Pteridium aquilinum* (L.) Kuhn.).

Study plots were established in eight of the units to be fertilized. Two 1-acre square plots were established in each of the eight units. Within each 1-acre plot, four 1/20-acre square subplots were laid out with boundaries of the subplots parallel to the boundaries of the main plots. The outer boundaries of subplots were 38.5 feet within the boundaries of the 1-acre plots. One of the two 1-acre plots was randomly selected as a control in each unit, and corners were marked with weather balloons to assure that no fertilizer was applied to this plot. The rest of the unit (including the other 1-acre plot) was treated with sulfated urea (40-0-0-6) in pellet from, applied by helicopter. Fertilizer traps were placed in the corners of some plots to monitor actual application rates. The traps consisted of aluminum rings 2 square feet in area positioned 2 feet above the ground and supporting a plastic bag to catch the fertilizer pellets. Prescribed rates of fertilization for the eight units were based on soil texture, soil depth, and annual precipitation. Prescribed rates of nitrogen (N) ranged from 275 to 350 lb/acre, but actual rates were as high as 528 lb/acre[3] (table 1). Fertilization was scheduled to be completed by early winter 1979, but inclement weather forced postponement of fertilization in units 6, 7, and 8 until July 1980.

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[1]Wenatchee Resource Inventory, 1976; on file at Wenatchee National Forest, Wenatchee, WA 98801.

[2]Scientific names are from Garrison and others (1976).

[3]We suspect that the helicopter pilots saw the fertilizer traps on some of the units and wanted to be certain that the prescribed rates were applied to the fertilized plots. In areas without traps it was impossible for the pilots to tell where the fertilized plot was located.

Table 1—Rates and dates of application of fertilizer to the 8 units studied[1]

Unit number	Date applied	Prescribed rate of application		Actual rate of application	
		Nitrogen	Sulfur	Nitrogen	Sulfur
		Pounds per acre			
1	11/17/79	275	41	—	—
2	11/18/79	300	45	—	—
3	11/17/79	300	45	—	—
4	11/20/79	300	45	399	60
5	11/20/79	300	45	528	79
6	7/8/80	300	45	—	—
7	7/8/80	300	45	434	65
8	7/15/80	350	53	261	39

[1]Fertilizer was sulfated urea (40-0-0-6) in pellet form.

Foliage Nutrient Content and Surface Area

Foliage samples were collected from Douglas-fir, Pacific silver fir, and one herbaceous species, bracken fern, for determination of nitrogen and sulfur content. Samples were collected from each of four pairs of fertilized and control plots in October and November of 1980 and 1984. Eight trees were sampled in each plot. Conifer foliage was collected from the upper portion of the south side of the crowns by use of a pole pruner. Needles and leaves were removed from the twigs, ovendried at 150 °F, and finely ground.

Nitrogen content (minus nitrate) was determined by a mercury catalyzed standard micro-Kjeldahl technique. Total sulfur was measured with a Leco high frequency induction furnace coupled to an automatic titrator following the method described by Tiedemann and Anderson (1971).[4]

Surface areas of needles from fertilized and control trees were compared for evaluation of possible increases in needle size in response to fertilization. Fifty needles were taken from each of the eight foliage samples collected from each control and each fertilized plot in 1984. Needles were taken from the midportion of the terminal growth extension of the twig. Surface areas (one side) of samples of 50 needles were measured with a Delta-T area measuring system.

A split-plot analysis of variance was used with the data for nitrogen and sulfur content of the foliage. Whole-plots are the control and fertilized treatments, whereas split-plots are time (1979, 1980, and 1984 for the trees and 1980 and 1984 for the bracken fern). Data for needle surface area were analyzed by a paired t-test.

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

Growth Measurements

Height and diameter of all trees on each subplot were measured before the start of the growing season in 1980 and again after five growing seasons. Diameters were measured to the nearest 0.1 inch with a diameter tape, and heights were measured to the nearest 0.5 feet with a height pole. Volumes for each tree were determined from the heights and diameters with the equations for second-growth Douglas-fir developed by Bruce and DeMars (1974).

The average diameter (the diameter equivalent to the average basal area, Dg), the average height, the basal area per acre, and the volume per acre were estimated for each of the 1-acre plots from data for the appropriate 1/20-acre subplots before treatment and five growing seasons after treatment. Periodic annual increments for height, average diameter, basal area per acre, and volume per acre were then determined. Percent inceases in annual growth rates for average diameter, basal area per acre, and volume per acre were calculated for each 1-acre plot by:

$$\text{Percent increase} = \frac{(100)\ (\text{periodic annual increment})}{\text{initial value}}.$$

Paired t-tests ($P \leqslant 0.05$) were used with values for controlled and fertilized plots from each area to test the hypothesis that fertilization did not increase the rate of tree growth. Analysis of covariance was also used for the periodic annual increments of basal area and volume; initial basal area was used as the covariate in the randomized block design. This analysis aids in the visualization of growth rates as a function of treatment and stand density.

Results and Discussion

Foliar Nutrients and Surface Area

Nitrogen concentration of Pacific silver fir needles for all foliage ages ranged from 0.95 to 0.99 percent for control plots and 1.13 to 1.84 percent for fertilized plots (table 2). Fertilization caused a significant increase ($P \leqslant 0.05$) in concentration of nitrogen in needles of silver fir in both 1979 and 1980, and nitrogen concentration in needles of fertilized trees was significantly higher ($P \leqslant 0.05$) in 1980 than in 1979. Year by treatment interaction was significant at the 0.05 level.

In Douglas-fir, nitrogen concentration in needles from control plots ranged from 1.15 to 1.36 percent in 1979, 1980, and 1984, compared with 1.18 to 1.80 percent in needles from fertilized plots. Fertilization apparently increased the nitrogen concentration in both 1979 and 1980, but differences were not significant. Foliage age differences also were not significantly different, nor was year by treatment interaction. Fertilization did result in a significant increase ($P \leqslant 0.05$) in nitrogen concentration in bracken fern collected in 1980.

The nitrogen concentration in Pacific silver fir needles in 1984, 5 years after fertilization, still was higher in fertilized trees than in the controls, but the difference was not significant. By 1984, there was no indication of a fertilizer effect on the nitrogen concentration in Douglas-fir needles. Nitrogen concentration in bracken fern, however, still was significantly higher ($P \leqslant 0.05$) for fertilized plots than for control plots.

Sulfur concentrations in Pacific silver fir needles of all ages from control and fertilized plots ranged from 0.05 to 0.07 percent. In Douglas-fir, sulfur concentrations were slightly higher, ranging from 0.07 to 0.09 percent. Within a given foliage age, there were no differences in sulfur concentrations between fertilized and control trees and no significant differences between years. Sulfur concentration in bracken fern collected in 1980, however, was significantly higher ($P \leqslant 0.05$) for fertilized plots than for control plots. Values for fertilized plots also were higher than those for controls in 1984, but the difference was not significant.

Table 2—Nitrogen and sulfur concentrations in foliage of Pacific silver fir and Douglas-fir trees and of bracken fern from control and fertilized plots

Fertilizer and year of foliage	Pacific silver fir[1]		Douglas-fir		Bracken fern[1]	
	Control	Fertilized[2]	Control	Fertilized[2]	Control	Fertilized
			Percent			
Nitrogen:						
1979	0.99	1.64*	1.36	1.65	—	—
1980	.99	1.84*	1.36	1.80	0.54	1.34*
1984	.95	1.13	1.15	1.18	.97	1.97*
Sulfur:[3]						
1979	.06	.07	.09	.09	—	—
1980	.06	.07	.08	.08	.06	.10*
1984	.05	.05	.07	.07	.05	.07

[1] *Indicates that the mean for the fertilizer treatment is significantly different ($P \leq 0.05$) from the mean for the control treatment.
[2] Samples collected in 1980 were divided into current year (1980) and previous year (1979) foliage. Only current year foliage was collected in 1984.
[3] Total sulfur.

Average needle surface area for Pacific silver fir from fertilized plots was 3.92 square inches per 50 needles compared with 2.82 square inches for control plots, an increase in surface area of 39 percent. The difference was not significant at the 0.05 level, but it was significant at the 0.06 level. For Douglas-fir, needle surface area for fertilized trees was 3.21 square inches per 50 needles compared with 2.91 square inches for control trees, with no significant difference.

The critical level of foliar nitrogen required for adequate growth is 1.15 percent for true firs and 1.20 percent for Douglas-fir (Powers 1983). By these criteria, nitrogen concentrations in 1979 and 1980 needles of Douglas-fir from unfertilized trees in our study were somewhat above threshold levels, whereas nitrogen concentrations in unfertilized Pacific silver fir indicated a deficiency. This may explain the 1.9-fold increase in foliar nitrogen concentration (1980 needles) in silver fir after fertilization compared with only a 1.3-fold increase in Douglas-fir. One concern about forest fertilization is that a large proportion of the added nutrients may be taken up by shallow-rooted vegetation rather than by trees. Bracken fern did in fact show the largest increase in foliar nitrogen (2.5-fold), but total loss to herbaceous vegetation depends on the amount of vegetation present.

Sulfur concentrations from 0.10 to 0.20 percent are considered adequate in foliage of conifer seedlings (Landis 1985). By this criterion, Douglas-fir and particularly Pacific silver fir trees in our study appear to be somewhat deficient in sulfur, but the low levels apparently are not unusual for forest trees. Will and Youngberg (1979), for example, reported a sulfur concentration of 0.06 percent for Pacific silver fir in central Oregon, and Clayton and Kennedy (1980) reported a sulfur concentration of 0.088 percent for current year needles of Douglas-fir in Idaho. Also, there was no increase in foliar sulfur concentration after fertilization in our study.

Similar results have been observed for Douglas-fir seedlings (Radwan and Shumway 1985). The lack of response in foliar concentration may be caused partly by a dilution effect resulting from increased foliar growth.

Growth Increment

The number of live trees per acre at the end of the 5-year monitoring period ranged from 150 to 325 (table 3). During this period there was very little mortality: 11 trees of the 697 trees on the 1/20-acre plots died. There was no evident relationship between mortality and fertilization. All stand characteristics and growth rates were calculated from data for trees alive 5 years after treatment. A total of 37 trees still living at the end of the 5 years (5.4 percent of the live trees) suffered damage. Seven of these trees were partially or completely girdled above the start of live crown, 4 were bent by snow, and 26 had broken tops. Twenty-four of the trees with broken tops were on fertilized plots, a significantly greater number (paired t-test, $P \leq 0.05$) than for the control plots. Miller and Pienaar (1973) reported increased breakage in fertilized Douglas-fir west of the Cascades in winter. They attributed the breakage to greater needle length which resulted in a larger accumulation of ice and snow and greater resistance to wind.

Initial average stand diameters ranged from 3.0 to 6.2 inches, and average heights ranged from 14.4 to 37.7 feet. Initial basal areas ranged from 9.4 to 56.3 square feet per acre and total volume ranged from 79.5 to 1,102 cubic feet per acre (table 3).

Fertilization significantly raised the percent increases in diameter growth and in growth of basal area and volume per acre. The average periodic annual increment for diameter was 0.33 inch for trees on control plots (an 8-percent annual increase) and 0.47 inch (a 12.1-percent annual increase) for trees on fertilized plots. The periodic annual basal area increment averaged 4.3 square feet per acre per year for the control plots (a 19.1-percent annual increase), and 6.1 square feet per acre per year (a 32.1-percent annual increase) for the fertilized plots. The average periodic annual volume increment for the control plots was 90.6 cubic feet per acre per year (a 32.4-percent annual increase), and 107.4 cubic feet per acre per year for the fertilized plots (a 48.4-percent increase). Adjusted means from analysis of covariance for periodic annual basal area growth (fig. 1) were 4.1 square feet per acre per year for the control plots and 6.4 square feet for the fertilized plots. Similar adjusted means for volume growth (fig. 2) were 81.7 and 116.3 cubic feet per acre per year. These adjusted means were significantly higher ($P \leq 0.05$) for the fertilization treatment.

Height growth of all trees on fertilized and control plots averaged 2.3 and 2.1 feet per year, respectively. Differences in these values were not significant. Because more trees experienced top damage on the fertilized plots, a comparison of treatments was made with the height growth of trees that displayed no apparent top damage. Differences between treatments were still not quite significant at the 5-percent level of probability.

Table 3—Some initial stand values for fertilized and control plots and stand values in the fall of 1984, 5 years after treatment[1/]

Stand parameter	Unit	Control		Fertilized	
		Average	Range	Average	Range
Trees per acre	Number	220.0	150-270	229.4	150-325
Initial values:					
Dg[2/]	Inches	4.4	3.0-6.2	4.0	3.2-5.3
Basal area	Square feet per acre	25.3	9.4-56.3	20.6	10.1-32.5
Height	Feet	22.0	14.4-37.7	20.7	15.3-27.5
Volume	Cubic feet per acre	345.9	79.5-1,101.8	243.3	88.1-503.3
1984 values:					
Dg	Inches	6.1	4.7-7.7	6.4	5.8-7.3
Basal area	Square feet per acre	46.8	21.8-87.9	51.5	33.8-71.0
Height	Feet	32.3	24.8-49.5	32.0	21.3-41.5
Volume	Cubic feet per acre	798.9	286.6-2,110.9	780.4	397.0-1,295.0

[1/]Values are for trees alive in 1984.
[2/]Diameter equivalent to initial average basal area.

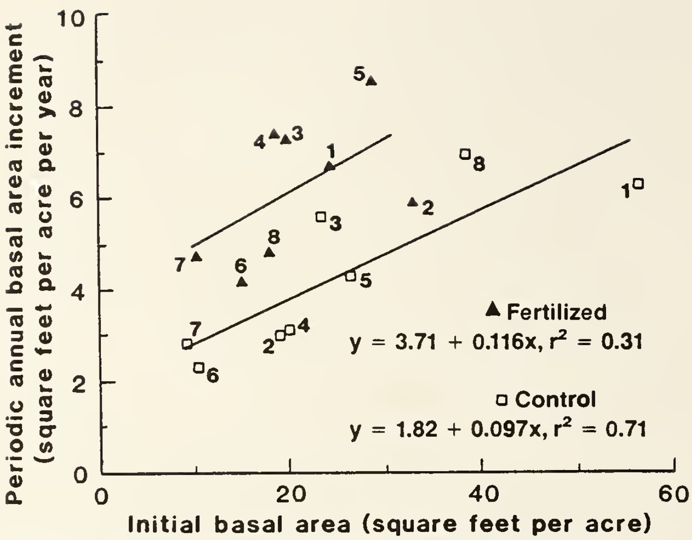

Figure 1.—Periodic annual basal area increment as a function of initial basal area for the fertilized and control plots. Numbers next to the plotted points refer to the locations. Slopes of the two regression lines are not significantly different, but the regression line for the fertilized plots is higher ($P \leq 0.05$) than the regression line for the control plots.

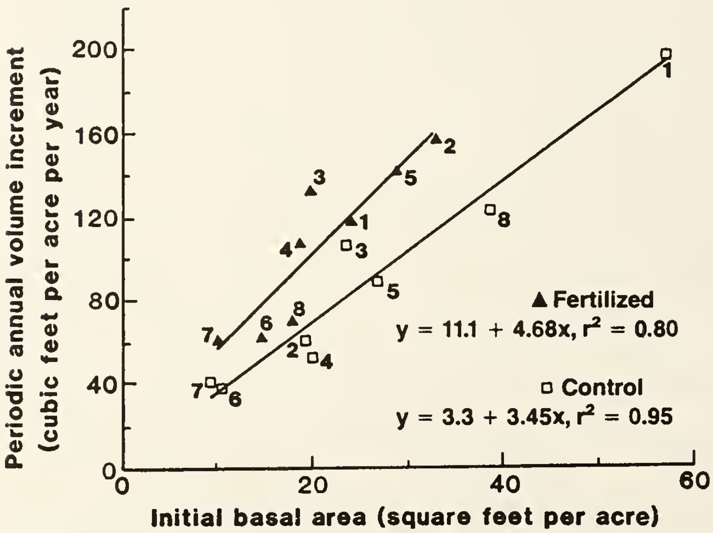

Figure 2.—Periodic annual volume increment as a function of initial basal area for the fertilized and control plots. Numbers next to the plotted points refer to the locations. Slopes of the two regression lines are not significantly different, but the regression line for the fertilized plot is higher ($P \leq 0.05$) than the regression line for the control plot.

Summary and Conclusions

Fertilization caused (1) a significant increase in the nitrogen concentration in the current and 1-year-old needles of Pacific silver fir the first growing season after treatment and in the foliage of bracken fern for the entire 5-year period, (2) a significant increase in the diameter growth of the trees as well as an increase in stand basal area and volume, and (3) an increase in top breakage. The increased top breakage after fertilization may not be particularly important, however, because of the relatively low numbers of trees damaged.

Growth rates will be remeasured at periodic intervals to determine how long the response to fertilization lasts. Other potential benefits besides increased tree growth need to be specifically identified. When total wood production after fertilization is available and values are placed on other possible benefits, an economic analysis can be made.

Conversions

1 inch = 2.540 centimeters
1 foot = 30.480 centimeters; 0.3048 meter
1 square inch = 6.452 square centimeters
1 square foot = 929 square centimeters; 0.0929 square meter
1 acre = 0.4047 hectare
1 square foot/acre = 0.2296 square meter/hectare
1 cubic foot/acre = 0.0700 cubic meter/hectare
1 pound/acre = 1.1208 kilograms/hectare
5/9 (°F-32) = °C

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Volume and Average Stumpage Price of Selected Species on the National Forests of the Pacific Northwest Region, 1973 to 1984

Florence K. Ruderman and Richard W. Haynes

Abstract

Stumpage prices have been compiled for major species for each National Forest of the Pacific Northwest Region of the USDA Forest Service for 1973-84.

Keywords: Stumpage prices, National Forests, Pacific Northwest.

Average stumpage prices from USDA Forest Service timber sales for major species in the Pacific Northwest Region have been published quarterly by the Pacific Northwest Research Station since 1963 (see, for example, Ruderman and Warren 1985). These prices have been widely used as standard measures of timber values in the Pacific Northwest. Beginning in 1977, stumpage price data for the 19 National Forests (fig. 1) in the Pacific Northwest Region were also included. The reason for adding these data was to provide forest planners and others with prices specific to geographic areas that were comparable to those published quarterly by the Pacific Northwest Research Station as regionwide averages. The available historical data and annual summaries for selected areas for 1977-80 have never been published. The purpose of this note is to present the 1973 through 1984 stumpage price data for each National Forest of the Pacific Northwest Region. Some of the more important trends in the data will also be summarized for the two subregions (the east side and the west side of the Cascade Range) that comprise the Pacific Northwest Region.

FLORENCE K. RUDERMAN (retired) was a statistical assistant and RICHARD W. HAYNES is a research forester at the Pacific Northwest Research Station, Forestry Sciences Laboratory, P.O. Box 3890, Portland, Oregon 97208.

Briefly, these stumpage prices are volume-weighted averages of bid prices minus credits for road costs, and they include an allowance (Knutson-Vandenburg (KV) funds) for improving a sale area after timber harvest. The resulting series of prices have been called the statistical high bid value or, more commonly, sold prices. Until 1984, this series was the most common definition of stumpage prices. There are two other measures of Forest Service stumpage prices. The least commonly used are the prices paid for timber harvested from Forest Service sales. This price is called the cut price and for an individual sale is the adjusted high bid price when the logs are scaled after harvest. This latter series is available only as an "all species" average, whereas sold prices are available for the principal species and all species averages. The second measure which in 1984 became the common measure of value is the high bid price. This series is another form of the sold price but is not adjusted for reimbursed road costs. It purports to represent total returns to the U.S. Treasury.

The major distinction between cut and sold prices is that the cut price represents the current value of timber being harvested, whereas the sold price represents the price paid for timber for future harvest.

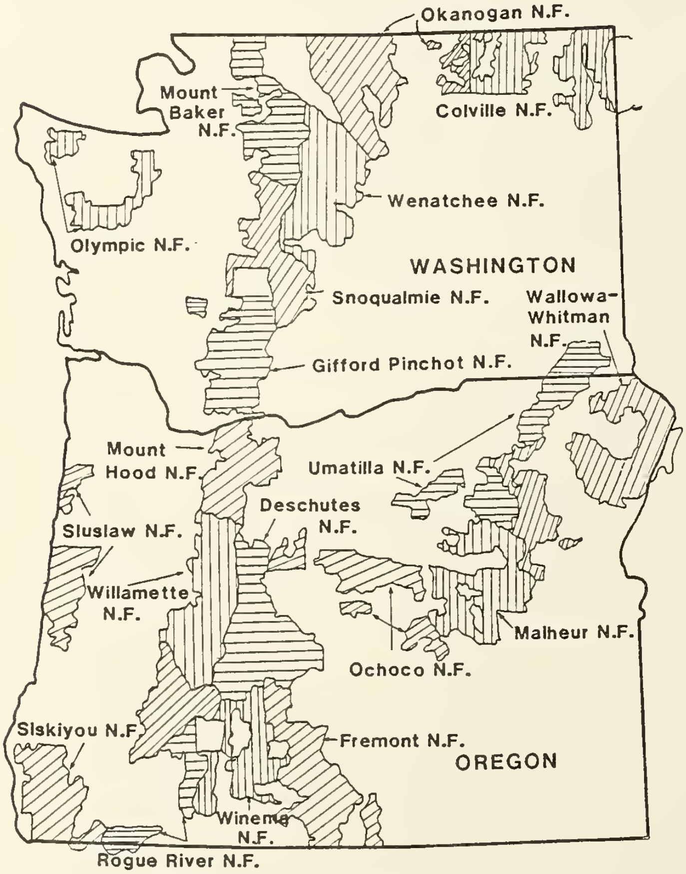

Figure 1—Names and locations of the National Forests (NF) in the Pacific Northwest Region.

Forest by Forest Stumpage Prices

Quarterly stumpage price series for each of the 19 National Forests in the Pacific Northwest Region are given in appendix tables 2 through 29. The price series in the tables were compiled from individual timber sale records. In the quarterly series, these prices have always been reported as preliminary in the sense that they do not include sales with a total value less than $2,000. Official sales records do include all sales but in the past have not been available in time for publication. All reported series are volume-weighted averages and are expressed in nominal dollars per thousand board feet, Scribner scale; that is, they have not been adjusted for inflation. Tables 2 through 29 are summaries of volume and average stumpage prices for the various National Forests in the Pacific Northwest Region as they now exist. This means that data for the Snoqualmie National Forest for 1973 and 1974 were combined with the data for the Mount Baker National Forest. The Mount Hood National Forest is treated as a west-side Forest in tables 2 and 13 even though two Districts contain east-side timber types. Finally, data for the Colville National Forest start in the fourth quarter of 1974 when that Forest was transferred from the Rocky Mountain Region to the Pacific Northwest Region.

Price Trends Summarized

Figures 2 to 8 summarize some of the price series. These figures show two trends. First, there is much intraregional variation in stumpage prices even for the same species, such as Douglas-fir in the west side.[1] Second, there is much variation among prices for various species, which raises questions about how good all species averages are in some applications. One concern is that these all species averages are greatly influenced by the major species in an area. To illustrate the extent to which the all species averages are influenced by Douglas-fir in the west side and ponderosa pine in the east side, we have computed "other species" averages for these regions.

Figure 2 shows the relationships among the stumpage prices for the east-side National Forests, west-side National Forests, and the entire Region. For the most part, price patterns are the same for both east-side and west-side Forests. Figure 3 shows stumpage prices for the major west-side species and figure 4 for the major east-side species. In the east side the sharp increase in prices after 1977 were attributable to both the use of sealed bidding during 1977 (Haynes 1980) and the high levels of housing starts in the late seventies. The increase in west-side prices reflects the bidding frenzy in the late 1970's as firms tried to position themselves for what was expected to be sustained high levels of housing starts in the 1980's as the World War II baby boom moved into the housing market. The lower prices since 1982 reflect a realignment of expectations about the future and the effects of increased lumber production in Canada and the South.

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[1] For scientific names, see "Common and Scientific Names."

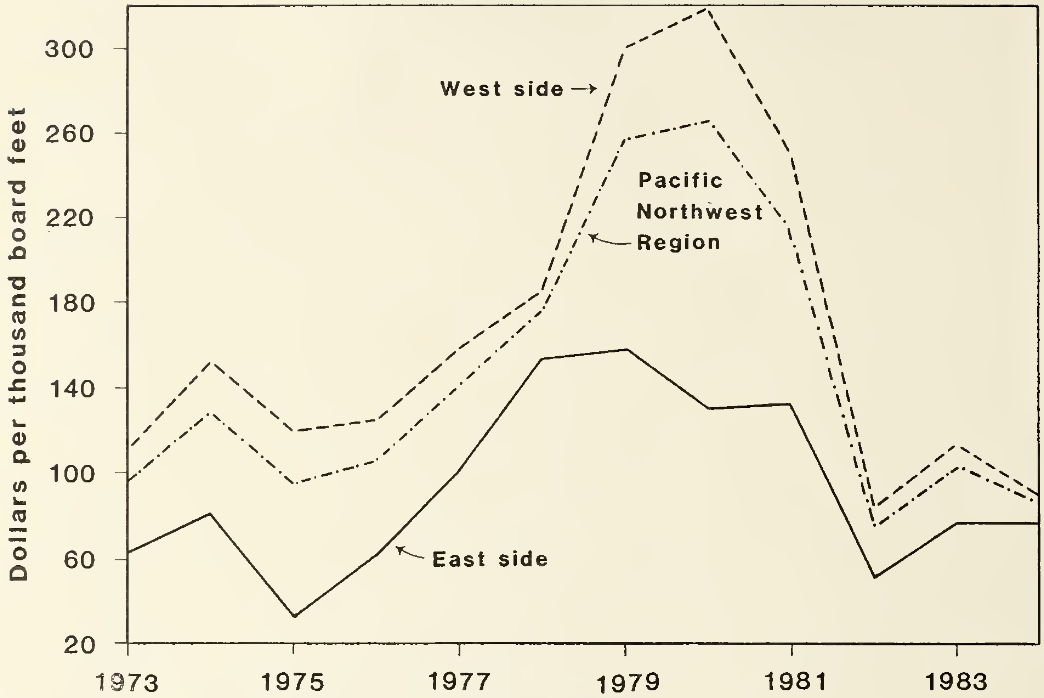

Figure 2—Average stumpage price of all species in east-side and west-side National Forests and the Pacific Northwest Region.

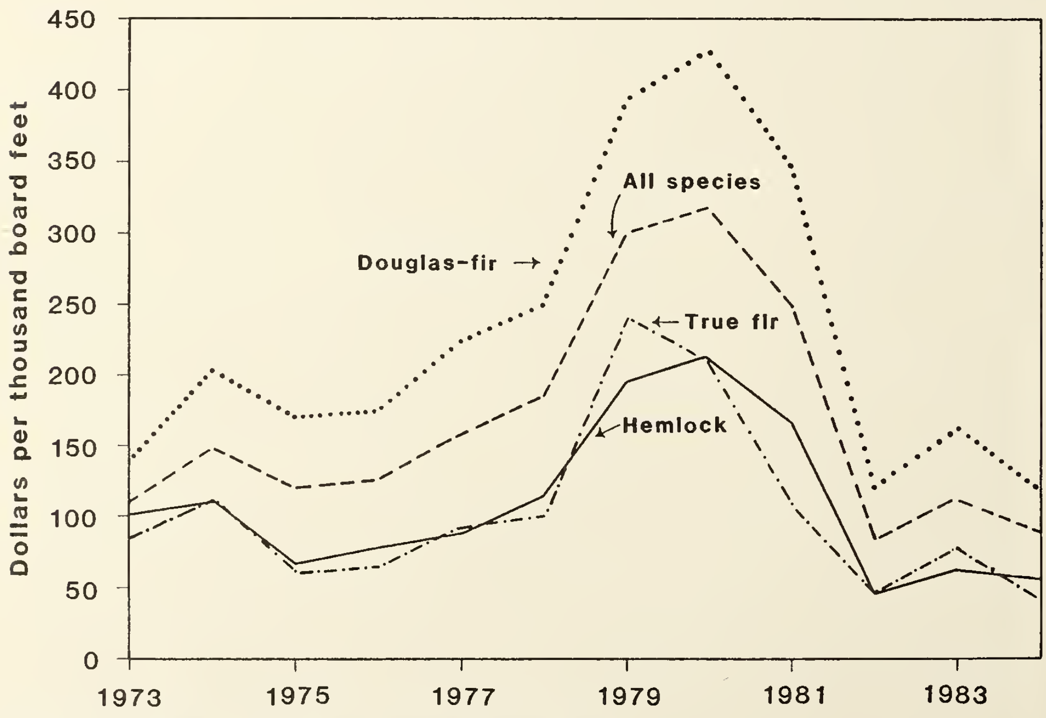

Figure 3—Stumpage prices for major west-side species, Pacific Northwest Region.

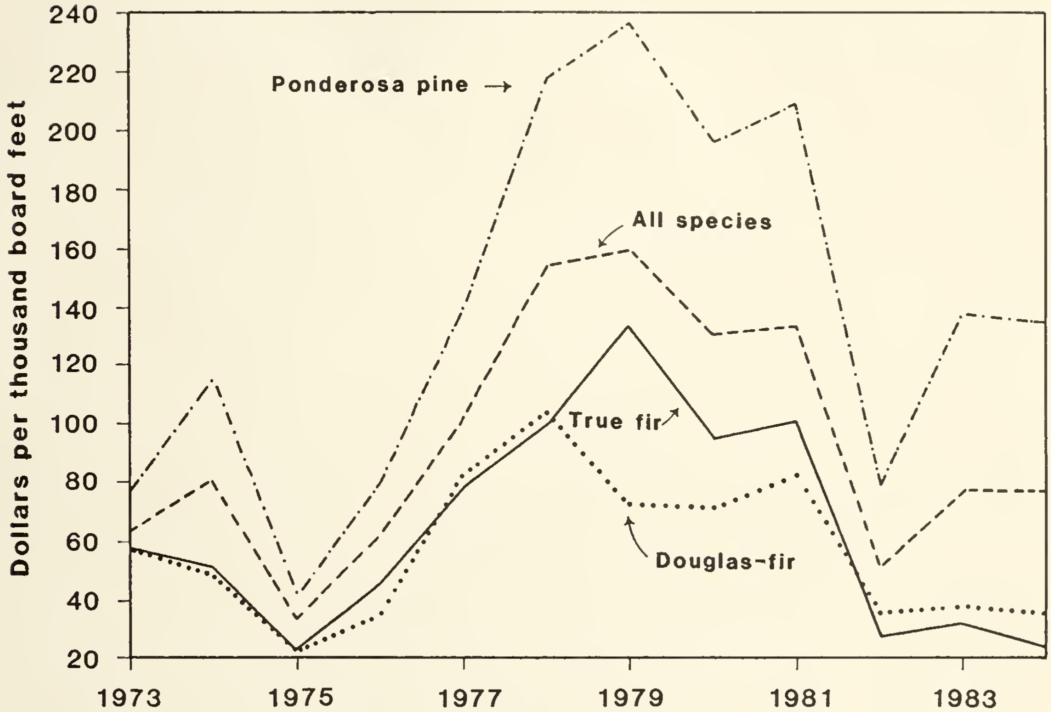

Figure 4—Stumpage prices for major east-side species, Pacific Northwest Region.

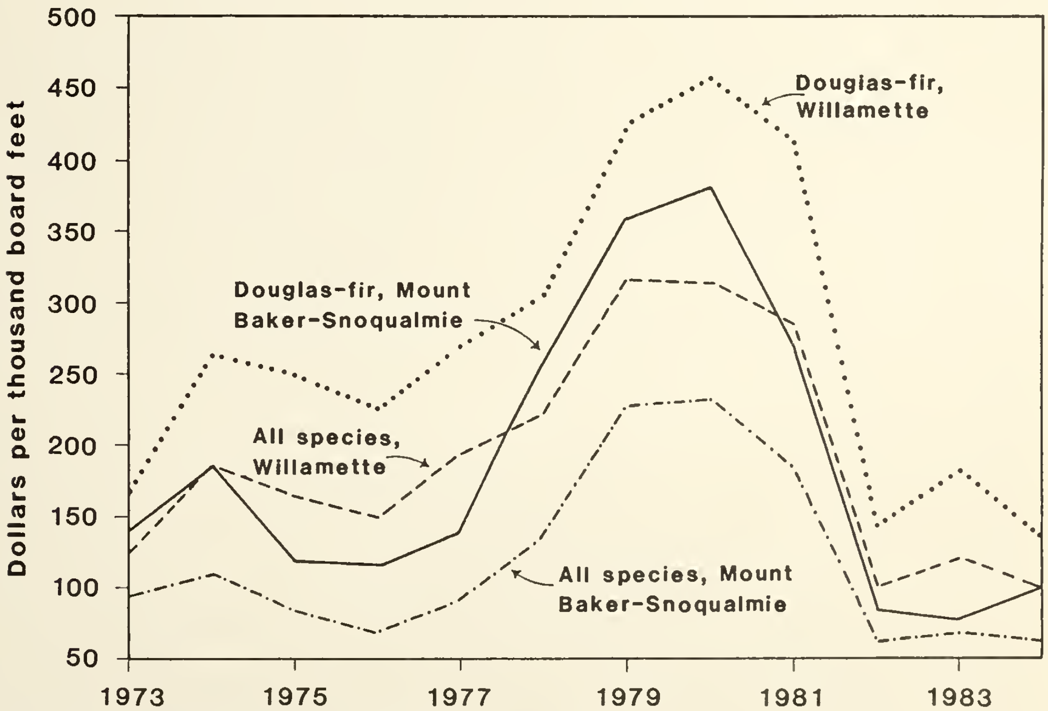

Figure 5—Stumpage prices on the Willamette and Mount Baker-Snoqualmie National Forests.

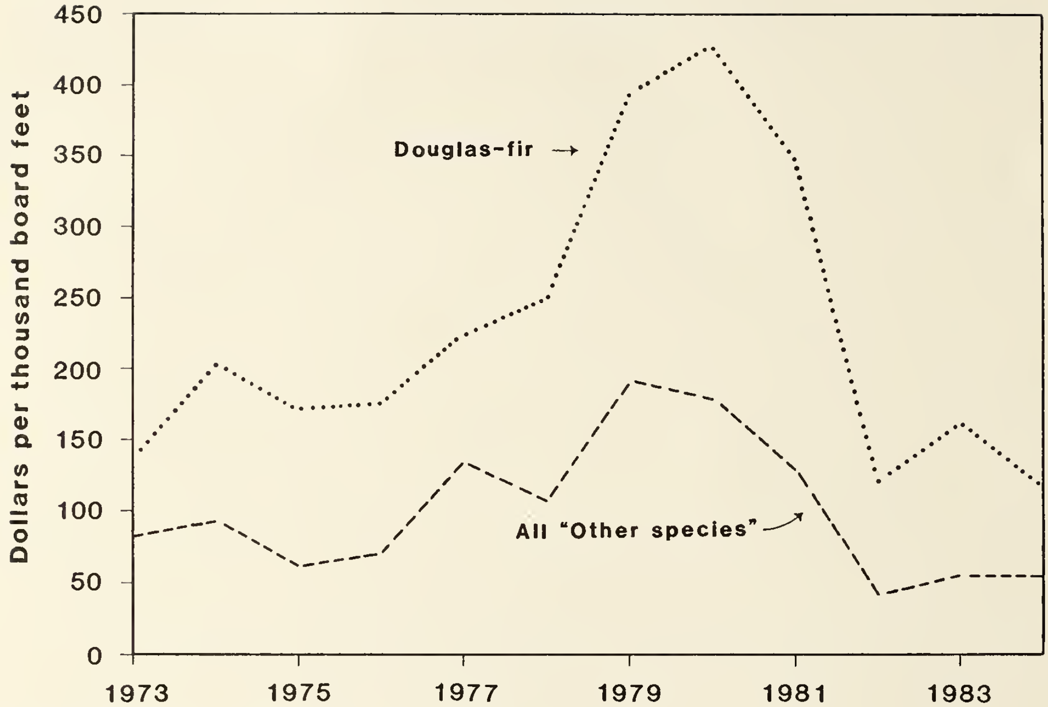

Figure 6—Stumpage prices for Douglas-fir and all other species, Pacific Northwest Region, west side.

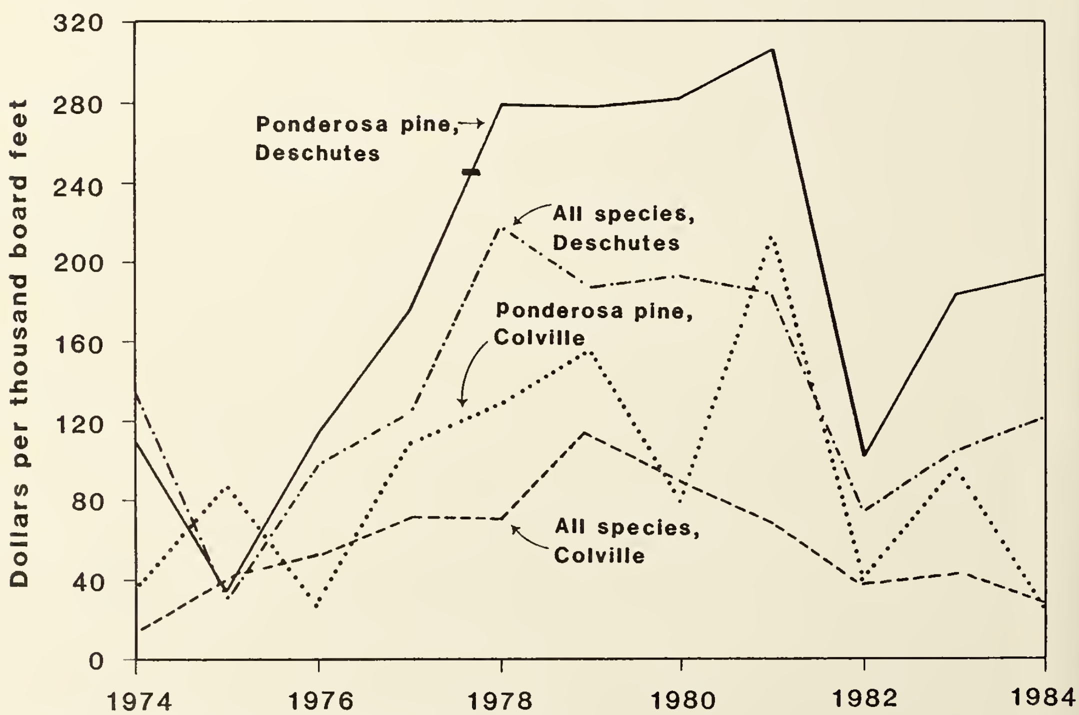

Figure 7—Stumpage prices on the Deschutes and Colville National Forests.

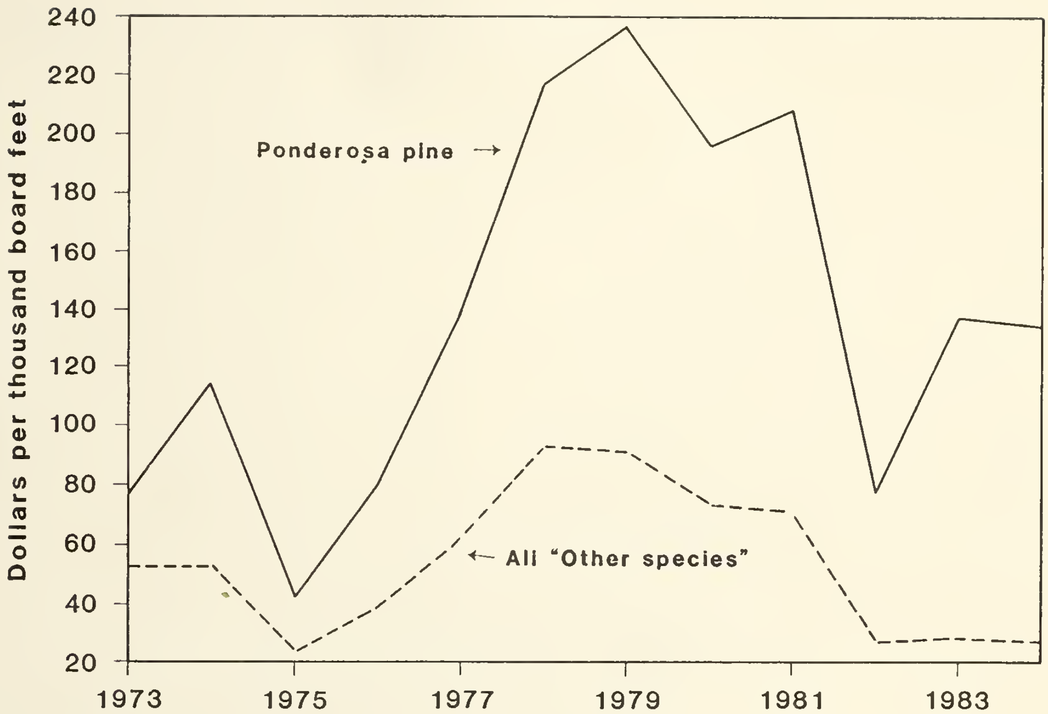

Figure 8—Stumpage prices for ponderosa pine and all other species.

Figure 5 illustrates the range in prices for Douglas-fir in the west side. During 1980, for example, there was a $75 difference in Douglas-fir prices between the Willamette and Mount Baker-Snoqualmie National Forests. The difference in the all species average is even larger, reflecting the smaller proportion of Douglas-fir in the Mount Baker-Snoqualmie and a larger proportion of species of low value. The influence of these species can be illustrated by recomputing the all species average without Douglas-fir. For the Region as a whole, this difference is shown in figure 6 and is summarized in table 1. Excluding Douglas-fir while lowering the value of the all species average does not alter the trend of sharp rises in prices during the early and the late 1970's. Prices of other species have, however, been almost constant since 1982.

Figure 7 illustrates the range in prices found in the east side for ponderosa pines. These prices vary throughout the east side; the highest prices are in eastern Oregon. Recomputing the all species average for the east side shows the extent to which the increases in stumpage values during the late 1970's were shared by all species (fig. 8). It also shows how the prices for other species have not recovered since 1982 to the levels observed during the late 1970's.

Table 1—Ponderosa pine, Douglas-fir, other species, and all species stumpage prices for the east side and west side of the Pacific Northwest Region

(In dollars per thousand board feet)

Year	East side			West side		
	Ponderosa pine	Other species	All species	Douglas-fir	Other species	All species
1973	76.44	52.79	62.74	139.52	81.16	111.10
1974	114.94	52.84	80.33	202.67	94.01	151.49
1975	41.95	23.81	33.60	170.99	62.75	119.39
1976	80.25	39.04	61.70	176.10	71.30	125.06
1977	138.68	61.81	100.49	224.67	134.10	158.54
1978	217.47	92.86	153.33	249.98	108.36	185.92
1979	236.54	90.45	159.09	394.40	192.19	300.31
1980	196.47	73.22	130.45	428.58	178.29	318.63
1981	208.57	71.67	133.50	348.02	129.62	249.54
1982	78.18	27.33	51.47	121.14	42.58	84.53
1983	137.50	29.02	77.29	163.01	55.21	113.48
1984	134.83	27.35	77.07	118.90	54.81	90.28

Common and Scientific Names

Common name	Scientific name
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco
Ponderosa pine	*Pinus ponderosa* Dougl. ex Laws.
Spruce:	
Engelmann spruce	*Picea engelmannii* Parry ex Engelm.
Sitka spruce	*Picea sitchensis* (Bong.) Carr.
True firs:	
California red fir	*Abies magnifica* A. Murr.
Grand fir	*Abies grandis* (Dougl. ex D. Don) Lindl.
Noble fir	*Abies procera* Rehd.
Pacific silver fir	*Abies amabilis* Dougl. ex Forbes
Shasta red fir	*Abies magnifica* var. *shastensis* Lemm.
Subalpine fir	*Abies lasiocarpa* (Hook.) Nutt.
White fir	*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.
Western hemlock	*Tsuga heterophylla* (Raf.) Sarg.

Acknowledgment

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Appendix

Table 2—Volume and average stumpage price of selected species on the Mount Hood National Forest of the Pacific Northwest Region, 1973-84[1]

(Volume in thousand board feet, Scribner scale; value in dollars per thousand board feet)

YEAR AND QUARTER	DOUGLAS-FIR WEST SIDE VOLUME	DOUGLAS-FIR WEST SIDE VALUE	DOUGLAS-FIR EAST SIDE VOLUME	DOUGLAS-FIR EAST SIDE VALUE	PONDEROSA AND JEFFREY PINES VOLUME	PONDEROSA AND JEFFREY PINES VALUE	WESTERN HEMLOCK VOLUME	WESTERN HEMLOCK VALUE	TRUE FIRS[2] VOLUME	TRUE FIRS[2] VALUE	ALL SPECIES VOLUME	ALL SPECIES VALUE
1973:												
1st quarter	0,617	76.49	300	45.55	330	63.90	7,950	77.51	4,535	45.62	24,954	62.09
2d quarter	91,948	142.94	--	--	--	--	41,022	74.60	1,200	13.86	165,811	99.52
3d quarter	64,742	130.93	5,100	65.95	9,800	76.04	23,120	86.36	4,000	56.76	124,202	99.97
4th quarter	60,300	166.14	10,990	110.83	2,915	72.74	34,465	153.65	5,350	79.08	126,365	137.53
Total or average	225,607	143.15	16,390	101.04	13,045	75.00	106,557	102.94	15,085	57.91	441,332	108.41
1974:												
1st quarter	18,700	200.03	18,700	147.07	7,700	82.25	7,980	118.49	8,800	70.88	75,245	119.21
2d quarter	26,140	243.76	8,800	162.56	4,000	83.02	8,970	100.69	3,100	65.56	56,400	166.77
3d quarter	25,837	240.85	7,850	184.23	1,560	86.10	11,370	179.15	--	--	53,149	188.28
4th quarter	28,370	177.00	28,925	121.08	4,800	57.98	11,070	55.61	5,205	20.03	88,860	109.94
Total or average	99,127	215.61	64,275	142.03	18,060	76.30	39,390	114.28	17,105	54.45	273,654	139.42
1975:												
1st quarter	45,250	171.04	1,230	70.00	--	--	15,120	92.32	--	--	70,945	124.93
2d quarter	82,760	165.11	21,660	125.96	920	10.87	47,763	45.34	--	--	181,069	119.86
3d quarter	32,360	191.14	5,350	27.05	4,940	12.85	12,913	46.19	3,850	57.43	72,565	110.81
4th quarter	50,160	172.58	26,300	64.34	3,310	32.99	33,765	73.66	12,340	35.89	140,260	99.13
Total or average	210,530	172.16	54,620	05.25	9,170	19.92	109,561	60.65	16,190	41.01	472,839	113.17
1976:												
1st quarter	9,005	145.19	980	46.35	490	22.17	5,025	124.90	1,370	26.66	19,094	109.92
2d quarter	46,185	105.82	10,200	110.52	1,134	47.51	29,850	107.49	5,660	26.76	129,671	127.96
3d quarter	17,845	93.71	2,400	95.62	3,100	122.95	21,445	29.67	220	46.19	51,378	59.61
4th quarter	11,041	214.32	250	41.71	170	109.09	4,500	126.96	90	45.68	20,281	187.87
Total or average	84,076	165.66	13,830	102.15	4,894	94.92	60,820	82.93	7,340	27.56	220,424	115.98
1977:												
1st quarter	40,840	198.66	16,100	224.13	9,500	92.51	20,060	145.88	5,300	48.06	122,452	177.50
2d quarter	60,145	209.91	5,500	87.80	--	--	21,305	116.60	770	69.34	107,759	166.46
3d quarter	33,475	197.36	10,620	79.59	5,510	59.01	16,780	06.73	1,020	52.07	72,237	130.37
4th quarter	73	109.74	--	--	1,000	88.83	31	56.35	--	--	1,104	94.59
Total or average	134,533	203.36	32,220	153.22	16,010	80.75	66,176	121.41	7,090	51.54	303,552	148.93
1978:												
1st quarter	72,558	234.07	17,506	184.52	4,800	158.61	37,534	132.83	--	--	155,108	176.32
2d quarter	4,180	218.52	11,830	105.99	3,310	151.88	3,580	113.93	2,085	96.90	27,661	126.17
3d quarter	70,920	167.04	5,051	62.64	1,640	171.63	46,055	208.75	19,839	72.97	167,157	149.46
4th quarter	12,900	240.73	2,530	75.57	3,700	157.77	13,950	190.58	2,360	56.76	37,870	180.96
Total or average	160,558	204.59	36,917	135.21	13,450	158.31	101,119	175.81	24,284	73.45	387,796	161.62
1979:												
1st quarter	84,306	361.74	18,130	202.53	--	--	39,860	183.71	3,000	127.76	164,381	261.75
2d quarter	28,337	372.91	17,410	174.80	5,873	179.75	23,790	149.81	9,201	68.05	95,222	212.99
3d quarter	58,743	416.90	4,574	213.69	1,407	162.35	34,155	234.93	7,985	177.77	110,441	336.15
4th quarter	32,431	558.79	4,700	389.97	2,200	189.53	5,314	72.96	2,400	100.00	60,765	383.17
Total or average	203,817	410.54	44,814	212.55	9,480	179.44	103,119	203.71	22,586	118.17	430,809	287.17
1980:												
1st quarter	66,294	372.19	6,880	175.11	5,650	95.82	28,543	232.60	8,375	159.47	129,489	301.00
2d quarter	45,751	201.12	3,250	14.30	--	--	26,718	400.54	9,812	244.71	95,223	244.70
3d quarter	45,895	189.77	8,470	135.65	--	--	37,640	352.69	9,230	189.66	117,976	224.63
4th quarter	37,005	530.73	1,667	27.61	1,600	429.00	13,001	35.12	55	174.57	60,871	345.98
Total or average	194,945	319.19	20,267	120.71	7,250	169.35	105,902	293.41	27,472	199.92	403,559	272.17
1981:												
1st quarter	40,070	461.08	13,700	315.91	2,100	13.45	22,540	139.28	5,860	133.85	99,321	294.97
2d quarter	36,818	318.02	7,170	245.92	330	35.38	18,684	137.69	2,138	34.75	77,169	213.96
3d quarter	92,045	259.88	3,160	56.71	2,850	523.09	37,770	207.09	12,826	44.52	189,162	192.48
4th quarter	19,857	441.86	7,300	27.96	7,400	204.71	5,380	33.64	8,978	69.12	57,545	199.25
Total or average	188,790	333.06	31,330	206.66	12,600	240.19	04,374	162.55	29,802	60.83	423,197	221.35
1982:												
1st quarter	58,930	161.54	990	46.72	2,380	44.56	18,387	24.72	3,050	71.29	98,044	106.29
2d quarter	39,047	74.77	9,700	10.47	2,300	10.47	15,328	38.08	--	--	74,064	53.20
3d quarter	75,990	84.92	2,190	84.30	200	13.23	33,554	50.98	11,783	18.28	148,240	60.70
4th quarter	11,240	36.30	12,900	30.44	560	27.67	12,150	17.81	3,080	16.56	51,302	25.61
Total or average	185,207	104.21	25,780	28.13	5,440	27.26	79,419	37.33	17,913	27.01	371,650	66.39
1983:												
1st quarter	96,955	207.60	4,120	27.70	1,480	17.28	42,635	73.30	210	7.37	190,449	126.51
2d quarter	23,639	196.75	1,150	21.91	1,090	93.23	8,240	121.90	1,310	3.39	41,954	142.02
3d quarter	28,252	174.36	11,400	49.78	1,000	20.33	19,015	99.67	10,280	16.32	82,599	97.96
4th quarter	33,418	136.56	6,350	38.53	5,160	08.56	14,657	182.83	8,030	34.01	80,853	106.02
Total or average	182,264	188.01	23,020	41.33	8,730	69.24	84,547	102.96	19,830	22.53	395,045	118.01
1984:												
1st quarter	54,226	150.24	4,300	31.20	3,920	42.50	36,413	125.74	4,210	53.85	131,257	106.72
2d quarter	22,297	133.12	9,680	78.73	1,600	14.67	14,141	81.83	2,140	26.27	63,516	98.14
3d quarter	49,778	121.88	8,500	26.17	3,600	36.74	21,230	07.59	500	46.18	103,737	85.25
4th quarter	18,995	73.25	4,055	105.42	470	45.81	17,325	25.20	2,470	12.64	52,750	46.56
Total or average	145,296	127.83	27,335	59.66	9,590	35.86	09,109	90.14	9,320	36.18	351,260	89.79

[1] Prices for individual sales may vary from the averages shown in this table because of differences in species mix, quality, road costs, logging and processing costs, size and length of sale, number of bidders, and other related price determinants. Prices for stumpage in National Forest lands are statistical high bids. The statistical high bid is defined as the bid price minus credits for road costs; it includes an allowance for sale-area betterment (K-V funds).

[2] Does not include noble fir or Shasta red fir.

Source--U.S. Department of Agriculture. Pacific Northwest Region includes Oregon and Washington.

Table 3—Volume and average stumpage price of selected species on the Rogue River National Forest of the Pacific Northwest Region, 1973-84[1]

(Volume in thousand board feet, Scribner scale; value in dollars per thousand board feet)

Year and quarter	Douglas-fir West side Volume	Douglas-fir West side Value	Douglas-fir East side Volume	Douglas-fir East side Value	Ponderosa and Jeffrey pines Volume	Ponderosa and Jeffrey pines Value	Western hemlock Volume	Western hemlock Value	True firs[2] Volume	True firs[2] Value	All species Volume	All species Value
1973:												
1st quarter	16,785	77.60	--	--	721	62.76	--	--	17,010	48.63	50,890	53.62
2d quarter	37,925	112.15	--	--	3,985	40.19	--	--	9,485	47.67	62,820	84.87
3d quarter	9,950	144.44	--	--	3,595	86.31	1,120	54.24	5,495	83.65	25,800	169.59
4th quarter	25,456	120.66	--	--	4,780	84.13	50	4.03	18,289	70.35	55,205	92.89
Total or average	90,116	111.68	--	--	13,081	70.16	1,170	52.09	50,279	60.19	194,715	90.21
1974:												
1st quarter	4,674	225.84	--	--	983	166.53	--	--	9,325	131.35	17,340	155.14
2d quarter	39,699	244.95	--	--	10,478	238.77	--	--	2,367	14.68	92,814	187.10
3d quarter	1,707	173.21	--	--	--	--	--	--	1,013	99.55	3,351	146.48
4th quarter	37,361	112.26	--	--	6,855	59.98	670	27.03	31,309	44.67	95,401	70.21
Total or average	83,441	183.00	--	--	18,316	167.98	670	27.03	44,014	62.69	208,906	130.42
1975:												
1st quarter	2,321	107.70	--	--	--	--	--	--	--	--	6,553	113.71
2d quarter	47,438	135.42	--	--	10,324	75.63	--	--	27,678	68.53	118,104	95.46
3d quarter	14,727	103.49	--	--	--	--	--	--	13,390	36.83	39,532	61.81
4th quarter	31,930	147.25	--	--	4,274	38.45	--	--	26,152	67.05	79,414	94.55
Total or average	96,416	133.79	--	--	14,598	68.75	--	--	67,220	61.64	243,603	90.20
1976:												
1st quarter	2,375	157.01	--	--	1,045	155.41	--	--	603	84.90	4,345	139.26
2d quarter	38,420	153.04	--	--	1,732	56.39	--	--	20,135	09.65	70,659	116.49
3d quarter	16,188	116.52	--	--	2,529	07.88	--	--	9,794	91.37	48,348	103.47
4th quarter	2,470	124.72	--	--	40	102.35	--	--	1,360	77.25	5,277	95.17
Total or average	59,453	142.00	--	--	5,346	90.90	--	--	31,892	89.56	128,629	111.49
1977:												
1st quarter	33,257	212.00	--	--	1,450	90.52	--	--	25,613	140.85	81,127	151.16
2d quarter	21,430	226.31	--	--	1,630	133.21	--	--	10,790	93.00	51,205	184.50
3d quarter	18,595	169.65	--	--	3,540	83.18	--	--	23,400	136.31	53,380	137.15
4th quarter	6,825	305.63	--	--	--	--	--	--	4,170	124.75	12,890	217.70
Total or average	80,107	213.97	--	--	6,620	97.12	--	--	63,973	130.07	198,602	160.31
1978:												
1st quarter	27,865	230.99	--	--	2,566	77.25	--	--	19,995	96.20	59,961	162.22
2d quarter	25,237	225.90	--	--	1,409	164.49	--	--	7,800	216.04	50,501	201.98
3d quarter	26,223	200.11	--	--	1,997	176.64	--	--	17,020	218.98	60,975	193.72
4th quarter	7,872	262.37	--	--	1,060	132.52	--	--	3,117	244.55	13,563	228.25
Total or average	87,197	223.06	--	--	7,032	131.29	--	--	47,932	168.96	185,000	188.10
1979:												
1st quarter	39,919	244.31	--	--	2,697	196.54	--	--	31,805	523.60	85,828	338.70
2d quarter	11,832	266.79	--	--	498	171.13	--	--	12,390	345.42	28,035	293.49
3d quarter	53,730	373.05	--	--	--	--	600	163.83	16,450	267.71	95,240	327.11
4th quarter	964	286.29	--	--	6	158.20	--	--	405	157.12	1,425	245.45
Total or average	106,445	312.17	--	--	3,201	192.51	600	163.83	61,050	416.06	210,528	326.80
1900:												
1st quarter	40,873	407.58	--	--	1,250	103.66	--	--	28,420	384.85	97,843	337.52
2d quarter	8,580	140.94	--	--	120	75.23	--	--	4,980	822.17	21,730	379.89
3d quarter	53,470	391.01	--	--	9,862	101.15	--	--	14,795	560.28	103,401	328.20
4th quarter	8,280	324.72	--	--	1,230	433.76	--	--	2,730	199.39	14,340	284.14
Total or average	111,203	372.87	--	--	12,462	133.98	--	--	50,925	468.64	237,314	333.61
1981:												
1st quarter	12,930	245.61	--	--	80	83.11	125	275.00	11,140	194.60	33,680	220.55
2d quarter	25,790	392.10	--	--	590	230.25	--	--	15,575	129.69	59,750	267.40
3d quarter	65,595	324.77	--	--	2,790	76.06	165	51.36	15,800	36.95	110,280	234.13
4th quarter	10,805	390.19	--	--	580	41.96	--	--	7,710	45.00	28,785	175.64
Total or average	115,120	337.10	--	--	4,040	93.82	290	147.76	50,225	101.91	232,495	233.47
1982:												
1st quarter	40,500	179.33	--	--	4,625	29.62	400	15.31	26,495	97.10	79,767	140.49
2d quarter	1,980	75.67	--	--	495	54.19	--	--	1,115	120.06	4,880	69.33
3d quarter	36,345	89.48	--	--	4,370	98.74	--	--	24,290	36.11	73,835	70.41
4th quarter	18,970	157.77	--	--	540	69.69	--	--	4,840	99.99	33,915	142.85
Total or average	97,795	139.66	--	--	10,030	63.10	430	15.31	56,740	71.69	192,397	12.21
1983:												
1st quarter	24,750	204.44	--	--	3,850	70.71	110	14.13	10,570	164.63	48,810	157.15
2d quarter	22,775	159.25	--	--	520	27.05	--	--	16,755	97.87	44,841	117.49
3d quarter	29,665	105.60	--	--	1,067	54.21	--	--	19,405	159.47	57,797	114.85
4th quarter	22,675	209.96	--	--	1,205	147.22	--	--	11,330	108.55	41,890	161.45
Total or average	99,865	166.02	--	--	6,642	78.52	110	14.13	58,060	132.70	193,338	137.05
1984:												
1st quarter	31,190	196.47	--	--	2,145	119.01	--	--	5,175	89.05	61,275	146.69
2d quarter	23,646	134.24	--	--	930	59.47	1,750	15.75	8,940	28.68	45,036	106.19
3d quarter	32,360	113.12	--	--	45	82.70	--	--	19,460	74.58	63,805	114.17
4th quarter	21,571	138.69	--	--	590	47.57	--	--	15,075	49.92	44,649	98.82
Total or average	108,767	146.97	--	--	3,710	92.28	1,750	15.75	48,650	60.04	214,765	118.58

[1]Prices for individual sales may vary from the averages shown in this table because of differences in species mix, quality, road costs, logging and processing costs, size and length of sale, number of bidders, and other related price determinants. Prices for stumpage in National Forest lands are statistical high bids. The statistical high bid is defined as the bid price minus credits for road costs; it includes an allowance for sale-area betterment (K-V funds).

[2]Does not include noble fir or Shasta red fir.

Source--U.S. Department of Agriculture. Pacific Northwest Region includes Oregon and Washington.

Table 4—Volume and average stumpage price of selected species on the Siskiyou National Forest of the Pacific Northwest Region, 1973-84[1/]

(Volume in thousand board feet, Scribner scale; value in dollars per thousand board feet)

YEAR AND QUARTER	DOUGLAS-FIR				PONDEROSA AND JEFFREY PINES		WESTERN HEMLOCK		TRUE FIRS[2/]		ALL SPECIES	
	WEST SIDE		EAST SIDE									
	VOLUME	VALUE	VOLUME	VALUE	VOLUME	VALUE	VOLUME	VALUE	VOLUME	VALUE	VOLUME	VALUE
1973:												
1st quarter	6,100	24.39	--	--	--	--	40	2.00	--	--	6,320	25.05
2d quarter	116,925	113.35	--	--	--	--	2,120	45.35	2,800	8.43	153,135	125.20
3d quarter	5,710	125.81	--	--	--	--	70	91.66	--	--	7,342	113.04
4th quarter	73,250	121.63	--	--	--	--	755	42.53	830	34.96	91,953	159.99
Total or average	201,985	114.02	--	--	--	--	2,935	45.14	3,630	14.49	258,750	134.77
1974:												
1st quarter	5,739	205.46	--	--	--	--	130	74.11	70	17.46	7,656	227.66
2d quarter	83,860	192.26	--	--	900	46.62	1,620	36.84	940	9.32	107,625	226.96
3d quarter	11,724	116.92	--	--	20	112.45	50	79.62	190	39.49	14,878	116.75
4th quarter	67,796	127.12	--	--	--	--	843	19.23	3,530	286.13	88,229	125.18
Total or average	169,119	161.37	--	--	920	48.05	2,643	33.87	4,730	217.23	218,388	178.36
1975:												
1st quarter	5,430	185.14	--	--	--	--	20	2.24	--	--	7,440	161.05
2d quarter	70,125	141.06	--	--	130	12.30	1,100	4.93	2,850	208.00	90,285	178.09
3d quarter	14,625	144.50	--	--	--	--	90	24.52	320	81.19	18,670	188.09
4th quarter	61,880	126.68	--	--	--	--	940	16.18	1,400	17.74	76,950	120.71
Total or average	150,060	138.94	--	--	130	12.30	2,150	10.65	4,570	140.86	193,345	155.56
1976:												
1st quarter	10,916	121.36	--	--	430	20.55	123	58.11	--	--	17,484	267.96
2d quarter	61,950	150.41	--	--	--	--	880	18.29	2,930	20.22	87,140	166.60
3d quarter	25,240	142.70	--	--	--	--	240	67.68	260	23.40	32,905	152.18
4th quarter	14,021	144.38	--	--	95	135.00	--	--	300	21.95	18,840	128.55
Total or average	112,127	145.09	--	--	525	41.26	1,243	31.76	3,490	20.61	156,369	170.32
1977:												
1st quarter	47,790	212.88	--	--	1,000	113.01	1,750	104.11	355	66.95	63,540	198.00
2d quarter	17,730	170.06	--	--	400	55.17	10	2.00	--	--	28,740	120.78
3d quarter	49,450	229.48	--	--	850	90.06	1,130	39.95	1,840	293.65	70,490	239.33
4th quarter	18,865	195.08	--	--	210	102.16	400	48.44	150	93.46	23,365	183.28
Total or average	133,835	210.83	--	--	2,540	93.50	3,290	74.99	2,345	246.53	186,135	199.88
1978:												
1st quarter	52,470	264.95	--	--	--	--	890	57.79	860	280.75	66,990	252.24
2d quarter	14,860	259.31	--	--	20	134.05	440	153.86	280	59.56	19,670	255.08
3d quarter	77,620	217.93	--	--	290	139.85	1,200	35.35	1,690	20.96	93,070	265.87
4th quarter	7,941	319.14	--	--	--	--	240	6.99	20	59.65	9,445	285.06
Total or average	152,900	243.33	--	--	310	136.67	2,770	46.47	2,850	103.41	189,175	260.88
1979:												
1st quarter	55,536	331.81	--	--	--	--	1,330	49.67	740	54.88	69,390	429.61
2d quarter	14,850	386.96	--	--	--	--	450	48.00	--	--	18,240	403.68
3d quarter	76,530	450.02	--	--	421	67.11	1,490	35.01	5,130	371.33	102,700	481.45
4th quarter	7,534	462.22	--	--	10	105.62	50	49.32	500	121.34	9,328	403.42
Total or average	154,450	402.05	--	--	431	68.01	3,320	43.22	6,370	314.94	199,658	452.68
1900:												
1st quarter	67,739	735.53	--	--	--	--	1,150	55.43	240	26.10	84,249	705.34
2d quarter	31,955	580.38	--	--	1,290	11.31	--	--	2,040	39.09	44,365	445.04
3d quarter	65,680	588.35	--	--	320	49.27	130	17.00	60	33.03	83,538	493.96
4th quarter	46,610	590.48	--	--	190	71.58	1,900	19.34	305	23.59	56,720	651.48
Total or average	211,984	615.69	--	--	1,800	24.42	3,180	32.29	2,645	35.95	268,872	585.35
1981:												
1st quarter	53,458	584.80	--	--	--	--	960	18.12	140	9.15	63,662	523.91
2d quarter	30,470	481.51	--	--	--	--	780	22.27	350	17.07	38,628	426.51
3d quarter	53,130	213.01	--	--	--	--	1,760	21.28	2,280	166.12	68,678	208.37
4th quarter	25,815	166.91	--	--	160	50.27	2,250	25.46	2,210	19.39	38,620	218.23
Total or average	162,873	377.96	--	--	160	50.27	5,750	22.52	4,980	86.12	209,588	346.24
1982:												
1st quarter	21,948	122.84	--	--	40	131.13	40	6.02	230	38.72	25,923	133.89
2d quarter	35,067	79.20	--	--	50	20.16	960	23.08	430	14.39	44,546	97.43
3d quarter	48,550	86.02	--	--	60	38.96	540	23.78	3,110	45.28	60,083	103.97
4th quarter	53,725	98.31	--	--	--	--	530	11.89	10	6.00	63,332	105.22
Total or average	159,290	93.74	--	--	150	57.27	2,070	20.07	3,780	41.39	193,884	106.88
1983:												
1st quarter	33,305	205.84	--	--	110	45.98	1,460	8.92	200	11.92	40,870	182.95
2d quarter	37,750	133.89	--	--	860	24.16	40	33.38	530	12.76	49,450	122.69
3d quarter	36,560	167.95	--	--	150	102.11	2,300	12.86	880	42.49	45,527	162.97
4th quarter	16,110	161.83	--	--	290	48.12	490	24.10	--	--	20,700	194.58
Total or average	123,725	167.47	--	--	1,410	35.82	4,290	13.00	1,610	28.91	156,547	159.64
1984:												
1st quarter	25,394	94.22	--	--	60	47.93	250	33.67	830	42.89	31,523	103.12
2d quarter	11,765	54.28	--	--	10	50.36	500	9.94	130	11.27	16,680	254.51
3d quarter	44,320	66.76	--	--	--	--	65	8.50	705	18.39	53,275	74.64
4th quarter	26,540	76.58	--	--	480	123.42	790	15.78	690	28.82	37,510	77.49
Total or average	108,019	74.27	--	--	550	113.86	1,605	16.45	2,355	33.19	138,988	103.45

1/Prices for individual sales may vary from the averages shown in this table because of differences in species mix, quality, road costs, logging and processing costs, size and length of sale, number of bidders, and other related price determinants. Prices for stumpage in National Forest lands are statistical high bids. The statistical high bid is defined as the bid price minus credits for road costs; it includes an allowance for sale-area betterment (K-V funds).

2/Does not include noble fir or Shasta red fir.

Source--U.S. Department of Agriculture. Pacific Northwest Region includes Oregon and Washington.

Table 5—Volume and average stumpage price of selected species on the Siuslaw National Forest of the Pacific Northwest Region, 1973-84[1/]

(Volume in thousand board feet, Scribner scale; value in dollars per thousand board feet)

YEAR AND QUARTER	DOUGLAS-FIR				PONDEROSA AND JEFFREY PINES		WESTERN HEMLOCK		TRUE FIRS[2/]		ALL SPECIES	
	WEST SIDE		EAST SIDE									
	VOLUME	VALUE	VOLUME	VALUE	VOLUME	VALUE	VOLUME	VALUE	VOLUME	VALUE	VOLUME	VALUE
1973:												
1st quarter	29,610	109.15	--	--	--	--	10,319	72.21	--	--	47,853	85.15
2d quarter	101,782	133.73	--	--	--	--	22,710	133.12	--	--	143,191	121.71
3d quarter	19,824	146.59	--	--	--	--	629	89.91	--	--	22,341	134.43
4th quarter	66,018	148.38	--	--	--	--	9,081	99.34	--	--	85,563	128.05
Total or average	217,234	136.00	--	--	--	--	42,739	110.60	--	--	298,948	118.62
1974:												
1st quarter	42,548	168.52	--	--	--	--	4,636	134.37	--	--	55,340	150.60
2d quarter	93,036	233.74	--	--	--	--	21,289	163.51	--	--	128,043	204.02
3d quarter	11,731	268.17	--	--	--	--	3,242	85.10	--	--	15,812	222.11
4th quarter	104,818	125.36	--	--	--	--	18,028	53.64	--	--	136,570	107.29
Total or average	252,133	179.28	--	--	--	--	47,195	113.29	--	--	335,765	156.72
1975:												
1st quarter	560	116.35	--	--	--	--	810	28.17	--	--	2,890	76.32
2d quarter	119,302	94.82	--	--	--	--	9,719	106.66	--	--	148,290	89.42
3d quarter	39,527	141.37	--	--	--	--	7,282	46.60	--	--	58,130	115.30
4th quarter	98,457	172.66	--	--	--	--	22,760	152.09	--	--	135,118	156.05
Total or average	257,846	131.73	--	--	--	--	40,571	119.80	--	--	344,428	119.82
1976:												
1st quarter	14,692	189.94	--	--	--	--	--	--	--	--	16,058	175.52
2d quarter	94,403	172.10	--	--	--	--	9,100	103.50	--	--	116,890	153.20
3d quarter	21,100	144.70	--	--	--	--	664	29.82	--	--	23,132	135.00
4th quarter	25,530	227.26	--	--	--	--	5,310	174.24	--	--	32,840	207.50
Total or average	155,725	179.11	--	--	--	--	15,074	125.17	--	--	188,920	162.31
1977:												
1st quarter	76,857	246.75	--	--	--	--	10,450	103.63	--	--	102,075	210.33
2d quarter	61,475	240.42	--	--	--	--	3,490	67.41	--	--	72,288	212.98
3d quarter	52,628	245.14	--	--	--	--	11,710	283.78	--	--	71,574	236.43
4th quarter	40,602	261.08	--	--	--	--	5,681	131.89	--	--	51,389	226.42
Total or average	231,562	247.21	--	--	--	--	31,331	172.05	--	--	297,326	220.03
1978:												
1st quarter	104,572	254.04	--	--	--	--	13,178	171.26	--	--	134,933	222.94
2d quarter	54,680	257.49	--	--	--	--	5,530	153.86	--	--	68,640	230.45
3d quarter	94,515	295.30	--	--	--	--	9,790	114.67	--	--	111,512	263.55
4th quarter	16,335	252.21	--	--	--	--	7,237	160.41	--	--	24,811	219.25
Total or average	270,102	269.07	--	--	--	--	35,735	150.87	--	--	339,896	237.51
1979:												
1st quarter	79,741	338.92	--	--	--	--	10,776	197.75	--	--	99,559	298.31
2d quarter	44,410	394.38	--	--	--	--	3,470	237.13	--	--	54,253	347.69
3d quarter	151,138	476.47	--	--	--	--	28,382	272.12	--	--	192,473	422.78
4th quarter	24,814	447.17	--	--	--	--	9,050	368.09	--	--	36,961	399.43
Total or average	300,103	425.36	--	--	--	--	51,678	271.07	--	--	383,246	377.56
1980:												
1st quarter	90,218	468.10	--	--	--	--	16,000	338.69	--	--	117,017	427.43
2d quarter	48,200	453.06	--	--	--	--	4,150	205.41	--	--	54,521	419.59
3d quarter	160,070	448.08	--	--	--	--	11,139	210.38	--	--	183,744	413.71
4th quarter	30,430	481.26	--	--	--	--	1,200	55.96	--	--	32,403	456.67
Total or average	328,918	457.37	--	--	--	--	32,489	267.23	--	--	387,685	422.27
1981:												
1st quarter	164,660	444.38	--	--	--	--	16,986	187.79	--	--	192,240	403.16
2d quarter	71,746	378.44	--	--	--	--	12,322	140.47	--	--	94,133	327.58
3d quarter	64,699	312.77	--	--	--	--	13,711	185.39	100	54.51	88,186	272.74
4th quarter	75,268	236.19	--	--	--	--	4,302	53.47	--	--	84,905	214.65
Total or average	376,373	367.55	--	--	--	--	47,321	162.56	100	54.51	459,464	327.81
1982:												
1st quarter	84,360	132.20	--	--	--	--	8,671	26.50	--	--	100,769	117.48
2d quarter	38,514	85.94	--	--	--	--	7,800	30.33	--	--	48,586	76.35
3d quarter	101,920	119.41	--	--	--	--	18,650	21.04	--	--	133,194	70.42
4th quarter	63,290	100.53	--	--	--	--	10,540	70.96	--	--	81,495	91.21
Total or average	288,084	114.53	--	--	--	--	45,661	35.19	--	--	364,044	88.89
1983:												
1st quarter	118,891	168.04	--	--	--	--	14,160	84.68	--	--	150,423	145.39
2d quarter	55,931	169.09	--	--	--	--	9,320	114.63	--	--	70,127	151.61
3d quarter	49,228	124.96	--	--	--	--	5,330	38.27	--	--	62,375	106.88
4th quarter	48,216	147.33	--	--	--	--	3,060	63.55	100	43.97	55,930	133.35
Total or average	272,266	156.80	--	--	--	--	31,870	83.65	100	43.97	338,855	137.60
1984:												
1st quarter	82,871	173.78	--	--	--	--	17,712	89.85	--	--	109,600	151.00
2d quarter	52,585	132.15	--	--	--	--	5,750	74.94	--	--	61,398	123.19
3d quarter	45,520	101.91	--	--	--	--	2,670	58.38	--	--	57,458	85.97
4th quarter	71,022	109.14	--	--	--	--	3,720	41.85	--	--	84,976	100.72
Total or average	251,998	133.89	--	--	--	--	29,852	78.18	--	--	313,432	120.00

1/Prices for individual sales may vary from the averages shown in this table because of differences in species mix, quality, road costs, logging and processing costs, size and length of sale, number of bidders, and other related price determinants. Prices for stumpage in National Forest lands are statistical high bids. The statistical high bid is defined as the bid price minus credits for road costs; it includes an allowance for sale-area betterment (K-V funds).

2/Does not include noble fir or Shasta red fir.

Source--U.S. Department of Agriculture. Pacific Northwest Region includes Oregon and Washington.

Table 6—Volume and average stumpage price of selected species on the Umpqua National Forest of the Pacific Northwest Region, 1973-84[1]

(Volume in thousand board feet, Scribner scale; value in dollars per thousand board feet)

YEAR AND QUARTER	DOUGLAS-FIR WEST SIDE VOLUME	DOUGLAS-FIR WEST SIDE VALUE	DOUGLAS-FIR EAST SIDE VOLUME	DOUGLAS-FIR EAST SIDE VALUE	PONDEROSA AND JEFFREY PINES VOLUME	PONDEROSA AND JEFFREY PINES VALUE	WESTERN HEMLOCK VOLUME	WESTERN HEMLOCK VALUE	TRUE FIRS[2] VOLUME	TRUE FIRS[2] VALUE	ALL SPECIES VOLUME	ALL SPECIES VALUE
1973:												
1st quarter	30,470	86.62	--	--	1,900	39.37	2,100	26.55	700	42.70	61,295	52.20
2d quarter	36,670	124.29	--	--	2,300	39.76	2,540	31.81	2,400	24.48	52,090	95.21
3d quarter	80,630	145.93	--	--	1,300	75.69	7,520	65.81	2,000	77.08	123,725	113.69
4th quarter	87,590	123.32	--	--	530	49.79	7,410	58.56	8,400	50.74	127,090	98.26
Total or average	235,360	126.47	--	--	6,030	48.27	19,570	54.44	13,500	49.56	364,200	95.31
1974:												
1st quarter	51,860	247.64	--	--	--	--	10,730	60.12	1,400	81.87	95,565	161.96
2d quarter	30,874	212.50	--	--	--	--	5,860	69.60	3,035	52.82	52,574	167.57
3d quarter	68,031	200.98	--	--	75	72.45	8,010	58.99	13,035	105.12	115,856	153.19
4th quarter	80,036	160.59	--	--	--	--	16,200	54.68	5,407	60.69	129,665	111.27
Total or average	230,851	190.99	--	--	75	72.45	40,800	59.10	22,877	86.26	393,660	143.43
1975:												
1st quarter	48,535	239.43	--	--	--	--	3,040	48.82	--	--	87,700	146.35
2d quarter	37,750	180.77	--	--	80	32.15	9,260	26.60	--	--	57,958	130.04
3d quarter	74,414	137.49	--	--	900	57.92	9,710	20.25	3,519	11.24	122,468	107.37
4th quarter	81,361	172.48	--	--	1,300	40.87	11,890	16.67	8,300	21.12	121,175	125.55
Total or average	242,060	174.95	--	--	2,280	47.29	33,900	23.29	11,819	18.18	389,309	125.19
1976:												
1st quarter	37,521	196.92	--	--	320	67.48	6,830	121.87	667	4.15	56,356	151.26
2d quarter	66,030	175.29	--	--	2,500	72.82	5,800	26.15	1,420	39.00	101,855	133.47
3d quarter	27,130	124.74	--	--	--	--	4,540	52.03	560	33.13	43,643	95.37
4th quarter	48,440	172.28	--	--	--	--	4,250	54.16	1,800	41.58	69,875	139.52
Total or average	179,121	171.35	--	--	2,820	72.21	21,420	67.71	4,447	34.07	271,729	132.60
1977:												
1st quarter	110,470	222.37	--	--	2,200	78.99	9,190	53.03	9,270	50.00	166,600	169.69
2d quarter	66,660	243.92	--	--	2,000	83.80	380	74.17	7,160	69.97	87,721	203.41
3d quarter	81,540	239.60	--	--	--	--	5,720	59.25	300	41.66	100,250	196.96
4th quarter	29,910	196.58	--	--	--	--	2,620	58.39	1,200	50.73	43,070	166.34
Total or average	288,580	229.54	--	--	4,200	81.28	17,910	56.25	17,930	57.88	405,641	194.35
1978:												
1st quarter	105,416	207.24	--	--	2,220	63.90	6,445	53.45	5,200	50.08	144,147	170.17
2d quarter	47,558	245.32	--	--	--	--	2,497	70.63	4,120	56.39	65,325	199.03
3d quarter	97,890	280.49	--	--	--	--	9,460	63.65	5,630	60.01	134,065	250.97
4th quarter	40,590	322.24	--	--	160	131.36	4,720	86.58	690	46.75	50,380	275.13
Total or average	291,454	254.07	--	--	2,380	68.43	23,122	66.24	15,640	55.30	393,917	215.88
1979:												
1st quarter	107,814	376.41	--	--	1,586	134.24	14,213	71.45	1,316	113.87	147,535	340.02
2d quarter	60,155	370.95	--	--	--	--	7,340	78.68	4,315	618.46	90,430	314.39
3d quarter	62,170	460.46	--	--	1,900	72.94	2,710	29.99	5,080	60.13	92,564	369.49
4th quarter	45,230	580.67	--	--	40	219.27	2,810	80.52	7,250	66.14	65,956	425.60
Total or average	275,369	428.07	--	--	3,526	102.17	27,073	70.20	17,961	202.89	396,485	342.64
1980:												
1st quarter	99,935	510.89	--	--	505	90.59	9,480	345.42	15,480	89.58	142,240	399.36
2d quarter	55,480	494.79	--	--	--	--	5,180	63.27	3,230	17.59	82,805	352.64
3d quarter	82,320	487.81	--	--	600	43.62	6,750	14.31	3,160	17.41	114,570	368.31
4th quarter	58,940	477.14	1,600	11.69	400	67.53	3,920	28.44	4,830	11.63	89,070	352.72
Total or average	296,675	494.77	1,600	11.69	1,505	68.42	25,330	150.43	26,700	24.92	428,685	372.35
1981:												
1st quarter	77,420	445.54	--	--	700	128.60	5,700	60.07	4,510	27.56	116,535	313.80
2d quarter	28,356	338.96	--	--	140	216.44	1,050	30.95	1,750	21.61	38,717	265.74
3d quarter	99,150	362.79	--	--	--	--	9,700	24.32	4,440	35.68	154,373	260.04
4th quarter	28,255	362.74	--	--	--	--	2,460	44.82	600	25.46	35,572	278.27
Total or average	233,181	387.36	--	--	840	143.24	18,910	38.13	11,300	29.72	345,197	283.13
1982:												
1st quarter	79,930	171.06	--	--	290	10.00	0,260	15.65	5,180	9.94	122,140	120.00
2d quarter	75,040	84.02	--	--	--	--	2,720	23.05	2,940	15.44	108,005	69.34
3d quarter	75,100	95.76	--	--	100	10.00	4,090	15.20	4,300	7.63	114,510	74.43
4th quarter	36,240	193.24	--	--	--	--	2,750	6.02	4,900	10.31	53,660	137.29
Total or average	266,310	128.32	--	--	390	10.00	17,820	15.19	17,320	10.41	390,315	95.49
1983:												
1st quarter	123,411	221.48	--	--	--	--	5,900	19.97	12,600	10.44	167,911	168.46
2d quarter	47,883	203.88	--	--	--	--	2,500	18.96	--	--	58,931	168.97
3d quarter	60,640	162.88	--	--	1,390	123.59	800	45.70	1,270	7.35	81,230	137.43
4th quarter	44,850	142.15	--	--	--	--	--	--	--	--	50,890	135.45
Total or average	276,784	192.74	--	--	1,390	123.59	9,200	21.93	13,870	10.16	358,962	156.84
1984:												
1st quarter	100,233	160.61	--	--	--	--	--	--	--	--	120,593	146.73
2d quarter	51,180	106.21	--	--	--	--	800	15.04	--	--	68,150	92.76
3d quarter	109,430	49.32	--	--	--	--	2,260	18.84	10,990	13.07	157,840	50.36
4th quarter	44,160	100.04	--	--	900	51.41	--	--	4,610	21.32	64,178	70.49
Total or average	305,003	102.78	--	--	900	51.41	3,060	17.85	15,600	15.51	410,761	88.82

[1]Prices for individual sales may vary from the averages shown in this table because of differences in species mix, quality, road costs, logging and processing costs, size and length of sale, number of bidders, and other related price determinants. Prices for stumpage in National Forest lands are statistical high bids. The statistical high bid is defined as the bid price minus credits for road costs; it includes an allowance for sale-area betterment (K-V funds).

[2]Does not include noble fir or Shasta red fir.

Source--U.S. Department of Agriculture. Pacific Northwest Region includes Oregon and Washington.

Table 7—Volume and average stumpage price of selected species on the Willamette National Forest of the Pacific Northwest Region, 1973-84[1]

(Volume in thousand board feet, Scribner scale; value in dollars per thousand board feet)

Year and quarter	Douglas-fir: West side Volume	Douglas-fir: West side Value	Douglas-fir: East side Volume	Douglas-fir: East side Value	Ponderosa and Jeffrey pines Volume	Ponderosa and Jeffrey pines Value	Western hemlock Volume	Western hemlock Value	True firs[2] Volume	True firs[2] Value	All species Volume	All species Value
1973:												
1st quarter	48,920	153.38	--	--	--	--	17,365	93.58	650	4.28	78,060	119.31
2d quarter	106,036	146.71	--	--	--	--	24,640	68.27	10,830	159.23	174,460	112.71
3d quarter	43,520	173.00	--	--	--	--	11,710	74.61	--	--	67,720	127.25
4th quarter	143,010	177.55	--	--	--	--	20,760	65.49	20,490	57.22	215,490	135.12
Total or average	341,486	163.96	--	--	--	--	74,475	74.39	31,970	90.70	535,730	124.52
1974:												
1st quarter	56,621	244.51	--	--	7,200	65.05	--	--	9,600	143.09	87,801	185.04
2d quarter	247,063	295.69	--	--	--	--	73,130	133.58	2,407	52.26	375,840	224.87
3d quarter	64,181	273.02	--	--	--	--	20,440	48.52	1,600	78.76	108,721	176.08
4th quarter	172,930	219.02	--	--	--	--	53,170	56.81	3,330	58.23	301,340	139.88
Total or average	540,795	263.13	--	--	7,200	65.05	146,740	93.91	16,937	107.42	873,702	185.48
1975:												
1st quarter	35,880	238.27	--	--	--	--	11,030	19.78	--	--	70,520	139.64
2d quarter	170,820	246.71	--	--	1,500	26.74	46,530	54.73	4,500	6.40	287,990	157.73
3d quarter	61,732	282.85	--	--	--	--	9,680	24.47	--	--	94,060	191.52
4th quarter	182,585	243.35	--	--	1,700	41.29	50,040	66.82	3,450	27.38	293,630	165.84
Total or average	451,017	249.63	--	--	3,200	34.47	117,280	54.10	7,950	15.50	746,200	163.47
1976:												
1st quarter	68,670	270.78	--	--	--	--	8,420	33.36	5,600	31.62	120,050	162.52
2d quarter	190,915	222.54	--	--	--	--	59,905	60.28	3,770	9.12	320,940	147.78
3d quarter	49,196	175.79	--	--	--	--	14,560	34.84	--	--	84,175	117.74
4th quarter	58,400	222.93	--	--	--	--	18,700	135.48	--	--	100,900	163.78
Total or average	367,181	225.36	--	--	--	--	101,585	68.25	9,370	22.57	626,065	149.15
1977:												
1st quarter	208,723	279.47	--	--	--	--	60,800	100.90	2,470	154.01	352,128	194.35
2d quarter	90,260	270.40	--	--	--	--	24,263	103.01	200	27.25	139,110	197.17
3d quarter	91,270	237.48	--	--	--	--	21,826	65.77	4,010	21.76	137,869	170.79
4th quarter	44,430	290.58	--	--	100	21.10	4,150	66.44	--	--	61,210	230.12
Total or average	434,683	269.90	--	--	100	21.10	111,039	93.74	6,680	70.83	690,317	193.39
1978:												
1st quarter	87,394	316.93	--	--	13	194.15	30,645	66.86	400	26.07	143,512	213.50
2d quarter	103,680	263.12	--	--	20	183.47	29,655	103.54	1,200	16.71	164,815	191.30
3d quarter	252,639	320.26	--	--	420	131.65	54,624	72.42	942	52.01	378,074	235.05
4th quarter	29,690	321.44	--	--	--	--	7,930	213.31	435	41.34	46,480	233.42
Total or average	473,403	307.20	--	--	453	135.82	122,854	87.64	2,977	32.74	732,881	220.89
1979:												
1st quarter	193,414	385.94	--	--	--	--	31,864	114.55	300	50.00	283,936	287.29
2d quarter	96,492	478.22	--	--	--	--	22,611	100.07	910	66.07	145,909	350.25
3d quarter	195,351	452.46	--	--	590	107.62	70,448	182.46	2,400	90.90	319,418	339.43
4th quarter	28,672	345.40	--	--	--	--	6,493	70.38	--	--	45,308	240.50
Total or average	513,929	426.23	--	--	590	107.62	131,416	146.28	3,610	81.24	794,571	317.17
1980:												
1st quarter	223,143	496.60	--	--	--	--	51,570	109.65	14,370	62.21	357,265	338.35
2d quarter	127,629	366.30	--	--	--	--	19,650	230.10	2,256	24.64	194,842	281.00
3d quarter	95,625	435.31	--	--	--	--	25,265	77.60	1,730	40.98	163,888	281.77
4th quarter	85,489	511.23	--	--	--	--	9,960	39.31	--	--	135,165	342.05
Total or average	531,886	456.67	--	--	--	--	106,445	117.70	18,356	55.59	851,160	314.91
1981:												
1st quarter	196,469	493.53	--	--	--	--	30,361	117.61	90	104.96	290,440	349.46
2d quarter	59,265	354.77	--	--	--	--	13,825	140.15	1,195	177.97	95,462	253.22
3d quarter	170,633	395.95	--	--	600	38.04	32,350	20.40	2,611	60.38	272,395	239.98
4th quarter	28,041	268.58	--	--	--	--	8,650	54.33	720	19.06	43,691	191.82
Total or average	454,408	411.39	--	--	600	38.04	85,186	77.93	4,616	85.25	701,988	284.00
1982:												
1st quarter	130,735	176.69	--	--	--	--	34,340	32.68	1,760	38.42	218,886	121.16
2d quarter	123,220	124.03	--	--	--	--	16,410	13.36	2,160	10.46	188,055	93.50
3d quarter	154,710	127.06	--	--	--	--	28,580	47.53	530	10.20	269,840	88.04
4th quarter	104,120	146.11	--	--	--	--	23,580	85.58	540	226.67	168,950	109.11
Total or average	512,785	142.86	--	--	--	--	102,910	45.84	4,990	43.69	845,731	102.04
1983:												
1st quarter	179,580	193.90	--	--	500	34.13	30,760	13.10	8,660	19.68	301,018	119.98
2d quarter	66,320	147.59	--	--	--	--	10,730	84.17	1,440	23.79	103,322	111.70
3d quarter	84,610	194.59	--	--	1,300	137.97	19,690	33.75	940	59.40	138,995	130.50
4th quarter	91,215	172.10	--	--	--	--	17,840	48.31	2,300	11.05	149,255	119.77
Total or average	421,725	182.04	--	--	1,800	109.13	79,020	35.84	13,340	21.44	692,590	120.81
1984:												
1st quarter	128,986	170.66	--	--	300	234.72	27,715	33.94	360	12.62	214,576	116.06
2d quarter	46,665	150.85	--	--	500	286.01	10,107	40.82	680	15.83	78,897	108.04
3d quarter	245,407	118.84	--	--	--	--	37,688	54.78	4,830	27.19	354,229	93.07
4th quarter	75,230	123.86	--	--	--	--	14,870	29.54	800	22.59	116,480	89.39
Total or average	496,288	136.08	--	--	800	266.78	90,380	42.68	6,670	24.69	764,182	100.51

[1] Prices for individual sales may vary from the averages shown in this table because of differences in species mix, quality, road costs, logging and processing costs, size and length of sale, number of bidders, and other related price determinants. Prices for stumpage in National Forest lands are statistical high bids. The statistical high bid is defined as the bid price minus credits for road costs; it includes an allowance for sale-area betterment (K-V funds).

[2] Does not include noble fir or Shasta red fir.

Source--U.S. Department of Agriculture. Pacific Northwest Region includes Oregon and Washington.

Table 8—Volume and average stumpage price of selected species on the National Forests of western Oregon, 1973-84 1/

(Volume in thousand board feet, Scribner scale; value in dollars per thousand board feet)

YEAR AND QUARTER	DOUGLAS-FIR				PONDEROSA AND JEFFREY PINES		WESTERN HEMLOCK		TRUE FIRS 2/		ALL SPECIES	
	WEST SIDE		EAST SIDE									
	VOLUME	VALUE	VOLUME	VALUE	VOLUME	VALUE	VOLUME	VALUE	VOLUME	VALUE	VOLUME	VALUE
1973:												
1st quarter	140,502	110.28	300	45.55	2,951	47.84	37,774	80.54	22,895	46.63	269,372	78.05
2d quarter	491,286	131.03	--	--	6,285	40.04	93,032	85.37	26,715	85.18	751,507	110.52
3d quarter	224,376	146.33	5,100	65.95	14,695	78.52	44,169	78.99	11,495	73.15	371,130	116.69
4th quarter	455,624	149.22	10,990	118.83	8,225	77.88	72,521	110.63	53,359	62.55	701,666	127.95
Total or average	1,311,788	137.24	16,390	101.04	32,156	68.02	247,496	90.90	114,464	65.71	2,093,675	113.28
1974:												
1st quarter	180,222	221.11	18,700	147.07	15,883	79.67	23,476	94.70	29,195	114.34	338,947	157.73
2d quarter	520,672	256.55	8,800	162.56	15,378	187.01	110,869	131.87	11,849	44.97	813,296	209.82
3d quarter	183,211	230.51	7,850	184.23	1,655	85.80	43,112	87.70	15,838	101.32	311,767	168.84
4th quarter	491,361	166.29	28,925	121.08	11,655	59.16	99,981	55.25	48,781	62.22	840,065	117.54
Total or average	1,375,466	216.20	64,275	142.03	44,571	111.57	277,438	94.25	105,663	80.55	2,304,075	162.97
1975:												
1st quarter	137,976	211.85	1,230	70.00	--	--	30,020	59.54	--	--	252,056	137.71
2d quarter	526,195	170.85	21,660	125.96	12,954	64.67	114,372	52.46	35,028	71.90	879,696	129.47
3d quarter	237,253	181.67	5,350	27.05	5,840	19.79	39,675	34.57	21,569	36.15	405,119	127.92
4th quarter	516,176	189.30	26,380	64.34	10,584	37.50	119,345	76.14	51,322	52.64	860,498	140.02
Total or average	1,417,600	183.37	54,620	85.25	29,378	45.87	303,412	89.70	107,919	55.60	2,397,369	133.86
1976:												
1st quarter	143,179	221.95	980	46.35	2,285	89.14	20,398	85.70	8,240	32.47	233,387	163.86
2d quarter	497,903	188.96	10,200	110.52	5,366	62.17	105,535	75.13	33,915	62.08	827,155	142.99
3d quarter	156,699	141.97	2,400	95.62	5,629	107.19	41,449	34.16	10,834	85.81	283,581	106.74
4th quarter	159,902	199.28	250	41.71	305	116.72	32,760	128.39	3,550	53.69	248,013	160.57
Total or average	957,683	187.93	13,830	102.15	13,585	86.59	200,142	76.71	56,539	61.79	1,592,136	142.33
1977:												
1st quarter	517,937	245.59	16,100	224.13	14,150	91.66	110,250	108.39	43,008	110.08	887,922	181.06
2d quarter	317,700	239.02	5,500	87.80	4,110	100.07	49,448	106.11	18,920	83.62	486,823	188.00
3d quarter	326,958	230.07	10,620	79.59	9,900	70.32	57,166	115.42	30,570	127.02	513,800	185.67
4th quarter	140,705	245.95	--	--	1,310	85.79	12,882	93.08	5,520	107.81	193,028	207.63
Total or average	1,303,300	240.56	32,220	153.22	29,470	85.40	229,746	109.79	98,018	109.93	2,081,573	186.29
1978:												
1st quarter	450,284	251.91	17,506	184.52	9,599	115.00	88,692	109.22	26,455	92.08	704,651	197.58
2d quarter	250,195	253.78	11,830	105.99	4,759	155.68	41,702	108.84	15,485	139.38	396,612	199.33
3d quarter	619,807	274.74	5,051	62.64	4,347	167.75	121,129	126.62	45,121	124.05	944,853	225.86
4th quarter	115,328	298.70	2,530	75.57	4,920	151.48	34,077	177.04	6,622	143.11	182,549	234.41
Total or average	1,435,614	265.85	36,917	135.21	23,625	140.50	285,600	124.64	93,683	118.90	2,228,665	212.90
1979:												
1st quarter	560,730	358.24	18,130	202.53	4,283	173.47	98,043	144.68	37,161	463.98	850,629	303.71
2d quarter	256,076	411.77	17,410	174.80	6,371	179.08	57,661	125.71	26,816	284.70	432,089	310.75
3d quarter	597,662	448.37	4,574	213.69	4,318	106.19	137,785	221.67	37,045	223.85	912,836	374.35
4th quarter	139,645	495.79	4,700	389.97	2,256	189.60	23,717	185.71	10,555	79.94	219,743	369.19
Total or average	1,554,113	414.11	44,814	212.55	17,228	160.79	317,206	177.74	111,577	304.84	2,415,297	337.63
1980:												
1st quarter	588,202	498.21	6,880	175.11	7,405	97.33	106,743	197.21	66,885	204.29	928,103	386.95
2d quarter	317,595	393.57	3,250	14.38	1,410	16.75	55,698	294.51	22,318	299.94	493,486	320.43
3d quarter	503,060	440.84	8,470	135.65	10,702	96.41	80,924	218.45	28,975	350.76	767,117	367.72
4th quarter	266,754	504.40	3,267	19.81	3,420	368.58	29,981	35.47	7,920	77.94	388,569	397.70
Total or average	1,675,611	462.14	21,867	112.73	23,017	132.27	273,346	205.59	126,098	246.94	2,577,275	363.86
1981:												
1st quarter	545,007	472.55	13,700	315.91	2,880	43.38	76,672	134.26	21,740	142.00	795,878	358.91
2d quarter	252,445	373.47	7,170	245.92	1,060	167.76	46,661	134.82	21,008	111.90	403,859	282.91
3d quarter	545,252	319.43	3,160	56.71	6,240	276.58	95,456	118.44	38,057	48.75	883,074	233.34
4th quarter	188,041	281.09	7,300	27.96	8,140	190.08	23,042	45.51	20,218	51.41	289,118	215.44
Total or average	1,530,745	378.15	31,330	206.66	18,320	195.19	241,831	119.67	101,023	82.48	2,371,929	281.73
1982:												
1st quarter	416,403	161.87	990	46.72	7,335	34.24	70,178	27.69	36,715	79.48	645,529	121.00
2d quarter	312,868	98.27	9,700	10.47	2,845	18.25	43,218	26.01	6,645	31.31	468,136	79.89
3d quarter	492,615	107.39	2,190	84.30	4,730	92.49	85,414	41.40	44,013	28.89	799,702	77.66
4th quarter	287,585	129.57	12,900	30.44	1,100	48.30	49,550	60.65	13,370	52.99	452,654	101.74
Total or average	1,509,471	124.75	25,780	28.13	16,010	49.58	248,360	38.69	100,743	50.69	2,366,021	94.54
1983:												
1st quarter	576,892	197.91	4,120	27.70	5,940	53.09	95,025	51.14	32,240	63.46	899,481	139.11
2d quarter	254,298	166.50	1,150	21.91	2,470	55.25	30,830	98.11	20,035	84.11	368,625	134.08
3d quarter	288,955	161.59	11,400	49.78	4,907	90.62	47,135	60.04	32,775	102.67	468,513	124.05
4th quarter	256,484	160.52	6,350	38.53	6,655	97.42	36,047	103.97	21,760	70.44	399,518	129.32
Total or average	1,376,629	177.52	23,020	41.33	19,972	77.35	209,037	69.18	106,810	80.79	2,136,137	133.33
1984:												
1st quarter	422,900	163.59	4,300	31.28	6,425	77.07	82,090	86.73	10,575	68.81	668,824	127.68
2d quarter	208,138	125.98	9,680	78.73	3,040	73.12	33,048	61.89	11,890	27.32	333,677	112.88
3d quarter	526,815	98.55	8,500	26.17	3,645	37.31	63,913	64.51	36,485	48.30	790,344	83.46
4th quarter	257,518	108.35	4,855	105.42	2,440	63.56	36,705	28.44	23,645	39.26	400,543	83.06
Total or average	1,415,371	123.80	27,335	59.66	15,550	64.86	215,756	66.43	82,595	45.32	2,193,388	101.35

1/ Prices for individual sales may vary from the averages shown in this table because of differences in species mix, quality, road costs, logging and processing costs, size and length of sale, number of bidders, and other related price determinants. Prices for stumpage in National Forest lands are statistical high bids. The statistical high bid is defined as the bid price minus credits for road costs; it includes an allowance for sale-area betterment (K-V funds).

2/ Does not include noble fir or Shasta red fir.

Source--U.S. Department of Agriculture. Pacific Northwest Region includes Oregon and Washington.

Table 9—Volume and average stumpage price of selected species on the Gifford Pinchot National Forest of the Pacific Northwest Region, 1973-84[1]

(Volume in thousand board feet, Scribner scale; value in dollars per thousand board feet)

Year and quarter	Douglas-fir West side Volume	Douglas-fir West side Value	Douglas-fir East side Volume	Douglas-fir East side Value	Ponderosa and Jeffrey pines Volume	Ponderosa and Jeffrey pines Value	Western hemlock Volume	Western hemlock Value	True firs[2] Volume	True firs[2] Value	All species Volume	All species Value
1973:												
1st quarter	27,370	161.05	--	--	--	--	24,590	187.47	8,280	179.79	73,380	152.24
2d quarter	58,145	155.81	--	--	--	--	14,345	101.81	2,500	63.19	102,889	129.98
3d quarter	43,970	158.84	--	--	--	--	21,990	158.17	10,222	221.51	96,480	134.81
4th quarter	44,538	186.83	--	--	--	--	33,635	135.83	7,410	118.53	105,517	133.11
Total or average	174,023	165.34	--	--	--	--	94,560	149.29	28,412	168.56	378,266	136.40
1974:												
1st quarter	34,790	117.26	--	--	--	--	15,740	99.64	7,070	153.66	62,710	131.22
2d quarter	73,430	232.25	--	--	--	--	42,350	191.05	33,710	191.56	180,675	182.43
3d quarter	24,458	173.61	--	--	600	3.19	15,690	336.97	4,127	92.12	51,954	194.24
4th quarter	115,925	124.89	--	--	1,600	126.50	31,010	140.32	39,130	123.74	216,235	117.00
Total or average	248,603	160.35	--	--	2,200	92.87	105,290	184.34	84,037	151.91	511,574	146.69
1975:												
1st quarter	41,440	152.96	--	--	--	--	4,570	17.74	--	--	59,280	111.56
2d quarter	99,407	157.61	--	--	--	--	34,535	128.55	16,706	77.18	184,143	126.50
3d quarter	26,809	237.96	--	--	1,100	44.55	7,200	114.48	4,310	101.09	48,622	164.72
4th quarter	69,300	190.33	--	--	4,400	34.70	43,800	118.16	15,100	135.03	147,790	141.18
Total or average	236,956	175.45	--	--	5,500	36.67	90,105	116.76	36,116	104.22	439,835	133.65
1976:												
1st quarter	12,400	159.12	--	--	--	--	2,780	163.46	2,230	111.54	20,550	136.49
2d quarter	92,422	150.52	--	--	1,400	50.51	65,593	132.71	26,340	61.45	219,530	115.10
3d quarter	15,270	141.40	--	--	--	--	6,200	62.09	--	--	25,903	108.02
4th quarter	48,960	184.36	--	--	--	--	23,950	80.27	7,500	110.33	89,313	133.67
Total or average	169,052	160.13	--	--	1,400	50.51	98,523	116.38	36,070	74.71	355,296	120.49
1977:												
1st quarter	30,740	217.04	--	--	--	--	17,920	111.76	12,500	115.08	87,080	131.51
2d quarter	49,980	185.13	--	--	--	--	16,520	85.36	22,830	67.64	106,405	121.64
3d quarter	94,020	180.58	--	--	2,800	94.71	66,630	111.34	26,480	69.86	223,619	127.25
4th quarter	21,600	195.97	--	--	400	89.42	11,000	70.28	5,650	100.88	44,080	132.37
Total or average	196,340	189.14	--	--	3,200	94.05	112,070	103.54	67,460	80.09	461,184	127.25
1978:												
1st quarter	14,158	224.35	--	--	--	--	10,760	135.67	--	--	29,218	165.58
2d quarter	55,035	199.01	--	--	5,600	175.00	17,760	82.43	14,010	77.31	119,305	134.20
3d quarter	131,160	181.08	--	--	3,200	246.73	43,030	282.03	75,800	105.93	295,670	159.36
4th quarter	15,130	285.93	--	--	--	--	14,520	115.92	1,200	58.28	34,210	180.18
Total or average	215,483	195.87	--	--	8,800	200.97	86,070	194.55	91,010	100.90	478,403	154.96
1979:												
1st quarter	67,460	315.12	--	--	1,000	296.00	36,830	215.41	40,000	183.49	167,220	224.86
2d quarter	30,140	281.47	--	--	500	103.40	21,340	298.76	15,280	195.74	79,265	231.55
3d quarter	114,867	433.03	--	--	3,300	272.17	51,131	418.86	30,660	346.95	242,994	352.13
4th quarter	14,727	344.76	--	--	--	--	6,265	471.10	780	198.36	25,587	325.79
Total or average	227,194	372.22	--	--	4,800	280.39	115,566	334.68	86,720	243.57	515,066	290.95
1980:												
1st quarter	29,220	376.01	--	--	1,400	88.94	12,120	214.02	7,800	226.49	60,150	273.45
2d quarter	43,160	336.67	--	--	--	--	32,221	337.22	6,900	342.30	97,290	291.05
3d quarter	82,216	303.28	--	--	--	--	42,160	432.16	15,870	64.25	138,809	272.51
4th quarter	56,180	257.81	--	--	--	--	20,870	203.49	23,000	249.32	115,989	213.36
Total or average	210,776	308.08	--	--	1,400	88.94	107,371	334.60	53,570	203.15	412,238	260.38
1981:												
1st quarter	18,900	582.42	--	--	--	--	2,200	27.80	6,600	12.58	29,670	378.09
2d quarter	39,377	170.32	--	--	--	--	32,260	374.97	6,100	55.32	86,807	226.19
3d quarter	213,035	226.55	--	--	--	--	139,765	198.60	34,165	159.07	439,526	188.55
4th quarter	25,150	139.95	--	--	--	--	29,410	101.00	3,840	147.10	71,145	101.32
Total or average	296,462	234.42	--	--	--	--	203,635	210.60	50,705	126.62	627,148	192.83
1982:												
1st quarter	56,670	123.90	--	--	--	--	84,510	44.00	--	--	176,330	64.72
2d quarter	31,790	114.83	--	--	15,080	20.09	--	--	270	6.83	61,764	67.80
3d quarter	49,754	54.70	--	--	--	--	44,830	49.16	740	99.96	111,039	48.07
4th quarter	59,010	171.80	--	--	--	--	25,680	105.06	4,450	18.75	105,630	124.10
Total or average	197,224	119.31	--	--	15,080	20.09	155,020	55.61	5,460	29.17	454,763	74.87
1983:												
1st quarter	45,050	116.43	--	--	--	--	17,800	90.65	24,315	92.27	101,545	112.84
2d quarter	67,290	143.18	--	--	--	--	13,750	49.96	19,085	81.11	115,155	107.04
3d quarter	40,881	113.83	--	--	--	--	11,630	55.24	36,690	57.15	104,881	71.24
4th quarter	64,534	158.46	--	--	--	--	10,253	56.35	16,060	103.94	103,814	125.71
Total or average	217,755	147.01	--	--	--	--	53,433	65.89	96,150	78.61	425,395	104.15
1984:												
1st quarter	51,530	87.98	--	--	--	--	5,890	36.15	14,920	64.06	82,660	69.97
2d quarter	38,345	130.06	--	--	--	--	18,813	89.94	11,300	76.43	79,423	98.06
3d quarter	58,310	100.03	--	--	--	--	31,360	46.72	9,600	93.06	116,919	76.49
4th quarter	59,015	119.91	--	--	--	--	40,885	71.74	12,395	26.49	125,570	86.21
Total or average	207,200	108.25	--	--	--	--	96,948	64.27	48,215	63.07	404,572	82.35

[1] Prices for individual sales may vary from the averages shown in this table because of differences in species mix, quality, road costs, logging and processing costs, size and length of sale, number of bidders, and other related price determinants. Prices for stumpage in National Forest lands are statistical high bids. The statistical high bid is defined as the bid price minus credits for road costs; it includes an allowance for sale-area betterment (K-V funds).

[2] Does not include noble fir or Shasta red fir.

Source--U.S. Department of Agriculture. Pacific Northwest Region includes Oregon and Washington.

Table 10—Volume and average stumpage price of selected species on the Mount Baker-Snoqualmie National Forest of the Pacific Northwest Region, 1973-84[1]

(Volume in thousand board feet, Scribner scale; value in dollars per thousand board feet)

Year and quarter	Douglas-fir				Ponderosa and Jeffrey pines		Western hemlock		True firs[2]		All species	
	West side		East side									
	Volume	Value	Volume	Value	Volume	Value	Volume	Value	Volume	Value	Volume	Value
1973:[3]												
1st quarter	11,850	99.23	9,600	41.15	6,360	125.26	28,390	125.89	6,400	127.75	72,045	97.92
2d quarter	19,758	176.93	11,440	65.46	7,060	70.55	34,155	105.37	28,480	74.52	124,217	88.81
3d quarter	10,305	114.74	4,060	76.96	3,120	94.51	56,405	119.99	8,180	120.55	99,695	99.42
4th quarter	7,865	141.75	1,000	63.27	8,200	92.60	23,120	116.19	10,105	114.59	61,175	95.95
Total or average	49,778	140.00	26,100	58.23	24,740	94.95	142,070	117.04	53,165	90.52	357,932	94.84
1974:[3]												
1st quarter	5,425	153.30	6,700	76.61	6,600	71.68	16,485	119.46	4,436	139.92	50,166	96.23
2d quarter	15,640	212.42	9,650	81.58	6,120	81.25	71,935	135.22	8,255	57.06	140,850	111.49
3d quarter	15,251	184.93	2,350	69.44	1,200	93.97	24,312	127.80	2,450	63.12	50,104	113.24
4th quarter	15,354	164.57	--	--	150	106.96	37,728	121.56	10,298	177.04	83,212	117.94
Total or average	51,670	183.88	18,700	00.66	14,070	78.26	150,460	128.93	25,439	120.66	324,412	111.05
1975:												
1st quarter	835	194.49	--	--	--	--	7,165	82.90	--	--	16,245	79.50
2d quarter	22,835	110.69	--	--	--	--	77,930	93.86	4,345	108.07	139,612	85.91
3d quarter	24,754	117.32	--	--	--	--	24,480	65.14	240	55.00	84,795	86.06
4th quarter	16,393	132.16	--	--	--	--	39,457	75.40	850	21.25	69,613	80.30
Total or average	64,817	119.73	--	--	--	--	149,032	83.73	5,435	92.15	310,265	84.36
1976:												
1st quarter	7,490	140.34	--	--	--	--	24,340	88.09	3,260	92.70	45,470	81.36
2d quarter	14,337	93.66	--	--	--	--	46,541	41.86	7,700	60.60	86,073	56.27
3d quarter	5,225	139.85	--	--	--	--	19,200	73.83	13,760	64.09	56,680	72.30
4th quarter	7,380	119.40	--	--	--	--	13,790	66.66	--	--	25,742	83.79
Total or average	34,432	116.34	--	--	--	--	103,871	61.91	24,720	66.79	213,965	69.16
1977:												
1st quarter	24,915	142.99	--	--	60,990	79.38	--	--	480	68.25	101,379	93.16
2d quarter	18,435	149.18	--	--	--	--	68,685	75.48	6,520	73.99	108,775	88.81
3d quarter	8,076	185.54	--	--	--	--	42,384	69.83	980	65.10	64,509	107.11
4th quarter	9,100	80.08	--	--	--	--	18,300	80.91	1,700	17.63	35,912	71.51
Total or average	60,526	141.09	--	--	60,990	79.38	129,369	74.40	9,680	62.91	310,575	92.03
1978:												
1st quarter	13,020	218.02	--	--	--	--	28,163	84.81	2,100	62.07	55,640	137.12
2d quarter	4,570	166.29	--	--	--	--	1,320	63.41	1,250	73.64	23,926	102.00
3d quarter	42,500	283.71	--	--	--	--	63,030	88.74	48,610	78.54	167,937	133.82
4th quarter	13,881	252.85	--	--	--	--	4,990	104.61	940	53.55	32,391	166.79
Total or average	73,971	259.10	--	--	--	--	97,503	102.04	52,900	77.33	279,894	135.57
1979:												
1st quarter	14,840	407.13	--	--	--	--	46,674	153.74	280	51.00	75,563	210.53
2d quarter	7,149	261.81	--	--	--	--	39,373	136.15	8,360	102.63	69,290	148.29
3d quarter	27,912	374.77	--	--	--	--	70,388	276.38	27,400	234.34	140,567	277.33
4th quarter	3,795	287.02	--	--	--	--	769	179.63	2,135	160.02	17,416	220.76
Total or average	53,696	362.47	--	--	--	--	157,204	204.37	38,175	199.99	302,836	227.88
1980:												
1st quarter	31,666	358.47	--	--	--	--	68,679	225.30	5,340	183.84	134,223	227.51
2d quarter	31,299	417.04	--	--	--	--	30,902	199.47	24,150	179.37	98,703	260.72
3d quarter	11,135	372.21	--	--	--	--	22,006	180.27	1,930	123.19	49,316	221.30
4th quarter	2,360	266.44	--	--	1,000	150.00	13,630	202.04	7,180	161.84	35,793	184.15
Total or average	76,460	381.60	--	--	1,000	150.00	135,297	209.70	38,600	173.92	318,035	231.89
1981:												
1st quarter	20,300	358.33	--	--	--	--	24,601	228.38	28,660	158.68	91,856	211.67
2d quarter	12,500	269.09	--	--	--	--	30,504	127.71	6,325	139.29	57,962	191.43
3d quarter	27,975	220.71	--	--	--	--	52,378	166.60	7,850	148.82	125,420	170.63
4th quarter	7,160	199.43	--	--	--	--	4,270	83.10	3,710	46.90	21,945	110.70
Total or average	67,935	268.49	--	--	--	--	111,753	190.96	46,545	145.47	297,183	182.94
1982:												
1st quarter	21,549	94.98	--	--	3,000	16.64	28,429	81.64	26,515	102.07	104,289	83.17
2d quarter	11,460	100.34	--	--	9,790	74.26	6,384	52.22	8,480	34.04	42,230	65.29
3d quarter	13,130	58.91	--	--	--	--	44,208	40.63	31,055	36.38	113,445	37.94
4th quarter	8,580	77.77	--	--	--	--	8,320	113.35	3,600	104.60	28,205	85.74
Total or average	54,719	84.75	--	--	12,790	60.75	87,341	61.75	69,650	64.63	288,169	63.00
1983:												
1st quarter	9,370	104.91	--	--	--	--	30,893	52.63	11,200	86.55	70,010	57.24
2d quarter	17,835	67.54	--	--	--	--	39,531	67.19	13,410	133.81	88,278	75.51
3d quarter	7,796	96.14	--	--	--	--	16,256	93.03	7,945	65.88	42,481	84.42
4th quarter	15,315	81.19	--	--	--	--	10,745	64.02	17,760	78.22	52,940	68.94
Total or average	50,316	78.90	--	--	--	--	97,425	66.53	50,315	92.96	254,509	70.55
1984:												
1st quarter	20,245	113.46	--	--	--	--	28,217	75.50	15,060	42.95	89,575	86.94
2d quarter	10,165	136.72	--	--	--	--	22,526	50.46	15,365	52.23	61,000	65.42
3d quarter	19,725	100.58	--	--	--	--	36,200	50.96	24,630	20.18	107,224	54.34
4th quarter	12,180	46.92	--	--	--	--	12,160	17.27	12,900	34.37	48,330	31.00
Total or average	62,315	100.17	--	--	--	--	99,103	53.70	67,955	35.17	306,129	62.40

[1]Prices for individual sales may vary from the averages shown in this table because of differences in species mix, quality, road costs, logging and processing costs, size and length of sale, number of bidders, and other related price determinants. Prices for stumpage in National Forest lands are statistical high bids. The statistical high bid is defined as the bid price minus credits for road costs; it includes an allowance for sale-area betterment (K-V funds).

[2]Does not include noble fir or Shasta red fir.

[3]Mount Baker National Forest combined with the Snoqualmie National Forest July 1, 1974; however, for this report, the statistics have been combined for all of 1973 and the first 6 months of 1974.

Source--U.S. Department of Agriculture. Pacific Northwest Region includes Oregon and Washington.

Table 11—Volume and average stumpage price of selected species on the Olympic National Forest of the Pacific Northwest Region, 1973-84[1]

(Volume in thousand board feet, Scribner scale; value in dollars per thousand board feet)

Year and quarter	Douglas-fir West side Volume	Douglas-fir West side Value	Douglas-fir East side Volume	Douglas-fir East side Value	Ponderosa and Jeffrey pines Volume	Ponderosa and Jeffrey pines Value	Western hemlock Volume	Western hemlock Value	True firs[2] Volume	True firs[2] Value	All species Volume	All species Value
1973:												
1st quarter	23,010	69.07	--	--	--	--	37,100	63.47	2,200	22.10	66,595	63.06
2d quarter	15,180	88.73	--	--	--	--	67,440	68.10	6,400	32.20	110,341	65.97
3d quarter	3,500	69.56	--	--	--	--	17,200	70.94	--	--	23,455	67.28
4th quarter	9,930	190.18	--	--	--	--	38,455	113.26	--	--	64,080	124.80
Total or average	51,620	98.18	--	--	--	--	160,195	78.17	8,600	29.61	264,471	79.61
1974:												
1st quarter	1,478	87.82	--	--	--	--	12,490	74.64	--	--	16,653	71.52
2d quarter	28,686	85.09	--	--	--	--	62,090	79.96	7,580	61.73	112,086	76.02
3d quarter	3,362	130.73	--	--	--	--	17,844	110.01	--	--	22,988	111.37
4th quarter	31,015	93.91	--	--	--	--	59,025	61.44	245	10.40	91,062	78.68
Total or average	64,541	91.77	--	--	--	--	151,449	75.84	7,825	60.12	242,791	80.06
1975:												
1st quarter	69,810	47.32	--	--	--	--	49,120	17.83	--	--	142,800	33.08
2d quarter	27,145	38.76	--	--	--	--	44,585	48.83	8,000	2.00	95,742	39.73
3d quarter	12,400	10.82	--	--	--	--	21,700	75.69	1,300	81.07	41,676	79.50
4th quarter	33,370	74.74	--	--	--	--	68,383	35.52	--	--	110,703	46.95
Total or average	142,725	57.39	--	--	--	--	183,788	38.76	9,300	13.05	390,921	43.58
1976:												
1st quarter	9,100	93.75	--	--	--	--	11,388	57.85	--	--	23,603	64.79
2d quarter	59,128	101.64	--	--	--	--	74,342	45.04	4,500	8.43	152,349	65.26
3d quarter	18,085	141.78	--	--	--	--	55,515	100.93	--	--	83,293	103.12
4th quarter	19,290	134.46	--	--	--	--	26,310	64.54	--	--	48,697	93.36
Total or average	105,603	113.83	--	--	--	--	167,555	67.49	4,500	8.43	307,942	79.91
1977:												
1st quarter	31,335	128.97	--	--	--	--	48,510	50.81	--	--	99,730	75.29
2d quarter	14,402	142.24	--	--	--	--	15,567	59.68	--	--	33,319	102.24
3d quarter	45,220	140.65	--	--	--	--	67,307	58.04	8,250	36.50	143,519	87.64
4th quarter	12,509	168.85	--	--	--	--	9,786	98.21	--	--	35,729	93.95
Total or average	103,466	140.74	--	--	--	--	141,170	58.52	8,250	36.50	312,297	85.97
1978:												
1st quarter	8,553	173.65	--	--	--	--	59,364	73.59	13,000	110.79	92,438	102.66
2d quarter	26,700	150.32	--	--	--	--	37,052	60.07	5,800	24.28	78,651	92.15
3d quarter	57,430	101.64	--	--	--	--	83,600	70.56	10,500	89.13	160,137	85.41
4th quarter	457	227.97	--	--	--	--	720	118.82	--	--	1,677	155.04
Total or average	93,140	123.21	--	--	--	--	180,736	69.60	29,300	85.90	332,903	92.14
1979:												
1st quarter	26,120	170.15	--	--	--	--	88,989	132.41	6,900	118.50	135,175	135.93
2d quarter	10,519	249.54	--	--	--	--	42,983	140.71	4,290	27.57	62,600	146.64
3d quarter	47,962	122.30	--	--	--	--	56,683	147.02	27,550	70.31	155,037	124.68
4th quarter	20,530	226.56	--	--	--	--	19,330	185.00	30	20.54	42,540	199.42
Total or average	105,131	167.28	--	--	--	--	207,985	143.00	38,770	74.12	395,352	140.05
1980:												
1st quarter	3,980	181.17	--	--	--	--	9,900	162.87	2,190	68.28	20,878	166.87
2d quarter	40,130	325.25	--	--	--	--	53,350	119.64	22,000	146.46	137,070	150.16
3d quarter	49,000	81.73	--	--	--	--	67,450	138.18	37,370	216.84	177,418	115.58
4th quarter	4,305	172.70	--	--	--	--	18,195	261.88	--	--	31,482	232.96
Total or average	97,415	148.93	--	--	--	--	148,895	148.29	61,560	165.27	366,848	141.49
1981:												
1st quarter	25,135	270.29	--	--	--	--	41,345	242.38	2,000	65.56	77,915	221.42
2d quarter	1,078	126.26	--	--	--	--	4,890	143.70	2,290	138.83	12,958	139.79
3d quarter	33,880	226.68	--	--	--	--	96,490	135.90	32,538	117.61	170,450	157.42
4th quarter	2,923	94.31	--	--	--	--	4,450	37.52	470	48.77	8,693	57.02
Total or average	63,016	236.21	--	--	--	--	147,175	163.10	37,298	115.23	270,016	171.81
1982:												
1st quarter	10,740	122.14	--	--	--	--	17,080	91.81	3,510	82.80	41,930	80.70
2d quarter	20,300	60.12	--	--	480	15.10	53,640	27.69	8,255	50.60	95,040	36.01
3d quarter	22,240	38.05	--	--	--	--	55,290	21.24	38,750	12.31	127,950	21.09
4th quarter	8,135	117.57	--	--	--	--	12,865	10.82	4,550	10.49	39,720	79.78
Total or average	61,415	70.58	--	--	480	15.10	138,875	31.45	55,065	20.16	304,640	41.60
1983:												
1st quarter	46,930	26.79	--	--	--	--	79,970	43.98	--	--	155,480	33.09
2d quarter	17,310	97.56	--	--	--	--	53,680	64.40	2,900	159.44	93,857	76.36
3d quarter	48,100	76.61	--	--	--	--	33,090	58.00	7,850	68.39	139,250	47.79
4th quarter	10,400	107.52	--	--	800	97.18	16,290	76.71	17,300	21.54	56,190	69.47
Total or average	122,740	63.16	--	--	800	97.18	183,030	55.71	28,050	48.91	444,777	51.64
1984:												
1st quarter	10,416	106.72	--	--	--	--	27,084	41.80	3,760	41.39	58,904	61.98
2d quarter	3,700	34.71	--	--	--	--	13,420	40.00	21,530	13.05	48,452	28.01
3d quarter	34,290	32.35	--	--	--	--	49,920	18.50	7,250	9.18	106,910	25.75
4th quarter	3,220	73.50	--	--	--	--	14,290	28.75	40	36.50	19,502	42.18
Total or average	51,626	50.09	--	--	--	--	104,714	28.68	32,580	15.55	233,768	36.72

[1]Prices for individual sales may vary from the averages shown in this table because of differences in species mix, quality, road costs, logging and processing costs, size and length of sale, number of bidders, and other related price determinants. Prices for stumpage in National Forest lands are statistical high bids. The statistical high bid is defined as the bid price minus credits for road costs; it includes an allowance for sale-area betterment (K-V funds).

[2]Does not include noble fir or Shasta red fir.

Source--U.S. Department of Agriculture. Pacific Northwest Region includes Oregon and Washington.

Table 12—Volume and average stumpage price of selected species on the National Forests of western Washington, 1973-84[1]

(Volume in thousand board feet, Scribner scale; value in dollars per thousand board feet)

Year and quarter	Douglas-fir				Ponderosa and Jeffrey pines		Western hemlock		True firs[2]		All species	
	West side		East side									
	Volume	Value	Volume	Value	Volume	Value	Volume	Value	Volume	Value	Volume	Value
1973:												
1st quarter	62,230	115.27	9,600	41.15	6,360	125.26	90,080	116.99	16,880	139.51	212,820	105.74
2d quarter	93,083	149.35	11,440	65.46	7,060	70.55	115,940	83.25	37,380	66.51	337,447	93.90
3d quarter	57,775	145.57	4,060	76.96	3,120	94.51	95,595	119.95	18,402	176.63	219,630	111.54
4th quarter	62,333	181.68	1,000	63.27	8,200	92.60	95,210	121.95	17,515	116.25	230,772	120.95
Total or average	275,421	148.17	26,100	58.23	24,740	94.95	396,825	109.04	90,177	112.31	1,000,669	106.53
1974:												
1st quarter	41,693	121.12	6,700	76.61	6,600	71.68	44,715	99.96	11,506	148.36	129,531	109.99
2d quarter	117,756	193.77	9,650	81.58	6,120	81.75	176,875	128.94	49,545	149.27	433,611	131.88
3d quarter	43,071	174.17	2,350	69.44	1,800	63.71	57,846	179.05	6,577	81.32	125,126	146.53
4th quarter	162,294	122.72	--	--	1,750	124.83	127,763	98.46	49,673	134.23	390,509	108.26
Total or average	364,814	151.56	18,700	80.66	16,270	80.24	407,199	123.31	117,301	139.02	967,767	123.40
1975:												
1st quarter	112,085	87.47	--	--	--	--	60,335	24.67	--	--	217,433	57.62
2d quarter	138,587	138.23	--	--	--	--	157,050	88.71	29,051	61.10	407,897	95.61
3d quarter	63,963	166.12	--	--	1,100	44.55	53,380	76.08	5,850	94.75	175,093	106.34
4th quarter	129,123	145.18	--	--	4,400	34.70	168,117	69.14	15,000	107.05	359,245	93.56
Total or average	443,758	131.45	--	--	5,500	36.67	438,882	70.78	49,901	78.84	1,159,668	89.47
1976:												
1st quarter	28,990	133.75	--	--	--	--	38,508	84.59	5,490	100.35	89,623	89.64
2d quarter	165,887	128.18	--	--	1,400	50.51	186,476	75.09	38,540	55.10	457,952	87.46
3d quarter	38,580	141.37	--	--	--	--	80,915	91.53	13,760	64.09	165,876	93.35
4th quarter	75,630	165.30	--	--	--	--	64,050	70.88	7,500	110.33	163,752	113.84
Total or average	309,087	139.43	--	--	1,400	50.51	369,949	78.94	65,290	67.14	877,203	93.72
1977:												
1st quarter	86,990	164.11	--	--	60,990	73.38	66,430	67.25	12,980	113.35	288,189	98.56
2d quarter	82,817	169.67	--	--	--	--	100,471	74.88	29,350	69.05	248,499	104.67
3d quarter	147,316	168.60	--	--	2,800	94.71	176,321	81.01	35,710	62.03	431,647	111.07
4th quarter	43,209	163.71	--	--	400	89.42	39,086	82.25	7,350	81.63	115,721	101.62
Total or average	360,332	167.17	--	--	64,190	80.11	382,308	77.14	85,390	73.93	1,084,056	105.27
1978:												
1st quarter	35,731	209.91	--	--	--	--	98,287	83.55	15,100	104.28	177,296	123.85
2d quarter	86,305	182.21	--	--	5,600	175.00	56,132	78.52	21,060	62.49	221,882	115.82
3d quarter	231,090	180.37	--	--	3,200	246.43	189,660	124.59	134,910	94.73	623,744	133.50
4th quarter	29,468	269.45	--	--	--	--	20,230	149.43	2,140	56.20	68,278	173.20
Total or average	382,594	190.41	--	--	8,800	200.95	364,309	107.80	173,210	91.16	1,091,200	130.82
1979:												
1st quarter	108,420	292.79	--	--	1,000	396.00	172,493	155.91	47,180	301.32	377,958	190.19
2d quarter	47,808	271.63	--	--	500	103.40	103,696	171.51	27,930	142.04	211,155	179.05
3d quarter	190,741	346.37	--	--	3,300	272.17	178,202	276.11	85,610	221.88	538,598	267.14
4th quarter	39,052	277.01	--	--	--	--	26,364	252.83	2,945	168.75	85,543	241.56
Total or average	386,021	315.05	--	--	4,800	280.39	480,755	209.14	163,665	193.27	1,213,254	226.03
1980:												
1st quarter	64,866	355.49	--	--	1,400	88.94	90,699	216.98	15,330	189.03	215,251	234.34
2d quarter	114,589	319.60	--	--	--	--	116,473	201.01	53,050	186.91	333,063	224.08
3d quarter	142,351	232.41	--	--	--	--	131,696	359.35	55,170	146.09	365,543	189.43
4th quarter	62,845	252.31	--	--	1,000	150.00	52,695	223.28	30,180	228.51	183,264	211.02
Total or average	384,651	282.39	--	--	2,400	114.38	391,563	220.60	153,730	180.64	1,097,121	212.37
1981:												
1st quarter	64,335	389.76	--	--	--	--	68,146	230.40	37,260	127.80	199,441	240.23
2d quarter	52,955	192.74	--	--	--	--	67,654	287.35	14,715	104.41	157,727	206.32
3d quarter	274,890	225.97	--	--	--	--	288,633	171.83	74,553	139.88	735,396	178.28
4th quarter	35,233	148.25	--	--	--	--	38,130	91.58	8,020	94.99	101,783	99.56
Total or average	427,413	240.10	--	--	--	--	462,563	190.74	134,548	129.98	1,194,347	185.62
1982:												
1st quarter	88,959	116.68	--	--	3,000	16.64	130,019	58.51	30,025	99.82	322,549	72.76
2d quarter	63,550	94.74	--	--	25,350	40.92	60,024	30.30	17,005	41.65	199,034	52.09
3d quarter	85,124	51.00	--	--	--	--	144,328	35.85	70,545	22.08	352,434	35.01
4th quarter	75,725	155.32	--	--	--	--	46,865	80.66	12,600	40.30	173,555	107.72
Total or average	313,358	103.73	--	--	28,350	38.35	381,236	48.22	130,175	44.33	1,047,572	61.93
1983:												
1st quarter	101,350	94.01	--	--	--	--	128,663	52.51	35,515	90.46	327,835	63.31
2d quarter	102,435	122.30	--	--	--	--	106,961	64.07	35,395	107.52	297,290	87.99
3d quarter	96,777	93.91	--	--	--	--	60,976	66.81	52,485	60.16	286,612	61.80
4th quarter	90,249	139.48	--	--	800	97.18	37,288	67.46	51,120	67.12	212,944	96.74
Total or average	390,811	111.90	--	--	800	97.18	333,888	60.50	174,515	77.97	1,124,681	75.83
1984:												
1st quarter	82,191	96.63	--	--	--	--	61,191	56.79	33,740	52.11	231,139	74.40
2d quarter	52,210	124.60	--	--	--	--	54,759	61.46	48,195	40.45	188,875	69.55
3d quarter	112,325	79.46	--	--	--	--	117,480	36.04	41,480	35.12	331,053	52.93
4th quarter	74,415	105.96	--	--	--	--	67,335	52.78	25,335	30.51	193,402	67.97
Total or average	321,141	97.33	--	--	--	--	300,765	48.64	148,750	39.92	944,469	64.59

[1]Prices for individual sales may vary from the averages shown in this table because of differences in species mix, quality, road costs, logging and processing costs, size and length of sale, number of bidders, and other related price determinants. Prices for stumpage in National Forest lands are statistical high bids. The statistical high bid is defined as the bid price minus credits for road costs; it includes an allowance for sale-area betterment (K-V funds).

[2]Does not include noble fir or Shasta red fir.

Source--U.S. Department of Agriculture. Pacific Northwest Region includes Oregon and Washington.

Table 13—Volume and average stumpage price of selected species on the National Forests of western Oregon and western Washington, 1973-84[1]

(Volume in thousand board feet, Scribner scale; value in dollars per thousand board feet)

YEAR AND QUARTER	DOUGLAS-FIR				PONDEROSA AND JEFFREY PINES		WESTERN HEMLOCK		TRUE FIRS[2]		ALL SPECIES	
	WEST SIDE		EAST SIDE									
	VOLUME	VALUE	VOLUME	VALUE	VOLUME	VALUE	VOLUME	VALUE	VOLUME	VALUE	VOLUME	VALUE
1973:												
1st quarter	202,732	111.81	9,900	41.29	9,311	100.72	127,854	106.22	42,575	80.39	482,192	90.27
2d quarter	584,369	133.95	11,440	65.46	13,345	56.18	208,972	84.20	61,295	77.69	1,088,954	105.37
3d quarter	282,151	146.17	9,160	70.83	17,815	81.32	139,764	107.00	29,897	136.84	590,760	114.78
4th quarter	517,957	153.13	11,990	114.20	16,425	85.23	167,731	117.05	70,874	75.82	932,438	126.22
Total or average	1,587,209	139.55	42,490	74.74	56,896	79.73	644,321	102.07	204,641	86.24	3,094,344	111.09
1974:												
1st quarter	221,915	202.32	25,400	128.49	22,483	77.32	68,191	98.15	40,701	123.96	460,478	144.53
2d quarter	638,428	246.22	18,450	122.62	21,478	157.00	287,744	130.07	61,394	129.15	1,246,907	182.72
3d quarter	226,282	219.80	10,200	157.79	3,455	74.29	100,958	140.04	22,415	95.45	436,893	162.45
4th quarter	653,655	155.48	20,925	121.08	13,405	67.73	227,744	79.49	98,454	98.55	1,230,574	114.60
Total or average	1,740,280	203.22	02,975	128.20	60,821	103.19	684,637	111.54	222,964	111.30	3,382,852	150.03
1975:												
1st quarter	250,061	156.10	1,230	70.00	--	--	90,355	35.81	--	--	469,489	100.62
2d quarter	664,782	164.05	21,660	125.96	12,954	64.47	271,422	26.85	64,079	67.00	1,287,593	118.75
3d quarter	301,646	178.11	5,350	27.05	6,940	23.72	93,055	58.38	27,419	48.65	580,212	121.41
4th quarter	645,299	180.47	26,380	64.34	14,984	36.75	287,462	72.05	66,322	64.93	1,219,743	126.33
Total or average	1,861,358	170.99	54,620	05.25	34,878	44.42	742,294	66.43	157,820	62.95	3,557,037	119.39
1976:												
1st quarter	172,169	207.10	980	46.35	2,285	89.14	58,906	84.97	13,730	59.61	323,010	143.27
2d quarter	663,790	173.77	10,200	110.52	6,766	59.75	292,011	75.10	72,455	50.37	1,205,107	123.20
3d quarter	195,279	141.85	2,400	95.62	5,629	107.19	122,364	72.10	24,594	73.66	449,457	101.80
4th quarter	235,532	188.37	250	41.71	305	116.72	96,810	90.90	11,050	92.13	411,765	141.99
Total or average	1,266,770	176.10	13,830	102.15	14,985	83.21	570,091	78.16	121,829	64.66	2,469,339	125.06
1977:												
1st quarter	604,927	233.07	16,100	224.13	75,140	81.69	175,680	92.92	55,988	110.84	1,176,111	160.85
2d quarter	400,517	224.68	5,500	87.80	4,110	100.07	149,919	85.18	48,270	74.37	735,322	159.84
3d quarter	474,274	210.97	10,620	79.59	12,700	75.69	233,487	89.43	66,200	92.00	945,447	151.61
4th quarter	183,914	229.69	--	--	1,710	86.64	51,968	84.94	12,870	92.86	308,749	167.89
Total or average	1,663,632	224.67	32,220	153.22	93,660	81.77	612,054	89.02	183,408	93.17	3,165,629	158.54
1978:												
1st quarter	486,015	248.82	17,506	104.52	9,599	115.00	186,979	95.73	41,555	96.51	881,947	182.76
2d quarter	336,500	235.42	11,830	105.99	10,359	166.12	97,834	91.44	36,545	95.07	618,494	169.37
3d quarter	050,897	249.11	5,051	62.64	7,547	201.11	310,789	125.38	180,031	102.07	1,568,597	189.13
4th quarter	144,796	292.74	2,530	75.57	4,920	151.48	54,307	166.76	8,762	121.08	250,827	217.75
Total or average	1,818,200	249.98	36,917	135.21	32,425	156.91	649,909	115.20	266,893	100.90	3,319,865	185.92
1979:												
1st quarter	669,150	347.72	18,130	202.53	5,283	215.59	270,536	151.84	84,341	301.32	1,228,587	268.79
2d quarter	303,884	389.72	17,410	174.80	6,871	173.57	161,357	155.14	54,746	211.92	643,244	267.52
3d quarter	788,403	423.69	4,574	213.69	7,618	178.09	315,907	252.37	122,655	222.48	1,451,434	334.57
4th quarter	178,697	280.09	4,700	389.97	2,256	189.60	50,081	221.05	13,500	99.32	305,286	333.43
Total or average	1,940,134	394.40	44,814	212.55	22,020	186.85	797,961	196.66	275,242	238.49	3,628,551	300.31
1980:												
1st quarter	653,068	484.04	6,880	175.11	8,805	96.00	197,442	206.29	82,215	201.45	1,143,354	358.22
2d quarter	432,184	373.96	3,250	14.30	1,410	16.75	172,171	231.25	75,368	220.38	826,549	281.60
3d quarter	645,411	394.87	8,470	135.68	10,782	96.41	212,620	231.40	84,145	216.56	1,132,660	295.96
4th quarter	329,599	456.33	3,267	19.81	4,420	319.13	82,676	155.17	38,100	197.21	571,833	337.87
Total or average	2,060,262	428.58	21,867	112.73	25,417	130.58	664,909	214.43	279,828	210.52	3,674,396	310.63
1981:												
1st quarter	609,342	463.81	13,700	315.91	2,800	43.38	144,818	179.50	59,000	133.03	995,319	335.13
2d quarter	305,400	342.13	7,170	245.92	1,060	167.76	114,315	225.09	35,723	108.00	561,586	261.40
3d quarter	820,142	288.10	3,160	56.71	6,240	276.58	384,009	158.56	112,610	109.00	1,618,470	208.32
4th quarter	223,274	260.13	7,300	27.96	8,140	190.08	61,172	74.23	28,238	63.78	390,901	185.27
Total or average	1,958,150	348.02	31,330	206.66	18,320	195.19	704,394	166.34	235,571	109.61	3,566,276	249.54
1982:												
1st quarter	505,362	153.92	990	46.72	10,335	29.14	200,197	47.71	66,740	88.63	968,078	104.93
2d quarter	376,418	97.67	9,700	10.47	28,195	38.63	103,242	28.51	23,650	38.74	667,170	71.60
3d quarter	577,739	99.00	2,190	84.30	4,730	92.49	229,742	37.92	114,550	24.70	1,152,136	64.61
4th quarter	363,310	134.94	12,900	30.44	1,100	48.30	96,415	70.38	25,970	46.83	626,209	103.40
Total or average	1,822,829	121.14	25,780	28.13	44,360	42.40	629,596	44.46	230,918	47.10	3,413,593	84.53
1983:												
1st quarter	678,242	182.39	4,120	27.70	5,940	53.09	223,688	51.93	67,755	77.62	1,227,316	119.31
2d quarter	356,733	153.81	1,150	21.91	2,470	55.25	137,791	71.69	55,430	99.06	665,915	113.50
3d quarter	385,732	144.61	11,400	49.78	4,907	90.62	108,111	63.86	85,260	76.50	755,125	100.42
4th quarter	346,733	155.05	6,350	30.53	7,455	97.39	73,335	85.40	72,880	68.11	612,462	117.87
Total or average	1,767,440	163.01	23,020	41.33	20,772	78.11	542,925	63.84	281,325	79.04	3,269,818	113.48
1984:												
1st quarter	505,091	152.69	4,300	31.28	6,425	77.07	143,281	73.94	44,315	56.10	899,963	114.00
2d quarter	260,348	125.70	9,600	78.73	3,040	73.12	87,807	61.62	60,085	37.85	522,552	97.21
3d quarter	639,140	95.19	8,500	26.17	3,645	37.31	181,393	46.07	77,965	41.29	1,121,397	74.45
4th quarter	331,933	107.82	4,055	105.42	2,440	63.56	104,040	44.19	48,980	34.74	593,945	78.15
Total or average	1,736,512	118.90	27,335	59.66	15,550	64.86	516,521	56.07	231,345	41.84	3,137,857	90.28

[1] Prices for individual sales may vary from the averages shown in this table because of differences in species mix, quality, road costs, logging and processing costs, size and length of sale, number of bidders, and other related price determinants. Prices for stumpage in National Forest lands are statistical high bids. The statistical high bid is defined as the bid price minus credits for road costs; it includes an allowance for sale-area betterment (K-V funds).

[2] Does not include noble fir or Shasta red fir.

Source--U.S. Department of Agriculture. Pacific Northwest Region includes Oregon and Washington.

Table 14—Volume and average stumpage price of selected species on the Deschutes National Forest of the Pacific Northwest Region, 1973-84[1]

(Volume in thousand board feet, Scribner scale; value in dollars per thousand board feet)

Year and quarter	Douglas-fir: West side Volume	Douglas-fir: West side Value	Douglas-fir: East side Volume	Douglas-fir: East side Value	Ponderosa and Jeffrey pines Volume	Ponderosa and Jeffrey pines Value	Western hemlock Volume	Western hemlock Value	True firs[2] Volume	True firs[2] Value	All species Volume	All species Value
1973:												
1st quarter	4,600	48.54	2,200	37.52	--	--	--	--	8,100	43.55	72,620	50.25
2d quarter	4,450	97.52	--	--	--	--	--	--	4,660	58.76	56,465	71.65
3d quarter	--	--	960	75.47	29,240	129.29	--	--	4,355	82.43	48,580	102.35
4th quarter	--	--	440	74.94	18,390	132.79	--	--	1,050	79.07	25,960	110.39
Total or average	9,050	72.62	3,600	52.21	48,630	127.96	--	--	18,165	58.82	203,625	76.28
1974:												
1st quarter	--	--	440	74.94	47,580	159.95	--	--	1,470	94.75	64,360	125.17
2d quarter	--	--	2,770	101.80	26,040	176.34	--	--	180	32.86	31,642	155.30
3d quarter	--	--	3,550	82.38	28,050	144.17	--	--	1,995	81.10	44,270	106.45
4th quarter	--	--	1,950	20.70	34,840	63.53	--	--	2,030	44.90	42,423	56.95
Total or average	--	--	8,710	74.37	136,510	135.23	--	--	5,675	70.16	182,695	110.02
1975:												
1st quarter	--	--	350	36.61	5,610	67.98	--	--	640	30.50	7,752	55.73
2d quarter	--	--	5,100	10.03	55,030	27.01	--	--	5,820	4.06	80,928	26.74
3d quarter	--	--	20	25.78	14,275	35.93	--	--	1,180	28.54	23,963	26.14
4th quarter	--	--	--	--	29,870	32.65	--	--	1,400	6.29	40,490	25.96
Total or average	--	--	5,470	11.79	104,785	32.03	--	--	9,040	9.47	153,133	27.91
1976:												
1st quarter	--	--	1,150	43.94	45,670	127.92	--	--	2,100	81.29	56,810	118.36
2d quarter	--	--	4,060	73.33	40,560	94.38	--	--	3,300	61.65	69,880	73.38
3d quarter	--	--	110	35.66	42,670	114.15	--	--	1,520	70.23	49,295	104.26
4th quarter	--	--	2,200	59.10	8,718	92.95	--	--	--	--	11,806	80.70
Total or average	--	--	7,520	64.12	137,610	111.55	--	--	6,920	69.50	187,791	95.56
1977:												
1st quarter	--	--	3,525	120.08	27,056	136.87	--	--	2,830	99.02	53,811	103.15
2d quarter	--	--	--	--	33,126	153.87	--	--	--	--	70,596	78.07
3d quarter	--	--	1,750	68.26	49,030	179.72	--	--	7,940	105.00	78,123	134.95
4th quarter	--	--	--	--	29,448	223.27	--	--	54	82.70	32,838	205.89
Total or average	--	--	5,275	102.92	138,660	174.50	--	--	10,824	107.04	235,368	120.52
1978:												
1st quarter	--	--	8,190	141.71	24,670	196.22	--	--	6,140	145.00	43,330	165.26
2d quarter	--	--	2,720	98.05	43,190	283.84	--	--	260	97.47	58,631	225.25
3d quarter	--	--	7,200	130.71	43,950	310.04	--	--	2,100	103.73	63,305	240.03
4th quarter	--	--	--	--	15,700	289.56	--	--	--	--	21,633	220.38
Total or average	--	--	18,110	130.78	127,510	276.62	--	--	8,500	133.35	186,899	215.70
1979:												
1st quarter	--	--	6,300	166.87	18,284	289.14	--	--	300	89.90	33,082	196.74
2d quarter	--	--	8,100	102.24	30,570	372.35	--	--	2,350	95.95	53,320	237.58
3d quarter	--	--	2,320	155.70	48,560	260.43	--	--	9,390	100.87	87,962	180.10
4th quarter	--	--	--	--	11,970	82.08	--	--	4,000	20.21	20,070	57.27
Total or average	--	--	16,720	134.01	109,384	277.00	--	--	16,040	79.83	194,434	186.00
1980:												
1st quarter	--	--	2,600	89.70	53,900	232.62	--	--	6,230	63.03	71,810	187.88
2d quarter	--	--	590	56.35	27,650	289.40	--	--	--	--	35,470	232.39
3d quarter	--	--	8,770	71.02	26,422	340.72	--	--	2,740	5.82	63,082	174.18
4th quarter	--	--	2,180	48.71	9,710	375.11	--	--	1,110	7.93	22,520	189.45
Total or average	--	--	14,140	70.41	117,682	281.99	--	--	10,080	41.41	192,882	191.77
1981:												
1st quarter	--	--	3,310	6.70	26,047	332.30	--	--	3,100	21.42	47,177	192.83
2d quarter	--	--	890	226.35	39,205	324.80	--	--	6,090	15.78	55,385	240.63
3d quarter	--	--	3,070	30.34	40,130	271.69	--	--	4,420	13.59	74,870	155.02
4th quarter	--	--	--	--	20	32.10	--	--	--	--	9,578	33.95
Total or average	--	--	7,270	43.57	105,402	306.38	--	--	13,690	16.38	187,010	183.71
1982:												
1st quarter	--	--	1,280	23.53	37,930	121.45	--	--	2,040	13.62	45,960	104.15
2d quarter	--	--	300	117.00	30,653	93.92	--	--	1,137	2.18	53,372	61.38
3d quarter	--	--	5,210	43.10	31,930	76.11	--	--	5,140	31.63	63,260	50.28
4th quarter	--	--	2,360	13.16	30,500	109.76	--	--	3,310	7.30	36,350	95.17
Total or average	--	--	9,150	35.52	131,013	101.24	--	--	11,627	18.66	198,942	73.90
1983:												
1st quarter	--	--	--	--	28,160	144.71	--	--	130	3.68	40,710	104.32
2d quarter	--	--	1,720	117.09	9,913	228.70	--	--	197	20.00	25,049	112.34
3d quarter	--	--	430	39.21	27,207	175.42	--	--	4,100	18.37	72,047	77.75
4th quarter	--	--	--	--	10,040	271.46	--	--	50	1.00	10,588	258.45
Total or average	--	--	2,150	101.43	75,320	183.75	--	--	4,477	17.82	148,394	103.77
1984:												
1st quarter	--	--	1,930	309.66	20,900	100.87	--	--	2,880	30.17	31,200	144.65
2d quarter	--	--	620	34.61	16,885	236.38	--	--	1,169	28.42	25,255	174.60
3d quarter	--	--	7,020	39.14	40,037	193.00	--	--	1,899	22.50	76,842	108.41
4th quarter	--	--	--	--	15,999	160.43	--	--	1,500	13.83	31,874	82.09
Total or average	--	--	9,620	94.53	93,821	192.49	--	--	7,448	24.65	165,171	120.30

[1] Prices for individual sales may vary from the averages shown in this table because of differences in species mix, quality, road costs, logging and processing costs, size and length of sale, number of bidders, and other related price determinants. Prices for stumpage in National Forest lands are statistical high bids. The statistical high bid is defined as the bid price minus credits for road costs; it includes an allowance for sale-area betterment (K-V funds).

[2] Does not include noble fir or Shasta red fir.

Source--U.S. Department of Agriculture. Pacific Northwest Region includes Oregon and Washington.

Table 15—Volume and average stumpage price of selected species on the Fremont National Forest of the Pacific Northwest Region, 1973-84[1]

(Volume in thousand board feet, Scribner scale; value in dollars per thousand board feet)

YEAR AND QUARTER	DOUGLAS-FIR WEST SIDE		DOUGLAS-FIR EAST SIDE		PONDEROSA AND JEFFREY PINES		WESTERN HEMLOCK		TRUE FIRS[2]		ALL SPECIES	
	VOLUME	VALUE	VOLUME	VALUE	VOLUME	VALUE	VOLUME	VALUE	VOLUME	VALUE	VOLUME	VALUE
1973:												
1st quarter	--	--	--	--	--	--	--	--	8,160	51.53	30,750	62.17
2d quarter	--	--	--	--	--	--	--	--	6,930	76.73	32,173	83.31
3d quarter	--	--	--	--	37,501	108.26	--	--	1,235	84.47	43,436	97.24
4th quarter	--	--	--	--	24,380	93.52	--	--	3,970	66.60	31,110	83.89
Total or average	--	--	--	--	61,831	102.45	--	--	20,295	65.09	137,469	83.11
1974:												
1st quarter	--	--	--	--	43,700	206.51	--	--	4,900	102.80	50,700	188.49
2d quarter	--	--	--	--	1,650	142.77	--	--	--	--	13,075	24.47
3d quarter	--	--	--	--	130	91.80	--	--	--	--	1,130	11.00
4th quarter	--	--	--	--	49,990	92.77	--	--	1,700	17.90	82,000	58.00
Total or average	--	--	--	--	95,470	145.70	--	--	6,600	80.93	146,905	99.69
1975:												
1st quarter	--	--	20,200	110.47	--	--	--	--	--	--	21,240	105.77
2d quarter	--	--	--	--	29,250	44.87	--	--	34,600	10.06	86,702	23.59
3d quarter	--	--	--	--	20,250	42.66	--	--	2,700	11.80	29,079	35.73
4th quarter	--	--	--	--	58,780	33.10	--	--	10,250	11.01	80,495	28.87
Total or average	--	--	20,200	110.47	108,280	38.07	--	--	47,550	10.37	217,516	35.19
1976:												
1st quarter	--	--	--	--	11,500	109.51	--	--	3,200	20.93	14,700	90.23
2d quarter	--	--	--	--	28,210	76.43	--	--	2,300	17.31	32,210	68.99
3d quarter	--	--	--	--	12,200	70.49	--	--	--	--	12,200	70.49
4th quarter	--	--	--	--	36,570	91.31	--	--	600	33.30	37,370	90.16
Total or average	--	--	--	--	88,480	86.06	--	--	6,100	20.78	96,480	80.61
1977:												
1st quarter	--	--	--	--	23,800	170.62	--	--	10,350	65.87	40,550	134.72
2d quarter	--	--	--	--	29,800	138.07	--	--	7,700	106.45	47,247	114.18
3d quarter	--	--	--	--	31,300	160.18	--	--	1,400	70.60	32,710	156.33
4th quarter	--	--	--	--	18,700	77.57	--	--	--	--	18,700	77.57
Total or average	--	--	--	--	103,600	141.31	--	--	19,450	82.27	139,207	125.15
1978:												
1st quarter	--	--	--	--	29,500	109.08	--	--	7,250	69.17	36,850	101.32
2d quarter	--	--	--	--	--	--	--	--	--	--	--	:
3d quarter	--	--	--	--	85,329	248.78	--	--	14,980	78.52	102,345	220.86
4th quarter	--	--	--	--	1,130	122.13	--	--	3	1.00	1,184	122.41
Total or average	--	--	--	--	115,959	212.01	--	--	22,233	75.46	140,379	188.65
1979:												
1st quarter	--	--	--	--	38,320	205.51	--	--	10,200	76.12	51,020	172.92
2d quarter	--	--	--	--	16,150	149.26	--	--	2,200	44.52	18,450	137.09
3d quarter	--	--	--	--	31,053	183.35	--	--	17,602	164.11	57,029	187.44
4th quarter	--	--	--	--	9,190	449.79	--	--	7,600	35.28	19,277	241.37
Total or average	--	--	--	--	94,713	212.36	--	--	37,602	107.20	145,776	183.12
1980:												
1st quarter	--	--	--	--	32,610	206.24	--	--	9,800	362.84	53,243	201.28
2d quarter	--	--	--	--	4,806	174.63	--	--	550	34.36	5,646	155.15
3d quarter	--	--	--	--	43,545	278.92	--	--	13,670	21.68	69,298	184.15
4th quarter	--	--	--	--	967	115.70	--	--	--	--	2,177	89.85
Total or average	--	--	--	--	81,928	241.94	--	--	24,020	161.16	130,364	188.32
1981:												
1st quarter	--	--	--	--	18,400	296.02	--	--	6,900	22.69	30,106	230.49
2d quarter	--	--	--	--	18,800	166.51	--	--	11,700	135.62	39,300	131.27
3d quarter	--	--	--	--	58,353	162.16	--	--	12,680	323.35	75,503	187.22
4th quarter	--	--	--	--	9,530	167.31	--	--	650	15.25	10,180	157.60
Total or average	--	--	--	--	105,083	186.84	--	--	31,930	183.32	155,089	179.52
1982:												
1st quarter	--	--	--	--	36,720	107.60	--	--	6,920	15.39	48,390	85.25
2d quarter	--	--	--	--	32,820	96.55	--	--	5,800	17.79	42,120	78.90
3d quarter	--	--	--	--	18,980	39.98	--	--	12,970	15.47	32,080	29.95
4th quarter	--	--	--	--	13,740	80.19	--	--	5,220	28.36	26,460	53.57
Total or average	--	--	--	--	102,260	87.82	--	--	30,910	18.06	149,050	65.93
1983:												
1st quarter	--	--	--	--	12,290	67.24	--	--	3,750	11.24	25,455	45.33
2d quarter	--	--	--	--	22,450	196.39	--	--	1,300	10.93	23,950	184.69
3d quarter	--	--	--	--	51,943	125.27	--	--	9,320	41.25	66,698	106.60
4th quarter	--	--	--	--	7,580	137.02	--	--	5,400	28.89	12,980	92.03
Total or average	--	--	--	--	94,253	135.60	--	--	19,770	30.19	129,083	107.54
1984:												
1st quarter	--	--	--	--	13,910	104.15	--	--	9,920	44.34	24,980	76.03
2d quarter	--	--	--	--	24,070	127.08	--	--	6,100	11.60	36,870	86.57
3d quarter	--	--	--	--	45,792	90.69	--	--	12,303	21.28	58,985	75.02
4th quarter	--	--	--	--	11,490	79.49	--	--	970	14.74	20,440	52.60
Total or average	--	--	--	--	95,252	103.75	--	--	29,293	26.87	141,275	74.97

1/Prices for individual sales may vary from the averages shown in this table because of differences in species mix, quality, road costs, logging and processing costs, size and length of sale, number of bidders, and other related price determinants. Prices for stumpage in National Forest lands are statistical high bids. The statistical high bid is defined as the bid price minus credits for road costs; it includes an allowance for sale-area betterment (K-V funds).

2/Does not include noble fir or Shasta red fir.

Source--U.S. Department of Agriculture. Pacific Northwest Region includes Oregon and Washington.

Table 16—Volume and average stumpage price of selected species on the Malheur National Forest of the Pacific Northwest Region, 1973-84[1]

(Volume in thousand board feet, Scribner scale; value in dollars per thousand board feet)

YEAR AND QUARTER	DOUGLAS-FIR				PONDEROSA AND JEFFREY PINES		WESTERN HEMLOCK		TRUE FIRS[2]		ALL SPECIES	
	WEST SIDE		EAST SIDE									
	VOLUME	VALUE	VOLUME	VALUE	VOLUME	VALUE	VOLUME	VALUE	VOLUME	VALUE	VOLUME	VALUE
1973:												
1st quarter	--	--	6,990	33.79	54,930	51.53	--	--	4,900	34.47	80,555	41.06
2d quarter	--	--	5,620	49.56	54,610	56.10	--	--	3,370	60.94	72,034	49.93
3d quarter	--	--	60	85.00	1,140	104.36	--	--	--	--	2,114	67.81
4th quarter	--	--	3,340	58.38	16,680	72.79	--	--	1,990	71.37	24,126	65.71
Total or average	--	--	16,010	44.65	127,360	56.75	--	--	10,260	50.32	178,829	49.95
1974:												
1st quarter	--	--	9,090	78.25	67,200	84.54	--	--	5,340	74.79	95,705	77.09
2d quarter	--	--	15,800	50.52	22,600	101.47	--	--	8,200	62.60	57,190	63.30
3d quarter	--	--	3,581	41.34	19,365	104.84	--	--	2,140	50.27	27,171	86.06
4th quarter	--	--	3,900	46.00	25,400	89.55	--	--	2,000	42.12	33,400	79.17
Total or average	--	--	32,371	56.74	134,565	91.25	--	--	17,680	62.47	213,466	74.86
1975:												
1st quarter	--	--	2,503	2.58	12,290	8.54	--	--	--	--	18,960	6.76
2d quarter	--	--	3,943	2.84	41,815	12.57	--	--	435	3.73	56,230	10.24
3d quarter	--	--	1,095	20.12	30,950	33.82	--	--	490	27.69	34,805	33.36
4th quarter	--	--	11,990	2.82	48,509	12.67	--	--	6,870	1.86	74,164	9.23
Total or average	--	--	19,531	4.21	133,564	17.16	--	--	7,795	3.59	184,159	13.84
1976:												
1st quarter	--	--	--	--	80	42.25	--	--	--	--	90	37.67
2d quarter	--	--	7,690	9.30	47,050	50.01	-	--	5,230	3.21	67,600	39.12
3d quarter	--	--	3 400	31.71	30,200	65.39	--	--	1,000	44.20	35,500	60.67
4th quarter	--	--	730	45.53	8,200	75.38	--	--	210	57.04	9,700	70.12
Total or average	--	--	11,820	17.98	85,530	57.87	--	--	6,440	11.33	112,970	48.55
1977:												
1st quarter	--	--	615	45.90	3,595	100.54	--	--	715	62.15	9,520	58.58
2d quartter	--	--	10,084	50.91	77,000	101.28	--	--	8,000	60.20	98,600	91.50
3d quarter	--	--	5,583	51.44	26,452	145.86	--	--	5,492	72.71	52,900	97.76
4th quarter	--	--	5,000	62.91	29,250	185.67	--	--	6,805	62.93	42,385	146.90
Total or average	--	--	21,362	53.76	136,297	128.23	--	--	21,812	64.26	203,405	103.14
1978:												
1st quarter	--	--	4,785	61.25	29,820	217.12	--	--	7,080	49.99	46,095	157.41
2d quarter	--	--	3,270	78.69	18,720	240.76	--	--	3,160	96.92	27,120	191.22
3d quarter	--	--	10,769	57.94	37,835	191.88	--	--	14,481	58.54	71,000	127.84
4th quarter	--	--	135	78.06	445	199.00	--	--	2,860	190.97	3,741	175.58
Total or average	--	--	18,959	62.50	86,820	211.13	--	--	27,581	74.48	147,956	149.88
1979:												
1st quarter	--	--	364	85.37	3,759	128.46	--	--	80	12.35	4,253	121.23
2d quarter	--	--	3,710	20.57	21,780	221.01	--	--	3,615	21.90	30,787	162.42
3d quarter	--	--	11,355	26.35	87,765	208.69	--	--	7,700	24.57	110,500	170.76
4th quarter	--	--	6,070	7.82	37,230	210.72	--	--	3,540	10.20	56,350	141.01
Total or average	--	--	21,499	21.12	150,534	208.97	--	--	14,935	20.45	201,890	160.14
1980:												
1st quarter	--	--	4,156	12.23	19,966	159.17	--	--	970	20.35	26,792	122.04
2d quarter	--	--	6,840	14.81	61,200	120.38	--	--	8,250	53.69	80,650	101.57
3d quarter	--	--	3,800	2.59	28,000	86.42	--	--	7,600	108.30	45,930	92.36
4th quarter	--	--	1,860	21.04	9,180	111.29	--	--	3,820	7.40	18,670	58.93
Total or average	--	--	16,656	12.08	118,346	118.19	--	--	20,640	63.64	172,042	97.67
1981:												
1st quarter	--	--	9,400	48.90	36,850	221.74	--	--	7,150	13.28	66,800	148.88
2d quarter	--	--	--	--	89	122.10	--	--	--	--	89	122.10
3d quarter	--	--	12,682	15.62	75,927	157.23	--	--	8,317	19.55	105,656	117.52
4th quarter	--	--	4,385	7.76	24,913	92.37	--	--	8,360	169.78	46,158	82.02
Total or average	--	--	26,467	26.14	137,779	162.73	--	--	23,827	70.38	218,703	119.61
1982:												
1st quarter	--	--	1,970	8.77	25,270	87.45	--	--	2,235	4.52	30,290	74.12
2d quarter	--	--	3,910	13.18	14,600	19.14	--	--	1,165	14.39	21,810	16.24
3d quarter	--	--	3,290	6.00	65,280	52.99	--	--	1,300	1.00	71,620	48.72
4th quarter	--	--	2,875	10.74	28,260	28.03	--	--	885	8.66	33,075	25.35
Total or average	--	--	12,045	9.91	133,410	50.53	--	--	5,585	6.42	156,795	44.18
1983:												
1st quarter	--	--	5,815	11.71	62,330	117.01	--	--	4,635	2.58	75,845	99.54
2d quarter	--	--	1,630	9.50	27,930	133.96	--	--	1,156	8.75	30,975	123.60
3d quarter	--	--	7,141	8.82	34,929	171.37	--	--	3,510	8.38	50,800	121.82
4th quarter	--	--	6,295	19.80	23,260	137.77	--	--	4,155	18.35	39,250	87.22
Total or average	--	--	20,881	12.99	148,449	135.93	--	--	13,456	9.51	196,870	106.63
1984:												
1st quarter	--	--	8,920	7.83	57,880	172.39	--	--	11,300	3.77	79,350	127.19
2d quarter	--	--	9,040	15.68	38,125	177.63	--	--	6,090	1.00	55,295	128.00
3d quarter	--	--	11,340	6.69	48,650	128.68	--	--	8,720	2.14	76,594	83.31
4th quarter	--	--	5,830	6.18	26,600	77.19	--	--	6,600	1.13	40,570	52.64
Total or average	--	--	35,130	9.21	171,255	146.35	--	--	32,710	2.29	251,809	102.01

[1] Prices for individual sales may vary from the averages shown in this table because of differences in species mix, quality, road costs, logging and processing costs, size and length of sale, number of bidders, and other related price determinants. Prices for stumpage in National Forest lands are statistical high bids. The statistical high bid is defined as the bid price minus credits for road costs; it includes an allowance for sale-area betterment (K-V funds).

[2] Does not include noble fir or Shasta red fir.

Source--U.S. Department of Agriculture. Pacific Northwest Region includes Oregon and Washington.

Table 17—Volume and average stumpage price of selected species on the Ochoco National Forest of the Pacific Northwest Region, 1973-84[1]

(Volume in thousand board feet, Scribner scale; value in dollars per thousand board feet)

YEAR AND QUARTER	DOUGLAS-FIR				PONDEROSA AND JEFFREY PINES		WESTERN HEMLOCK		TRUE FIRS[2]		ALL SPECIES	
	WEST SIDE		EAST SIDE									
	VOLUME	VALUE	VOLUME	VALUE	VOLUME	VALUE	VOLUME	VALUE	VOLUME	VALUE	VOLUME	VALUE
1973:												
1st quarter	--	--	8,600	63.63	27,930	64.57	--	--	--	--	41,470	56.78
2d quarter	--	--	5,600	109.59	32,200	70.54	--	--	2,000	115.89	51,320	63.28
3d quarter	--	--	6,716	73.26	37,030	96.84	--	--	--	--	48,374	84.71
4th quarter	--	--	4,070	70.62	28,075	94.97	--	--	3,250	79.62	45,990	72.80
Total or average	--	--	24,986	77.69	125,235	82.46	--	--	5,250	93.44	187,154	69.72
1974:												
1st quarter	--	--	--	--	--	--	--	--	--	--	--	:
2d quarter	--	--	954	51.22	25,035	84.64	--	--	255	11.63	33,977	64.07
3d quarter	--	--	3,000	62.88	27,850	106.04	--	--	1,400	67.53	35,214	93.30
4th quarter	--	--	4,872	2.81	15,528	53.04	--	--	700	1.00	23,654	35.88
Total or average	--	--	8,826	28.46	68,413	86.18	--	--	2,355	41.70	92,845	67.97
1975:												
1st quarter	--	--	--	--	8,450	11.41	--	--	--	--	12,450	8.20
2d quarter	--	--	2,900	29.13	43,600	99.29	--	--	--	--	49,380	90.20
3d quarter	--	--	885	2.00	25,207	66.72	--	--	300	1.00	28,077	60.53
4th quarter	--	--	630	11.80	51,990	39.39	--	--	--	--	53,400	38.54
Total or average	--	--	4,415	21.22	129,247	62.32	--	--	300	1.00	143,307	58.01
1976:												
1st quarter	--	--	--	--	3,700	72.25	--	--	--	--	4,700	60.71
2d quarter	--	--	7,590	7.94	37,280	62.85	--	--	950	13.15	46,800	53.02
3d quarter	--	--	1,384	30.11	21,683	74.36	--	--	1,000	32.14	24,638	69.74
4th quarter	--	--	500	47.01	22,550	91.89	--	--	--	--	23,150	90.54
Total or average	--	--	9,474	13.24	85,213	73.87	--	--	1,950	22.89	99,288	66.28
1977:												
1st quarter	--	--	--	--	3,050	100.61	--	--	--	--	3,050	100.61
2d quarter	--	--	2,400	84.61	42,200	140.89	--	--	700	84.23	45,800	135.85
3d quarter	--	--	9,300	94.40	44,000	222.86	--	--	4,700	99.71	58,000	192.24
4th quarter	--	--	1,650	28.77	6,000	116.20	--	--	3,300	104.20	10,950	99.41
Total or average	--	--	13,350	84.53	95,250	175.91	--	--	8,700	99.87	117,800	159.32
1978:												
1st quarter	--	--	9,700	140.04	34,400	244.75	--	--	3,900	149.21	50,600	212.52
2d quarter	--	--	--	--	--	--	--	--	--	--	--	:
3d quarter	--	--	11,830	124.42	78,660	316.49	--	--	1,500	165.03	91,990	289.32
4th quarter	--	--	1,700	52.75	3,000	167.14	--	--	800	62.32	6,000	110.95
Total or average	--	--	23,230	125.70	116,060	291.38	--	--	6,200	141.83	148,590	255.97
1979:												
1st quarter	--	--	3,100	122.55	39,550	301.90	--	--	200	78.88	43,250	288.18
2d quarter	--	--	12,200	267.27	--	--	--	--	--	--	12,200	267.27
3d quarter	--	--	15,400	85.74	48,800	347.10	--	--	5,200	94.36	71,100	264.67
4th quarter	--	--	300	41.29	7,900	225.78	--	--	--	--	8,200	219.03
Total or average	--	--	31,000	160.43	96,250	318.57	--	--	5,400	93.79	134,750	269.68
1980:												
1st quarter	--	--	6,080	33.86	24,520	221.40	--	--	1,600	18.30	33,900	187.87
2d quarter	--	--	2,563	21.45	33,906	193.90	--	--	835	20.59	39,606	187.19
3d quarter	--	--	11,100	28.23	35,140	137.39	--	--	6,300	34.07	52,540	101.91
4th quarter	--	--	2,020	102.21	15,220	211.62	--	--	--	--	17,840	200.56
Total or average	--	--	21,763	35.87	108,786	184.31	--	--	8,735	29.89	143,886	157.87
1981:												
1st quarter	--	--	--	--	--	--	--	--	--	--	--	:
2d quarter	--	--	7,580	19.95	70,690	278.33	--	--	1,600	8.46	79,870	248.40
3d quarter	--	--	8,300	158.28	29,120	237.27	--	--	--	--	37,420	219.75
4th quarter	--	--	1,400	15.79	20,800	156.46	--	--	1,000	13.41	23,200	141.80
Total or aaveraage	--	--	17,280	86.06	120,610	247.40	--	--	2,600	10.36	140,490	223.17
1982:												
1st quarter	--	--	--	--	5,750	72.64	--	--	--	--	5,750	72.64
2d quarter	--	--	11,100	20.66	37,490	43.68	--	--	800	20.62	50,290	37.59
3d quarter	--	--	1,400	9.43	25,732	60.20	--	--	551	7.07	59,578	28.27
4th quarter	--	--	5,500	22.44	16,300	18.90	--	--	4,400	20.24	26,200	19.87
Total or average	--	--	18,000	20.33	85,272	45.88	--	--	5,751	19.03	141,818	38.87
1983:												
1st quarter	--	--	2,400	16.29	44,170	77.54	--	--	--	--	46,570	74.38
2d quarter	--	--	4,250	27.83	18,120	91.60	--	--	1,700	24.29	24,070	75.59
3d quarter	--	--	4,770	8.88	31,347	109.82	--	--	--	--	36,117	96.47
4th quarter	--	--	2,350	18.86	27,420	139.01	--	--	1,665	15.82	33,685	115.38
Total or average	--	--	13,770	17.73	121,057	101.93	--	--	3,365	20.10	140,442	90.11
1984:												
1st quarter	--	--	3,400	20.07	23,890	112.50	--	--	2,300	15.07	29,560	94.40
2d quarter	--	--	5,150	21.79	53,650	133.34	--	--	2,050	7.56	61,200	118.99
3d quarter	--	--	3,500	8.82	10,470	132.09	--	--	41	5.04	20,185	72.81
4th quarter	--	--	5,300	30.98	11,020	77.89	--	--	2,900	35.44	19,220	58.55
Total or average	--	--	17,350	21.65	99,030	122.01	--	--	7,291	21.01	130,165	97.32

[1] Prices for individual sales may vary from the averages shown in this table because of differences in species mix, quality, road costs, logging and processing costs, size and length of sale, number of bidders, and other related price determinants. Prices for stumpage in National Forest lands are statistical high bids. The statistical high bid is defined as the bid price minus credits for road costs; it includes an allowance for sale-area betterment (K-V funds).

[2] Does not include noble fir or Shasta red fir.

Source--U.S. Department of Agriculture. Pacific Northwest Region includes Oregon and Washington.

Table 18—Volume and average stumpage price of selected species on the Umatilla National Forest of the Pacific Northwest Region, 1973-84[1/]

(Volume in thousand board feet, Scribner scale; value in dollars per thousand board feet)

Year and quarter	Douglas-fir: West side Volume	Douglas-fir: West side Value	Douglas-fir: East side Volume	Douglas-fir: East side Value	Ponderosa and Jeffrey pines Volume	Ponderosa and Jeffrey pines Value	Western hemlock Volume	Western hemlock Value	True firs[2/] Volume	True firs[2/] Value	All species Volume	All species Value
1973:												
1st quarter	--	--	480	17.21	540	11.67	--	--	3,920	16.33	5,000	15.73
2d quarter	--	--	27,330	52.08	44,680	57.43	--	--	27,000	50.97	127,890	49.13
3d quarter	--	--	5,800	55.94	6,750	74.98	--	--	2,850	53.78	17,000	60.98
4th quarter	--	--	27,500	54.20	21,200	72.85	--	--	44,600	39.49	106,200	46.25
Total or average	--	--	61,110	53.13	73,170	63.72	--	--	78,370	42.80	256,090	48.07
1974:												
1st quarter	--	--	2,830	70.20	70	28.19	--	--	51,220	40.19	61,940	36.48
2d quarter	22,840	52.62	--	--	9,330	119.94	3,200	122.47	71,140	47.25	115,250	55.62
3d quarter	3,220	46.21	--	--	6,200	106.69	--	--	6,860	68.10	74,890	23.39
4th quarter	--	--	4,800	16.79	10,500	28.86	--	--	1,500	18.61	17,900	23.66
Total or average	26,060	51.83	7,630	36.60	26,100	79.91	3,200	122.47	130,720	45.25	269,980	40.17
1975:												
1st quarter	--	--	6,400	4.44	9,000	5.44	--	--	--	--	15,400	5.02
2d quarter	--	--	16,600	2.32	20,800	9.47	--	--	6,100	2.34	58,600	10.10
3d quarter	--	--	530	7.47	2,100	6.37	--	--	390	25.81	3,420	10.77
4th quarter	--	--	1,785	7.23	9,900	13.60	--	--	200	1.00	13,065	12.57
Total or average	--	--	25,315	3.31	41,800	9.43	--	--	6,690	3.67	90,485	9.62
1976:												
1st quarter	--	--	1,000	5.98	700	42.13	--	--	--	--	3,500	14.48
2d quarter	--	--	27,100	21.43	41,800	52.31	--	--	16,800	10.15	123,060	27.92
3d quarter	--	--	1,720	30.88	2,950	96.74	--	--	400	43.06	5,150	69.65
4th quarter	--	--	6,020	50.52	4,465	51.72	--	--	1,790	52.66	16,020	40.06
Total or average	--	--	35,840	26.34	49,915	54.74	--	--	18,990	14.85	147,730	30.37
1977:												
1st quarter	--	--	10,800	99.92	9,670	132.49	--	--	1,720	80.06	32,190	112.57
2d quarter	--	--	13,075	83.88	2,100	94.48	--	--	13,825	92.56	30,200	85.72
3d quarter	--	--	18,555	60.96	27,860	79.83	--	--	15,300	41.95	71,110	54.60
4th quarter	--	--	3,800	48.58	2,500	34.52	--	--	--	--	19,875	13.97
Total or average	--	--	46,230	75.53	42,130	89.96	--	--	30,845	66.76	153,375	60.29
1978:												
1st quarter	--	--	12,200	132.26	16,100	101.60	--	--	3,900	88.28	37,600	104.81
2d quarter	--	--	3,450	71.71	7,760	158.82	--	--	5,140	52.87	24,390	92.23
3d quarter	--	--	10,800	111.91	21,480	214.08	--	--	15,200	75.63	80,138	111.52
4th quarter	--	--	--	--	270	256.67	--	--	--	--	570	160.80
Total or average	--	--	26,450	116.05	45,610	165.22	--	--	24,240	72.84	142,698	106.65
1979:												
1st quarter	--	--	11,500	58.72	20,900	250.89	--	--	4,500	105.56	38,900	169.44
2d quarter	--	--	5,600	91.16	--	--	5,650	207.95	10,000	71.05	24,650	115.41
3d quarter	--	--	13,600	52.00	11,600	318.60	--	--	11,100	20.83	48,500	108.22
4th quarter	--	--	10,500	138.52	18,500	231.17	--	--	1,100	73.26	41,580	141.97
Total or average	--	--	41,200	85.39	51,000	259.14	5,650	207.95	26,700	56.08	153,630	134.01
1980:												
1st quarter	--	--	2,600	120.59	5,830	37.53	--	--	9,300	19.56	32,480	40.58
2d quarter	--	--	3,800	6.03	23,400	87.27	--	--	--	--	32,284	64.67
3d quarter	--	--	16,700	41.76	18,200	179.65	--	--	31,300	68.74	83,180	76.93
4th quarter	--	--	600	9.64	400	9.64	--	--	500	9.64	12,127	13.92
Total or average	--	--	23,700	43.87	47,830	115.68	--	--	41,100	56.89	160,071	62.27
1981:												
1st quarter	--	--	7,400	171.95	16,200	179.07	--	--	4,500	17.20	30,000	142.99
2d quarter	--	--	9,300	50.06	4,300	256.17	--	--	23,500	40.08	51,420	55.14
3d quarter	--	--	18,000	144.91	13,600	172.06	--	--	23,300	140.28	69,700	118.86
4th quarter	--	--	800	15.81	900	232.15	--	--	--	--	9,516	30.24
Total or average	--	--	35,500	122.79	35,000	187.18	--	--	51,300	83.58	160,636	97.72
1982:												
1st quarter	--	--	5,400	37.99	13,800	129.82	--	--	4,120	1.20	26,640	79.51
2d quarter	--	--	--	--	--	--	--	--	8,200	18.93	19,200	46.09
3d quarter	--	--	6,030	14.44	10,280	21.37	--	--	12,440	16.85	60,030	10.75
4th quarter	--	--	4,300	32.57	4,800	36.57	--	--	3,900	27.57	15,700	27.04
Total or average	--	--	15,730	27.48	28,880	75.72	--	--	28,660	16.66	121,570	33.50
1983:												
1st quarter	--	--	7,000	27.90	6,000	120.39	--	--	13,500	19.39	40,770	29.23
2d quarter	--	--	1,000	9.65	1,300	13.65	--	--	4,800	28.57	10,100	17.58
3d quarter	--	--	4,600	10.57	4,710	63.06	--	--	21,600	23.79	48,660	27.63
4th quarter	--	--	5,420	26.09	3,570	32.93	--	--	21,170	28.73	49,900	17.88
Total or average	--	--	18,020	21.92	15,580	74.12	--	--	61,070	24.90	149,430	24.13
1984:												
1st quarter	--	--	--	--	--	--	--	--	6,180	53.25	16,070	24.39
2d quarter	--	--	--	--	--	--	--	--	--	--	--	:
3d quarter	--	--	--	--	--	--	--	--	12,550	15.82	48,630	20.50
4th quarter	--	--	2,800	18.91	1,600	22.91	--	--	7,600	13.91	16,000	12.30
Total or average	--	--	2,800	18.91	1,600	22.91	--	--	26,330	24.05	80,700	20.56

1/Prices for individual sales may vary from the averages shown in this table because of differences in species mix, quality, road costs, logging and processing costs, size and length of sale, number of bidders, and other related price determinants. Prices for stumpage in National Forest lands are statistical high bids. The statistical high bid is defined as the bid price minus credits for road costs; it includes an allowance for sale-area betterment (K-V funds).

2/Does not include noble fir or Shasta red fir.

Source--U.S. Department of Agriculture. Pacific Northwest Region includes Oregon and Washington.

Table 19—Volume and average stumpage price of selected species on the Wallowa-Whitman National Forest of the Pacific Northwest Region, 1973-84[1]

(Volume in thousand board feet, Scribner scale; value in dollars per thousand board feet)

Year and quarter	Douglas-fir West side Volume	Douglas-fir West side Value	Douglas-fir East side Volume	Douglas-fir East side Value	Ponderosa and Jeffrey pines Volume	Ponderosa and Jeffrey pines Value	Western hemlock Volume	Western hemlock Value	True firs[2] Volume	True firs[2] Value	All species Volume	All species Value
1973:												
1st quarter	--	--	5,300	39.89	2,590	32.80	--	--	2,200	34.41	11,930	33.34
2d quarter	--	--	24,485	66.70	23,870	67.03	--	--	15,025	74.69	90,275	61.85
3d quarter	--	--	11,800	63.20	32,100	76.46	--	--	2,200	74.18	50,000	66.30
4th quarter	--	--	7,630	34.39	7,530	45.68	--	--	8,320	20.21	28,300	29.91
Total or average	--	--	49,215	57.97	66,090	67.99	--	--	27,745	55.12	181,305	56.24
1974:												
1st quarter	--	--	5,276	28.59	840	55.48	--	--	4,300	33.16	10,410	32.66
2d quarter	--	--	16,685	25.38	3,270	64.67	--	--	12,000	21.46	41,065	23.01
3d quarter	--	--	5,440	55.38	21,050	103.87	--	--	1,380	64.85	30,320	05.93
4th quarter	--	--	13,600	42.37	13,600	92.47	--	--	7,450	18.00	38,890	52.33
Total or average	--	--	41,001	35.41	38,760	95.51	--	--	25,130	24.82	120,685	49.10
1975:												
1st quarter	--	--	--	--	3,300	6.30	--	--	--	--	15,300	5.01
2d quarter	--	--	26,500	21.36	30,050	18.95	--	--	12,600	32.11	81,320	20.30
3d quarter	--	--	--	--	700	5.90	--	--	2,100	3.90	5,230	5.43
4th quarter	--	--	22,700	18.72	32,700	22.70	--	--	12,100	6.70	68,280	18.68
Total or average	--	--	49,200	20.15	66,750	21.16	--	--	26,800	18.43	170,130	17.82
1976:												
1st quarter	--	--	8,600	5.71	22,800	31.24	--	--	1,800	3.90	35,500	22.17
2d quarter	--	--	29,000	15.95	32,995	45.59	--	--	10,300	10.59	73,595	28.51
3d quarter	--	--	9,000	83.92	10,833	72.98	--	--	4,700	34.95	24,533	69.71
4th quarter	--	--	9,140	55.88	9,980	00.94	--	--	2,800	39.56	25,220	58.97
Total or average	--	--	55,740	31.91	76,608	49.79	--	--	19,600	19.96	158,840	38.29
1977:												
1st quarter	--	--	5,600	52.23	11,750	181.65	--	--	6,700	68.67	28,160	68.56
2d quarter	--	--	2,600	45.68	32,000	58.81	--	--	3,400	73.67	40,600	59.39
3d quarter	--	--	20,985	36.95	33,755	67.50	--	--	5,590	28.28	83,045	41.30
4th quarter	--	--	--	--	--	--	--	--	--	--	23,450	2.05
Total or average	--	--	29,185	40.67	77,505	66.06	--	--	15,690	55.36	175,255	44.72
1978:												
1st quarter	--	--	16,890	63.81	18,000	87.10	--	--	2,915	35.35	38,760	71.42
2d quarter	--	--	13,900	67.04	22,200	103.04	--	--	7,200	62.56	46,450	91.10
3d quarter	--	--	24,820	60.77	53,860	162.83	--	--	8,670	61.78	116,495	94.94
4th quarter	--	--	1,000	101.59	2,400	144.58	--	--	150	11.00	5,050	101.18
Total or average	--	--	56,610	63.94	96,460	134.48	--	--	18,935	57.61	206,755	89.82
1979:												
1st quarter	--	--	8,800	37.76	9,120	119.97	--	--	2,900	21.67	22,570	67.86
2d quarter	--	--	12,712	52.65	11,625	100.12	--	--	5,660	54.14	40,285	52.78
3d quarter	--	--	36,325	28.76	60,894	113.02	--	--	20,990	17.07	155,894	58.03
4th quarter	--	--	9,500	69.82	4,131	115.43	--	--	4,900	40.79	30,921	56.28
Total or average	--	--	67,337	40.24	05,770	112.13	--	--	34,450	26.92	249,670	57.85
1980:												
1st quarter	--	--	14,350	220.27	19,863	35.10	--	--	1,380	24.11	37,303	105.81
2d quarter	--	--	2,760	32.50	2,439	76.40	--	--	--	--	7,199	45.78
3d quarter	--	--	6,510	55.39	19,948	80.75	--	--	1,900	7.69	74,831	27.08
4th quarter	--	--	16,074	43.43	14,315	124.86	--	--	13,700	21.48	59,159	48.29
Total or average	--	--	39,694	108.56	56,565	75.77	--	--	16,980	20.15	178,492	51.19
1981:												
1st quarter	--	--	10,000	53.87	7,035	23.34	--	--	5,300	207.69	54,520	34.06
2d quarter	--	--	18,483	94.06	27,148	54.74	--	--	9,174	9.99	56,505	59.31
3d quarter	--	--	21,265	75.14	41,055	43.48	--	--	8,000	98.08	87,020	49.26
4th quarter	--	--	7,020	18.94	7,830	13.08	--	--	6,300	14.77	54,310	13.42
Total or average	--	--	56,768	71.20	83,068	42.59	--	--	28,774	71.94	252,355	40.51
1982:												
1st quarter	--	--	17,796	24.73	9,143	31.93	--	--	13,315	9.31	56,980	16.20
2d quarter	--	--	2,500	6.00	5,010	38.61	--	--	1,400	1.00	16,423	19.04
3d quarter	--	--	14,110	17.05	22,605	49.41	--	--	12,400	24.16	86,205	21.58
4th quarter	--	--	7,978	31.95	14,060	96.54	--	--	5,100	22.09	63,598	29.25
Total or average	--	--	42,384	12.99	51,610	58.85	--	--	32,215	16.69	223,206	22.20
1983:												
1st quarter	--	--	12,405	19.60	14,340	62.81	--	--	12,700	18.91	61,545	24.53
2d quarter	--	--	16,930	11.30	14,120	39.00	--	--	10,100	5.25	43,446	18.40
3d quarter	--	--	4,100	27.27	4,208	159.16	--	--	920	40.17	13,758	69.44
4th quarter	--	--	4,060	26.62	10,392	137.80	--	--	6,500	26.22	36,237	50.17
Total or average	--	--	37,495	17.45	43,060	02.53	--	--	30,220	16.57	154,986	32.79
1984:												
1st quarter	--	--	16,330	34.85	10,060	96.48	--	--	11,010	49.89	58,220	37.51
2d quarter	--	-	6,035	82.26	19,015	189.11	--	--	1,200	28.07	26,450	156.39
3d quarter	--	--	9,105	19.51	15,585	48.71	--	--	11,100	38.01	41,865	37.10
4th quarter	--	--	7,379	33.51	7,867	88.90	--	--	7,790	7.58	37,322	28.11
Total or average	--	--	38,849	38.36	52,527	114.70	--	--	31,100	34.20	163,857	54.46

[1]Prices for individual sales may vary from the averages shown in this table because of differences in species mix, quality, road costs, logging and processing costs, size and length of sale, number of bidders, and other related price determinants. Prices for stumpage in National Forest lands are statistical high bids. The statistical high bid is defined as the bid price minus credits for road costs; it includes an allowance for sale-area betterment (K-V funds).

[2]Does not include noble fir or Shasta red fir.

Source--U.S. Department of Agriculture. Pacific Northwest Region includes Oregon and Washington.

Table 20—Volume and average stumpage price of selected species on the Winema National Forest of the Pacific Northwest Region, 1973-84[1]

(Volume in thousand board feet, Scribner scale; value in dollars per thousand board feet)

Year and quarter	Douglas-fir West side Volume	Douglas-fir West side Value	Douglas-fir East side Volume	Douglas-fir East side Value	Ponderosa and Jeffrey pines Volume	Ponderosa and Jeffrey pines Value	Western hemlock Volume	Western hemlock Value	True firs[2] Volume	True firs[2] Value	All species Volume	All species Value
1973:												
1st quarter	1,700	91.48	1,400	71.94	21,250	98.56	--	--	5,700	47.04	32,750	81.56
2d quarter	--	--	--	--	850	86.12	--	--	--	--	4,050	52.05
3d quarter	--	--	240	86.09	9,640	80.66	--	--	2,280	105.82	18,230	80.98
4th quarter	8,850	120.91	--	--	--	--	--	--	90	39.56	11,300	100.35
Total or average	10,550	116.16	1,640	74.01	31,740	92.79	--	--	8,070	63.56	66,330	82.80
1974:												
1st quarter	--	--	1,850	97.24	17,360	207.42	--	--	5,900	98.51	28,410	157.64
2d quarter	--	--	950	299.22	15,300	268.42	--	--	6,050	177.82	53,600	194.49
3d quarter	--	--	--	--	--	--	--	--	160	54.13	2,977	18.66
4th quarter	--	--	1,290	83.39	15,910	124.95	--	--	9,788	88.52	29,800	106.03
Total or average	--	--	4,090	139.79	48,570	199.62	--	--	21,898	115.66	114,787	157.85
1975:												
1st quarter	--	--	1,430	144.26	12,100	95.42	--	--	--	--	16,550	84.03
2d quarter	--	--	1,700	15.10	34,850	110.17	--	--	9,110	92.11	57,900	91.13
3d quarter	--	--	8,600	83.88	--	--	--	--	--	--	15,282	52.96
4th quarter	--	--	2,300	91.02	44,500	86.07	--	--	5,450	26.12	66,250	66.85
Total or average	--	--	14,030	82.87	91,450	96.49	--	--	14,560	67.41	155,982	76.32
1976:												
1st quarter	--	--	2,350	7.34	1,500	61.00	--	--	3,950	212.24	10,900	91.07
2d quarter	--	--	490	53.40	20,680	136.26	--	--	4,990	92.90	38,010	112.13
3d quarter	--	--	--	--	1,391	95.58	--	--	2,380	189.85	5,071	129.72
4th quarter	--	--	4,720	176.69	16,740	135.38	--	--	8,050	105.21	37,010	126.96
Total or average	--	--	7,560	116.06	40,311	131.69	--	--	19,370	134.26	90,991	116.62
1977:												
1st quarter	--	--	--	--	17,425	173.58	--	--	900	111.46	19,525	163.60
2d quarter	--	--	1,000	116.28	22,850	196.81	--	--	5,200	101.49	36,300	145.80
3d quarter	--	--	29,480	215.58	--	--	--	--	--	--	35,400	187.17
4th quarter	--	--	2,500	67.17	17,955	141.31	--	--	14,060	167.12	40,806	138.11
Total or average	--	--	32,980	201.32	58,230	172.75	--	--	20,160	147.71	132,031	157.14
1978:												
1st quarter	--	--	3,750	102.53	21,640	163.71	--	--	9,240	100.34	36,140	140.63
2d quarter	80	110.00	1,100	141.04	4,560	215.32	--	--	4,910	137.91	10,650	171.29
3d quarter	--	--	35,000	371.28	--	--	--	--	9,520	177.99	45,420	324.89
4th quarter	--	--	2,240	89.00	22,746	280.93	--	--	7,360	201.95	34,156	243.48
Total or average	80	110.00	42,090	326.29	48,946	223.02	--	--	31,030	154.21	126,366	237.24
1979:												
1st quarter	--	--	2,200	107.33	17,100	334.66	--	--	4,250	291.72	32,750	255.85
2d quarter	--	--	1,400	89.01	36,850	300.25	--	--	10,600	456.52	59,050	295.93
3d quarter	--	--	2,000	63.60	14,209	332.94	--	--	7,800	290.04	36,915	248.97
4th quarter	--	--	1,700	73.05	34,360	389.06	--	--	8,460	188.53	47,020	324.02
Total or average	--	--	7,300	83.85	102,519	341.00	--	--	31,110	319.39	175,735	286.11
1980:												
1st quarter	--	--	2,200	32.05	30,891	348.71	--	--	6,617	280.57	50,028	261.21
2d quarter	--	--	100	49.96	19,550	375.83	--	--	6,600	35.25	30,700	251.08
3d quarter	--	--	--	--	17,300	341.48	--	--	1,500	1.00	20,000	296.44
4th quarter	--	--	--	--	21,250	305.31	--	--	1,400	1.00	27,300	246.57
Total or average	--	--	2,300	32.83	88,991	342.90	--	--	16,117	129.81	128,028	261.16
1981:												
1st quarter	--	--	4,250	889.34	52,500	345.01	--	--	17,450	95.56	76,690	307.54
2d quarter	--	--	2,400	200.46	20,600	309.88	--	--	11,800	371.87	39,550	287.79
3d quarter	--	--	2,300	511.00	4,500	381.40	--	--	3,000	16.09	10,500	281.51
4th quarter	--	--	970	7.92	15,890	226.21	--	--	8,830	7.56	28,330	130.82
Total or average	--	--	9,920	548.77	93,490	318.83	--	--	41,080	150.21	155,070	268.45
1982:												
1st quarter	--	--	1,700	694.00	28,100	190.41	--	--	11,500	106.98	52,400	151.12
2d quarter	--	--	3,300	212.99	19,600	162.99	--	--	2,450	3.54	32,100	131.41
3d quarter	--	--	--	--	29,300	71.71	--	--	950	7.27	33,600	64.65
4th quarter	--	--	900	12.93	9,110	165.67	--	--	7,400	89.27	21,100	107.43
Total or average	--	--	5,900	321.07	86,110	141.17	--	--	22,300	85.51	139,200	121.34
1983:												
1st quarter	--	--	800	6.41	48,600	247.80	--	--	10,900	62.57	66,000	195.24
2d quarter	--	--	--	--	4,700	12.84	--	--	11,200	130.49	16,600	120.65
3d quarter	--	--	--	--	13,350	228.40	--	--	4,750	31.57	18,900	170.68
4th quarter	--	--	--	--	19,220	197.25	--	--	270	102.00	25,300	156.35
Total or average	--	--	800	6.41	85,870	225.80	--	--	27,120	85.59	126,800	174.06
1984:												
1st quarter	--	--	2,010	37.66	31,390	132.38	1,100	111.00	6,790	15.59	44,590	125.62
2d quarter	--	--	500	45.94	16,600	276.93	--	--	1,900	107.79	40,050	128.85
3d quarter	--	--	2,600	25.46	9,520	131.76	--	--	26,150	37.73	38,730	59.58
4th quarter	--	--	1,000	6.00	11,400	132.88	--	--	6,200	56.53	19,300	97.17
Total or average	--	--	6,110	27.96	68,910	167.20	1,100	111.00	41,040	40.15	142,670	104.75

[1] Prices for individual sales may vary from the averages shown in this table because of differences in species mix, quality, road costs, logging and processing costs, size and length of sale, number of bidders, and other related price determinants. Prices for stumpage in National Forest lands are statistical high bids. The statistical high bid is defined as the bid price minus credits for road costs; it includes an allowance for sale-area betterment (K-V funds).

[2] Does not include noble fir or Shasta red fir.

Source--U.S. Department of Agriculture. Pacific Northwest Region includes Oregon and Washington.

Table 21—Volume and average stumpage price of selected species on the National Forests of eastern Oregon, 1973-84[1]

(Volume in thousand board feet, Scribner scale; value in dollars per thousand board feet)

Year and quarter	Douglas-fir West side Volume	Douglas-fir West side Value	Douglas-fir East side Volume	Douglas-fir East side Value	Ponderosa and Jeffrey pines Volume	Ponderosa and Jeffrey pines Value	Western hemlock Volume	Western hemlock Value	True firs[2] Volume	True firs[2] Value	All species Volume	All species Value
1973:												
1st quarter	6,300	60.13	24,970	47.51	107,240	63.59	--	--	32,980	40.93	275,075	52.24
2d quarter	4,450	97.52	63,035	62.65	156,210	61.30	--	--	58,985	63.43	434,207	59.76
3d quarter	--	--	25,576	64.96	153,401	99.90	--	--	12,920	79.03	228,534	84.53
4th quarter	8,850	120.91	42,980	52.78	116,255	90.33	--	--	63,270	42.37	272,986	63.38
Total or average	19,600	96.06	156,561	57.90	533,106	79.19	--	--	168,155	52.29	1,210,802	63.54
1974:												
1st quarter	--	--	19,486	65.36	176,750	146.91	--	--	73,130	52.30	311,525	102.94
2d quarter	22,840	52.62	37,159	49.43	103,225	142.19	3,200	122.47	97,825	53.33	345,799	83.32
3d quarter	3,220	46.21	15,571	59.75	102,645	115.81	--	--	13,935	66.69	215,972	68.35
4th quarter	--	--	30,412	32.81	165,768	81.43	--	--	25,168	49.07	268,067	60.74
Total or average	26,060	51.83	102,628	49.10	548,388	120.40	3,200	122.47	210,058	53.35	1,141,363	80.54
1975:												
1st quarter	--	--	10,683	23.77	70,950	56.92	--	--	640	30.50	107,652	41.40
2d quarter	--	--	56,743	13.69	259,395	47.17	--	--	68,665	23.76	471,062	35.57
3d quarter	--	--	3,415	10.59	90,782	48.86	--	--	7,160	13.64	127,496	39.01
4th quarter	--	--	39,535	13.53	281,299	36.39	--	--	34,620	10.51	393,239	29.60
Total or average	--	--	110,376	14.52	702,426	44.05	--	--	110,085	19.19	1,099,449	34.41
1976:												
1st quarter	--	--	13,100	9.38	85,950	95.47	--	--	11,050	98.01	126,200	80.50
2d quarter	--	--	75,930	19.74	248,575	69.15	--	--	43,870	23.15	451,235	49.36
3d quarter	--	--	15,614	61.60	121,927	86.33	--	--	11,000	74.22	156,387	80.56
4th quarter	--	--	23,310	78.79	107,223	94.61	--	--	13,450	80.59	160,276	86.89
Total or average	--	--	127,954	34.54	563,675	81.72	--	--	79,370	50.38	894,098	65.95
1977:												
1st quarter	--	--	20,540	88.76	96,346	142.47	--	--	23,215	73.42	186,806	104.39
2d quarter	--	--	29,159	71.27	239,076	123.53	--	--	39,625	87.40	369,343	98.67
3d quarter	--	--	85,653	110.44	212,397	150.62	--	--	40,422	64.27	411,288	111.64
4th quarter	--	--	13,030	55.23	103,853	161.63	--	--	24,219	130.74	189,004	113.79
Total or average	--	--	148,382	95.50	651,672	141.19	--	--	127,481	85.78	1,156,441	106.68
1978:												
1st quarter	--	--	55,515	106.06	174,130	170.56	--	--	40,425	91.58	289,375	140.63
2d quarter	80	110.00	24,440	76.04	96,430	220.56	--	--	20,670	83.74	167,241	159.64
3d quarter	--	--	100,419	186.70	321,114	250.31	--	--	66,451	88.32	570,693	189.67
4th quarter	--	--	5,075	79.05	45,691	264.39	--	--	11,173	186.52	72,334	209.49
Total or average	80	110.00	185,449	145.03	637,365	225.03	--	--	138,719	96.50	1,099,643	173.50
1979:												
1st quarter	--	--	32,264	83.87	147,033	256.03	--	--	22,430	115.82	225,825	198.44
2d quarter	--	--	43,722	125.10	116,975	264.23	5,650	207.95	34,425	181.81	238,742	192.27
3d quarter	--	--	81,000	47.65	302,881	227.50	--	--	79,782	92.34	567,900	154.44
4th quarter	--	--	28,070	82.00	123,281	266.60	--	--	29,600	76.37	223,418	171.98
Total or average	--	--	185,056	77.48	690,170	246.79	5,650	207.95	166,237	111.19	1,255,885	172.66
1980:												
1st quarter	--	--	31,986	126.14	187,580	210.89	--	--	35,897	169.07	305,556	170.69
2d quarter	--	--	16,653	18.44	172,951	187.10	--	--	16,235	48.34	231,555	150.48
3d quarter	--	--	46,880	42.75	188,555	207.82	--	--	65,010	54.11	408,861	116.66
4th quarter	--	--	22,734	40.44	71,042	229.10	--	--	20,530	16.41	159,793	118.26
Total or average	--	--	118,253	62.59	620,128	205.41	--	--	137,672	77.25	1,105,765	138.91
1981:												
1st quarter	--	--	34,360	176.74	157,032	276.70	--	--	44,480	71.76	305,293	182.49
2d quarter	--	--	38,653	79.47	180,832	246.20	--	--	63,864	111.46	322,119	173.57
3d quarter	--	--	65,617	106.47	262,685	171.52	--	--	59,717	141.07	460,669	134.39
4th quarter	--	--	14,575	14.37	79,883	138.41	--	--	25,140	63.74	181,272	75.73
Total or average	--	--	153,205	106.66	680,432	211.75	--	--	193,201	105.12	1,269,353	147.52
1982:												
1st quarter	--	--	28,146	52.31	156,713	118.81	--	--	40,130	37.48	266,410	85.77
2d quarter	--	--	21,110	48.97	140,173	80.99	--	--	20,952	14.53	235,315	60.60
3d quarter	--	--	30,040	19.58	204,107	57.01	--	--	45,751	19.34	406,373	36.89
4th quarter	--	--	23,913	24.80	117,570	73.74	--	--	30,215	38.05	222,483	48.48
Total or average	--	--	103,209	35.73	618,563	81.28	--	--	137,048	28.04	1,130,581	55.62
1983:												
1st quarter	--	--	28,420	19.38	215,890	135.54	--	--	45,615	27.15	356,895	89.67
2d quarter	--	--	25,530	21.00	98,533	133.73	--	--	30,453	56.52	174,190	91.09
3d quarter	--	--	21,041	13.42	167,694	147.43	--	--	44,200	26.93	306,980	90.92
4th quarter	--	--	18,125	23.09	101,472	158.41	--	--	39,210	27.16	206,140	86.87
Total or average	--	--	93,116	19.20	583,589	142.63	--	--	159,478	32.70	1,046,005	89.57
1984:												
1st quarter	--	--	32,640	42.77	158,030	145.67	1,100	111.00	50,380	31.52	283,970	97.00
2d quarter	--	--	21,345	37.24	168,345	173.27	--	--	18,509	19.67	245,120	127.52
3d quarter	--	--	33,565	18.63	170,044	126.64	--	--	72,763	26.53	361,031	70.37
4th quarter	--	--	22,309	22.70	85,976	100.45	--	--	33,560	19.68	184,726	54.54
Total or average	--	--	109,859	30.24	582,395	141.42	1,100	111.00	175,212	25.93	1,075,647	87.71

[1] Prices for individual sales may vary from the averages shown in this table because of differences in species mix, quality, road costs, logging and processing costs, size and length of sale, number of bidders, and other related price determinants. Prices for stumpage in National Forest lands are statistical high bids. The statistical high bid is defined as the bid price minus credits for road costs; it includes an allowance for sale-area betterment (K-V funds).

[2] Does not include noble fir or Shasta red fir.

Source--U.S. Department of Agriculture. Pacific Northwest Region includes Oregon and Washington.

Table 22—Volume and average stumpage price of selected species on the Colville National Forest of the Pacific Northwest Region, 1974-84[1/]

(Volume in thousand board feet, Scribner scale; value in dollars per thousand board feet)

YEAR AND QUARTER	DOUGLAS-FIR				PONDEROSA AND JEFFREY PINES		WESTERN HEMLOCK		TRUE FIRS[3/]		ALL SPECIES	
	WEST SIDE		EAST SIDE									
	VOLUME	VALUE	VOLUME	VALUE	VOLUME	VALUE	VOLUME	VALUE	VOLUME	VALUE	VOLUME	VALUE
1974:												
1st quarter	--	--	--	--	--	--	--	--	--	--	--	--
2d quarter	--	--	--	--	--	--	--	--	--	--	--	--
3d quarter	--	--	--	--	--	--	--	--	--	--	--	--
4th quarter	--	--	17,850	12.21	4,930	33.66	--	--	5,465	2.37	57,170	10.50
Total or average	--	--	17,850	12.21	4,930	33.66	--	--	5,465	2.37	57,170	10.50
1975:												
1st quarater	--	--	--	--	--	--	--	--	--	--	135	59.93
2d quarter	--	--	5,750	2.83	1,975	155.72	1,960	1.00	415	6.51	24,540	50.06
3d quarter	--	--	--	--	--	--	--	--	--	--	--	--
4th quarter	--	--	10,395	36.65	3,710	49.91	--	--	360	19.45	22,625	28.42
Total or average	--	--	16,145	24.60	5,685	86.67	1,960	1.00	775	12.52	47,300	39.74
1976:												
1st quarter	--	--	34	11.41	--	--	--	--	5	10.91	78	42.26
2d quarter	--	--	13,145	38.62	668	27.27	2,480	21.63	2,810	10.43	25,995	35.59
3d quarter	--	--	--	--	--	--	--	--	1,900	1.00	31,980	62.27
4th quarter	--	--	--	--	--	--	--	--	665	46.00	845	46.46
Total or average	--	--	13,179	38.55	668	27.27	2,480	21.63	5,380	10.98	58,898	50.24
1977:												
1st quarter	--	--	5,500	44.76	300	124.77	700	68.88	1,300	62.41	17,600	58.89
2d quarter	--	--	2,990	54.43	--	--	2,600	133.06	40	40.30	9,400	78.08
3d quarter	--	--	14,121	69.66	4,100	105.72	6	65.00	5,700	56.44	42,400	72.42
4th quarter	--	--	18	84.79	13	67.82	--	--	6	79.48	55	74.58
Total or average	--	--	22,629	61.61	4,413	106.90	3,306	119.35	7,046	57.47	69,455	69.76
1978:												
1st quarter	--	--	5,891	83.80	530	97.07	--	--	28	25.91	8,916	70.61
2d quarter	--	--	204	102.85	--	--	--	--	115	62.96	369	83.18
3d quarter	--	--	17,080	76.15	1,230	139.79	4,750	31.71	9,913	61.23	63,526	69.71
4th quarter	--	--	516	58.08	--	--	--	--	15	91.76	1,240	45.05
Total or average	--	--	23,691	77.89	1,760	126.98	4,750	31.71	10,071	61.20	74,051	69.47
1979:												
1st quarter	--	--	93	112.05	209	92.54	--	--	700	87.03	3,647	81.24
2d quarter	--	--	656	23.45	693	68.74	1,700	7.88	374	26.45	4,369	79.02
3d quarter	--	--	13,907	144.99	1,603	200.41	410	29.62	6,595	48.25	66,110	116.32
4th quarter	--	--	340	95.00	--	--	--	--	--	--	4,150	161.29
Total or average	--	--	14,996	138.34	2,505	154.99	2,110	12.11	7,669	50.73	78,276	114.99
1980:												
1st quarter	--	--	5,636	86.40	1,060	268.13	--	--	2,500	18.79	12,896	68.02
2d quarter	--	--	10,600	110.92	--	--	80	68.06	800	46.77	14,775	110.69
3d quarter	--	--	12,360	181.64	3,115	14.43	6,590	27.33	3,950	74.24	54,145	87.40
4th quarter	--	--	1,051	233.33	55	25.12	--	--	1,115	14.71	2,483	107.53
Total or average	--	--	29,647	140.08	4,230	78.15	6,670	27.82	8,365	47.11	84,299	89.11
1981:												
1st quarter	--	--	8,055	124.62	--	--	--	--	1,200	14.93	12,275	106.05
2d quarter	--	--	2,951	50.46	500	41.88	--	--	742	43.12	19,330	28.54
3d quarter	--	--	10,091	78.13	365	445.00	980	44.25	8,210	70.39	59,336	73.05
4th quarter	--	--	--	--	--	--	--	--	--	--	--	--
Total or average	--	--	21,097	92.01	865	211.98	980	44.25	10,152	61.84	90,941	68.04
1982:												
1st quarter	--	--	7,248	87.32	2,885	44.06	450	39.50	1,320	21.88	16,261	68.63
2d quarter	--	--	2,901	31.39	115	13.36	850	34.05	3,345	21.89	32,415	20.40
3d quarter	--	--	2,900	47.87	--	--	--	--	--	--	3,900	43.52
4th quarter	--	--	7,109	38.45	400	17.55	--	--	918	8.58	11,238	36.20
Total or average	--	--	20,158	56.44	3,400	39.90	1,300	35.94	5,583	19.70	63,814	36.89
1983:												
1st quarter	--	--	77	80.89	700	24.04	176	50.25	2,300	12.95	30,600	20.29
2d quarter	--	--	3,998	160.63	--	--	74	65.82	3,905	16.83	14,935	58.10
3d quarter	--	--	7,000	51.29	3,300	96.79	1,792	6.94	110	47.53	31,210	39.78
4th quarter	--	--	772	108.97	750	151.97	--	--	7,380	53.53	20,494	69.90
Total or average	--	--	11,847	92.14	4,750	94.72	2,042	12.81	13,695	36.17	97,239	42.81
1984:												
1st quarter	--	--	539	124.68	73	81.59	--	--	2,526	22.22	19,309	36.86
2d quarter	--	--	349	75.00	1,000	19.35	--	--	242	45.95	13,471	18.32
3d quarter	--	--	592	68.07	20	73.01	--	--	902	29.42	8,226	32.16
4th quarter	--	--	15,465	27.44	--	--	120	10.88	4,217	15.38	30,283	24.13
Total or average	--	--	16,945	32.94	1,093	24.49	120	10.88	7,887	20.11	71,289	27.41

1/Colville National Forest transferred from Region 1 to the Pacific Northwest Region in October 1974.

2/Prices for individual sales may vary from the averages shown in this table because of differences in species mix, quality, road costs, logging and processing costs, size and length of sale, number of bidders, and other related price determinants. Prices for stumpage in National Forest lands are statistical high bids. The statistical high bid is defined as the bid price minus credits for road costs; it includes an allowance for sale-area betterment (K-V funds).

3/Does not include noble fir or Shasta red fir.

Source--U.S. Department of Agriculture. Pacific Northwest Region includes Oregon and Washington.

Table 23—Volume and average stumpage price of selected species on the Okanogan National Forest of the Pacific Northwest Region, 1973-84[1]

(Volume in thousand board feet, Scribner scale; value in dollars per thousand board feet)

Year and quarter	Douglas-fir West side Volume	Douglas-fir West side Value	Douglas-fir East side Volume	Douglas-fir East side Value	Ponderosa and Jeffrey pines Volume	Ponderosa and Jeffrey pines Value	Western hemlock Volume	Western hemlock Value	True firs[2] Volume	True firs[2] Value	All species Volume	All species Value
1973:												
1st quarter	--	--	8,020	40.92	3,890	42.07	--	--	--	--	12,350	39.86
2d quarter	--	--	11,590	64.18	17,650	43.82	--	--	--	--	31,755	49.57
3d quarter	--	--	13,670	70.14	23,300	64.81	--	--	--	--	40,690	60.78
4th quarter	--	--	700	97.00	100	90.64	--	--	--	--	1,100	96.82
Total or average	--	--	33,980	61.76	44,940	54.66	--	--	--	--	85,895	54.09
1974:												
1st quarter	--	--	8,600	60.50	20,700	61.05	--	--	--	--	32,500	54.93
2d quarter	--	--	17,565	59.11	13,110	96.97	--	--	--	--	31,975	72.27
3d quarter	--	--	10,460	69.27	4,890	89.45	--	--	--	--	16,640	74.75
4th quarter	--	--	10,720	63.32	4,700	94.46	--	--	--	--	15,480	72.67
Total or average	--	--	47,345	62.56	43,400	78.71	--	--	--	--	96,595	66.93
1975:												
1st quarter	--	--	--	--	3,400	17.38	--	--	--	--	11,600	15.24
2d quarter	--	--	22,300	18.75	29,000	15.45	--	--	--	--	52,500	16.52
3d quarter	--	--	12,000	0.83	--	--	--	--	--	--	21,600	63.58
4th quarter	--	--	18,800	75.20	2,200	60.69	--	--	--	--	11,000	142.57
Total or average	--	--	53,100	36.61	34,600	18.51	--	--	--	--	96,700	41.22
1976:												
1st quarter	--	--	--	--	--	--	--	--	--	--	--	:
2d quarter	--	--	21,100	28.93	20,600	40.50	--	--	--	--	41,700	34.65
3d quarter	--	--	60	2.00	160	43.35	--	--	--	--	220	32.29
4th quarter	--	--	9,300	64.64	2,700	44.38	--	--	--	--	12,320	59.91
Total or average	--	--	30,460	39.78	23,460	40.97	--	--	--	--	54,240	40.37
1977:												
1st quarter	--	--	--	--	--	--	--	--	--	-	--	:
2d quarter	--	--	3,600	62.77	700	96.35	--	--	--	--	4,300	68.24
3d quarter	--	--	19,900	89.96	5,100	86.01	--	--	--	--	25,000	89.15
4th quarter	--	--	107	67.15	82	98.24	--	--	--	--	320	80.71
Total or average	--	--	23,607	85.70	5,882	87.41	--	--	--	--	29,620	07.08
1978:												
1st quarter	--	--	10,100	134.91	--	--	--	--	--	--	10,100	134.91
2d quarter	--	--	19,600	37.85	9,900	58.49	--	--	--	--	30,300	45.44
3d quarter	--	--	58,090	51.66	7,120	218.46	--	--	--	--	70,510	66.03
4th quarter	--	--	--	--	--	--	--	--	--	--	--	:
Total or average	--	--	87,790	58.16	17,020	125.39	--	--	--	--	110,910	66.68
1979:												
1st quarter	--	--	11,853	19.84	4,800	60.29	--	--	--	--	17,453	34.91
2d quarter	--	--	4,000	54.60	3,420	82.76	--	--	--	--	7,720	66.14
3d quarter	--	--	40,965	37.13	19,220	214.24	--	--	--	--	64,465	87.76
4th quarter	--	--	2,600	54.78	2,300	299.55	--	--	--	--	4,900	169.67
Total or average	--	--	59,418	35.63	29,740	180.87	--	--	--	--	94,538	80.48
1980:												
1st quarter	--	--	15,490	134.52	4,300	354.09	--	--	--	--	21,190	171.31
2d quarter	--	--	1,060	11.82	--	--	--	--	--	--	1,200	10.78
3d quarter	--	--	11,980	20.21	7,220	64.61	--	--	--	--	20,860	32.22
4th quarter	--	--	16,000	145.04	--	--	--	--	--	--	16,300	142.45
Total or average	--	--	44,530	104.63	11,520	172.67	--	--	--	--	59,550	112.16
1981:												
1st quarter	--	--	18,421	14.62	7,529	104.91	--	--	--	--	25,950	40.82
2d quarter	--	--	3,600	102.00	--	--	--	--	--	--	13,100	116.50
3d quarter	--	--	9,350	57.89	13,435	69.06	--	--	--	--	24,085	61.75
4th quarter	--	--	--	--	--	--	--	--	--	--	--	:
Total or average	--	--	31,371	37.54	20,964	81.94	--	--	--	--	63,135	64.51
1982:												
1st quarter	--	--	5,300	17.17	8,550	40.52	--	--	--	--	13,850	31.58
2d quarter	--	--	15,140	63.95	--	--	--	--	--	--	15,140	63.95
3d quarter	--	--	8,908	16.19	2,780	44.00	--	--	--	--	11,760	22.91
4th quarter	--	--	160	21.00	--	--	--	--	--	--	690	11.70
Total or average	--	--	29,508	40.90	11,330	41.40	--	--	--	--	41,440	40.62
1983:												
1st quarter	--	--	20,300	27.56	9,200	141.17	--	--	--	--	31,300	61.09
2d quarter	--	--	22,000	67.45	1,935	71.00	--	--	--	--	23,935	67.74
3d quarter	--	--	16,500	40.22	7,054	13.72	--	--	--	--	24,754	32.22
4th quarter	--	--	16,300	64.71	1,200	115.00	--	--	--	--	18,800	64.22
Total or average	--	--	75,100	50.09	19,389	86.18	--	--	--	--	98,789	56.06
1984:												
1st quarter	--	--	7,191	86.27	120	25.37	--	--	--	--	8,111	86.44
2d quarter	--	--	8,020	29.88	3,100	16.59	--	--	--	--	11,120	26.17
3d quarter	--	--	10,800	23.65	6,000	13.12	--	--	--	--	16,800	19.89
4th quarter	--	--	16,617	21.27	3,683	26.23	--	--	--	--	22,600	38.40
Total or average	--	--	42,628	34.46	12,903	18.04	--	--	--	--	58,631	37.43

1/Prices for individual sales may vary from the averages shown in this table because of differences in species mix, quality, road costs, logging and processing costs, size and length of sale, number of bidders, and other related price determinants. Prices for stumpage in National Forest lands are statistical high bids. The statistical high bid is defined as the bid price minus credits for road costs; it includes an allowance for sale-area betterment (K-V funds).

2/Does not include noble fir or Shasta red fir.

Source--U.S. Department of Agriculture. Pacific Northwest Region includes Oregon and Washington.

Table 24—Volume and average stumpage price of selected species on the Wenatchee National Forest of the Pacific Northwest Region, 1973-84[1/]

(Volume in thousand board feet, Scribner scale; value in dollars per thousand board feet)

YEAR AND QUARTER	DOUGLAS-FIR				PONDEROSA AND JEFFREY PINES		WESTERN HEMLOCK		TRUE FIRS[2/]		ALL SPECIES	
	WEST SIDE		EAST SIDE									
	VOLUME	VALUE	VOLUME	VALUE	VOLUME	VALUE	VOLUME	VALUE	VOLUME	VALUE	VOLUME	VALUE
1973:												
1st quarter	1,500	55.03	10,910	23.88	439	20.70	1,015	46.72	7,984	96.97	26,988	45.56
2d quarter	1,950	117.26	30,945	62.09	6,090	34.22	1,900	112.11	13,960	99.09	58,850	70.09
3d quarter	--	--	746	75.24	--	--	489	03.23	496	75.10	1,996	67.52
4th quarter	--	--	6,895	54.23	6,545	44.62	--	--	3,685	71.27	20,225	52.11
Total or average	3,450	90.20	49,496	52.77	13,074	38.98	3,404	88.46	26,125	94.06	108,059	60.55
1974:												
1st quarter	--	--	3,600	67.44	1,500	75.16	--	--	1,840	117.21	8,100	73.57
2d quarter	2,700	62.66	22,224	44.41	13,498	85.01	11,750	95.31	11,500	38.81	70,622	55.62
3d quarter	--	--	190	30.23	440	64.84	95	132.98	74	36.04	1,092	52.68
4th quarter	--	--	7,240	27.94	6,360	29.91	--	--	7,740	28.15	22,360	28.47
Total or average	2,700	62.66	33,254	43.23	21,798	67.85	11,845	95.62	21,154	41.72	102,174	51.07
1975:												
1st quarter	--	--	11,060	35.33	8,000	10.53	5,100	18.99	--	--	29,100	24.46
2d quarter	--	--	29,330	20.74	8,670	22.30	2,300	108.05	8,660	51.82	64,310	39.09
3d quarter	--	--	18,940	11.82	9,200	9.81	--	--	5,400	3.96	58,630	10.22
4th quarter	--	--	21,109	26.10	9,568	21.33	--	--	6,961	60.46	39,008	31.08
Total or average	--	--	80,439	22.05	35,438	16.14	7,400	46.67	21,021	42.39	191,120	26.37
1976:												
1st quarter	--	--	4,420	5.90	6,431	95.27	--	--	36	8.83	12,987	49.88
2d quarter	--	--	21,110	46.83	6,820	85.42	6,500	12.17	6,570	59.44	46,040	44.94
3d quarter	--	--	13,209	6.38	348	13.31	--	--	5,953	3.70	27,240	20.48
4th quarter	--	--	2,675	60.87	3,600	83.99	--	--	415	63.01	6,750	72.79
Total or average	--	--	41,414	30.47	17,199	87.39	6,500	12.17	12,974	33.84	93,017	40.49
1977:												
1st quarter	--	--	9,339	72.39	992	9.99	5,600	80.39	1,919	43.97	19,413	63.47
2d quarter	--	--	22,140	37.16	7,214	81.00	70	83.66	7,467	42.65	38,831	48.34
3d quarter	--	--	17,819	46.60	12,880	91.11	--	--	9,674	34.88	41,613	56.55
4th quarter	--	--	2,385	124.08	525	13.45	--	--	--	--	3,150	97.00
Total or average	--	--	51,603	50.79	21,611	82.13	5,670	80.33	19,060	30.84	103,007	56.00
1978:												
1st quarter	--	--	3,747	93.17	1,586	79.52	--	--	1,100	60.88	6,602	82.71
2d quarter	--	--	6,321	70.17	3,060	85.12	--	--	2,090	112.55	11,830	83.34
3d quarter	--	--	61,449	59.54	30,350	149.82	13,978	175.93	21,648	136.95	137,501	116.93
4th quarter	--	--	2,620	31.80	2,260	274.35	--	--	--	--	4,880	144.13
Total or average	--	--	74,137	61.17	45,256	149.20	13,978	175.93	24,838	131.53	160,813	113.82
1979:												
1st quarter	--	--	30,528	95.21	15,925	111.16	3,700	172.93	15,345	150.73	68,473	111.60
2d quarter	--	--	3,540	146.65	1,400	330.59	54	17.57	1,031	58.30	6,225	170.77
3d quarter	--	--	58,833	59.80	22,795	95.98	8,370	359.14	18,867	357.61	119,315	136.07
4th quarter	--	--	1,150	34.41	840	66.98	--	--	80	79.16	2,070	49.36
Total or average	--	--	94,051	74.25	40,960	109.30	12,124	300.79	35,323	258.36	196,083	127.71
1980:												
1st quarter	--	--	16,727	35.32	10,842	111.21	2,900	127.66	8,451	299.16	41,955	119.62
2d quarter	--	--	4,062	36.94	97	129.92	--	--	1,980	220.47	6,289	95.57
3d quarter	--	--	54,659	37.58	20,770	17.06	13,320	379.14	35,050	121.33	136,833	104.42
4th quarter	--	--	2,000	9.60	1,000	90.00	--	--	1,000	8.60	5,140	24.73
Total or average	--	--	77,448	36.34	32,709	50.83	16,220	334.18	46,481	155.47	190,217	105.33
1981:												
1st quarter	--	--	10,795	19.50	5,161	282.95	--	--	4,852	6.31	22,594	76.07
2d quarter	--	--	18,839	10.15	63,385	465.48	1,200	45.00	7,800	79.89	35,964	107.23
3d quarter	--	--	60,344	73.77	16,465	120.68	13,596	136.39	34,085	111.99	128,900	96.25
4th quarter	--	--	75	5.22	--	--	--	--	5,045	69.67	6,020	59.45
Total or average	--	--	90,053	53.90	28,011	229.17	14,796	128.98	51,782	93.08	193,478	94.79
1982:												
1st quarter	--	--	4,330	20.51	130	48.87	1,900	179.90	1,900	11.67	8,560	53.91
2d quarter	--	--	19,849	12.81	8,100	33.54	4,560	107.57	3,403	95.97	38,712	35.49
3d quarter	--	--	45,990	31.15	14,760	10.56	1,754	24.15	30,370	23.04	100,974	23.79
4th quarter	--	--	2,370	47.09	4,050	74.12	--	--	110	26.64	6,530	63.51
Total or average	--	--	72,539	26.34	27,040	27.15	8,214	106.49	35,783	29.39	154,776	30.06
1983:												
1st quarter	--	--	5,260	127.60	2,100	68.18	2,140	19.13	5,010	114.81	16,720	86.67
2d quarter	--	--	4,930	121.51	2,400	41.32	--	--	4,025	18.65	14,320	62.00
3d quarter	--	--	56,019	27.90	13,070	67.17	16,500	6.21	31,950	17.61	125,732	25.49
4th quarter	--	--	7,685	14.23	6,315	58.18	--	--	6,470	43.26	21,580	35.73
Total or average	--	--	73,894	39.82	23,885	62.29	18,640	7.70	47,455	31.46	178,352	35.40
1984:												
1st quarter	--	--	30,578	62.64	12,655	56.09	2,960	15.81	5,277	20.95	52,770	52.92
2d quarter	--	--	21,999	39.50	4,980	85.93	--	--	13,500	6.12	41,439	33.34
3d quarter	--	--	13,600	26.15	6,000	46.37	--	--	8,930	20.66	35,880	26.45
4th quarter	--	--	9,300	26.43	4,000	25.98	--	--	--	--	13,300	26.29
Total or average	--	--	75,477	44.67	27,635	55.00	2,960	15.81	27,707	13.63	143,389	38.17

1/Prices for individual sales may vary from the averages shown in this table because of differences in species mix, quality, road costs, logging and processing costs, size and length of sale, number of bidders, and other related price determinants. Prices for stumpage in National Forest lands are statistical high bids. The statistical high bid is defined as the bid price minus credits for road costs; it includes an allowance for sale-area betterment (K-V funds).

2/Does not include noble fir or Shasta red fir.

Source--U.S. Department of Agriculture. Pacific Northwest Region includes Oregon and Washington.

Table 25—Volume and average stumpage price of selected species on the National Forests of eastern Washington, 1973-84[1]

(Volume in thousand board feet, Scribner scale; value in dollars per thousand board feet)

Year and quarter	Douglas-fir				Ponderosa and Jeffrey pines		Western hemlock		True firs[2]		All species	
	West side		East side									
	Volume	Value	Volume	Value	Volume	Value	Volume	Value	Volume	Value	Volume	Value
1973:												
1st quarter	1,500	55.03	18,930	31.10	4,329	39.90	1,015	46.72	7,984	96.97	39,338	43.77
2d quarter	1,950	117.26	42,535	62.66	23,740	41.36	1,900	112.11	13,960	99.09	90,605	62.90
3d quarter	--	--	14,416	70.40	23,300	64.81	489	83.23	496	75.10	42,686	61.10
4th quarter	--	--	7,595	58.17	6,645	45.32	--	--	3,685	71.27	21,325	54.42
Total or average	3,450	90.20	83,476	56.43	58,014	51.13	3,404	88.46	26,125	94.06	193,954	57.69
1974:												
1st quarter	--	--	12,200	62.55	22,200	62.00	--	--	1,840	117.21	40,600	58.65
2d quarter	2,700	62.66	39,789	50.90	26,608	90.90	11,750	95.31	11,500	38.81	102,597	60.81
3d quarter	--	--	10,650	68.57	5,330	87.37	95	132.98	74	36.04	17,732	73.39
4th quarter	--	--	35,810	30.69	15,990	50.04	--	--	13,205	17.48	95,010	24.86
Total or average	2,700	62.66	98,449	46.90	70,128	72.17	11,845	95.62	26,619	33.64	255,939	47.99
1975:												
1st quarter	--	--	11,060	35.33	11,400	12.57	5,100	18.99	--	--	40,835	21.96
2d quarter	--	--	55,550	18.10	39,165	23.64	4,260	58.80	8,025	56.13	137,850	32.23
3d quarter	--	--	30,940	10.66	9,200	9.81	--	--	5,400	3.96	80,230	24.59
4th quarter	--	--	50,304	45.81	15,598	35.52	--	--	7,421	34.36	82,713	39.63
Total or average	--	--	147,854	27.26	75,363	22.32	9,360	37.11	20,846	34.86	341,628	31.00
1976:												
1st quarter	--	--	4,454	5.95	6,431	95.27	--	--	41	9.07	13,065	49.83
2d quarter	--	--	55,355	38.06	28,088	51.13	8,980	14.78	9,380	44.75	113,735	39.03
3d quarter	--	--	13,269	6.36	508	22.77	--	--	7,853	3.05	59,440	43.01
4th quarter	--	--	11,975	63.80	6,300	67.01	--	--	1,080	49.98	19,915	63.70
Total or average	--	--	85,053	35.05	41,327	60.07	8,980	14.78	18,354	27.14	206,155	43.24
1977:												
1st quarter	--	--	14,839	62.15	1,292	36.64	6,300	86.22	3,219	51.42	37,013	61.30
2d quarter	--	--	28,730	42.17	7,914	82.34	2,670	131.76	7,507	42.63	52,531	55.30
3d quarter	--	--	51,840	69.53	22,080	92.65	6	65.00	15,374	42.87	109,013	70.20
4th quarter	--	--	2,510	121.30	620	25.80	--	--	6	79.50	3,525	95.17
Total or average	--	--	97,919	61.71	31,906	86.53	8,976	99.75	26,106	43.87	202,082	65.13
1978:												
1st quarter	--	--	19,738	111.73	2,116	83.96	--	--	1,128	60.01	25,618	99.15
2d quarter	--	--	26,125	46.18	12,960	64.78	--	--	2,205	109.97	42,499	56.04
3d quarter	--	--	136,619	58.27	46,700	160.02	18,728	139.35	31,561	113.17	271,537	92.66
4th quarter	--	--	3,136	36.13	2,260	274.35	--	--	15	91.83	6,120	124.06
Total or average	--	--	185,618	61.88	64,036	142.27	18,728	139.35	34,909	111.24	345,774	89.20
1979												
1st quarter	--	--	42,474	74.22	20,934	99.31	3,700	172.93	16,045	147.95	89,573	95.42
2d quarter	--	--	8,196	91.86	5,513	143.93	1,754	8.18	1,405	49.83	18,314	104.78
3d quarter	--	--	113,705	62.05	43,618	151.92	8,780	343.75	25,462	277.48	249,890	118.38
4th quarter	--	--	4,090	52.40	3,140	237.33	--	--	80	79.16	11,120	144.15
Total or average	--	--	168,465	66.33	73,205	139.94	14,234	258.00	42,992	221.33	368,897	112.91
1980:												
1st quarter	--	--	37,853	83.52	16,202	185.94	2,900	127.66	10,951	235.15	76,041	125.27
2d quarter	--	--	15,722	35.13	97	129.92	80	68.06	2,780	170.48	22,264	101.04
3d quarter	--	--	78,999	57.50	31,105	27.84	19,910	262.70	39,000	116.56	211,838	93.16
4th quarter	--	--	19,051	135.69	1,055	86.64	--	--	2,115	11.82	23,923	113.53
Total or average	--	--	151,625	76.68	48,459	82.18	22,890	244.91	54,846	138.93	334,066	102.45
1981:												
1st quarter	--	--	37,271	39.80	12,690	177.32	--	--	6,052	8.02	60,819	67.08
2d quarter	--	--	25,390	27.86	6,885	434.71	1,200	45.00	8,542	76.42	68,394	86.77
3d quarter	--	--	79,785	72.46	30,265	101.68	14,576	130.20	42,295	103.91	212,321	85.85
4th quarter	--	--	75	5.23	--	--	--	--	5,045	69.67	6,020	59.45
Total or average	--	--	142,521	55.94	49,840	166.94	15,776	123.72	61,934	87.96	347,554	82.29
1982:												
1st quarter	--	--	16,878	48.24	11,565	41.49	2,350	153.02	3,220	15.86	38,671	52.11
2d quarter	--	--	37,890	34.67	8,215	33.26	5,410	96.02	6,748	59.25	86,267	34.81
3d quarter	--	--	57,798	30.08	17,540	15.88	1,754	24.15	30,370	23.04	116,634	24.36
4th quarter	--	--	9,639	40.29	4,450	69.03	--	--	1,028	10.51	18,458	44.95
Total or average	--	--	122,205	34.82	41,770	32.05	9,514	96.85	41,366	28.08	260,030	33.42
1983:												
1st quarter	--	--	25,637	48.24	12,000	121.56	2,316	21.49	7,310	82.76	78,620	50.65
2d quarter	--	--	30,928	88.11	4,335	54.57	74	65.82	7,930	17.76	53,190	63.49
3d quarter	--	--	79,519	32.51	23,424	55.25	18,292	6.28	32,060	17.70	181,696	28.86
4th quarter	--	--	24,757	50.42	8,265	74.91	--	--	13,850	48.73	60,874	56.03
Total or average	--	--	160,841	48.47	48,024	75.14	20,682	8.20	61,150	32.51	374,380	42.77
1984:												
1st quarter	--	--	38,308	67.95	12,848	55.95	2,960	15.81	7,803	21.36	80,190	52.45
2d quarter	--	--	30,368	37.67	9,080	55.26	--	--	13,742	6.82	66,030	29.07
3d quarter	--	--	24,992	25.50	12,020	29.82	--	--	9,832	21.46	60,906	25.41
4th quarter	--	--	41,382	24.74	7,683	26.10	120	10.88	4,217	15.38	66,183	29.44
Total or average	--	--	135,050	39.98	41,631	42.75	3,080	15.62	35,594	15.07	273,309	35.20

[1] Prices for individual sales may vary from the averages shown in this table because of differences in species mix, quality, road costs, logging and processing costs, size and length of sale, number of bidders, and other related price determinants. Prices for stumpage in National Forest lands are statistical high bids. The statistical high bid is defined as the bid price minus credits for road costs; it includes an allowance for sale-area betterment (K-V funds).

[2] Does not include noble fir or Shasta red fir.

Source--U.S. Department of Agriculture. Pacific Northwest Region includes Oregon and Washington.

Table 26—Volume and average stumpage price of selected species on the National Forests of eastern Oregon and eastern Washington, 1973-84[1/]

(Volume in thousand board feet, Scribner scale; value in dollars per thousand board feet)

YEAR AND QUARTER	DOUGLAS-FIR				PONDEROSA AND JEFFREY PINES		WESTERN HEMLOCK		TRUE FIRS[2/]		ALL SPECIES	
	WEST SIDE		EAST SIDE									
	VOLUME	VALUE	VOLUME	VALUE	VOLUME	VALUE	VOLUME	VALUE	VOLUME	VALUE	VOLUME	VALUE
1973:												
1st quarter	7,800	59.15	43,900	40.43	111,569	62.67	1,015	46.72	40,964	51.85	314,413	51.18
2d quarter	6,400	103.53	105,570	62.65	179,950	58.67	1,900	112.11	72,945	70.25	524,812	60.30
3d quarter	--	--	39,992	66.92	176,701	95.26	489	83.23	13,416	78.88	271,220	80.84
4th quarter	8,850	120.91	50,755	53.40	122,900	87.90	--	--	66,955	43.96	294,311	62.73
Total or average	23,050	95.18	240,217	57.35	591,120	76.44	3,404	88.46	194,280	57.91	1,404,756	52.74
1974:												
1st quarter	--	--	31,685	64.28	198,950	137.43	--	--	74,970	53.89	352,125	97.83
2d quarter	25,540	53.68	76,948	50.19	129,833	131.68	14,950	101.13	109,325	51.80	448,396	78.17
3d quarter	3,220	46.21	26,221	63.33	107,975	114.40	95	132.98	14,009	66.52	233,704	68.73
4th quarter	--	--	66,222	31.66	181,758	78.67	--	--	38,373	38.20	363,077	51.35
Total or average	28,760	52.84	201,077	48.02	618,516	114.94	15,045	101.33	236,677	51.13	1,397,302	80.33
1975:												
1st quarter	--	--	21,743	29.65	82,350	50.78	5,100	18.99	640	30.50	148,487	36.05
2d quarter	--	--	112,293	15.87	298,560	44.08	4,260	58.80	76,690	27.15	608,912	34.82
3d quarter	--	--	34,355	10.66	99,982	45.27	--	--	12,560	9.48	207,726	33.44
4th quarter	--	--	89,839	31.61	296,897	36.24	--	--	42,041	14.72	475,952	31.35
Total or average	--	--	258,230	21.81	777,789	41.95	9,360	37.11	131,931	21.52	1,441,077	33.60
1976:												
1st quarter	--	--	17,554	8.51	92,381	95.46	--	--	11,091	97.69	139,265	77.70
2d quarter	--	--	131,285	27.46	276,663	67.32	8,980	14.78	53,250	26.96	564,970	47.28
3d quarter	--	--	28,883	36.22	122,435	86.07	--	--	18,853	44.57	215,827	70.22
4th quarter	--	--	35,285	73.70	113,523	93.08	--	--	14,530	78.31	180,191	84.32
Total or average	--	--	213,007	34.75	605,002	80.25	8,980	14.78	97,724	46.02	1,100,253	61.70
1977:												
1st quarter	--	--	35,379	77.59	97,638	141.07	6,300	86.22	26,434	70.74	223,819	97.27
2d quarter	--	--	57,889	56.83	246,990	122.21	2,670	131.76	47,132	80.33	421,874	93.27
3d quarter	--	--	137,493	95.67	234,477	145.17	6	65.00	55,796	58.37	520,301	102.96
4th quarter	--	--	15,540	65.91	104,473	160.83	--	--	24,225	130.73	192,529	113.44
Total or average	--	--	246,301	82.07	683,578	138.63	8,976	99.75	153,587	78.65	1,358,523	100.49
1978:												
1st quarter	--	--	75,253	107.55	176,246	169.52	--	--	41,553	90.72	314,993	137.26
2d quarter	80	110.00	50,565	60.61	109,390	202.11	--	--	22,875	86.27	209,740	138.65
3d quarter	--	--	237,038	112.68	367,814	238.84	18,728	139.35	98,012	96.32	842,230	158.40
4th quarter	--	--	8,211	62.66	47,951	264.86	--	--	11,188	186.40	78,454	202.83
Total or average	80	110.00	371,067	103.44	701,401	217.47	18,728	139.35	173,628	99.46	1,445,417	153.33
1979:												
1st quarter	--	--	74,738	78.38	167,967	236.50	3,700	172.93	38,473	129.23	315,398	169.18
2d quarter	--	--	51,918	119.85	122,488	258.82	7,404	160.63	35,830	176.63	257,056	186.04
3d quarter	--	--	194,705	56.06	346,499	217.98	8,780	343.75	105,244	137.13	817,790	143.20
4th quarter	--	--	32,160	78.24	126,421	265.87	--	--	29,680	76.38	234,538	170.66
Total or average	--	--	353,521	72.17	763,375	236.54	19,884	243.78	209,229	133.82	1,624,782	159.09
1980:												
1st quarter	--	--	69,839	103.04	203,782	208.90	2,900	127.66	46,848	184.52	381,597	161.64
2d quarter	--	--	32,375	50.83	173,048	187.07	80	68.06	19,015	62.35	253,819	146.14
3d quarter	--	--	125,879	52.00	219,660	182.33	19,910	262.70	104,010	77.53	620,699	108.64
4th quarter	--	--	41,785	87.13	72,097	227.02	--	--	22,645	15.98	183,716	117.65
Total or average	--	--	269,878	70.51	668,587	196.47	22,890	244.91	192,518	94.83	1,439,831	130.45
1981:												
1st quarter	--	--	71,631	105.49	169,722	269.27	--	--	50,532	63.60	366,112	163.32
2d quarter	--	--	64,403	58.68	187,717	252.64	1,200	45.00	72,406	107.32	390,513	158.36
3d quarter	--	--	145,402	87.81	292,950	164.30	14,576	130.20	102,012	125.66	672,990	119.08
4th quarter	--	--	14,650	14.32	79,883	138.41	--	--	30,185	64.73	187,292	75.21
Total or average	--	--	296,086	82.11	730,272	208.57	15,776	123.72	255,135	100.96	1,616,907	133.50
1982:												
1st quarter	--	--	45,024	50.79	168,298	113.49	2,350	153.02	43,350	35.87	305,081	81.50
2d quarter	--	--	59,000	39.79	148,388	78.35	5,410	96.02	27,700	25.42	321,582	53.68
3d quarter	--	--	87,838	26.49	221,647	53.75	1,754	24.15	76,121	20.82	523,007	34.10
4th quarter	--	--	33,552	29.25	122,020	73.56	--	--	31,243	37.14	240,941	48.21
Total or average	--	--	225,414	35.23	660,333	78.17	9,514	96.85	178,414	28.05	1,390,611	51.47
1983:												
1st quarter	--	--	54,057	33.08	227,890	134.80	2,316	21.49	52,925	34.84	435,515	82.62
2d quarter	--	--	56,458	57.77	102,868	130.40	74	65.82	38,383	48.51	227,380	84.63
3d quarter	--	--	100,560	28.52	191,118	136.13	18,292	6.28	76,260	23.05	488,676	67.85
4th quarter	--	--	42,882	38.87	109,737	152.12	--	--	53,060	32.79	268,814	79.84
Total or average	--	--	253,957	37.74	631,613	137.50	20,682	8.20	220,628	32.65	1,419,385	77.29
1984:												
1st quarter	--	--	70,948	56.37	170,878	138.92	4,060	41.60	58,183	30.16	364,160	87.19
2d quarter	--	--	51,713	37.31	177,425	168.23	--	--	32,251	14.20	311,150	106.63
3d quarter	--	--	58,557	21.56	182,064	120.24	--	--	82,595	25.93	422,737	63.89
4th quarter	--	--	63,691	24.02	93,659	94.35	120	10.88	37,777	19.20	250,909	47.92
Total or average	--	--	244,909	35.61	624,026	134.83	4,180	40.72	210,806	24.10	1,348,956	77.07

1/ Prices for individual sales may vary from the averages shown in this table because of differences in species mix, quality, road costs, logging and processing costs, size and length of sale, number of bidders, and other related price determinants. Prices for stumpage in National Forest lands are statistical high bids. The statistical high bid is defined as the bid price minus credits for road costs; it includes an allowance for sale-area betterment (K-V funds).

2/ Does not include noble fir or Shasta red fir.

Source--U.S. Department of Agriculture. Pacific Northwest Region includes Oregon and Washington.

Table 27—Volume and average stumpage price of selected species on the National Forests of the Pacific Northwest Region, 1973-84[1]

(Volume in thousand board feet, Scribner scale; value in dollars per thousand board feet)

Year and quarter	Douglas-fir: West side, Volume	Douglas-fir: West side, Value	Douglas-fir: East side, Volume	Douglas-fir: East side, Value	Ponderosa and Jeffrey pines, Volume	Ponderosa and Jeffrey pines, Value	Western hemlock, Volume	Western hemlock, Value	True firs[2], Volume	True firs[2], Value	All species, Volume	All species, Value
1973:												
1st quarter	210,532	109.86	53,800	40.59	120,880	65.60	128,869	105.75	83,539	66.40	796,605	74.84
2d quarter	590,779	133.62	117,010	62.93	193,295	58.49	210,872	84.45	134,240	73.65	1,613,766	90.71
3d quarter	282,151	146.17	49,152	67.65	194,516	93.99	140,253	106.92	43,313	118.89	861,980	104.10
4th quarter	526,807	152.59	62,745	65.02	139,325	87.58	167,731	117.05	137,829	60.34	1,226,749	110.99
Total or average	1,610,269	138.92	282,707	59.96	648,016	76.73	647,725	102.00	398,921	72.44	4,499,100	96.00
1974:												
1st quarter	221,915	202.32	57,086	92.85	221,433	131.33	68,191	98.15	115,671	78.55	820,603	124.49
2d quarter	663,968	238.81	95,398	64.20	151,331	135.27	302,694	128.64	170,719	79.62	1,695,303	155.06
3d quarter	229,502	217.37	36,421	89.79	111,430	113.16	101,053	140.03	36,424	04.32	670,597	129.79
4th quarter	653,655	155.48	95,147	58.85	195,163	77.91	227,744	79.49	136,027	81.63	1,593,651	100.19
Total or average	1,769,040	200.66	284,052	71.44	679,357	113.88	669,682	102.74	459,641	80.32	4,780,154	127.98
1975:												
1st quarter	250,061	156.10	22,973	31.81	82,350	50.78	95,455	34.91	640	30.50	617,976	85.10
2d quarter	664,782	164.05	133,953	33.67	311,514	44.93	275,682	73.21	140,769	45.29	1,896,505	91.00
3d quarter	301,216	178.37	39,705	12.86	106,922	43.87	93,055	58.38	39,979	36.35	787,938	98.22
4th quarter	645,299	180.47	116,219	39.04	311,881	36.26	287,462	72.05	108,363	45.45	1,695,695	99.67
Total or average	1,861,358	170.45	312,850	32.89	812,667	42.06	751,654	66.07	289,751	44.08	4,998,114	94.65
1976:												
1st quarter	172,169	207.10	18,534	10.51	94,666	95.30	58,906	84.97	24,821	76.62	462,275	123.51
2d quarter	663,790	173.77	141,485	33.45	283,429	67.14	300,991	73.30	125,705	45.06	1,850,077	100.02
3d quarter	195,279	141.85	31,283	40.78	128,064	87.00	122,364	72.10	43,447	61.04	665,284	91.55
4th quarter	235,532	188.37	35,535	73.48	113,828	93.15	96,810	90.90	25,580	84.28	591,956	124.44
Total or average	1,266,770	176.10	226,837	38.86	619,907	80.32	579,071	77.18	219,553	56.36	3,569,592	105.53
1977:												
1st quarter	604,927	23.81	51,479	284.66	172,778	115.24	182,980	92.69	82,422	97.98	1,399,930	150.68
2d quarter	400,517	224.68	63,389	231.47	251,100	121.85	152,589	66.34	95,402	77.32	1,157,196	135.57
3d quarter	474,274	210.97	148,113	94.52	247,177	141.59	233,493	89.43	122,076	76.63	1,465,748	134.34
4th quarter	183,914	229.69	15,540	65.91	106,183	159.38	51,968	84.94	37,095	117.59	501,278	146.98
Total or average	1,663,632	148.20	278,521	159.23	777,238	131.79	621,030	84.34	336,995	86.55	4,524,152	141.11
1978:												
1st quarter	486,015	248.82	92,759	122.07	185,845	166.70	106,979	95.73	83,108	93.62	1,196,940	170.78
2d quarter	336,580	235.39	62,395	69.21	119,749	198.99	97,834	91.44	59,420	91.68	828,234	161.59
3d quarter	850,897	249.11	242,089	111.64	375,361	238.09	329,517	126.17	278,043	100.05	2,410,827	178.40
4th quarter	144,796	292.74	10,786	65.42	52,871	254.31	54,307	166.76	19,950	158.06	329,281	214.19
Total or average	1,818,288	249.97	408,029	106.30	733,826	214.80	668,637	115.87	440,521	100.33	4,765,282	176.04
1979:												
1st quarter	669,150	347.72	92,868	102.62	173,250	235.86	274,236	152.12	122,816	247.41	1,543,985	248.44
2d quarter	303,884	389.72	69,328	133.65	129,359	254.29	168,761	155.38	90,576	197.96	900,300	244.25
3d quarter	788,403	423.69	199,279	59.67	354,117	217.13	324,767	254.84	227,899	183.06	2,269,224	265.68
4th quarter	178,697	447.01	36,860	117.98	128,677	264.53	50,081	221.05	43,180	83.55	539,824	262.71
Total or average	1,940,134	394.40	398,335	87.96	785,403	235.15	817,845	197.81	484,471	193.29	5,253,333	256.64
1980:												
1st quarter	653,068	484.04	76,719	109.50	212,587	204.23	200,342	205.15	129,063	195.30	1,524,951	309.03
2d quarter	432,184	373.96	35,625	47.50	174,458	185.69	172,251	231.18	94,383	188.55	1,080,368	249.78
3d quarter	645,411	394.87	134,349	57.27	230,442	178.31	232,530	234.08	188,155	139.71	1,753,359	229.65
4th quarter	329,599	456.33	45,052	82.25	76,517	232.34	82,676	155.17	60,745	129.65	755,549	284.32
Total or average	2,060,262	428.58	291,745	73.67	694,004	194.06	687,799	215.44	472,346	163.36	5,114,227	265.65
1981:												
1st quarter	609,342	463.81	85,331	139.27	172,602	265.50	144,818	179.50	109,532	101.00	1,361,431	288.93
2d quarter	305,400	342.13	71,573	77.44	188,777	252.66	115,515	223.22	108,129	107.81	952,099	219.14
3d quarter	820,142	288.10	148,562	87.15	299,190	166.64	398,665	157.53	214,622	116.96	2,291,460	182.11
4th quarter	223,274	260.13	21,950	18.86	88,023	143.19	61,172	74.23	58,423	64.27	578,193	149.62
Total or average	1,958,158	348.02	327,416	94.03	748,592	208.36	720,170	165.41	490,706	105.11	5,183,183	213.73
1982:												
1st quarter	505,362	153.92	46,014	50.70	178,613	108.62	202,547	48.93	110,090	67.86	1,273,159	99.32
2d quarter	376,418	97.67	68,700	35.65	176,583	72.01	108,652	31.87	51,350	31.56	988,752	65.77
3d quarter	577,739	99.08	90,028	27.90	226,377	54.56	231,496	37.81	190,679	23.15	1,675,143	55.09
4th quarter	363,310	134.94	46,452	29.58	123,120	73.34	96,415	70.38	57,213	41.54	867,150	88.07
Total or average	1,822,829	121.14	251,194	34.50	704,693	75.91	639,110	45.24	409,332	38.80	4,804,204	74.96
1983:												
1st quarter	678,242	182.39	58,177	32.69	233,830	132.73	226,004	51.62	120,680	58.85	1,662,831	109.70
2d quarter	356,733	153.91	57,608	56.70	105,338	128.63	137,865	71.69	93,813	78.38	893,295	105.15
3d quarter	385,732	144.61	111,960	30.68	196,025	134.99	126,403	55.53	161,520	51.26	1,243,801	87.62
4th quarter	346,733	155.05	49,232	38.82	117,192	148.64	73,335	85.40	125,940	53.23	879,476	106.32
Total or average	1,767,440	163.01	276,977	38.04	652,385	135.61	563,607	61.80	501,953	58.65	4,681,203	102.48
1984:												
1st quarter	505,091	152.69	75,248	54.93	177,303	136.68	147,341	73.06	102,498	41.37	1,264,123	106.27
2d quarter	260,348	125.70	61,393	43.84	180,465	165.64	87,807	61.82	92,336	29.59	833,702	100.72
3d quarter	639,140	95.19	67,057	22.15	185,709	118.62	181,393	46.07	160,560	33.39	1,544,134	71.56
4th quarter	331,933	107.82	68,546	29.79	96,099	93.57	104,160	44.16	86,757	27.97	844,854	69.17
Total or average	1,736,512	118.90	272,244	38.03	639,576	133.13	520,701	55.95	442,151	33.38	4,486,813	86.31

[1]Prices for individual sales may vary from the averages shown in this table because of differences in species mix, quality, road costs, logging and processing costs, size and length of sale, number of bidders, and other related price determinants. Prices for stumpage in National Forest lands are statistical high bids. The statistical high bid is defined as the bid price minus credits for road costs; it includes an allowance for sale-area betterment (K-V funds).

[2]Does not include noble fir or Shasta red fir.

Source--U.S. Department of Agriculture. Pacific Northwest Region includes Oregon and Washington.

Table 28—Volume and average stumpage price of selected species on the National Forests in the State of Oregon, 1973-84[1]

(Volume in thousand board feet, Scribner scale; value in dollars per thousand board feet)

Year and quarter	Douglas-fir West side Volume	Douglas-fir West side Value	Douglas-fir East side Volume	Douglas-fir East side Value	Ponderosa and Jeffrey pines Volume	Ponderosa and Jeffrey pines Value	Western hemlock Volume	Western hemlock Value	True firs[2] Volume	True firs[2] Value	All species Volume	All species Value
1973:												
1st quarter	146,802	108.13	25,270	47.49	110,191	63.17	37,774	80.54	55,875	43.27	544,447	65.01
2d quarter	495,736	130.73	63,035	62.64	162,495	60.47	93,032	85.37	85,700	70.21	1,185,714	91.93
3d quarter	224,376	146.33	30,676	65.12	168,096	98.02	44,159	78.99	24,415	76.26	599,664	104.44
4th quarter	464,474	148.68	53,970	66.23	124,480	89.50	72,521	110.63	116,629	51.60	974,652	109.87
Total or average	1,331,388	137.13	172,951	61.99	565,262	78.56	247,496	90.90	282,619	57.73	3,304,477	95.05
1974:												
1st quarter	180,222	221.11	38,186	105.38	192,633	141.36	23,476	94.70	102,325	70.00	650,472	131.49
2d quarter	543,512	247.98	45,959	71.09	118,603	148.00	114,059	131.60	109,674	52.43	1,159,095	172.08
3d quarter	186,431	227.32	23,421	101.47	104,300	115.33	43,112	87.70	29,773	35.11	527,739	127.71
4th quarter	491,361	166.29	59,337	75.84	177,423	79.96	99,981	55.25	73,949	57.74	1,108,132	103.80
Total or average	1,401,526	213.14	166,903	84.89	592,959	119.74	280,638	94.57	315,721	62.45	3,445,438	135.66
1975:												
1st quarter	137,976	211.85	11,913	28.54	70,950	56.92	30,020	59.54	640	30.50	359,708	108.88
2d quarter	526,195	170.85	78,403	44.71	272,349	47.99	114,372	52.46	103,693	40.02	1,350,758	96.72
3d quarter	237,253	181.67	8,765	20.64	96,622	47.11	39,675	34.57	28,729	30.54	532,615	106.64
4th quarter	516,176	189.30	65,915	33.87	291,883	36.43	119,345	76.14	85,942	35.67	1,253,737	105.39
Total or average	1,417,600	183.37	164,996	37.93	731,804	44.13	303,412	89.70	219,004	37.04	3,496,818	102.59
1976:												
1st quarter	143,179	221.95	14,080	11.95	88,235	95.31	20,398	85.70	19,290	70.01	359,587	134.63
2d quarter	497,903	188.96	86,130	30.49	253,941	69.00	105,535	75.13	77,785	40.13	1,278,390	109.94
3d quarter	156,699	141.97	18,014	66.13	127,556	87.25	41,449	34.16	21,834	79.97	439,968	97.43
4th quarter	159,902	199.28	23,560	78.39	107,528	94.68	32,760	128.39	17,000	74.97	408,289	131.65
Total or average	957,683	187.93	141,784	41.14	577,260	81.84	200,142	76.71	135,909	55.13	2,486,234	114.96
1977:												
1st quarter	517,937	245.59	36,640	148.24	110,496	135.96	110,250	108.39	66,223	97.23	1,074,728	167.74
2d quarter	317,700	239.02	34,659	73.89	243,186	123.13	49,448	106.11	58,545	85.91	856,166	149.47
3d quarter	326,958	230.07	96,273	107.97	222,297	147.05	57,166	115.42	70,992	91.29	925,088	152.76
4th quarter	140,705	245.95	13,030	55.23	105,163	160.43	12,082	93.08	29,739	126.48	382,032	161.20
Total or average	1,303,300	240.56	180,602	105.79	681,142	138.78	229,746	109.79	225,499	96.28	3,238,014	157.86
1978:												
1st quarter	450,284	251.91	73,021	124.87	183,729	167.65	38,692	109.22	66,880	91.78	994,026	181.00
2d quarter	250,275	253.73	36,270	85.81	101,189	217.51	41,702	108.84	36,155	84.26	563,853	187.56
3d quarter	619,007	274.74	105,470	180.76	325,461	249.21	121,129	126.62	111,572	102.77	1,515,546	212.23
4th quarter	115,328	298.70	7,650	77.89	50,611	253.42	34,077	177.04	17,795	170.37	254,883	227.34
Total or average	1,435,694	265.84	222,366	143.40	660,990	222.01	285,600	124.64	232,402	105.53	3,328,308	199.88
1979:												
1st quarter	560,730	358.24	50,394	126.56	151,316	253.69	98,043	144.68	59,591	332.93	1,076,454	281.63
2d quarter	256,076	411.77	61,132	139.26	123,346	259.83	63,311	133.05	61,241	226.86	670,831	268.58
3d quarter	597,662	448.37	85,574	56.53	307,199	225.19	137,785	221.67	116,827	134.04	1,480,736	290.01
4th quarter	139,645	495.79	32,770	126.17	125,537	265.23	23,717	185.71	40,155	77.31	443,161	269.77
Total or average	1,554,113	414.11	229,870	103.81	707,398	244.69	322,856	178.27	277,014	188.96	3,671,182	281.19
1980:												
1st quarter	588,202	498.21	38,866	134.81	194,985	206.58	106,743	197.21	102,782	191.99	1,233,659	333.38
2d quarter	317,595	393.57	19,903	17.78	174,361	185.72	55,698	294.51	38,553	192.10	725,041	266.15
3d quarter	503,060	440.84	55,350	56.97	199,337	201.79	80,924	218.45	93,985	145.56	1,175,978	266.74
4th quarter	266,754	504.40	26,001	43.09	74,462	235.51	29,981	35.47	28,450	33.54	548,362	316.27
Total or average	1,675,611	462.14	140,120	70.42	643,145	202.79	273,346	205.59	263,770	158.37	3,683,040	296.32
1981:												
1st quarter	545,007	472.55	48,060	216.41	159,912	272.50	76,672	134.26	66,220	94.42	1,101,171	310.00
2d quarter	252,445	373.47	45,823	105.52	181,892	245.25	46,661	134.82	84,872	111.56	725,978	234.39
3d quarter	545,252	319.43	68,777	104.19	268,925	173.95	95,456	118.44	97,774	105.13	1,343,743	199.42
4th quarter	188,041	281.09	21,875	18.91	88,023	143.19	23,042	45.51	45,358	58.24	470,390	161.60
Total or average	1,530,745	378.15	184,535	123.63	698,752	211.19	241,831	119.67	294,224	97.35	3,641,282	234.95
1982:												
1st quarter	416,403	161.87	29,136	52.12	164,048	115.03	70,178	27.69	76,845	57.55	911,939	110.71
2d quarter	312,868	98.27	30,810	36.85	143,018	79.74	43,218	26.01	27,597	18.57	703,451	73.44
3d quarter	492,615	107.39	32,230	23.98	208,837	57.81	85,414	41.40	89,764	24.02	1,206,075	63.92
4th quarter	287,585	129.57	36,813	26.77	118,670	73.50	49,550	60.65	43,585	42.63	675,137	84.20
Total or average	1,509,471	124.75	128,989	34.21	634,573	80.48	248,360	38.69	237,791	37.63	3,496,602	81.95
1983:												
1st quarter	576,892	197.91	32,540	20.43	221,830	133.33	95,025	51.14	77,855	42.19	1,256,376	125.50
2d quarter	254,298	166.50	26,680	21.04	101,003	131.81	30,830	98.11	50,488	67.47	542,815	120.28
3d quarter	288,955	161.59	32,441	26.20	172,601	145.82	47,135	60.04	76,975	59.18	775,493	110.93
4th quarter	256,484	160.52	24,475	27.09	108,127	154.66	36,047	103.97	60,970	42.60	605,658	114.75
Total or average	1,376,629	177.52	116,136	23.59	603,561	140.47	209,037	69.18	266,288	51.99	3,182,142	118.94
1984:												
1st quarter	422,900	163.59	36,940	41.43	164,455	142.99	83,190	87.05	60,955	37.99	952,794	118.54
2d quarter	208,138	125.98	31,025	50.18	171,385	171.49	33,048	61.89	30,399	22.66	578,797	119.07
3d quarter	526,815	98.55	42,065	20.15	173,689	124.76	63,913	64.51	109,248	33.80	1,152,175	79.35
4th quarter	257,518	108.35	27,164	37.49	88,416	99.43	36,705	28.44	57,205	27.77	585,269	74.06
Total or average	1,415,371	123.80	137,194	36.10	597,945	139.42	216,856	66.65	257,807	32.14	3,269,035	96.86

[1]Prices for individual sales may vary from the averages shown in this table because of differences in species mix, quality, road costs, logging and processing costs, size and length of sale, number of bidders, and other related price determinants. Prices for stumpage in National Forest lands are statistical high bids. The statistical high bid is defined as the bid price minus credits for road costs; it includes an allowance for sale-area betterment (K-V funds).

[2]Does not include noble fir or Shasta red fir.

Source--U.S. Department of Agriculture. Pacific Northwest Region includes Oregon and Washington.

Table 29—Volume and average stumpage price of selected species on the National Forests in the State of Washington, 1973-84[1]

(Volume in thousand board feet, Scribner scale; value in dollars per thousand board feet)

Year and quarter	Douglas-fir: West side Volume	Douglas-fir: West side Value	Douglas-fir: East side Volume	Douglas-fir: East side Value	Ponderosa and Jeffrey pines Volume	Ponderosa and Jeffrey pines Value	Western hemlock Volume	Western hemlock Value	True firs[2] Volume	True firs[2] Value	All species Volume	All species Value
1973:												
1st quarter	63,730	113.85	79,070	42.79	10,609	90.69	91,095	116.21	24,864	125.85	252,158	98.36
2d quarter	95,033	140.69	180,045	62.83	30,800	48.06	117,840	83.72	51,340	75.37	428,052	87.33
3d quarter	57,775	145.57	79,828	66.68	26,420	68.32	96,084	119.76	18,898	173.96	262,316	103.33
4th quarter	62,333	181.68	116,715	65.58	14,845	71.44	95,210	121.95	21,200	108.43	252,097	115.33
Total or average	278,871	147.46	455,658	60.73	82,754	64.23	400,229	108.86	116,302	108.21	1,194,623	90.60
1974:												
1st quarter	41,693	121.12	18,900	67.53	28,800	64.22	44,715	99.96	13,346	144.06	170,131	97.74
2d quarter	120,456	197.42	49,439	57.79	32,728	09.16	188,625	126.05	61,045	128.47	536,200	118.28
3d quarter	43,071	174.27	13,000	68.73	7,130	81.39	57,941	178.97	6,651	80.81	142,858	137.45
4th quarter	162,294	122.72	35,810	30.69	17,740	57.42	127,763	98.46	62,878	109.71	485,519	91.94
Total or average	367,514	153.06	117,149	52.29	86,398	73.69	419,044	122.53	143,920	119.52	1,334,716	108.13
1975:												
1st quarter	112,085	87.47	11,060	35.33	11,400	12.57	65,435	23.61	--	--	258,268	51.98
2d quarter	138,587	138.23	55,550	18.10	39,165	23.64	161,310	87.92	37,076	60.02	545,747	79.60
3d quarter	63,963	166.12	30,940	10.66	10,300	13.52	53,380	76.08	11,250	51.17	255,323	80.65
4th quarter	129,123	145.48	50,304	45.81	19,998	33.78	168,117	69.14	22,421	82.96	441,958	83.46
Total or average	443,758	183.37	147,854	27.26	80,863	23.30	448,242	70.08	70,747	65.88	1,501,296	76.17
1976:												
1st quarter	28,990	133.75	4,454	5.95	6,431	95.27	38,500	84.59	5,531	99.67	102,688	84.57
2d quarter	165,887	128.18	55,355	38.06	29,488	51.10	195,456	72.32	47,920	53.07	571,687	77.83
3d quarter	38,580	141.37	13,269	6.36	508	22.77	80,915	91.53	21,613	41.91	225,316	80.07
4th quarter	75,630	165.30	11,975	63.80	6,300	67.01	64,050	70.88	8,580	102.73	183,667	108.41
Total or average	309,087	139.43	85,053	35.05	42,727	59.76	378,929	77.42	83,644	58.36	1,083,358	84.12
1977:												
1st quarter	06,990	164.11	14,839	62.15	62,282	78.49	72,730	68.89	16,199	101.04	325,202	94.32
2d quarter	82,817	169.67	28,730	42.17	7,914	82.35	103,141	76.36	36,857	63.67	301,030	96.05
3d quarter	147,316	168.60	51,840	69.53	24,880	92.88	176,327	81.01	51,084	56.26	540,660	102.83
4th quarter	43,209	163.71	2,510	121.38	1,020	50.75	39,086	82.25	7,356	81.63	119,246	101.43
Total or average	360,332	167.17	97,919	61.71	96,096	02.24	391,284	77.66	111,496	66.89	1,286,138	98.86
1978:												
1st quarter	35,731	209.91	19,738	111.73	2,116	83.96	98,287	83.55	16,228	101.20	202,914	120.73
2d quarter	86,305	182.21	26,125	46.18	18,560	98.03	56,132	78.52	23,265	66.99	264,381	106.21
3d quarter	231,090	180.37	136,619	58.27	49,900	165.56	208,388	125.92	166,471	98.22	895,281	121.11
4th quarter	29,468	269.45	3,136	36.13	2,260	274.35	20,230	149.43	2,155	56.45	74,398	169.15
Total or average	382,594	190.41	185,618	61.88	72,836	149.36	383,037	109.34	208,119	94.53	1,436,974	120.80
1979:												
1st quarter	108,420	292.79	42,474	74.22	21,934	112.83	176,193	156.26	63,225	166.79	467,531	172.03
2d quarter	47,808	271.63	8,196	91.86	6,013	140.56	105,450	168.79	29,335	137.62	229,469	173.13
3d quarter	190,741	346.37	113,705	62.05	46,918	160.38	186,982	279.28	111,072	234.63	788,488	219.99
4th quarter	39,052	277.01	4,090	52.40	3,140	237.33	26,364	252.83	3,025	166.38	96,663	230.36
Total or average	386,021	315.05	168,465	66.33	78,005	148.58	494,989	210.55	206,657	199.10	1,582,151	199.66
1980:												
1st quarter	64,866	355.49	37,853	83.52	17,602	121.41	93,599	214.21	26,281	208.25	291,292	205.87
2d quarter	114,589	319.60	15,722	35.13	97	129.93	116,553	200.92	55,830	186.10	355,327	216.37
3d quarter	142,351	232.41	78,999	57.50	31,105	27.84	151,606	242.42	94,170	133.86	577,381	154.11
4th quarter	62,845	252.31	19,051	135.69	2,055	117.47	52,695	223.24	32,295	214.32	207,187	199.77
Total or average	384,651	287.39	151,625	76.68	50,859	83.70	414,453	221.94	208,576	169.67	1,431,187	186.71
1981:												
1st quarter	64,335	389.76	37,271	39.80	12,690	177.32	68,146	230.40	43,312	111.06	260,260	199.77
2d quarter	52,955	192.74	25,390	27.86	6,885	434.71	68,854	283.12	23,257	94.13	226,121	170.16
3d quarter	274,890	225.97	79,785	72.46	30,265	101.68	303,209	169.83	116,848	126.86	947,717	157.57
4th quarter	35,233	148.25	75	5.23	--	--	38,130	91.58	13,065	85.21	107,803	97.32
Total or average	427,413	240.10	142,521	55.94	49,840	166.94	478,339	188.53	196,482	116.74	1,541,901	162.33
1982:												
1st quarter	88,959	116.68	16,878	48.25	14,565	36.37	132,369	60.19	33,245	91.69	361,220	70.55
2d quarter	63,550	94.74	37,890	34.97	33,565	39.04	65,434	35.74	23,753	46.65	285,301	46.86
3d quarter	85,124	51.00	57,798	30.08	17,540	15.88	146,082	35.71	100,915	22.37	469,068	32.37
4th quarter	75,725	155.32	9,639	40.29	4,450	69.03	46,865	80.66	13,628	38.05	192,013	101.69
Total or average	313,358	103.73	122,205	34.82	70,120	34.60	390,750	49.40	171,541	40.41	1,307,602	56.27
1983:												
1st quarter	101,350	94.01	25,637	48.24	12,000	121.56	130,979	51.96	42,825	89.15	406,455	60.86
2d quarter	102,435	122.30	30,928	88.11	4,335	54.57	107,035	64.08	43,325	91.09	350,480	84.27
3d quarter	96,777	93.91	79,519	32.51	23,424	55.25	79,268	52.84	84,545	44.06	468,308	49.02
4th quarter	90,249	139.48	24,757	50.42	9,065	76.87	37,288	67.46	64,970	63.20	273,818	87.69
Total or average	390,811	111.90	160,841	48.47	48,824	75.50	354,570	57.45	235,665	66.18	1,499,061	67.54
1984:												
1st quarter	82,191	96.63	38,308	67.95	12,848	55.95	64,151	54.90	41,543	46.34	311,329	68.75
2d quarter	52,210	124.60	30,368	37.37	9,080	55.69	54,759	61.46	61,937	32.99	254,905	59.06
3d quarter	112,325	79.46	24,992	25.50	12,020	29.82	117,480	36.04	51,312	32.50	391,959	48.65
4th quarter	74,415	105.96	41,382	24.74	7,683	26.10	67,455	52.78	29,552	38.35	259,585	58.15
Total or average	321,141	97.33	135,050	39.98	41,631	42.75	303,845	48.30	184,344	35.12	1,217,778	57.99

[1] Prices for individual sales may vary from the averages shown in this table because of differences in species mix, quality, road costs, logging and processing costs, size and length of sale, number of bidders, and other related price determinants. Prices for stumpage in National Forest lands are statistical high bids. The statistical high bid is defined as the bid price minus credits for road costs; it includes an allowance for sale-area betterment (K-V funds).

[2] Does not include noble fir or Shasta red fir.

Source--U.S. Department of Agriculture. Pacific Northwest Region includes Oregon and Washington.

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Interim Definitions for Old-Growth Douglas-Fir and Mixed-Conifer Forests in the Pacific Northwest and California

Old-Growth Definition Task Group

Abstract

Interim definitions of old-growth forests are provided to guide efforts in land-management planning until comprehensive definitions based on research that is currently underway can be formulated. The basic criteria for identifying old-growth Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and mixed-conifer forests in western Washington and Oregon and California are given.

Keywords: Old growth, old-growth stands, mixed stands, Coniferae, Pacific Northwest, California.

Introduction

Old-growth forests are of increasing interest in the Pacific Northwest. The acreage of such forests in the Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) region has declined from approximately 15 million acres at the time of settlement to 5 million acres at present (Society of American Foresters 1984). Almost all the remaining acreage is on Federal lands and about 80 percent is unreserved and potentially available for logging. Concerns are emerging about old-growth forests and their various functions, such as providing habitat for wildlife. Consequently, disposition of old-growth forests has become an important and controversial issue in land-use planning on National Forests and Bureau of Land Management lands.

Consideration of the issue has been hampered by different concepts of old-growth forests. For example, economists often view any forest past financial maturity as "overmature" or "old" in contrast with biological or esthetic definitions. Uniform definitions of old-growth forests are essential for a variety of purposes, including inventories to estimate the remaining acreage. Research is underway that will provide objective criteria for old-growth conditions in various forest types. An example is the Old-Growth Wildlife Habitat Research and Development Program and related projects initiated in western Oregon and Washington and northwestern California in 1982.

The Task Group is composed of: J.F. Franklin (chairman), chief plant ecologist, USDA Forest Service, Pacific Northwest Research Station; F. Hall, regional ecologist, USDA Forest Service, Pacific Northwest Region; W. Laudenslayer, regional wildlife ecologist, USDA Forest Service, Tahoe National Forest; C. Maser, research biologist, U.S. Department of the Interior, Bureau of Land Management, Oregon State Office; J. Nunan, silviculturist, USDA Forest Service, Pacific Northwest Region; J. Poppino, project leader, Forest, Inventory and Analysis for Pacific Coast States, USDA Forest Service, Pacific Northwest Research Station; C.J. Ralph, project leader, USDA Forest Service, Pacific Southwest Forest and Range Experiment Station; T. Spies, research forester, USDA Forest Service, Pacific Northwest Research Station, formerly research associate, Department of Forest Science, Oregon State University.

Working definitions are needed immediately, however, to guide current planning efforts, to restructure inventory procedures, and to clarify issues. To meet this need, the Old-Growth Wildlife Habitat Research and Development Program Steering Committee,[1] a joint effort of the Pacific Northwest and Pacific Southwest Regions of the USDA Forest Service and the Oregon State Office of the U.S. Department of the Interior Bureau of Land Management, created the Old-Growth Definition Task Group. The task group was given the responsibility for developing interim definitions of old growth for use in ongoing management planning and project work.

Definitions of old-growth Douglas-fir and Sierra mixed-conifer forests are presented in this paper. They are based on biological criteria and are generally applicable west of the crest of the Cascade Range and the Sierra Nevada. These definitions are intended for use until more refined definitions emerge from research that is underway.

Methods

The Old-Growth Definition Task Group views old growth as an ecological concept, the third of three basic biological stages in forest development. These forest stages are young, mature, and old; or, as sometimes distinguished by foresters, immature, mature, and overmature. Although transitions between these three stages are gradual, maturation or the transition from youth to maturity for a stand is often indexed in forestry by the culmination of mean annual wood increment (age at which the average yearly increase in volume, based on total stand age, reaches a maximum). In Douglas-fir forests of the Northwest, maturation typically occurs at 80 to 110 years. The mature forest represents a relatively stable stage with substantial continued growth and biomass accumulation, albeit at a slower rate than in the young forest. Transition from the mature to old-growth stage is gradual and not usually apparent in Douglas-fir stands until they are 175 to 200 years old. Development of old-growth conditions is also progressive so that "young" old-growth stands (for example, 250 years of age) display old-growth characteristics, such as decadence in dominant trees, with less frequency and intensity than in stands 500 years old.

The definitions provided here are developed from existing descriptions of old growth and from data bases and the experience and judgment of the task group. Published characterizations of old-growth Douglas-fir forests include those of the Society of American Foresters (1984) and Franklin and Spies (1984), although both are based mainly on Franklin and others (1981). Major unpublished data sets are those of Forsman and others[2] for the Coast Range and Spies[3] for the central and southern Cascade Range of Oregon and Washington and the Coast Range of Oregon. An extensive series of permanent sample plots, extending from the Olympic Peninsula to the southern Sierra Nevada, provide additional data (see footnote 3).

[1]Committee was chaired by M.A. Kerrick, supervisor, Willamette National Forest, USDA Forest Service.

[2]Manuscript in preparation, "Structure and composition of old-growth, mature, and second-growth forests of Douglas-fir and western hemlock in the Oregon Coast Ranges and Olympic Mountains, Washington," by Eric D. Forsman, Jerry F. Franklin, and E. Charles Meslow. On file with Research Work Unit 4151, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331.

[3]Thomas A. Spies, unpublished data on file with Research Work Unit 4151, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, OR 97331.

Several concepts are central to the development of the definitions. First, plant-community series are used to stratify the descriptions. Characteristics of old-growth Douglas-fir forests vary considerably between the southern Cascade Range (south of lat. 44° to 45° N.), central and northern Cascade Range, and Klamath Mountains. Plant-community series, which consist of plant associations or habitat types with the same major climax tree species (for example, western hemlock (*Tsuga heterophylla* (Raf.) Sarg.)), can be used to distinguish some major variations in old-growth characteristics. The series are a major hierarchical level in the comprehensive plant-community classification being developed for National Forests and Bureau of Land Management lands throughout the Douglas-fir region.

Second, multiple criteria are used rather than a single characteristic, such as size or age of trees. Old-growth forests are too complex in structure and composition to allow simple characterizations. Discrimination between young, mature, and old-growth conditions requires use of several features. Equally important is the need to recognize as many attributes as possible because each might eventually prove important in the functioning of old-growth forests and, hence, to managers interested in old-growth conditions.

Third, these definitions are based on minimal criteria rather than average values. For example, eight large Douglas-firs per acre (20 per ha) is a criterion for old-growth stands on western hemlock sites (table 1) although most stands typically contain 15 to 45 trees, depending on age and history. Any old-growth attribute exhibits a range of levels over a sample of stands. We chose levels for characteristics that were in the low to very low range so that the definition would encompass nearly all the old-growth stands for which we have data. Even at these minimum levels, old-growth values still generally lie outside the range of values found in most, if not all, young and mature forests. The minimum values presented should not be taken as levels that are adequate or optimum for specific old-growth functions nor are they close to mean or median values for sampled old-growth stands. Subsequent definitions will include considerations of average values and standard deviations as well as minimal values.

Stand area is an important consideration in judging whether an old-growth forest patch is a functional ecological unit, if it otherwise meets the criteria listed in table 1. A minimum stand of 80 acres was the criterion originally included in the definitions. Patches of smaller size were not viewed as viable old-growth units because of their dominance by edge effects (penetration of external environmental influences) and vulnerability to major disturbances such as windthrow. The size criterion was dropped because of objections that minimum acreages for a viable old-growth stand depended on management objectives and the nature of surrounding areas. Minimum acreages to meet objectives of spotted owl habitat may be very different from minimum acreages for elk thermal cover, for example. Acreage necessary to maintain integrity of old-growth stands will be higher when surrounded by clearcuts than for old growth surrounded by partially cut or intact mature forest (Harris 1984). Nevertheless, anyone using these definitions will need to identify a minimal acreage of old-growth stand below which the extent of edge influence (alteration of interior stand conditions) and vulnerability to catastrophe are unacceptable based on management objectives.

Table 1—Interim minimum standards for old-growth Douglas-fir and mixed-conifer forests in western Washington and Oregon and in California[1]

Stand characteristic	Douglas-fir on western hemlock sites (western hemlock, Pacific silver fir)	Douglas-fir on mixed-conifer sites (white fir, Douglas-fir)	Douglas-fir on mixed-evergreen sites (tanoak, Douglas-fir)	Sierra mixed-conifer forests (white fir)
Live trees	2 or more species with wide range of ages and tree sizes	2 or more species with wide age range and full range of tree sizes	Douglas-fir and evergreen hardwood (tanoak, Pacific madrone, and canyon live oak) associates (40 to 60 percent of canopy)	2 or more species with wide age range and full range of tree sizes
	Douglas-fir ≥8 per acre of trees >32-in diameter or >200 years old	Douglas-fir, ponderosa pine, or sugar pine ≥8 per acre of trees >30-in diameter or >200 years old	Douglas-fir or sugar pine ≥6 per acre of trees >32-in diameter or >200 years old	Douglas-fir, sugar pine, or ponderosa pine ≥8 per acre of trees >32-in diameter or >200 years old
	Tolerant associates (western hemlock, western redcedar, Pacific silver fir, grand fir, or bigleaf maple) ≥12 per acre of trees >16-in diameter	Intermediate and small size classes are typically white fir, Douglas-fir, and incense-cedar, singly or in mixture	Intermediate and small size classes may be evergreen hardwoods or include a component of conifers (e.g., Douglas-fir or white fir)	Intermediate and small size classes are typically white fir with Douglas-fir or incense-cedar or both in some stands
Canopy	Deep, multilayered canopy	Multilayered canopy	Douglas-fir emergent above evergreen hardwood canopy	Multilayered canopy
Snags	Conifer snags ≥4 per acre which are >20-in diameter and >15 ft tall	Conifer snags ≥1-1/2 per acre that are >20-in diameter and >15 ft tall	Conifer snags ≥1-1/2 per acre that are >20-in diameter and >15 ft tall	Conifer snags ≥3 per acre that are 20-in diameter and >15 ft tall
Logs	Logs ≥15 tons per acre including 4 pieces per acre ≥24-in diameter and >50 ft long	Logs ≥10 tons per acre including 2 pieces per acre ≥24-in diameter and >50 ft long	Logs ≥10 tons per acre including 2 pieces per acre ≥24-in diameter and >50 ft long	Logs ≥10 tons per acre including 2 pieces per acre ≥24-in diameter and >50 ft long

1/ Major series are shown in parentheses.

Interim Definitions

The basic criteria or minimum standards for old-growth Douglas-fir and for Sierra mixed-conifer forest are provided in table 1. Standards are provided for three groups of Douglas-fir site conditions representing different geographical areas and recognizable by plant-community series. Characteristics used are: (1) live trees—number and minimum size of both seral and climax dominants, (2) canopy conditions, (3) snags—minimum number of snags (standing dead trees) of specific size, (4) down logs—minimum tonnage and numbers of pieces of specific size. Values for snag size reflect requirements of primary cavity-nesting animals. Similarly, functional roles of logs require at least some pieces of larger dimensions (see, for example, Harmon and others 1986). Decadence in dominant live trees, such as presence of broken or multiple tops and heart rot, is an important feature of old-growth Douglas-fir stands; it is not included, however, because of difficulties in quantifying decadence.

Old-Growth Douglas-Fir on Western Hemlock Sites

Most old-growth Douglas-fir forests in northwestern Oregon and western Washington are in moist environments characterized by the western hemlock and Pacific silver fir (*Abies amabilis* Dougl. ex Forbes) series. These sites are equivalent to the Western Hemlock Zone and lower elevations in the Pacific Silver Fir Zone (Franklin and Dyrness 1973).

Two or more species must be present that together provide a full range of tree sizes (table 1). Eight or more large (>32-in diameter) or old (>200 years) Douglas-firs must be present per acre. The age alternative to size is to accommodate low-quality sites where Douglas-firs are unable to attain large diameters even in three or four centuries. One or more shade-tolerant associates—western hemlock, Pacific silver fir, western redcedar (*Thuja plicata* Donn ex D. Don), grand fir (*Abies grandis* (Dougl ex D. Don) Lindl.), or bigleaf maple (*Acer macrophyllum* Pursh)—must be present and collectively provide at least 12 trees per acre with a minimum diameter of 16 inches. Bigleaf maple is particularly characteristic of the Coast Range in Oregon, although it may also be important to stands at low elevations in the Cascade Range and Olympic Mountains.

It is important to distinguish old-growth forests in the Douglas-fir region from old-growth Douglas-fir forests; the latter are simply a subset of the former. By definition, Douglas-fir has to be a significant component for a stand to qualify as old-growth Douglas-fir. The task group chose a minimum of eight Douglas-firs per acre based on characteristics of stands up to 650 years of age. Stands in which trees exceed 700 years are sometimes distinguished as "super old growth." Douglas-fir density is typically well below eight per acre in such stands so that, by the task group's definition, they are old-growth forests dominated by some other species, often western hemlock or western redcedar. The scattered Douglas-firs give the "super old-growth" forest much of their distinctive character, however.

When Douglas-fir is not present at required levels on habitats belonging to the western hemlock or Pacific silver fir series, either because of historical absence (level of establishment in original stand) or stand antiquity (lost through successional processes), a stand may still qualify as old growth but of some type other than Douglas-fir. For example, if Douglas-fir has been replaced successionally by western hemlock, the stand probably represents an old-growth western hemlock forest. Similarly, western redcedar is often the dominant tree in old-growth stands on moist to wet sites.

The Douglas-fir old-growth criteria in table 1 can be modified for use with other species or types. The major change is replacement of Douglas-fir as the dominant species. For example, Sitka spruce (*Picea sitchensis* (Bong.) Carr.) or western redcedar can be substituted for Douglas-fir to provide interim definitions of old-growth Sitka spruce and western redcedar forests. In old-growth western hemlock or Pacific silver fir forests, these species would dominate all size classes including the requisite eight trees per acre over 32 inches in diameter.

Snag and log criteria in table 1 are substantially less than values typically encountered in old-growth stands. This accommodates the low levels found occasionally in old-growth stands in the Oregon Coast Range. Mean log values in 250- and 500-year-old Douglas-fir stands are about 20 and 35 tons per acre, respectively (see footnote 3). Snag levels are also low in many Coast Range stands because wind is the predominant agent of mortality; levels may actually fall below four snags per acre in some of these stands.

Old-Growth Douglas-Fir on Mixed-Conifer Sites

Douglas-fir is an important component of the mixed-conifer forests found in southwestern Oregon and northern California (Franklin and Dyrness 1973). The white fir (*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.) and Douglas-fir series characterize these environments, which are substantially drier than those typified by the western hemlock series.

Douglas-fir, sugar pine (*Pinus lambertiana* Dougl.), and ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) are considered functionally interchangeable as pioneer dominants in old-growth mixed-conifer forests. Literally, however, a stand in which more than 50 percent of the large trees are pine is more appropriately called an old-growth pine stand rather than an old-growth Douglas-fir stand. The minimum diameter of 30 inches reflects poorer average site conditions than are typical of the western hemlock series. Although the shade-tolerant white fir or incense-cedar (*Libocedrus decurrens* Torr.), or both, may be present in old-growth stands, Douglas-fir is both the climax and the pioneer species on some sites. Hence, the species composition of the smaller size classes of trees is not stipulated.

Douglas-fir or the pines can be successionally replaced by white fir in the absence of fire or other disturbances on some sites. The resulting forest would be considered old-growth white fir, although structurally it would have numbers of large trees, snags, and logs similar to those of old-growth mixed-conifer forest.

Old-Growth Douglas-Fir on Mixed-Evergreen Sites

Much of the Douglas-fir found in the Klamath Mountains region is part of a mixed-evergreen forest formation (Franklin and Dyrness 1973). These forests are composed of conifers, including Douglas-fir and sugar pine, and evergreen hardwoods typified by tanoak (*Lithocarpus densiflorus* (Hook & Arn.) Rehd.), Pacific madrone (*Arbutus menziesii* Pursh), and canyon live oak (*Quercus chrysolepis* Liebm.). Port-Orford-cedar (*Chamaecyparis lawsoniana* (A. Murr.) Parl.), grand or white fir, or ponderosa pine may also occur in these stands. The tanoak and Douglas-fir series are most representative of these sites (Atzet and Wheeler 1984).

Douglas-fir and sugar pine are considered functionally interchangeable as the pioneer conifer dominant in these old-growth forests (table 1). As with mixed-conifer sites, a forest in which more than 50 percent of the large trees are sugar pine is more appropriately called an old-growth sugar pine stand than an old-growth Douglas-fir stand. The conifer crowns typically emerge above a continuous canopy of evergreen hardwoods. Smaller tree sizes may be composed of either hardwoods or conifers, which will most likely be Douglas-fir.

Old-Growth Sierra Mixed-Conifer Forests

Old-growth mixed-conifer forests in the Sierra Nevada resemble those described for Douglas-fir on mixed-conifer sites (table 1). Douglas-fir, sugar pine, and ponderosa pine all function as pioneer dominants. Most of these stands belong to the white fir series; white fir is the major tolerant associate and dominates in the small-size classes. Incense-cedar can also be an important associate, especially on drier sites.

Stands of giant sequoia (*Sequoiadendron giganteum* (Lindl.) Buchholz) are a part of the Sierra mixed-conifer forest but are of a totally different dimension; their size characteristics lie far beyond the values in table 1.

Conclusions

These criteria for identifying old-growth forests are based on limited sampling and minimal values; that is, the lowest values generally encountered rather than mean values. Comments on these definitions are solicited by the Director, Pacific Northwest Research Station, USDA Forest Service, P.O. Box 3890, Portland, OR 97208. They will assist in developing a refined classification of old-growth Douglas-fir forests that will include averages and ranges for various old-growth characteristics.

Metric Equivalents

1 inch (in)	=	2.540 centimeters (cm)
1 foot (ft)	=	0.305 meter (m)
1 acre	=	0.405 hectare (ha)
1 ton	=	0.907 metric ton (t)
1 ton/acre	=	2.240 metric tons/hectare (t/ha)

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Early Lessons From Commercial Thinning in a 30-Year-Old Sitka Spruce-Western Hemlock Forest

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Abstract

A commercial thinning study was undertaken in a 30-year-old stand, precommercially thinned at 15 years of age, at Cascade Head Experimental Forest on the Oregon coast. Measurements obtained after three different thinning treatments are presented and include stand volume, basal area, current growth rate, scar damage, crown ratio, and sapwood radius. Method of establishing plots is given, and stand conditions before and after thinning are described.

Keywords: Thinning effects, commercial thinning, Sitka spruce, western hemlock, Oregon (Cascade Head Exp. For.), Cascade Head Exp. For.—Oregon.

Introduction

The Sitka spruce (*Picea sitchensis* (Bong.) Carr.) zone is a narrow strip stretching from Prince William Sound, Alaska, to as far south as Coos Bay, Oregon (fig. 1). In most areas in Oregon, the zone is no more than 1-2 miles wide, except where it extends inland along river valleys (Franklin and Dyrness 1973). The Sitka spruce zone is one of the most productive forest zones in the world (Fujimori and others 1976). Mature coniferous forest stands are dense and tall and are dominated by Sitka spruce, western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), with lush understories of ferns, herbs, shrubs, and cryptogams. Red alder (*Alnus rubra* Bong.) is abundant on disturbed sites and in riparian zones.[1/]

Climate in this zone is wet and mild. Precipitation, averaging 100 in per year, occurs primarily during the winter months. There is no pronounced summer drought, and summer fog is common.

Soils in this zone are deep, relatively rich, and fine textured. Inceptisols and ultisols are the most common soils (Ruth and Harris 1979). The surface layers of the soil are high in organic matter and total nitrogen and low in base saturation.

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[1/] Scientific names follow Garrison and others (1976)

Much of the Sitka spruce zone along the Oregon coast has been burned or clearcut in the last 100 years. Many acres of naturally regenerated stands of western hemlock and Sitka spruce are found on USDA Forest Service, on Bureau of Land Management (U.S. Department of the Interior), and on private industrial lands. Though most clearcuts are now planted, natural regeneration is so successful that many stands are overstocked. Young stands with over 1,000 trees per acre are common.

Precommercial thinning of stands is a prevalent practice. Most stands are scheduled for precommercial thinning when they are 10 to 15 years old. Residual stocking of 200 to 300 trees per acre is common. At these densities, commercial size—10 to 12 in in diameter at breast height (d.b.h.)—is reached at 25 to 30 years. Under conventional (conservative) thinning methods, the first commercial entry is not particularly profitable because of either the small volume removed or the expense of cable logging systems on steep slopes.

In the Hebo and Waldport Districts of the Siuslaw National Forest, about 2,000 acres of stands enter the 25-year age class annually. Many of these stands are dominated by western hemlock, now recognized as the number two timber-producing species in Oregon and Washington. Few of these precommercially thinned stands have been commercially thinned.

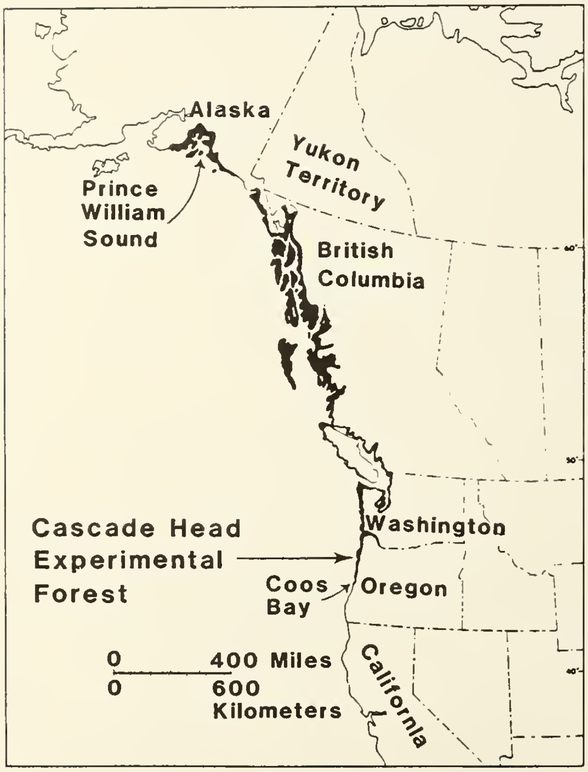

Figure 1.—Sitka spruce zone along the Pacific coast and location of Cascade Head Experimental Forest along the northern Oregon coast.

Trees in stands that reach harvestable size without thinning are more variable than trees in stands that have been thinned. Though basal area and cubic volume may be greater in unthinned stands, board-foot volumes are larger in thinned stands. Precommercial and commercial thinning can provide an early return on capital invested in growing stock, while growth is concentrated on fewer trees.

Little research has been done to determine the best spacings for different management objectives for these precommercially thinned western hemlock-Sitka spruce stands. Questions that should be answered are:

1. How intensively can these stands be managed?
2. What will the yields be under various treatments?
3. What level of damage to trees is acceptable under different levels of intensive management?
4. What kinds of logging systems are most economical and best adapted to these types of stands?

A long-term study has been established at the Cascade Head Experimental Forest, Siuslaw National Forest, north of Lincoln City (fig. 1) to focus on commercial thinning treatments and logging systems for these stands. The purpose of this report is to discuss the commercial thinning portion of the study. Intensive studies on logging cost and on the specific causes of damage (Kellogg and Hargrave in press) were initiated by the Forest Engineering Department, College of Forestry, Oregon State University, Corvallis, and are not discussed here.

The three objectives of this study are:

1. To determine the effects of three different commercial thinning treatments on diameter and height growth.
2. To determine the amount of damage and subsequent decay to the leave trees following logging.
3. To determine the relationship between leaf area and volume production by observing development in the three different treatments and in the control.

Information generated from this study will be used to determine the efficacy of different thinning regimes, spacings, and number of thinnings during rotation; the information may be appropriate for economic analysis. Initial stand descriptions and stand conditions after thinning are reported here.

Methods

Two 30-year-old stands were selected for the study at Cascade Head Experimental Forest. Each stand was part of a naturally regenerated clearcut (units 1A and 1C) that was precommercially thinned to an average spacing of about 13 ft at age 15. The stands were divided into sixteen 3- to 5-acre compartments that could be logged independently (fig. 2). Unit 1A contained compartments 1 to 12, and unit 1C contained compartments 13 to 16. Compartments in unit 1A were set out by contiguity and similarity of topographic surface. Compartments 1 to 4 were on a north slope, 5 to 8 on west and southwest slopes, and 9 to 12 on gentle to level slopes. Compartments in unit 1C were established in the same block, two on south-facing and two on north-facing slopes.

The experiment involved three treatments and a control, each with four replicates:

1. Narrow spacing, 18- by 18-ft target.
2. Wide spacing, 24- by 24-ft target.
3. Herringbone strip (see fig. 3).
4. Control (no thinning).

The narrow- and wide-spacing compartments were marked with the idea of removing thinned material by cable logging. Cleared corridors were arranged in a herringbone pattern in the third thinning treatment (see fig. 3A). Corridors were 15 ft wide, leave strips 30 ft wide. Cable removal of thinned material occurred here as well.

The narrow- and strip-thinning treatments were designed to yield adequate volumes for a profitable thinning operation and to leave sufficient trees for a second commercial thinning. The wide spacing was intended to leave only enough trees for a final removal of larger saw logs.

Before the thinning, one permanent sample plot was established in each compartment. A circular plot with a radius of 83 ft and an area of 0.5 acre was laid out in the geometric center of each compartment. A 25- to 30-ft buffer was maintained around the circumference of each plot. Plots were permanently marked in the field.

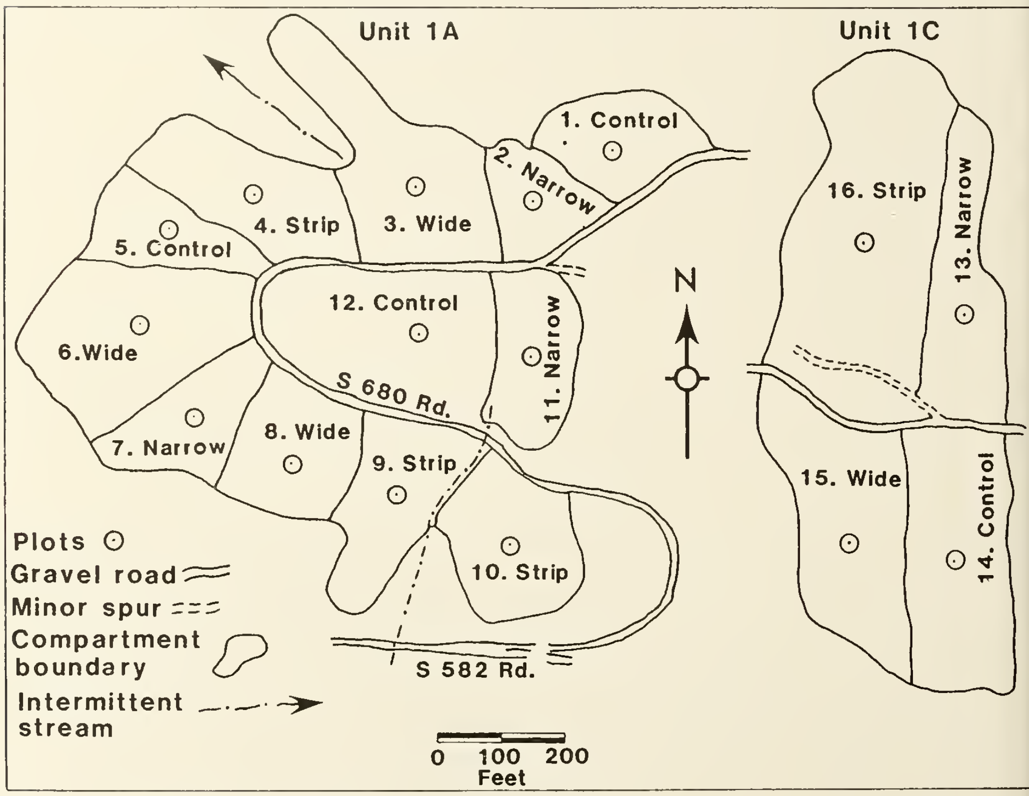

Figure 2.—Compartments, treatments, and plots for commercial thinning, Cascade Head Experimental Forest.

Prior to logging in all plots, trees with diameters 2 in or greater at breast height were tagged and measured for diameter at breast height. Crown class and scar condition (location, length, width, and height) were recorded for each tree.

Sapwood basal area and sapwood radial growth increments for 5 and 10 years were taken on 10 percent of the trees. Two cores were taken from the sample trees at right angles at breast height. The sapwood thickness was measured in the field for most samples. A few were brought in and stained with Bromcresol Green to increase confidence in the field determination. The mean of the two sapwood measurements was entered as the value for that tree. Sapwood basal area was determined because it is highly correlated to leaf area (Grier and Waring 1974).

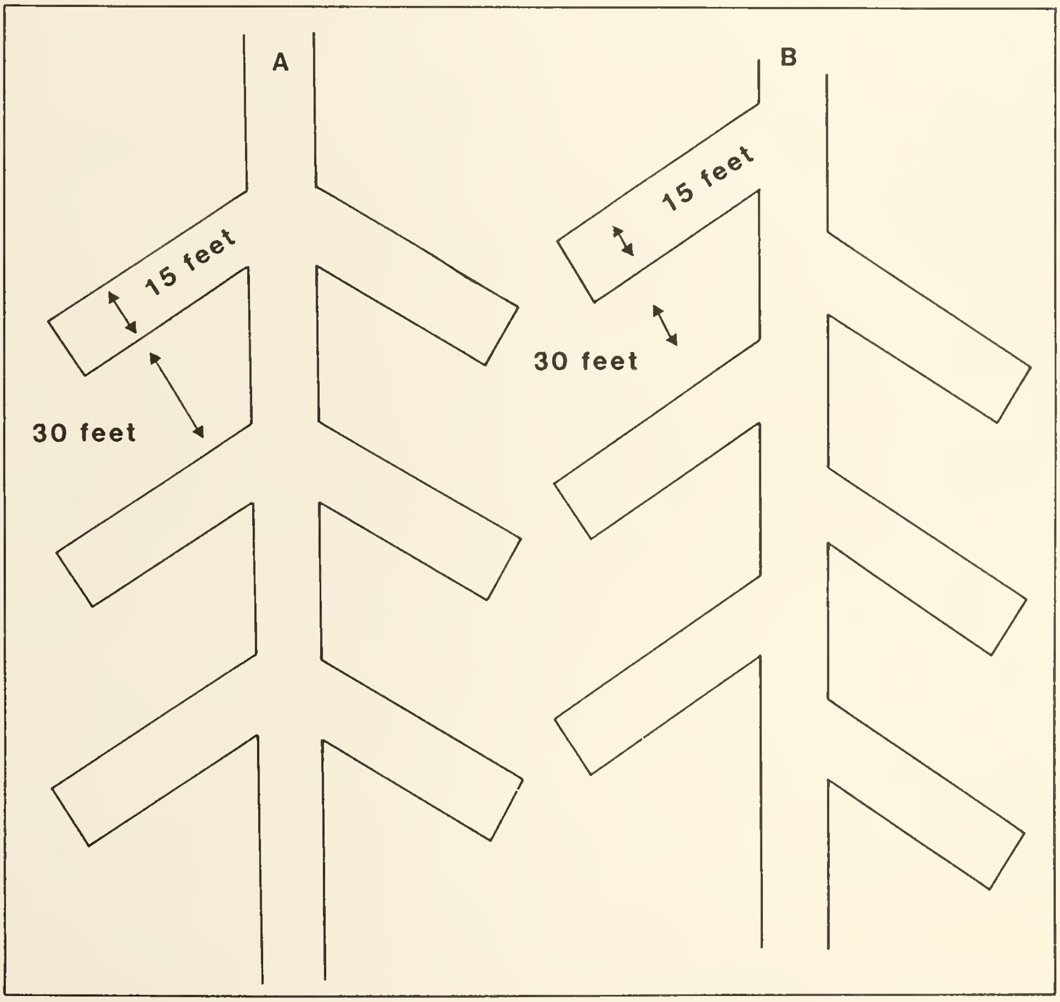

Figure 3.—The herringbone thinning was laid out in the pattern shown in **A** with the side corridors in opposite positions. A better arrangement would have the side corridors in alternating positions, as in **B**.

Crown length on the same 10-percent sample was estimated visually as a percentage of total height of the tree. Heights taken for the 10-percent sample were used to access tarif tables (Hoyer 1966, Turnbull and others 1980). The tarif equations derived were used later to estimate tree volumes. Average heights by crown class for western hemlock, Douglas-fir, and Sitka spruce are shown in table 1.

Vegetation data were gathered for each plot. Visual estimates of percentage of cover for shrubs, herbs, and mosses were taken. Visual estimates were also made for downed wood in two categories—that greater than 4 in in diameter and that less than 4 in in diameter.

After logging, each plot was revisited. All remaining trees were tallied on the data sheets. New scars were measured for location, length, width, and height. Control plots were not revisited. Plots will be remeasured every 5 years.

Volume growth was computed for the stand based on the measurement of 5- and 10-year diameter increments. To estimate growth for the two 5-year and the 10-year periods, regression equations were developed to predict average radial increment by diameter class. The relationship had the form: DIAMETER INCREMENT = a + b (d.b.h.). Then a 5- and 10-year increment was assigned to each tree on all the plots. The diameter of each tree at ages 20 and 25 years was then estimated from the diameter at breast height measured at age 30 and the growth estimates. The cubic- and board-foot volumes were computed using tarif tables (Hoyer 1966).

Data were entered into the Department of Forest Science Data Bank, Oregon State University, Corvallis. Documentation and data are available to those interested with permission of the authors. Statistical analysis was carried out using SPSS (Nie and others 1975) and SAS (SAS Institute, Inc., 1982).

Table 1—Average height of trees by species and crown class [1]

Species	Average height by crown class			
	Dominant	Codominant	Intermediate	Suppressed
	Feet			
Western hemlock	[2] 73.3 (97)	69.8 (32)	50.2 (13)	40.0 (4)
Sitka spruce	70.5 (6)	54.7 (11)	47.3 (31)	40.3 (11)
Douglas-fir	68.7 (7)	67.6 (3)	57.3 (1)	

1/ Because the samples were taken systematically (every 10th tree), the numbers of trees sampled in each class are proportional to their abundance in the stand.

2/ Number of sample trees is in parentheses.

Results

The stand conditions before and after thinning by treatment, species, and crown class are described in table 2. An analysis of variance was run on number of trees, diameter at breast height, basal area, and volume by treatment for the original stand condition, and no significant differences were detected. We therefore feel that the 16 plots encompassed most of the variation within the stands and that selection of treatments was not biased.

Table 2—Stand description, by treatment, species, and crown class, before and after thinning

	Trees/acre		Diameter at breast height		Basal area		Volume (to 6-inch top)/acre			
	Before	After	Before	After	Before	After	Before	After	Before	After
	Number		Inches		Square feet/acre		Cubic feet		Board feet Scribner	
Treatment:										
Control	254	254	11.3	11.3	195.6	195.6	5,320.9	5,320.9	24,852.2	24,852.2
Narrow	274	108	11.4	12.3	212.0	99.5	5,733.3	2,806.8	26,696.6	13,374.3
Strip	273	143	11.7	11.8	216.6	114.6	5,875.3	3,155.2	27,315.2	14,689.8
Wide	270	60	11.5	12.6	206.6	55.4	5,720.2	1,609.7	26,391.0	7,663.6
Species: 1/										
Western hemlock	181	96	12.2	12.8	153.8	86.7	4,422.4	2,522.2	20,760.5	11,962.7
Sitka spruce	64	33	9.4	9.8	37.4	19.5	866.8	454.5	3,768.6	1,993.1
Douglas-fir	12	8	14.4	15.7	12.9	8.4	373.2	246.4	1,784.6	1,189.1
Red alder	11	6	10.0	7.7	3.6	1.7	--	--	--	--
Crown class:										
Dominant	135	80	13.9	14.2	143.0	88.7	4,264.3	2,641.1	20,331.6	12,652.8
Codominant	59	24	10.6	10.8	38.7	15.6	949.7	390.0	4,148.5	1,701.9
Intermediate	46	21	8.5	8.1	19.8	8.3	369.4	140.7	1,512.5	575.8
Suppressed	28	16	5.7	6.1	6.2	3.7	79.1	51.3	321.1	214.5

-- = no data available.
1/ Species and crown class categories do not include data from control plots.

Diameters

Average diameter at breast height among the four major species did differ (table 2). All were significantly different ($p > 0.05$)[2/] except Sitka spruce and red alder. It was not surprising that average diameter at breast height was largest for Douglas-fir (14.4 in), but it was surprising that the average diameter at breast height for Sitka spruce (9.4 in) was smaller than that for western hemlock (12.2 in). There are several possible explanations. First, western hemlock has a larger average sapwood radius and a larger average crown ratio; this indicates western hemlock has greater leaf area than Sitka spruce does. A larger photosynthetic surface would normally grow a bigger tree. Another explanation could be related to the spruce weevil (*Pissodes strobi*), which has been evident in the area for a number of years. Weevils kill the leader, which results in trees with forked tops. Of the 118 trees with forked tops, 83 percent were Sitka spruce. Recovery from weevil attack takes time, and height of the tree is reduced. These factors could force spruce into a suppressed crown position.

Average stand diameters were similar to those for industrial and Federal stands at age 30 to 35 for commercial thinning. As would be expected, diameters at breast height by crown class were significantly different with a range from 5.7 to 13.9 in. Similar average diameters at breast height after thinning indicated trees of all diameter classes were removed in proportion to their abundance in the stand.

[2/] Unless otherwise noted, all significances are at the $p < 0.05$ level.

Basal Area

Average basal areas per acre after thinning for the narrow (99.4 ft^2) and strip (114.6 ft^2) treatments were similar and both were significantly different from the wide (55.4 ft^2) treatment. The average number of trees per acre remaining on the thinned plots (60 to 143 trees per acre) indicated a relatively heavy thinning. Examination of the density management diagram of Flewelling and others (1980) showed that the narrow thinning produced a stand that is at crown closure line. The wide treatment created a stand considerably below the crown closure line. If the trees were evenly spaced in the strip thinning, the stand would be near 0.3 relative density, which is thought to be ideal postthinning spacing.

Volume

Volumes for the stands before thinning (about 5,700 ft^3/acre to a 6-in top) were higher than those published in standard volume tables (Barnes 1962). Barnes reports volumes of 4,050 ft^2/acre at site index 180 for 30-year-old western hemlock with trees over 6.5 in d.b.h. The yields for our stands clearly exceeded this at age 30 (table 2).

Volumes left in the narrow and strip treatments were 50 percent and 46 percent of original volumes, respectively, with no significant differences between the two. In the wide treatment, 29 percent of the volume remained. Kellogg and Hargrave (in press), in an independent estimate, report that 34 percent of the volume remained. Though the thinning was profitable, fewer trees were left than were marked in the narrow and wide treatments because of removal of heavily damaged leave trees. Both treatments should have relatively long growth periods before the stand closes and growth slows. The narrow treatment with 108 trees per acre could be commercially thinned again to produce a widely spaced stand capable of growing to old-growth proportions.

Periodic annual increments (PAI) for all species combined (by plot) decreased after age 25 (table 3). The decrease in growth between ages 20 to 25 and 25 to 30 was 102 ft^3/acre per year and 602.8 board feet per acre per year. Mean annual increment (MAI) calculated for age 30 was 188.7 ft^3/acre per year (table 3). Thus, PAI had clearly peaked and was declining rapidly.

Sapwood Radius and Increment Growth

Five- and 10-year increment growths and sapwood radii are given in table 4. There were significant differences in 5- and 10-year increment growths (number of inches grown per year) between species and crown class, but not between treatments. Sitka spruce had the largest decline, possibly the result of weevil attacks and loss of dominant crown position. The slowdown in radial growth rate indicated thinning was timely.

Sapwood radii (table 4) were significantly different among species. Measurements indicated that western hemlock, a more tolerant species than the others, had more leaf area, which resulted in better growth. Sapwood radii in intermediate and suppressed crown classes were similar. Sapwood radii for the treatments were all similar.

Table 3—Periodic annual increment (PAI) at 5- and 10-year intervals and mean annual increment (MAI) at age 30 for all species combined

Age intervals	Volume (to 6-inch top) per acre per year	
Years	Cubic feet	Board feet Scribner
PAI:		
20-25	387.6	1,926.8
25-30	285.6	1,324.0
20-30	322.8	1,640.0
MAI:		
30	188.7	877.1

Table 4—Radial increment growth per year, by treatment, species, and crown class, for the last 5 and 10 years, sapwood radius, and crown ratio before thinning 1/

	5-year average	10-year average	Sapwood radius	Crown ratio
	Inches			Percent
Treatment:				
Control	0.14[a]	0.18[a]	2.9[a]	41[a]
Narrow	.12[a]	.18[a]	2.7[a]	32[a]
Strip	.12[a]	.16[a]	2.8[a]	33[a]
Wide	.12[a]	.18[a]	2.8[a]	38[a]
Species:				
Western hemlock	.07[a]	.20[a]	3.5[a]	39[a]
Sitka spruce	.05[a,b]	.16[a,b]	1.5[b]	26[b]
Douglas-fir	.04[b]	.12[b]	1.7[b]	37[a]
Crown class:				
Dominant	.07[a]	.20[a]	3.5[a]	42[a]
Codominant	.05[b]	.16[b]	2.6[b]	32[b]
Intermediate	.04[b]	.14[b]	1.9[c]	29[b]
Suppressed	.05[b]	.12[b]	1.5[c]	18[c]

1/ Variables followed by the same letter are not significantly different, $p < 0.05$.

Crown Ratios

Average crown ratios for treatments before and after thinning were not significantly different (table 4). Before thinning, both western hemlock and Douglas-fir had significantly larger crown ratios than did Sitka spruce. After thinning, only western hemlock and Sitka spruce were different. Crown ratios for crown classes were all significantly different before thinning.

Relation Between Sapwood Basal Area, Crown Ratio, and 5- and 10-Year Increments

Five- and 10-year increments for hemlock were not highly correlated to crown ratio alone. Multiple correlation coefficients at the 0.1 significance level rose from 0.19 to 0.40 when correlations were computed between increment growth and the combination of crown ratio and diameter at breast height. The correlation between increment growth and sapwood basal area was similar (0.42). On the other hand, sapwood basal area of hemlock was very well correlated with diameter at breast height (0.84) and diameter at breast height squared (0.88).

No significant correlations were found between sapwood basal area and crown ratio by species. The range of correlations was 0.33 to 0.57 for before and after thinning. Both small- and large-diameter trees had large crown ratios. The poor correlation probably resulted from including patches where small but open-grown trees had large crowns.

Scar Information

Before thinning, the number of scars per acre by treatment, species, and crown class was nominal (tables 5 and 6). Of the 2,154 trees sampled in the original stand, only 1.1 percent had scars. After thinning, 16 percent of the remaining 1,161 trees sustained scar damage (including controls). Excluding controls, scars per acre divided by trees per acre yielded higher percentages for the narrow (62 percent) and wide (81 percent) treatments than for the strip (16 percent) treatment.

All species of trees were scarred. Mean scar area per scarred tree, though extremely variable, was greater in the thin-barked spruce and hemlock than in the thick-barked Douglas-fir. Correlations of scar area, number of scars, and diameter at breast height showed no relation for any of the species.

Table 5—Scars per acre and scarred area per scarred tree, by treatment, species, and crown class, and percent of total number of scarred trees by treatment[1/]

	Scars/acre		Scarred area/scarred tree	
	Before	After	Before	After
	- - - Number - - - -		Square inches	
Treatment:				
Control	5 (1.7)	5 (1.7)	32.87	32.87
Narrow	1 (.5)	67 (50)	26.66	254.60
Strip	5 (1.7)	23 (13)	109.32	193.61
Wide	2 (.3)	49 (39)	47.38	264.12
Species:				
Western hemlock	2	25	145.36	242.27
Sitka spruce	1	7	136.22	256.82
Douglas-fir	<1	2	46.50	71.91
Crown class:				
Dominant	1	24	58.97	224.8
Codominant	<1	5	43.51	315.13
Intermediate	1	4	105.69	220.02
Suppressed	1	2	14.43	80.46

1/ Percentage of total trees scarred is in parentheses.

Table 6—Percentage of total number of trees scarred, by crown class, species, and treatment, before and after thinning

Crown class	Western hemlock		Sitka spruce		Douglas-fir	
	Before	After	Before	After	Before	After
	Percent					
Dominant	0.6	27.8	0	28.0	1.9	16.8
Codominant	.8	20.0	0	26.0	0	12.5
Intermediate	1.0	10.4	1.7	24.6	--	--
Suppressed	4.5	10.7	0	11.1	--	--

Crown class	Treatment							
	Control		Narrow		Strip		Wide	
	Before	After	Before	After	Before	After	Before	After
	Percent							
Dominant	1.3	1.3	0	43.0	0.8	15.0	0	52.0
Codominant	0	0	0	41.0	.5	11.0	1.4	43.0
Intermediate	1.0	1.0	1.1	33.0	5.1	12.1	.7	55.0
Suppressed	5.5	5.5	1.5	25.0	.8	8.5	0	13.0

-- = no trees in these crown classes.

Discussion

Data from individual treatments indicated which treatments should produce the best growth for the amount of money invested. Strip thinning was the cheapest treatment overall (Kellogg and Hargrave in press) and resulted in fewer scars. Trees were not spaced uniformly, however. Some trees were exposed on two or more sides, while others were not released at all. Studies on strip-thinned Douglas-fir (McCreary and Perry 1983) indicated that trees more than 10 ft from an open corridor respond poorly to the thinning. The same tests will be made for western hemlock. Because the trees were in strips, it was difficult to compare density to the other two treatments.

The Siuslaw National Forest does not have strict commercial thinning standards; rather, they differ according to site characteristics. On the average, though, the Hebo and Waldport Districts commercially thin to an 18- by 18-ft spacing, leaving trees that average 12 in d.b.h. This is similar to our treatments where the average diameter at breast height was near 12 in. The Siuslaw National Forest typically tries to remove about 40 percent of the total basal area. All treatments in this study removed more than that—54, 48, and 74 percent for the narrow, strip, and wide treatments, respectively. Basal area removed for western hemlock was 44 percent, for Douglas-fir 40 percent, and for Sitka spruce 49 percent. As mentioned, the wide treatment left very few trees per acre. This may make the stands less resistant to wind throw, a serious problem on the Oregon coast. Barring any significant wind damage, a wide spacing may result in longer periods of growth between commercial thinnings.

Using the density management diagram for site class 2 western hemlock from Flewelling and others (1980) shows that trees could grow to an average diameter of about 21 in in the narrow treatment and 26 in in the wide treatment before mortality from competition would occur. Predictions of this sort are impossible to make for the strip thinning because of the variability in spacing between leave trees.

Few data have been gathered on scar damage in commercially thinned stands **before** and after thinning. Most of the literature on decay resulting from logging scars is about stands that are more than 75 years old. Most of the literature is in general agreement that decay from scars may reduce growth, reduce volume, lower the quality of the stand, and sometimes even result in mortality. The size and locale of the logging scars affect the amount of decay. The higher up on the tree that scars occur, the lower is the incidence of infection. Depth of the scar is also important (Parker and Johnson 1960, Shea 1961, Wallis and Morrison 1975, Wallis and others 1971, Wright and Isaac 1956). This study is one of the first to look at scar damage before and after thinning on young stands.

In the future, crown ratio and sapwood basal area will be compared to scar damage and recovery to see if leaf area can affect a tree's ability to sustain injury. The data from the plots in this study will complement studies by the Forest Engineering Department, Oregon State University, Corvallis (Kellogg and Hargrave in press). This work involved a detailed study of logging costs and degree of scar damage.

The herringbone treatment could have yielded better results if an alternate system had been used. Large gaps were created at the intersection of two corridors with the skyline (fig. 3A). These gaps could have been reduced if the intersections of the corridors had alternated along the skyline (fig. 3B).

Plots will be monitored in the future. A detailed examination of scar damage and resultant decay will be carried out in 1993, 10 years after treatment. Remeasurement at 5-year intervals will give valuable information on growth and yield of coastal forest stands with different thinning treatments. The responses of different species and crown classes will be checked.

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Metric Equivalents

1 acre = 2.47 hectares
1 inch (in) = 2.5 centimeters
1 square inch (in^2) = 6.25 square centimeters
1 foot (ft) = 0.3 meter
1 square foot (ft^2) = 0.09 square meter
1 cubic foot (ft^3) = 0.27 cubic meter

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An Improved Method of Chemical Analysis for Low Levels of Nitrogen in Forest Streams or in Rainwater

Elly E. Holcombe, Duane G. Moore, and Richard L. Fredriksen

Abstract

A modification of the macro-Kjeldahl method that provides increased sensitivity was developed for determining very low levels of nitrogen in forest streams and in rainwater. The method is suitable as a routine laboratory procedure. Analytical range of the method is 0.02 to 1.5 mg/L with high recovery and excellent precision and accuracy. The range can be increased to include higher levels of nitrogen by dilution of samples at time of Nesslerization, or by using smaller volumes of samples at the start of the analysis.

Keywords: Chemical analysis, nitrogen, water analysis, laboratory methods.

Introduction

The Kjeldahl method (Kjeldahl 1883) for determination of nitrogen (N) in soil, in plant materials, in biological tissues, and in wastewater is well known and widely used. The standard Kjeldahl method, which uses boric acid in the final step, is satisfactory for levels of N as low as 1.0 mg/L (Crawther and Evans 1980). But the N content of streams and rainwater in uncontaminated forests of the Pacific Northwest is often as low as 0.01 mg/L (Fredriksen 1972). Successful routine analysis of a large number of water samples at this level requires improved sensitivity and elimination or control of contamination.

The method we developed is a combination of techniques from several sources (American Public Health Association 1976, Kjeldahl 1883, Morrison 1971, Rainwater and Thatcher 1960) augmented by careful control of contamination and a high degree of quality control. This paper describes this modified macro-Kjeldahl method and its accuracy, precision, and sensitivity. Procedures used to minimize contamination during the collection, subsampling, and analysis are also presented.

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Our method allows determination of 0.02 to 1.5 mg/L of N in water with a high degree of accuracy and precision. This is achieved by:

1. Carefully preventing contamination of the sample during collection, storage, and analysis.

2. Concentrating the sample fivefold.

3. Using a colorimetric method with Nessler's reagent and a 25-mm light path (Morrison 1971).

4. Using the most stable range on the colorimeter for measurements.

Description of the Method

The description of the method has been divided into four parts: equipment, reagents, working solutions, and analytical procedures.

Equipment

The equipment included:

1. Commercially available macro-Kjeldahl digestion and distillation equipment with hoods.

2. Kjeldahl flasks and racks, 800 mL.

3. Distillation receivers, 32- x 200-mm Pyrex glass test tubes, calibrated to 100 mL.

4. Fisher Electrophotometer II with 25-mm light path.

5. Teflon boiling chips, 1-cm cubes washed with dilute HCl to remove all traces of NH_4-N.

6. Pipettes and other glassware used only for this analysis to avoid contamination.

Reagents

The reagents required for the analytical procedures include:

1. Double-distilled water (DDW) or de-ionized water (DIW), free of ammonia. Distilled water is passed through a column of acid-washed granular charcoal and a mixed bed (anionic and cationic forms) of ion exchange resins. The water is redistilled in an all-glass still and is stored in a glass carboy, protected from the atmosphere. A commercial de-ionization system (Aqua Media), which incorporates a prefiltration step to remove particulates and organics, also produces water of adequate purity. Water purity is verified daily and must meet the following criteria:

   a. Conductivity—6.25 to 12.5 x 10^{-5} Seimens/m; and

   b. Nesslerization—100 mL DIW or DDW + 2 mL Nessler's reagent yields an optical density (O.D.) of less than 0.01 at 425 nm, usually 0.003 to 0.005 O.D.

2. NaOH, 10N. American Scientific, or dissolve 40 g Mallinckrodt reagent-grade NaOH in DIW and dilute to 1000 mL.

3. H_2SO_4, concentrated (36N). NH_3 free, analytical grade (J.T. Baker or Mallinckrodt).

4. $CuSO_4$, reagent grade (J.T. Baker or Mallinckrodt).

5. KCl, reagent grade (J.T. Baker).

6. Nessler's reagent. A.P.H.A. reagent for ammonia nitrogen (Hartman-Leddon or Fisher).

7. K_2HPO_4, reagent grade (J.T. Baker).

8. KH_2PO_4, reagent grade (J.T. Baker).

9. $Na_2B_4O_7 \cdot 10H_2O$, reagent grade (J.T. Baker or Mallinckrodt).

10. NH_4Cl, reagent grade (J.T. Baker or Mallinckrodt).

11. Na thiosulfate, reagent grade (J.T. Baker).

Working Solutions

Working solutions for the routine analysis of samples include:

1. a. 10N NaOH. Either dissolve 40 g NaOH and dilute to 1000 mL with DIW or use commercially prepared 10N NaOH.

   b. 0.1N NaOH. Dilute 10 mL of 10N NaOH to 1000 mL with DIW.

2. Digestion mix. Dissolve 20 g $CuSO_4$ + 100 g KCl in DDW or DIW and dilute to 1000 mL (equals 2 percent $CuSO_4$ and 10 percent KCl).

3. Borate buffer. Add 88 mL of 0.1N NaOH solution to 500 mL of a 0.025N sodium tetraborate solution (5.0 g anhydrous $Na_2B_4O_7$ or 9.5 g $Na_2B_4O_7 \cdot 10H_2O$ per 1000 mL) and dilute to 1000 mL with DIW or DDW.

4. Phosphate buffer solution, pH 7.4. Add 68.76 g K_2HPO_4 and 14.30 g KH_2PO_4 to a 1000-mL volumetric flask and add 800 mL DIW. Heat to just under boiling for 40 minutes. Cool and bring to volume with DDW or DIW. Adjust to pH 7.4 with appropriate acidic or basic phosphate salt. Store in refrigerator.

5. NH_4Cl. Dissolve 3.819 g oven-dried NH_4Cl in DIW and dilute to 1000 mL (equivalent to 1000 mg NH_4^+-N/L).

6. NH_4Cl standard, 10 mg/L NH_4^+-N. Dilute 10 mL of 1000 mg/L NH_4Cl stock solution with DIW to make 1000 mL (10 mg NH_4^+-N/L).

7. Trap solution. Dilute 1500 mL 10N NaOH and 75 g Na thiosulfate to 15 L with DIW.

8. Comparison digestion mix.[1/] 133 g K_2SO_4 + 100 g NaCl + 20 g $CuSO_4$ made to 1000 mL DDW. Use 5 mL for each sample or blank.

[1/] The comparison digestion mix is used by EPA and can be substituted for our mixture if desired.

Analytical Procedure

The analytical procedure permits analysis of free ammonia by distillation (item I, below) plus Nesslerization (III), by autoanalyzer (IV) (Crawther and Evans 1980), or by I plus titration (V) with 0.02 N H_2SO_4 plus indicator. Analysis of organic nitrogen is by digestion and distillation (II) plus III, or by II and V if concentration is greater than 1.5 mg/L (American Public Health Association 1976, Crawther and Evans 1980).

I. **Distillation of free NH_3.**—In duplicate, add 500 mL aliquots of a filtered or unfiltered water sample plus two Teflon boiling chips to 800-mL Kjeldahl flasks. Include duplicate 500 mL DIW reagent blanks in each set of 12 samples. Add 5 mL DIW to distillation receivers and set in place on distillation unit with tips of condenser delivery tubes extending into the water. Add 25 mL of phosphate buffer or borate solution[2/] to each sample and blank and immediately set each flask on the distillation unit. Stopper tightly and swirl each flask to mix the contents thoroughly. Heat to distill the free NH_3 into the distillation receivers. When distillation is well advanced, lower the receiver tubes to prevent aspirating the distillate into the flasks. Collect about 95 mL of distillate, rinse the tips of the delivery tubes with DIW into the receivers, and bring the volume of distillate to 100 mL with DIW. Cover the tubes with plastic wrap until ready to determine the N content by Nesslerization (III).

II. **Digestion and distillation of organic nitrogen.**—When the Kjeldahl flasks from the above distillation (I) have cooled sufficiently, add 5 mL of the digestion mixture and 10 mL H_2SO_4 to each flask.

Digestion: Mix the contents of each flask thoroughly by swirling, then heat on the digestion unit to remove water. For filtered samples, reflux for exactly 30 minutes beginning when the acid mixture starts to fume. For unfiltered samples, digest for 45 minutes after acid fumes (longer digestion periods result in loss of nitrogen). Remove the flasks, cool, and add 300 mL DIW. The samples are now ready for distillation.

Distillation: Add 10 mL DIW to Kimax receiver tubes and set in place on the distillation unit; be certain the receiver tips are submerged. Slowly add 50 mL 10N NaOH to each Kjeldahl flask; allow the solution to run down the side of the flask to the bottom. Then place the flask on the distillation unit, stopper tightly, and swirl to mix. Conduct the distillation as in (I) and determine N content by Nesslerization (III), or I and IV, or I and V, depending on concentration.

[2/] We compared results using both borate and phosphate buffers and found no difference.

III. **Determination of N in standards and samples by Nesslerization.—**

1. Prepare standard concentrations (100 mL) in duplicate using DIW. Prepare at least three concentrations that range from 0.2 to 1.50 mg/L NH_4^+-N and include 100 mL of DIW in duplicate as a blank.

2. Add 2 mL of Nessler's reagent to each sample distillate, standard, and blank. Mix well, and allow color to develop in the dark for 30 minutes (cover tubes with foil or place in dark to protect from fluorescent light, which changes the color of Nessler's reagent). The color development process is influenced by N concentration, temperature, time, and pH. Because of these variables, samples, standards, and blanks must all be handled in the same manner. At concentrations of N greater than 0.5 mg/L, it is important that the length of time between addition of the Nessler's reagent and reading the spectrophotometer must be the same $\pm$ 1 minute for each sample, standard, or blank in the set.

3. Measure color intensity with a spectrophotometer at 425 nm. Use DIW as a blank to zero the instrument. Record all readings in percentage of transmittance (%T) or O.D., depending on the most sensitive scale on the instrument. If %T is used, convert to O.D. by using conversion tables. Obtain corrected optical density (C.O.D.)[3/] readings for standards and samples by subtracting the average of the O.D. readings of the appropriate blanks. The mean O.D. of the digest blanks should be subtracted from the measured O.D. of the samples.

4. Include 500 mL DIW fortified with NH_4Cl and 500 mL DIW fortified with cysteine (fortified to various levels with standard materials) each time a set of samples is analyzed to test distillation and digestion procedures for percentage of recovery. Recoveries are commonly 94 to 100 percent for NH_4Cl by distillation and 94 to 98 percent for cysteine by digestion and distillation. If recovery is less than 89 percent, the entire distillation apparatus is checked for proper operation. Once each month a complete standard curve (0 to 2.5 mg/L NH_4Cl, and 0 to 1.0 mg/L cysteine) is run to monitor the accuracy of digestion and distillation steps.

After analysis of a set of samples, the Kjeldahl flasks must be thoroughly cleaned to ensure complete removal of any NaOH residue. Flasks are emptied as soon as possible and rinsed three times with hot tap water. (They may sit overnight filled with DIW at this step.) Next, the flasks are rinsed with dilute (0.5 N) HCl, followed by three rinses with hot tap water, and finally rinsed three times with DIW. The clean flasks are stored upside down on drying racks until used.

We originally used mercuric chloride ($HgCl_2$) as a preservative but discontinued this because it interfered with the determination of phosphate and reduced the recovery of N. Adding $HgCl_2$ to samples spiked with NH_4^+-N reduced recovery 12 to 15 percent during the first distillation. Part of the N complexed by the Hg is recovered in the second distillation, but recovery is still incomplete. We also elected not to use $HgCl_2$ to prevent possible mercury contamination of the laboratory. If $HgCl_2$ is used as a preservative, it must be added to blanks and standards at the same concentration.

[3/] C.O.D. is corrected optical density; it equals the optical density of the standard or sample minus the optical density of the blank.

IV. **Autoanalyzer.**—Analysis of free NH_3-N may also be accomplished by an automated method (Crawther and Evans 1980, United States Environmental Protection Agency 1979). Start with II and omit the distillation step in I. Add the digestion reagents, concentrated H_2SO_4, and boiling chips to each sample and begin the digestion. The analysis is for total dissolved N or, in the case of an unfiltered sample, total N. The concentration of free NH_3-N determined on the autoanalyzer must be subtracted from the results for total dissolved N to give the amount of organic N present in the sample. We use 500 mL of an unfiltered sample to analyze for total organic N. In analysis for the total N, the digestion time is increased to 45 minutes.

V. **Calculations.**—The concentration of N in a sample is calculated as follows:

1. Standard factor: Calculate a mean standard factor over the range of the standard concentrations:

$$\text{mg/L N per optical density unit} = \frac{\text{concentration of standard (mg/L)}}{\text{C.O.D. of standard}}.$$

2. Concentration factor: $\dfrac{\text{sample volume}}{\text{distillate volume}}$.

3. Calculation factor: $\dfrac{\text{mean standard factor}}{\text{concentration factor}}$.

4. Milligrams per liter of N sample: C.O.D. of sample multiplied by the calculation factor.

Example: C.O.D. of 0.5 mg/L NH_3-N standard = 0.082;

C.O.D. of sample = 0.072;

$$\text{Standard factor} = \frac{0.5}{0.082} = 6.09\text{[4/]};$$

$$\text{Concentration factor} = \frac{500 \text{ mL}}{100 \text{ mL}} = 5;$$

$$\text{Calculation factor} = \frac{6.09}{5} = 1.22; \text{ and}$$

$$\text{mg/L N in sample} = 0.072 \times 1.22 = 0.088 \text{ mg N/L}.$$

[4/] Normally the average of all the curve factors on the standard curve is used if the values are within the acceptable range of occurrence as defined by the United States Environmental Protection Agency (1979).

Evaluation of the Method

Sensitivity

The quantitative range of detection of this method for nitrogen in streamwater and precipitation is 0.02 to 1.50 mg/L. The sensitivity of this method is increased over the standard Kjeldahl method (1) by including a fivefold concentration step during digestion and distillation, (2) by Nesslerization of the distillate and colorimetric determination of NH_3-N (Fredriksen 1972), and (3) by employing a spectrophotometer with a 25-mm light path. The sensitivity can be further increased to approximately 0.002 mg/L N by using a spectrophotometer with a 100-mm light path.

The sensitivity of this method is illustrated by the results of analysis of 12 replicate aliquots of a single, filtered streamwater sample for free NH_3-N and soluble organic N (table 1). The sample contained 0.021 $\pm$ 0.003 mg/L free NH_3-N and 0.116 $\pm$ 0.006 mg/L soluble organic N. It is apparent from the optical density values presented that the readings are outside the instrument response range normally considered optimum (O.D. from 0.071 to 0.699, or between 85 and 20 %T). We have found, however, that adequate precision can also be obtained in that portion of the standard curve representing O.D. readings between 0.011 and 0.071 by (1) employing all the precautions noted to avoid contamination and (2) reading all reagent blanks, standards, and samples against a DIW blank. Reading against a DIW blank shifts the working range as far as possible toward the most stable region of instrument response. Similar data have been obtained with samples from other streams. These results demonstrate that our method adequately quantifies levels of N at one-fiftieth the level characteristic of the standard Kjeldahl method.

Table 1—Sensitivity and precision of the modified Kjeldahl method for determination of free NH_3-N and soluble organic N in a streamwater sample

Sample	Free NH_3-N		Soluble organic N	
	O.D.[1]	mg/L	O.D.	mg/L
1	0.014	0.0178	0.088	0.1118
2	.015	.0191	.092	.1168
3	.015	.0191	.089	.1130
4	.018	.0228	.093	.1181
5	.019	.0241	.098	.1245
6	.015	.0191	.095	.1206
7	.016	.0203	.096	.1219
8	.018	.0228	.096	.1219
9	.021	.0267	.087	.1105
10	.014	.0178	.088	.1118
11	.014	.0178	.083	.1054
12	.019	.0241	.089	.1130
Mean	0.021		0.116	
Range	0.0178 to 0.0267		0.1054 to 0.1245	
SD[2]	$\pm$0.003		$\pm$0.006	
CV[3] (%)	14.29		5.17	

[1] O.D. = optical density.
[2] SD = standard deviation.
[3] CV = coefficient of variation.

Precision

Precision can be greatly influenced by the care taken in laboratory operations. This is particularly important in achieving the full sensitivity and precision of this method. We have found the following to be important:

1. Include duplicate reagent blanks with each set of samples to detect contamination (possible sources are the Kjeldahl equipment, reagents, glassware, de-ionized water, and the air).

2. Prepare all reagents with DDW or DIW.

3. Chemically weather all new glassware in 2 N HCl for 3 days and then thoroughly wash and rinse prior to initial use.

4. Check each batch of Nessler's reagent for uniformity of color development by running a complete standard curve. The color should range from a light yellow to a red-brown. If it has a greenish tinge, or if a precipitate forms when the reagent is added to DDW, DIW, or standards, check all equipment and reagents for contaminants. Verify the purity of the water first; then check all possible sources of heavy metal or other contaminants. If all possible sources of interference are ruled out, the shipment of Nessler's reagent should not be used.

The precision we obtained with the modified Kjeldahl procedure had a coefficient of variation of about 5 percent for soluble organic N and 14 percent for NH_3-N. This was acceptable, especially considering the low levels of nitrogen being determined. Reproducibility of spectrophotometer readings for reagent blanks and standards is illustrated in table 2.

Free NH_3-N can be determined accurately at levels below 1.00 mg/L N ($\pm$ 0.003 mg/L); however, the coefficient of variation increases sharply as the concentration decreases below 0.1 mg/L N (fig. 1). Based on analysis of 11 replicate samples over a range in concentrations from 0.007 to 1.182 mg/L, the coefficient of variation was 16 percent or less for concentrations at 0.02 mg/L or less, 5 percent at 0.10 mg/L, and 0.4 percent at 1.18 mg/L. Because the soluble organic N content of stream samples being analyzed usually ranges from 0.10 to 1.00 mg/L, the coefficient of variation associated with such analyses will seldom exceed 5 percent.

Table 2—Precision of modified Kjeldahl method for 10 replicate reagent blanks and NH_4Cl standards

	Reagent blanks	Standards[1/]
	- - - - - - O.D.[2/] - - - - -	
Mean (n = 10)	0.007	0.1234
Standard deviation	$\pm$.0013	$\pm$.0023
Coefficient of variation (%)	18.57	1.86

[1/] 0.8 mg/L N as NH_4Cl.

[2/] O.D. = optical density.

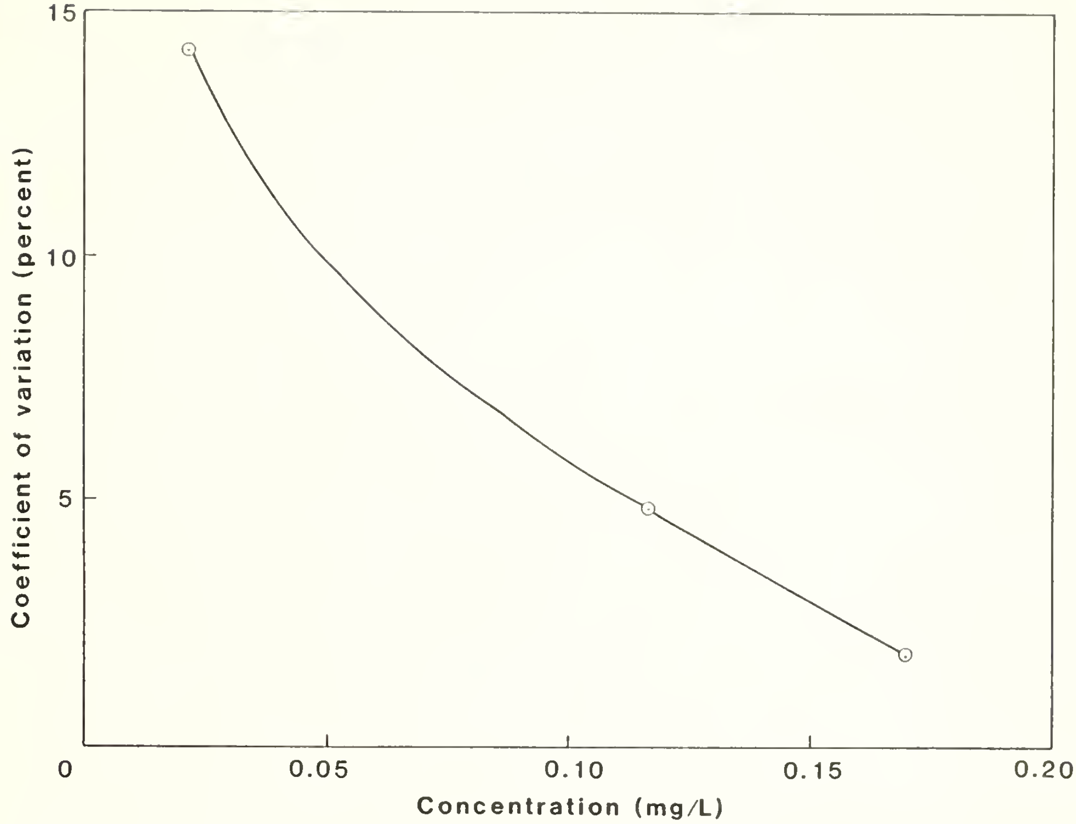

Figure 1.—The coefficient of variation of measuring various concentrations of organic nitrogen compounds in streamwater.

Accuracy

The accuracy of our procedure was evaluated by conducting recovery studies using bulk stream samples fortified with known amounts of inorganic and organic N compounds. NH_4Cl was used to measure the recovery of free NH_3-N, and L-glutamic acid was used to measure recovery of easily digested organic N compounds. More complex nitrogenous materials were represented by the ring compound, L-histidine. In 1982 we checked recovery with cysteine and NH_4Cl (table 3).

Table 3—Recovery of inorganic and organic forms of nitrogen [1] added to samples of streamwater

Form of N added	Number of determinations	Range	Mean	SD [2]	CV [3]
		- - - Percent recovery - - -			Percent
NH_4Cl	18	97.1 - 105.0	102.09	±2.14	2.10
L-Glutamic acid-HCl	12	95.6 - 103.4	99.5	±3.60	3.62
L-Histidine-HCl-H_2O	12	92.5 - 100.5	95.5	±3.50	3.66
Cysteine	14	83.2 - 109.9	97.08	±6.55	6.7

[1] Data include recovery of N added at low (0.02 mg/L), intermediate (0.2 mg/L), and high (1.00 mg/L) concentrations of NH_4Cl, L-glutamic acid, and L-histidine, and 0.233 mg/L cysteine.
[2] SD = standard deviation.
[3] CV = coefficient of variation.

Recovery of inorganic N appears to have exceeded the amount of NH_3-N added to the stream samples. Analysis of the samples for free NH_3-N prior to fortification indicated no detectable (less than 0.02 mg/L) inorganic nitrogen present. Adding a known amount of N to the sample to achieve a concentration of more than 0.02 mg/L made it possible to quantify the "total" NH_3-N present; that is, the added N plus any background N that was present at levels less than 0.02 mg/L. Our analysis of the fortified sample indicated that it contained approximately 0.003 mg/L NH_3-N as background before the NH_4Cl was added. These data show that if it is necessary to quantify background levels of less than 0.02 mg/L N, this can be done by the method of "known additions" using the modified Kjeldahl procedure. Essentially the same results were obtained using the EPA method (United States Environmental Protection Agency 1979).

Absolute accuracy determinations were lower for organic N than for inorganic N (table 3)—probably because of the additional steps in the procedure. Recovery of low levels of N in the straight-chain compound, L-glutamic acid, was slightly lower (97 percent) than recovery of intermediate and high concentrations. Recovery of N from the ring structure of L-histidine was reproducible but consistently lower (95.5 percent) than recovery from L-glutamic acid. Perhaps more complete recovery could be obtained by digesting for more than 30 minutes; however, our studies indicated that losses begin to occur after 30 minutes. This means that net recovery would probably not be increased. Using mercury as a catalyst would increase recovery, but we have avoided using mercury in the laboratory because of problems in the recovery of phosphorus and disposal of wastes.

Quality Control in Field and Laboratory

Quality control in both the field and laboratory is essential for accurate and precise measurements of N at the low levels made possible by our method. Contamination is the primary problem in obtaining consistent and accurate results. Sample collection, processing, subsampling, storage, atmospheric contaminants, and each analytical step are potential contributors to this problem.

We collected streamwater samples with automatic proportional stream samplers (Fredriksen 1969) that pumped the samples into acid-cleaned 20-L Nalgene carboys, which were protected by plastic garbage cans buried in the ground to minimize rapid changes in temperature and resultant loss of free NH_3. Protection from light limits the growth of bacteria and mold and prevents elevated levels of total nitrogen caused by contaminants. We collected composite samples at 3-week intervals and transported them to the laboratory as quickly as possible where they were filtered and analyzed immediately, or frozen until analyses could be done. During the summer months, we collected grab samples in 8-L, acid-rinsed containers once every 3 weeks and transported them to the laboratory in refrigerated chests. These samples of relatively unaltered streamwater can be frozen for up to 3 months without detectable loss of total nitrogen. There is some loss of NO_3-N during storage, however, and an aliquot must be removed for immediate NO_3-N analysis before freezing. The presence of heavy metals (including Hg) results in low recovery of N and may interfere with Nesslerization and with the determination of inorganic phosphorus. Calcium (above 250 mg/L) and the amines may also cause some interference.

We isolate the entire analytical process in a separate laboratory to minimize contamination from atmospheric sources (smoke, volatile contaminants, and nitrogenous reagents). All glassware and containers used in collection and analyses are used only for analyses in the Kjeldahl room. Washing of glassware and sample bottles, filtering and subsampling of stream samples, preparation of reagents, and the entire Kjeldahl analysis are conducted exclusively in this one laboratory. Smoking is not permitted, and only reagents used in this analysis should be stored here. Every container that will come in contact with a sample or a reagent used in the procedure has been treated for 1 week in 2 N HCl, thoroughly rinsed with DIW, and then stored covered or upside-down in the Kjeldahl laboratory until needed. Detergents and soaps are not used and are not kept in the laboratory.

Regular maintenance and cleaning of the Kjeldahl system is important. Connect 800-mL Kjeldahl flasks containing 400 mL of the trap solution to the distillation unit when it is not in use to prevent contamination (Crawther and Evans 1980). Keep the tips of the condenser delivery tubes under water. Before each use distill about 200 mL of water to flush the system. Periodically the distillation traps, stoppers, and glass tips of the condenser delivery tubes need to be removed, soaked in acid, thoroughly rinsed with DIW, and reinstalled. Rinse the stoppers daily with dilute HCl when the system is in use. The digestion manifold is also rinsed daily. Change the trap solution monthly, and follow a strict maintenance schedule to check for leaks, broken tubing, stiff corks, and decreased burner efficiency. Document any problems encountered as a means of evaluating past test results and building a solid base of information for future system operators.

Conclusions

The modified Kjeldahl procedure described has been used successfully in our laboratory for over 10 years with only minor modifications—such as switching from DDW to DIW, modifying the digestion mixture, and using some commercially prepared reagents. Large numbers of water samples have been analyzed for inorganic and organic N concentrations in the range of 0.02 to 1.5 mg/L with excellent precision and efficiency. A trained technician can analyze 100 to 150 samples (500 mL) per week for free NH_4-N and soluble organic-N. Many more samples can be analyzed if the sample volume is smaller and only total N is determined.

English Equivalents

1 gram (g) = 2.2046 x 10^{-3} pounds (avdp)
1 milligram (mg) = 2.2046 x 10^{-6} pounds (avdp)
1 liter (L) = 2.1134 pints (U.S., liq.)
1 milliliter (mL) = 2.1134 x 10^{-3} pints (U.S., liq.)
1 meter (m) = 39.37 inches
1 centimeter (cm) = 39.37 x 10^{-2} inches
1 millimeter (mm) = 39.37 x 10^{-3} inches
1 nanometer (nm) = 39.37 x 10^{-9} inches
1 milligram per liter (mg/L) = 1 part per million parts

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Drying Firewood in a Temporary Solar Kiln: A Case Study

George R. Sampson and
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Abstract

A pilot study was undertaken to determine drying rates for small diameter, unsplit paper birch firewood that was dried: (1) in a conventional top-covered pile; (2) in a simple, temporary solar kiln; and (3) in tree length. Drying rates were the same for firewood piles whether they were in the temporary solar kilns or only covered on top to keep rain or snow from entering the pile. Trees that were severed at the stump and left to dry in tree length form, complete with branches and leaves, however, dried slower than firewood cut to length, stacked, and top-covered or placed in the temporary solar kilns.

Keywords: Kiln drying (solar), drying rate, firewood, paper birch, *Betula papyrifera*, Alaska (interior), interior Alaska.

Firewood in Interior Alaska

A large volume of wood is used for heating homes in interior Alaska. Estimates of such use of firewood for the Fairbanks North Star Borough range from 32,000 to 69,000 cords annually (Laroe 1982; State of Alaska, Department of Natural Resources 1983). Laroe estimated that 59 percent of the 16,700 households in the Borough use wood as a primary or secondary source of heat.

High moisture content in firewood results in less effective burning of the wood and in a loss of energy in evaporating the water during burning. A cord of paper birch (*Betula papyrifera* Marsh.) firewood with 15 percent moisture (dry weight basis) would be expected to use an energy amount equal to 470,000 British thermal units (Btu) during burning to evaporate this moisture. An equivalent cord of paper birch that had a moisture content of 80 percent would be expected to use 2.5 million Btu (Ince 1979). The dry cord will produce more than a 12-percent increase in usable heat.

Unsplit paper birch cut to 16- to 18-inch lengths will not air dry to 20 percent moisture content in a single season. Any system that would accelerate drying to permit burning of dry wood the same year it is cut would be useful. Two solar kilns for drying lumber have been operated in Alaska (Northern Engineer 1982). This type of kiln could be used in drying firewood, but the cost is too high to justify its construction solely for this use.

Wengert (1979) suggested a less expensive solar kiln for drying firewood. An even simpler version of Wengert's design can be built by letting the stack of firewood substitute for the lumber framework in his design. The only investment necessary is the polyethylene film and a strip of roofing paper or other material to serve as a solar collector.

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Objective

The objective of this study was to determine the effectiveness of covering stacked paper birch firewood with polyethylene to raise the temperature and accelerate drying in the Fairbanks, Alaska, area.

Methods

During mid-May 1983, three stacks of cut-to-length, unsplit firewood were built from freshly cut paper birch trees averaging 6 inches in diameter at breast height. As each tree was cut into firewood length, pieces 3 inches in diameter and larger were randomly assigned to the three stacks. Each stack was about 18 inches wide, 8 feet long, and 5.5 feet high and contained approximately one-half cord. In two of the piles, individual pieces were oriented north-south and conventionally stacked. In the third pile, alternate tiers of pieces were oriented east-west to provide for better air circulation. The piles were on a gently sloping southern exposure.

Ten pieces in each pile were selected as indicators of moisture content. A small disk cut from the end of each sample piece was weighed, ovendried, and reweighed to establish green moisture content. The remainder of each sample piece was weighed before it was placed into the pile, so that both green weight and ovendry weight could be established. At the end of the study on September 16, these pieces were again weighed to determine the ending moisture content.

Four temperature sensors were placed in each pile. One sensor was placed in the approximate center of each quarter of the pile. These sensors were attached to an electrically operated data logger which printed the temperature readings for each sensor five times per day.

One of the conventionally stacked piles served as a control and was top covered with a strip of roofing paper to prevent wetting from above. The other two piles had the top and four sides covered with 6-mil polyethylene film to form a temporary solar kiln. Air inlet holes were provided at the bottom and vent holes at the top on each end. On the front side (south) the polyethylene was extended from the top to a point about 5 feet in front of the pile (fig. 1). In both temporary solar kiln piles, occasional pieces of firewood were extended 4 to 6 inches in the rear to provide space for air circulation between the cover and the stacked firewood. After 20 days, the ground area under the polyethylene film in front of each pile was covered by black roofing paper to provide material that would absorb more radiation than the ground.

As a check on the effectiveness of drying roundwood in short lengths, two trees were felled into a clearing near the three firewood piles and their crowns and limbs were left intact through the drying season. For each tree, two disks were removed from the bole 1 foot above the stump for weighing, ovendrying, and reweighing to establish initial moisture content. At the end of the study two disks were taken from each bole 2 feet above the butt to determine final moisture content.

Results

The firewood under the polyethylene film was no drier at the end of the study than the firewood in the control pile (table 1). At the beginning of the study, moisture content of individual pieces ranged from 73 to 108 percent (dry weight basis); at the end of the study, from 28 to 38 percent.

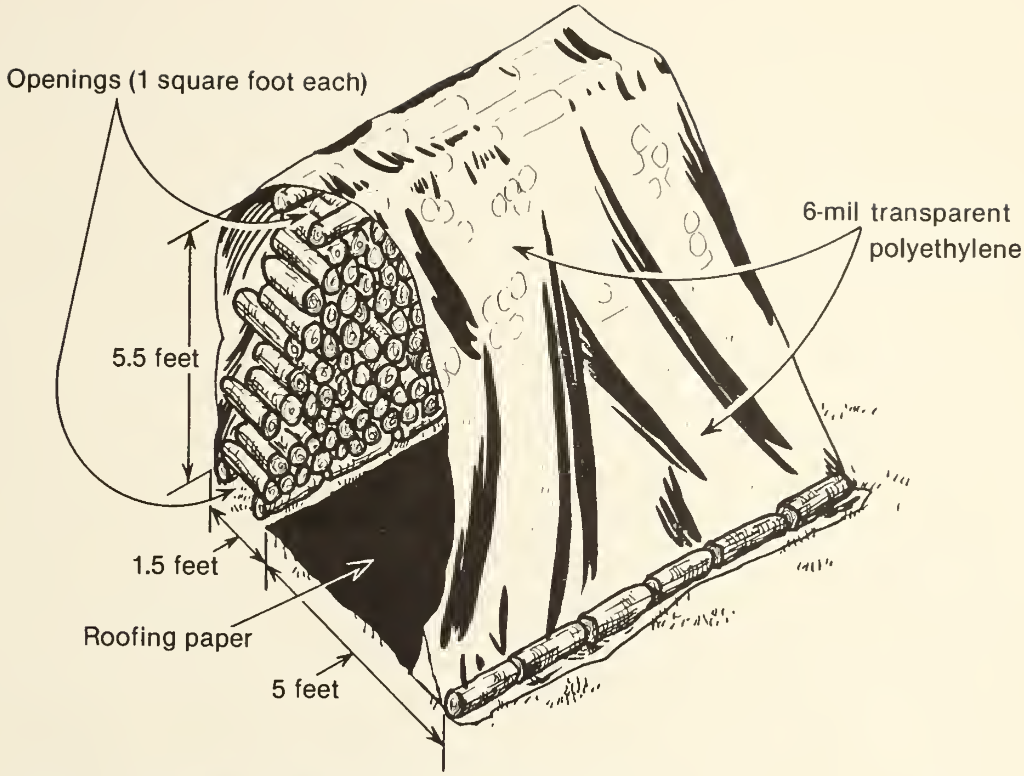

Figure 1—Firewood stack enveloped in polyethylene film to form a temporary solar kiln.

Table 1—Initial and ending moisture content for firewood piles and whole trees, by drying method

Drying method	Initial moisture	Ending moisture
	Percent	
Polyethylene covered piles:		
Conventional stack	86	34
Tiers in alternate directions	89	33
Control pile	92	33
Whole trees	72	49

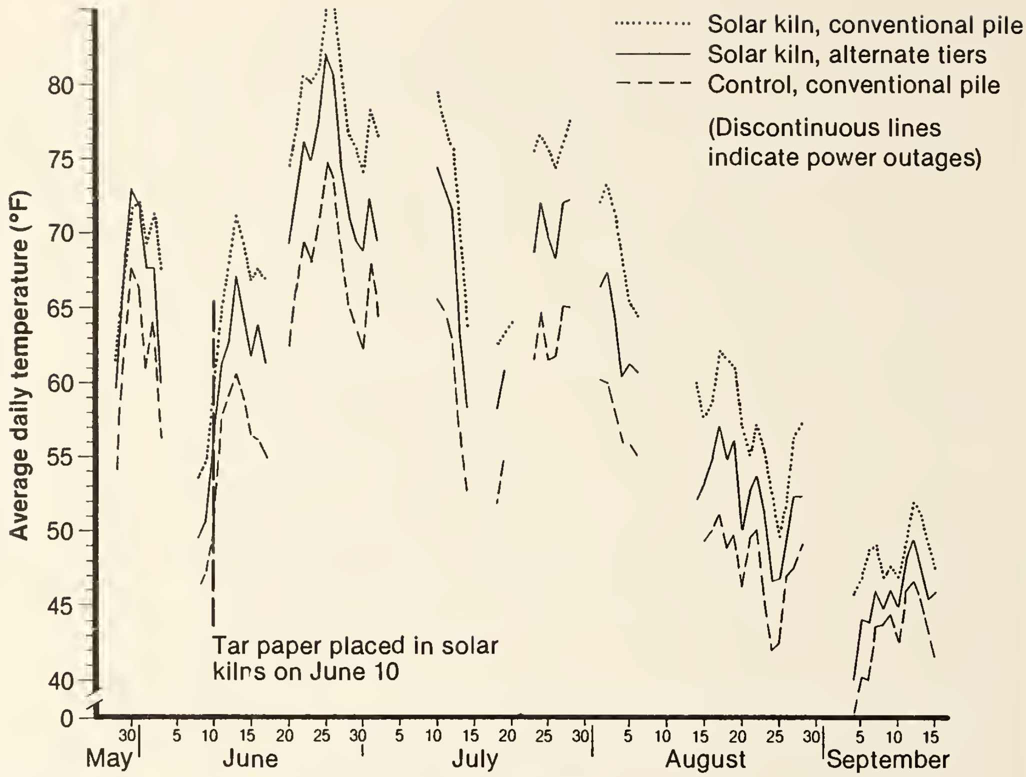

Figure 2—Average daily temperatures within the three firewood piles.

Temperatures within the polyethylene covered piles were consistently above those in the control pile (fig. 2). Temperature differences between the solar kiln and the control increased slightly after addition of the roofing paper; however, these temperatures were not high enough to result in faster drying compared with the control pile. Mold developed on the ends of pieces within the kilns, but there was no mold on pieces within the control pile.

The boles of the two trees that were felled and left to dry with limbs intact did not dry as rapidly as the cut-to-length and piled firewood (table 1).

Discussion and Conclusions

During the drying period, the temporary solar kiln with all pieces oriented in a north-south direction had an average daily temperature of 4.4 °F higher than the temporary solar kiln with alternate tiers oriented east-west. No specific measurements were made to determine whether this was caused by differences in radiation absorption, airflow, or the slight difference in location. Average temperatures within the solar kilns were 9.7 °F (north-south) and 5.3 °F (east-west) higher than average temperatures in the control pile.

During the 120-day drying period of this pilot study, the weather station at Fairbanks International Airport (5 miles from the study site) reported 9 clear days and 40 partly cloudy days based on observations between sunrise and sunset. The 30-year average for this period is 13 clear days and 34 partly cloudy days. The occurrence of mold on the ends of firewood pieces in the solar kilns may have been a result of higher temperatures and/or higher relative humidities than in the control pile. Data on relative humidities were not collected. Mold can develop on green lumber in dry kilns. It is prevented by sterilizing with near 100 percent relative humidity at a temperature of 130 °F or higher for 1 hour (Rasmussen 1961).

A simple, temporary solar kiln fashioned by covering a pile of firewood with polyethylene as was done in this study was not effective in reducing the moisture content of unsplit birch firewood below that of a covered control pile during a single summer. Others (Baker and others 1977, Wengert 1979) have suggested that a solar wood dryer built from polyethylene attached to a frame around a stack of wood is effective. Based on our observations, the only way to maintain high temperatures and avoid high humidities in the early stages of drying would be to have the stack of wood occupy much less space within the dryer or kiln or to add solar collectors and a system of fans. This means a more complex structure far more expensive in time and material than envisioned in our original design.

As in all case studies, the lack of replications limits the statistical validity of some of the conclusions. Because of the apparent ineffectiveness, we do not plan further research with this type of kiln.

Recommendations

For most types of firewood in interior Alaska, a waterproof top covering the stack is the most expense that can be economically justified. In Fairbanks, firewood stacked in piles 5 feet high would intercept the precipitation equivalent of 110 gallons of water per cord during June, July, August, and September of the average year (based on local climatological data). This amounts to more than half the volume of water that would be lost from a cord of birch from green wood to 15 percent moisture content. The actual effect of precipitation on drying of firewood is compounded by other factors. The bark of paper birch is almost waterproof, so theoretically, unsplit birch firewood would be little affected by wetting from the top. Split birch is subject to wetting from precipitation. Therefore, firewood piles should have a top cover to prevent rain or snow from entering the pile.

Our limited sample of two severed trees left to dry with limbs intact indicate that this method is less effective in producing dry paper birch at the end of the season than is cutting to length and stacking at the time of felling. Where wood is to be hauled a long distance before cutting to length, transport costs might be reduced by letting the trees dry before they are limbed and bucked. A study of moisture loss from felled eastern hardwoods showed that felling the trees and leaving the crowns intact resulted in a 5- to 10-percent reduction of moisture content in less than 7 days (Garrett 1983).

Metric Equivalents

1 mil = 0.00254 centimeter
1 inch = 2.54 centimeters
1 foot = 0.3048 meter
°F = 1.8 (°C) + 32
1 British thermal unit (Btu) = 1055 joules
1 cord = 3.625 cubic meters of stacked wood

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Research Note
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Botanical Reconnaissance of Meeks Table Research Natural Area, Washington

Reid Schuller and Shelley Evans

Abstract

A floristic survey of Meeks Table Research Natural Area in the Wenatchee National Forest, Washington, documents 159 vascular plant taxa representing 39 families. This paper provides estimates of abundance by plant community or by other habitat characteristics for all taxa listed. Plant communities are described and mapped based on current vegetation.

Keywords: Communities (plant), vascular plants, checklist (vascular plants), Res. Nat. Area—Meeks Table, Meeks Table Res. Nat. Area.

Environment

Meeks Table Research Natural Area (RNA) occupies a 27-ha tract along the eastern slopes of the Cascade Range in southern Washington. The RNA is in Yakima County within portions of sections 5 and 6, T. 15 N., R. 14 E., Willamette Meridian. It is administered by the Naches Ranger District, Wenatchee National Forest.

Meeks Table is an isolated, flat-topped butte that slopes gently eastward from its 1380-m summit to 1280 m, the lowest point within the RNA. The butte is a remnant of a basalt plateau that rose 150 m above the adjacent rolling terrain. Meeks Table is surrounded by 60- to 90-m, near-vertical cliffs that drop into long talus slopes (Franklin and others 1972).

The climate is modified continental. Winter temperatures are cool to cold. A major portion of the average annual precipitation falls as snow from October to March; in some places, snowfall persists into May. Spring rains typically give way to a warm-to-hot, dry period from July through August. Less than 10 percent of the average annual precipitation occurs during this period (Donaldson 1979, Franklin and Dyrness 1973).

Soils are partially described by Rummell (1951) and are further characterized by Tiedemann and Klock (1977). The soils beneath the forest overstory are weakly podzolized and have developed over buried soils in approximately 20 cm of volcanic ash. Nonforested areas support either a nonpodzolized shallow soil with biscuit-and-swale topography or wind-scoured barrens with negligible soil development.

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Community Types

Vegetation of Meeks Table has been described (Rummell 1951, Tiedemann and others 1972) and has been sampled and mapped (Tiedemann and Klock 1977). Boundaries for community types were adapted from Tiedemann and Klock (1977); however, names for community types have been changed from those appearing in Tiedemann and Klock (1977) for two reasons: First, three of their community types included *Artemisia rigida* (Nutt.) Gray in the community nomenclature. This species is not present on Meeks Table. *Artemisia arbuscula* Nutt. var. *arbuscula* is the major shrub species in areas that were previously mapped as *Artemisia rigida* community types (Tiedemann and Klock 1977). Second, community nomenclature has also been revised to reflect the current naming conventions used by the Pacific Northwest Region of the USDA Forest Service (Williams and Lillybridge 1983). A virgule (/) separates members of different life forms (trees, shrubs, herbs), and a hyphen (–) separates members of the same life form. Community types are described by the dominant overstory species in combination with a dominant understory species regardless of life form. Therefore, only two life forms are represented in the designation of community type rather than three, as used by Tiedemann and Klock (1977). Five communities are distinguishable at Meeks Table (fig. 1).

The *Artemisia arbuscula-Eriogonum douglasii/Poa secunda* community occupies 3 ha along the rocky southern exposure of Meeks Table (fig. 2). It is equivalent to the *Artemisia rigida/Poa sandbergii/Eriogonum douglasii* community described by Tiedemann and Klock (1977). *Artemisia arbuscula, Eriogonum douglasii,* and *Purshia tridentata* alternate codominance within the shrub layer. *Poa secunda* has the highest cover and frequency within the herbaceous layer.

The *Artemisia arbuscula/Sedum stenopetalum* community occupies 11 ha of the central and northern portions of Meeks Table (fig. 3). This community has been described by Tiedemann and Klock (1977) as *Artemisia rigida/Stipa occidentalis/ Phlox diffusa*. *Artemisia arbuscula* is the most common shrub, although it accounts for less that 5 percent of the canopy cover. *Sedum stenopetalum* is the most abundant herb; it averages 5 percent cover and 100 percent frequency throughout the community (Tiedemann and Klock 1977). Grasses such as *Stipa occidentalis* var. *minor* and *Danthonia unispicata* are present throughout, but at low cover values.

The *Artemisia arbuscula/Stipa occidentalis* var. *minor* community occupies a 1-ha area along the northern rim of Meeks Table (fig. 4). Tiedemann and Klock (1977) refer to this area as the *Artemisia rigida/Stipa occidentalis/Phlox diffusa* community. *Artemisia arbuscula* dominates the shrub layer and *Stipa occidentalis* var. *minor* is an abundant and conspicuous component of the herb layer. Other grasses such as *Danthonia intermedia* and *Poa secunda* are common locally within this community.

The *Pinus ponderosa/Calamagrostis rubescens* community occupies 7 ha of the central and southern portions of Meeks Table (fig. 5). This community is described by Tiedemann and Klock (1977) as *Pinus ponderosa/Calamagrostis rubescens/ Lupinus laxiflorus*. *Pinus ponderosa* is the major overstory tree, but size-class distribution suggests that *Pseudotsuga menziesii* will gradually attain a dominant position in most of this community in the absence of fire or other natural disturbance. *Calamagrostis rubescens* is abundant throughout the herbaceous layer and often accounts for 50 percent of cover. *Lupinus laxiflorus* var. *laxiflorus* is also abundant and accounts for 10 percent of cover in the herb layer.

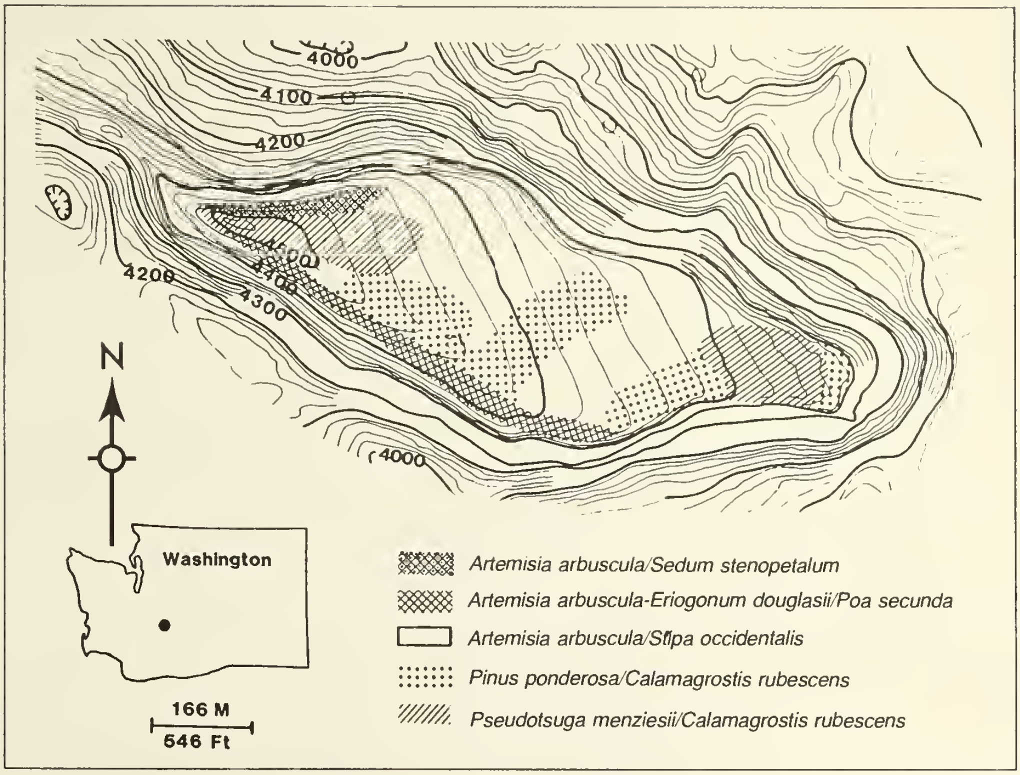

Figure 1—Plant communities at Meeks Table Research Natural Area, Washington.

Figure 2—*Artemisia arbuscula-Eriogonum douglasii/Poa secunda* community at Meeks Table Research Natural Area, Washington.

Figure 3—*Artemesia arbuscula/Sedum stenopetalum* community at Meeks Table Research Natural Area, Washington.

Figure 4—*Artemisia arbuscula/Stipa occidentalis* var. *minor* community at Meeks Table Research Natural Area, Washington.

Figure 5—*Pinus ponderosa/Calamagrostis rubescens* community at Meeks Table Research Natural Area, Washington.

The *Pseudotsuga menziesii/Calamagrostis rubescens* community occupies 6 ha along the eastern and western ends of Meeks Table. Tiedemann and Klock (1977) describe these areas as *Abies grandis/Calamagrostis rubescens/Arnica cordifolia*. These areas are currently dominated by *Pinus ponderosa* with *Pseudotsuga menziesii* as a minor associate in the tree canopy. *Abies grandis* and *Pseudotsuga menziesii* account for a disproportionately large amount of the density in smaller size classes. This suggests eventual replacement of or codominance with *Pinus ponderosa* in the absence of fire or other natural disturbance. This community also contains the greatest diversity of tree species at Meeks Table; it supports moderate amounts of *Larix occidentalis* and an occasional *Pinus contorta* and *Picea engelmannii*. Understory species are dominated by *Calamagrostis rubescens, Carex geyeri,* and *Arnica cordifolia*. Shrubs play a very minor role in the physiognomy and composition of this community.

Methods

A botanical reconnaissance was conducted on single-day visits during June, July, and September 1983 and during April, May, June, August, and October 1984. All communities on Meeks Table were inspected on at least two separate occasions. Specimens were identified primarily in the field. Difficult determinations were made from voucher specimens and were compared with specimens at the C. Leo Hitchcock Herbarium, University of Washington, Seattle. Voucher specimens of *Artemisia arbuscula* were determined by and are deposited in the Marion Ownbey Herbarium, Washington State University, Pullman.

Botanical nomenclature follows Hitchcock and Cronquist (1973) except for the use of *Poa secunda* Presl in preference to *Poa sandbergii* Vasey (Arnow 1981). Hitchcock and others (1955, 1959, 1961, 1964, 1969) were used as references throughout the project.

Within each plant community, abundance was estimated visually by using ordinal ranking: rare, infrequent, occasional, common, and abundant. Families are arranged alphabetically, as are genera and species.

A total of 159 vascular plant taxa representing 39 families are listed in the appendix. Table 1 indicates the number of taxa within each family represented in the RNA. Table 2 indicates the presence or absence of each taxon in the five plant communities described earlier and illustrated in figure 1.

Table 1—Vascular plant families and number of taxa in Meeks Table Research Natural Area

Family	Number of taxa
Aceraceae	1
Apiaceae	10
Asteraceae	29
Berberidaceae	1
Boraginaceae	1
Brassicaceae	2
Caprifoliaceae	1
Caryophyllaceae	6
Celastraceae	1
Crassulaceae	3
Cupressaceae	1
Cyperaceae	2
Ericaceae	5
Fabaceae	2
Gentianaceae	1
Grossulariaceae	2
Hydrangeaceae	1
Hydrophyllaceae	4
Iridaceae	1
Liliaceae	7
Loranthaceae	1
Onagraceae	2
Orchidaceae	4
Orobanchaceae	1
Pinaceae	6
Poaceae	19
Polemoniaceae	4
Polygonaceae	6
Polypodiaceae	1
Portulacaceae	2
Primulaceae	1
Ranunculaceae	3
Rhamnaceae	1
Rosaceae	10
Rubiaceae	1
Salicaceae	1
Saxifragaceae	3
Scrophulariaceae	10
Violaceae	2

Table 2—Presence or absence of vascular plant taxa within 5 plant communities in Meeks Table Research Natural Area

Species	Plant communities: *Artemisia arbuscula*-*Eriogonum douglasii*/*Poa secunda*	*Artemisia arbuscula*/*Sedum stenopetalum*	*Artemisia arbuscula*/*Stipa occidentalis* var. *minor*	*Pinus ponderosa*/*Calamagrostis rubescens*	*Pseudotsuga menziesii*/*Calamagrostis rubescens*	Other 1/
Abies grandis					X	
Acer glabrum						X
Achillea millefolium	X	X	X	X	X	
Agoseris aurantiaca						X
Agoseris glauca	X	X	X			
Agoseris heterophylla			X			
Agropyron spicatum						X
Agrostis exarata	X					
Allium acuminatum	X	X	X			
Amelanchier alnifolia					X	
Anaphalis margaritacea			X	X		
Antennaria dimorpha	X	X	X			
Antennaria flagellaris	X	X	X			
Antennaria luzuloides		X	X			
Antennaria microphylla	X	X	X	X	X	
Antennaria racemosa		X	X			
Arabis divaricarpa	X	X	X			
Arabis sparsiflora	X	X	X			
Arceuthobium douglasii					X	
Arctostaphylos nevadensis	X					X
Arctostaphylos uva-ursi	X		X			
Arenaria congesta var. *congesta*	X	X	X			
Arenaria congesta var. *prolifera*	X	X	X			
Arenaria macrophylla	X	X	X	X	X	
Arnica cordifolia				X	X	
Arnica fulgens			X		X	
Artemisia arbuscula	X	X	X			
Balsamorhiza careyana	X	X	X			
Balsamorhiza sagitatta						X
Berberis repens						X
Bromus carinatus			X	X	X	
Bromus tectorum	X					
Calamagrostis rubescens			X	X	X	
Calochortus macrocarpus						X
Calypso bulbosa				X	X	
Carex geyeri	X	X	X	X	X	
Castilleja miniata			X			
Castilleja thompsonii	X	X	X			
Ceanothus velutinus				X		
Chimaphila umbellata					X	
Claytonia lanceolata		X				
Collinsia parviflora	X	X	X	X	X	
Collomia grandiflora						X
Corallorhiza maculata				X		
Cordylanthus capitatus	X		X			
Crepis intermedia			X			
Cryptantha torreyana	X	X	X	X		
Cystopteris fragilis		X				X
Danthonia intermedia		X		X	X	
Danthonia unispicata	X	X	X			
Delphinium nuttallianum		X				
Dodecatheon cf *conjugens*						X

See footnote at end of table.

Table 2—Presence or absence of vascular plant taxa within 5 plant communities in Meeks Table Research Natural Area (continued)

Species	Plant communities					
	Artemisia arbuscula-Eriogonum douglasii/Poa secunda	Artemisia arbuscula/Sedum stenopetalum	Artemisia arbuscula/Stipa occidentalis var. minor	Pinus ponderosa/Calamagrostis rubescens	Pseudotsuga menziesii/Calamagrostis rubescens	Other 1/
Epilobium angustifolium				X	X	
Epilobium cf minutum	X		X			
Erigeron bloomeri	X	X				
Erigeron linearis	X	X	X			
Eriogonum compositum	X	X	X			
Eriogonum douglasii	X	X	X			
Eriogonum elatum			X			
Eriogonum umbellatum						X
Erythronium grandiflorum		X		X	X	
Festuca idahoensis	X	X	X			
Festuca occidentalis				X		
Festuca octoflora	X		X			
Festuca ovina				X	X	
Frasera speciosa				X	X	
Fritillaria pudica			X	X		
Galium multiflorum	X					X
Geum triflorum		X	X	X		
Goodyera oblongifolia				X		
Habenaria unalascensis					X	
Haplopappus carthamoides		X	X			
Haplopappus lanuginosus		X	X			
Haplopappus resinosus						X
Haplopappus stenophyllus	X	X				
Hesperochiron pumilus				X		
Heuchera cylindrica		X	X			
Hieracium albiflorum			X	X	X	X
Hieracium cynoglossoides			X	X		
Holodiscus discolor				X	X	
Holosteum umbellatum						X
Hydrophyllum capitatum	X					
Juniperus communis						X
Koeleria cristata	X	X	X	X	X	
Larix occidentalis		X		X	X	
Lewisia rediviva	X					
Lilium columbianum				X	X	
Linanthus harknessii			X			
Lithophragma bulbifera	X	X	X			
Lomatium canbyi	X					
Lomatium dissectum	X	X	X			
Lomatium gormanii	X	X	X			
Lomatium grayi	X					
Lomatium macrocarpum	X	X	X			
Lomatium nudicaule	X	X	X	X		
Lomatium triternatum	X	X	X	X	X	
Lomatium watsonii	X					
Luina nardosmia					X	
Lupinus laxiflorus	X	X	X	X	X	
Lupinus polyphyllus					X	
Madia glomerata			X			
Melica bulbosa	X					
Microseris nutans						X
Microseris troximoides	X	X	X			
Microsteris gracilis	X					
Mitella pentandra					X	

See footnote at end of table.

Table 2—Presence or absence of vascular plant taxa within 5 plant communities in Meeks Table Research Natural Area (continued)

Species	Plant communities					
	Artemisia arbuscula-Eriogonum douglasii/Poa secunda	Artemisia arbuscula/Sedum stenopetalum	Artemisia arbuscula/Stipa occidentalis var. minor	Pinus ponderosa/Calamagrostis rubescens	Pseudotsuga menziesii/Calamagrostis rubescens	Other 1/
Orobanche corymbosa	X					
Osmorhiza chilensis					X	
Pachistima myrsinites				X	X	
Pedicularis racemosa var. alba		X				
Pedicularis racemosa var. racemosa				X	X	
Penstemon attenuatus					X	
Penstemon fruiticosus					X	
Penstemon gairdneri	X		X			
Penstemon richardsonii						X
Perideridia gairdneri				X	X	
Phacelia linearis	X					
Phacelia sericea			X			
Philadelphus lewisii						X
Phlox diffusa	X	X	X			
Picea engelmannii					X	
Pinus contorta					X	
Pinus ponderosa				X	X	
Poa nervosa			X	X	X	
Poa secunda	X	X	X			
Polygonum aviculare						X
Polygonum kelloggii	X	X	X			
Potentilla arguta	X			X		
Potentilla fruticosa			X			X
Potentilla gracilis		X				X
Prunus virginiana				X	X	
Pseudotsuga menziesii				X	X	
Pterospora andromedea				X	X	
Purshia tridentata	X		X			X
Ranunculus glaberrimus var. ellipticus						X
Ranunculus glaberrimus var. glaberrimus						X
Ribes cereum	X					
Ribes viscosissimum						X
Rosa gymnocarpa					X	
Salix scouleriana					X	
Sedum lanceolatum	X					
Sedum leibergii	X	X	X			
Sedum stenopetalum	X	X	X	X		
Senecio integerrimus		X			X	
Setaria viridis						X
Silene douglasii				X	X	
Silene oregana			X	X		
Sisyrinchium douglasii	X	X	X	X		
Sitanion hystrix	X	X	X			
Spiraea betulifolia					X	
Stipa lemmonii	X	X				
Stipa occidentalis	X	X	X			
Symphoricarpos oreophilus				X	X	
Vaccinium myrtillus					X	
Viola nuttallii						X
Viola trinervata	X	X	X			
Zigadenus paniculatus	X	X	X			
Zigadenus venenosus	X	X	X	X		

1/ Presence under "other" is discussed in the entry for the taxon in the appendix.

Acknowledgment

We gratefully acknowledge the timely and informed assistance provided us by Joy Mastroguisseppe, Curator of the Marion Ownbey Herbarium, Washington State University, Pullman.

English Equivalents

1 centimeter (cm)	= 0.4 inch
1 meter (m)	= 3.3 feet
1 kilometer (km)	= 0.6 mile
1 hectare (ha)	= 2.5 acres

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Appendix

Vascular Plants by Family and Plant Community

Aceraceae

Acer glabrum Torr. var. *douglasii* (Hook.) Dippel, Douglas' maple—rare to occasional on deeper soils within open to semiopen forest.

Apiaceae (Umbelliferae)

Lomatium canbyi Coult. & Rose, Canby's desert-parsley—rare along southern exposure of *Artemisia-Eriogonum/Poa* community.

Lomatium dissectum (Nutt.) Math. & Const. var. *dissectum,* fern-leaved lomatium—rare to occasional in *Artemisia* communities; also occasional along talus slopes extending off Meeks Table.

Lomatium gormanii (Howell) Coult. & Rose, Gorman's desert-parsley—rare in all *Artemisia* communities.

Lomatium grayi Coult. & Rose, Gray's lomatium—occasional in all *Artemisia* communities.

Lomatium macrocarpum (Nutt.) Coult. & Rose, large-fruit lomatium—common in *Artemisia-Eriogonum/Poa* community; rare to infrequent in *Artemisia/Sedum* and *Artemisia/Stipa* communities.

Lomatium nudicaule (Pursh) Coult. & Rose, barestem lomatium—occasional in all *Artemisia* communities; rare in *Pinus/Calamagrostis* community.

Lomatium triternatum (Pursh) Coult. & Rose var. *triternatum,* nine-leaf lomatium—occasional in all *Artemisia* communities and in forest communities.

Lomatium watsonii Coult. & Rose, Watson's desert-parsley—rare in *Artemisia-Eriogonum/Poa* community.

Osmorhiza chilensis H. & A., mountain sweet-cicely—rare to occasional in *Pseudotsuga/Calamagrostis* community.

Perideridia gairdneri (H. & A.) Math., Gairdner's yampah—rare to infrequent in *Pinus/Calamagrostis* and *Pseudotsuga/Calamagrostis* communities.

Asteraceae (Compositae)

Achillea millefolium L. ssp. *lanulosa* (Nutt.) Piper, western yarrow—common in *Pseudotsuga/Calamagrostis* community; rare to infrequent in *Pinus/Calamagrostis* and all *Artemisia* communities.

Agoseris aurantiaca (Hook.) Greene, orange agoseris—rare in transition areas between forest and *Artemisia* communities where soils are deep and tree canopies are open.

Agoseris glauca (Pursh) Raf., pale agoseris—rare to occasional in all *Artemisia* communities.

Agoseris heterophylla (Nutt.) Greene var. *heterophylla,* annual agoseris—occasional in *Artemisia/Stipa* community.

Anaphalis margaritacea (L.) B. & H., pearly everlasting—occasional in *Artemisia/Stipa* and *Pinus/Calamagrostis* communities, and along transition areas between forest communities and *Artemisia* communities.

Antennaria dimorpha (Nutt.) T. & G., low pussy-toes—occasional to common in all *Artemisia* communities.

Antennaria flagellaris Gray, stolonous everlasting—occasional in *Artemisia-Eriogonum/Poa* community; present in other *Artemisia* communities, but relative abundance not determined.

Antennaria luzuloides T. & G., woodrush pussy-toes—common in *Artemisia/Sedum* and *Artemisia/Stipa* communities.

Antennaria microphylla Rydb., rosy pussy-toes—infrequent in all *Artemisia* communities; rare in *Pinus/Calamagrostis* and *Pseudotsuga/Calamagrostis* communities.

Antennaria racemosa Hook., raceme pussy-toes—common in *Artemisia/Sedum* community; infrequent in *Artemisia/Stipa* community.

Arnica cordifolia Hook. var. *cordifolia,* heart-leaf arnica—abundant in *Pseudotsuga/Calamagrostis* community; common in *Pinus/Calamagrostis* community.

Arnica fulgens Pursh, orange arnica—rare in *Pseudotsuga/Calamagrostis* and *Artemisia/Stipa* communities.

Artemisia arbuscula Nutt. var. *arbuscula,* low sagebrush—abundant in all *Artemisia* communities.

Balsamorhiza careyana Gray var. *intermedia* Cronq., Carey's balsamroot—occasional to common in *Artemisia/Sedum* and *Artemisia/Stipa* communities; rare in *Artemisia-Eriogonum/Poa* community.

Balsamorhiza sagittata (Pursh) Nutt., arrowleaf balsamroot—rare along transition between *Artemisia* communities and forest communities.

Crepis intermedia Gray, gray hawksbeard—rare to infrequent in *Artemisia/Stipa* community.

Erigeron bloomeri Gray var. *bloomeri,* scabland fleabane—occasional in *Artemisia-Eriogonum/Poa* and *Artemisia/Sedum* communities.

Erigeron linearis (Hook.) Piper, desert yellow daisy—common in *Artemisia/Sedum* community; occasional in *Artemisia-Eriogonum/Poa* community; rare in *Artemisia/Stipa* community.

Haplopappus carthamoides (Hook.) Gray var. *cusickii* Gray, Columbia goldenweed—occasional in *Artemisia/Sedum* community; rare in *Artemisia/Stipa* community.

Haplopappus lanuginosus Gray var. *lanuginosus,* woolly goldenweed—common in *Artemisia/Stipa* community; rare in *Artemisia/Sedum* community.

Haplopappus resinosus (Nutt.) Gray, gnarled goldenweed—rare along access trail on ridge near west end of Meeks Table.

Haplopappus stenophyllus Gray, narrow-leaf goldenweed—common in *Artemisia-Eriogonum/Poa* community; rare in *Artemisia/Sedum* community.

Hieracium albiflorum Hook., white-flowered hawkweed—common in *Pinus/Calamagrostis* community; rare in *Pseudotsuga/Calamagrostis* community.

Hieracium cynoglossoides Arv.-Touv., houndstongue hawkweed—occasional in forest communities; rare in *Artemisia/Stipa* community and in transition to *Pinus/Calamagrostis* community.

Luina nardosmia (Gray) Cronq. var. *glabrata* (Piper) Cronq., silvercrown luina—common in *Pseudotsuga/Calamagrostis* community.

Madia glomerata Hook., cluster tarweed—occasional in *Artemisia/Stipa* community.

Microseris nutans (Geyer) Schultz-Bip., nodding microseris—rare in transition areas between *Artemisia* communities and forest communities.

Microseris troximoides Gray, false agoseris—common in *Artemisia/Stipa* community; occasional in *Artemisia/Sedum* community; rare in *Artemisia-Eriogonum/Poa* community.

Senecio integerrimus Nutt. var. *exaltatus* (Gray) Cronq., western groundsel—occasional in *Artemisia/Sedum* community; rare in *Pseudotsuga/Calamagrostis* community.

Berberidaceae

Berberis repens Lindl., low Oregon grape—rare in open areas with moderate soil development.

Boraginaceae

Cryptantha torreyana (Gray) Greene, Torrey's cryptantha—occasional in *Artemisia/Stipa* community; rare to infrequent in *Artemisia-Eriogonum/Poa* and *Artemisia/Sedum* communities; rare in *Pinus/Calamagrostis* community.

Brassicaceae (Cruciferae)

Arabis divaricarpa Nels., spreadingpod rockcress—rare in all *Artemisia* communities.

Arabis cf *sparsiflora* Nutt. var. *subvillosa* (Wats.) Rollins, elegant rockcress—rare in all *Artemisia* communities.

Caprifoliaceae

Symphoricarpos oreophilus Gray var. *utahensis* (Rydb.) A. Nels., mountain snowberry—rare in forest communities.

Caryophyllaceae

Arenaria congesta Nutt. var. *congesta,* ballhead sandwort—rare in all *Artemisia* communities.

Arenaria congesta Nutt. var. *prolifera* Maguire, ballhead sandwort—occasional in *Artemisia-Eriogonum/Poa* community; common in *Artemisia/Sedum* and *Artemisia/Stipa* communities.

Arenaria macrophylla Hook., bigleaf sandwort—occasional in *Pinus/Calamagrostis* and *Pseudotsuga/Calamagrostis* communities; rare in all *Artemisia* communities.

Holosteum umbellatum L., jagged chickweed—occasional on south-facing slope immediately below ridge crest of Meeks Table.

Silene douglasii Hook. var. *douglasii,* Douglas' silene—rare in openings within forest communities.

Silene oregana Wats., Oregon silene—rare in *Artemisia/Stipa* and *Pinus/Calamagrostis* communities.

Celastraceae

Pachistima myrsinites (Pursh) Raf., mountain boxwood—rare in forest communities.

Crassulaceae

Sedum lanceolatum Torr. var. *lanceolatum,* lanceleaved stonecrop—rare in *Artemisia-Eriogonum/Poa* community.

Sedum leibergii Britt., Leiberg's stonecrop—occasional to common in all *Artemisia* communities.

Sedum stenopetalum Pursh, wormleaf stonecrop—abundant in *Artemisia/Sedum* community; common in *Artemisia/Stipa* community; occasional in *Artemisia-Eriogonum/Poa* community; rare in *Pinus/Calamagrostis* community.

Cupressaceae

Juniperus communis L. var. *montana* Ait., mountain juniper—rare in open areas with moderate soil development along east end of Meeks Table.

Cyperaceae

Carex geyeri Boott, elk sedge—abundant in forest communities; occasional in all *Artemisia* communities.

Carex rossii Boott, Ross sedge—reported by Rummell (1951) as occurring in *Pseudotsuga/Calamagrostis* community; not observed in 1983 or 1984.

Ericaceae

Arctostaphylos nevadensis Gray, pinemat manzanita—infrequent along transition between forest communities and *Artemisia-Eriogonum/Poa* and *Artemisia/Stipa* communities; rare in *Artemisia-Eriogonum/Poa* community.

Arctostaphylos uva-ursi (L.) Spreng., kinnikinnik—occasional in *Artemisia-Eriogonum/Poa* and *Artemisia/Stipa* communities.

Chimaphila umbellata (L.) Bart. var. *occidentalis* (Rydb.) Blake, prince's-pine—occasional in *Pseudotsuga/Calamagrostis* community.

Pterospora andromedea Nutt., woodland pinedrops—occasional in *Pinus/Calamagrostis* community; rare in *Pseudotsuga/Calamagrostis* community.

Vaccinium myrtillus L., low bilberry—rare in *Pseudotsuga/Calamagrostis* community.

Fabaceae (Leguminosae)

Lupinus laxiflorus Dougl. var. *laxiflorus,* spurred lupine—abundant in *Pinus/Calamagrostis* community; common in *Artemisia/Sedum* community; occasional in *Pseudotsuga/Calamagrostis* and *Artemisia/Stipa* communities; rare in *Artemisia-Eriogonum/Poa* community.

Lupinus polyphyllus Lindl. var. *burkei* (Wats.) Hitchc., bigleaf lupine—rare in *Pseudotsuga/Calamagrostis* community.

Gentianaceae

Frasera speciosa Dougl., giant frasera—occasional in forest communities.

Grossulariaceae

Ribes cereum Dougl. var. *cereum,* squaw currant—occasional in *Artemisia-Eriogonum/Poa* community.

Ribes viscosissimum Pursh var. *viscosissimum,* sticky currant—rare in transition area between *Pinus/Calamagrostis* and *Artemisia* communities.

Hydrangeaceae

Philadelphus lewisii Pursh, mock orange—occasional along upper slopes of Meeks Table.

Hydrophyllaceae

Hesperochiron pumilus (Griseb.) Porter, dwarf hesperochiron—reported to occur in *Pinus/Calamagrostis* community.

Hydrophyllum capitatum Dougl. var. *capitatum*, ballhead waterleaf—rare in *Artemisia-Eriogonum/Poa* community.

Phacelia linearis (Pursh) Holz., threadleaf phacelia—occasional in *Artemisia-Eriogonum/Poa* community.

Phacelia sericea (Grah.) Gray, silky phacelia—occasional in *Artemisia/Stipa* community.

Iridaceae

Sisyrinchium douglasii A. Dietr., grass-widows—occasional in *Artemisia/Sedum* and *Artemisia/Stipa* communities; infrequent in *Artemisia-Eriogonum/Poa* and *Pinus/Calamagrostis* communities.

Liliaceae

Allium acuminatum Hook., tapertip onion—occasional in all *Artemisia* communities.

Calochortus macrocarpus Dougl., sagebrush mariposa—rare in transition areas between forest communities and *Artemisia* communities.

Erythronium grandiflorum Pursh var. *grandiflorum*, pale fawn-lily—occasional in *Artemisia/Sedum*, *Pinus/Calamagrostis*, and *Pseudotsuga/Calamagrostis* communities.

Fritillaria pudica (Pursh) Spreng., yellow bell—occasional in *Pinus/Calamagrostis* community; rare in *Artemisia/Stipa* community.

Lilium columbianum Hanson, tiger lily—common in *Pseudotsuga/Calamagrostis* community; occasional in *Pinus/Calamagrostis* community.

Zigadenus paniculatus (Nutt.) Wats., panicled death-camas—common in all *Artemisia* communities.

Zigadenus venenosus Wats. var. *gramineus* (Rydb.) Walsh, meadow death-camas—rare in all *Artemisia* communities and in *Pinus/Calamagrostis* community.

Loranthaceae

Arceuthobium douglasii Engelm., Douglas dwarf mistletoe—rare in *Pseudotsuga/Calamagrostis* community.

Onagraceae

Epilobium cf *minutum* Lindl., small-flowered willowweed—rare in *Artemisia-Eriogonum/Poa* and *Artemisia/Stipa* communities.

Epilobium angustifolium L., fireweed—occasional in *Pseudotsuga/Calamagrostis* community; rare in *Pinus/Calamagrostis* community.

Orchidaceae

Calypso bulbosa (L.) Oakes, fairy slipper—rare in forest communities.

Corallorhiza maculata Raf., Pacific coralroot—rare in *Pinus/Calamagrostis* community.

Goodyera oblongifolia Raf., western rattlesnake-plantain—rare in *Pinus/Calamagrostis* community.

Habenaria unalascensis (Spreng.) Wats., Alaska rein-orchid—occasional in *Pseudotsuga/Calamagrostis* community.

Orobanchaceae

Orobanche corymbosa (Rydb.) Ferris, flat-topped broomrape—rare in *Artemisia-Eriogonum/Poa* community.

Pinaceae

Abies grandis (Dougl.) Forbes, grand fir—common in *Pseudotsuga/Calamagrostis* community.

Larix occidentalis Nutt., western larch—common in *Pseudotsuga/Calamagrostis* community; rare in *Pinus/Calamagrostis* and *Artemisia/Sedum* communities.

Picea engelmannii Parry, Engelmann spruce—rare in *Pseudotsuga/Calamagrostis* community.

Pinus contorta Dougl. var. *latifolia* Engelm., lodgepole pine—rare in *Pseudotsuga/Calamagrostis* community.

Pinus ponderosa Dougl., ponderosa pine—abundant in *Pinus/Calamagrostis* community; common in *Pseudotsuga/Calamagrostis* community.

Pseudotsuga menziesii (Franco) Mirbel var. *menziesii,* Douglas-fir—abundant in *Pseudotsuga/Calamagrostis* community; common in *Pinus/Calamagrostis* community except along transition into *Artemisia/Stipa* community.

Poaceae (Gramineae)

Agropyron spicatum (Pursh) Scribn. & Smith, bluebunch wheatgrass—rare along south-facing slope immediately below Meeks Table and in *Artemisia-Eriogonum/Poa* community.

Agrostis exarata Trin. var. *monolepsis* (Torr.) Hitchc., spike bentgrass—rare beneath *Purshia tridentata* within *Artemisia-Eriogonum/Poa* community.

Bromus carinatus H. & A. var. *carinatus,* California brome—occasional in forest communities; rare in *Artemisia/Stipa* community.

Bromus tectorum L., cheatgrass—occasional in *Artemisia-Eriogonum/Poa* community.

Calamagrostis rubescens Buckl., pinegrass—abundant in forest communities; rare in *Artemisia/Stipa* community.

Danthonia intermedia Vasey, timber danthonia—occasional in *Artemisia/Sedum* community; rare in forest communities.

Danthonia unispicata (Thurb.) Munro, onespike oatgrass—occasional in *Artemisia/Sedum* community; rare in *Artemisia/Stipa* and *Artemisia-Eriogonum/Poa* communities.

Festuca idahoensis Elmer var. *idahoensis,* Idaho fescue—rare in all *Artemisia* communities.

Festuca occidentalis Hook., western fescue—rare in openings in *Pinus/Calamagrostis* community.

Festuca octoflora Walt. var. *octoflora,* slender fescue—rare in *Artemisia-Eriogonum/Poa* and *Artemisia/Sedum* communities.

Festuca ovina L. var. *rydbergii* St.-Yves, sheep fescue—occasional in *Pseudotsuga/Calamagrostis* community; rare in *Pinus/Calamagrostis* community.

Koeleria cristata Pers., junegrass—occasional in *Pseudotsuga/Calamagrostis* community; rare in *Pinus/Calamagrostis* and all *Artemisia* communities.

Melica bulbosa Geter, oniongrass—occasional beneath *Purshia tridentata* within *Artemisia-Eriogonum/Poa* community.

Poa nervosa (Hook.) Vasey var. *wheeleri* (Vasey) Hitchc., Wheeler's bluegrass—occasional in forest communities and in *Artemisia/Stipa* community.

Poa secunda Presl, Sandberg's bluegrass—abundant in *Artemisia-Eriogonum/Poa* community; common in *Artemisia/Sedum* and *Artemisia/Stipa* communities.

Setaria viridis (L.) Beauv., green bristlegrass—rare along south slopes and ridge access trail to Meeks Table.

Sitanion hystrix (Nutt.) Smith var. *hordeoides* (Suksd.) Hitchc., bottlebrush squirreltail—occasional in *Artemisia-Eriogonum/Poa* and *Artemisia/Stipa* communities; rare in *Artemisia/Sedum* community.

Stipa lemmonii (Vasey) Scribn. var. *lemmonii,* Lemon's needlegrass—rare in *Artemisia-Eriogonum/Poa* and *Artemisia/Stipa* communities.

Stipa occidentalis Thurb. var. *minor* (Vasey) Hitchc., Columbia needlegrass—abundant in *Artemisia/Stipa* community; occasional in *Artemisia/Sedum* and *Artemisia-Eriogonum/Poa* communities.

Polemoniaceae

Collomia grandiflora Dougl., large-flowered collomia—rare in transition areas between *Pinus/Calamagrostis* community and *Artemisia/Stipa* and *Artemisia-Eriogonum/Poa* communities.

Linanthus harknessii (Curran) Greene, Harkness' linanthus—occasional in *Artemisia/Stipa* community.

Microsteris gracilis (Hook.) Greene var. *humilior* (Hook.) Cronq., pink microsteris—occasional in *Artemisia-Eriogonum/Poa* community.

Phlox diffusa Benth. var. *longistylis* (Wherry) Peck, spreading phlox—common in *Artemisia/Stipa* community; occasional in *Artemisia/Sedum* and *Artemisia-Eriogonum/Poa* communities.

Polygonaceae

Eriogonum compositum Dougl. var. *compositum,* northern buckwheat—occasional in *Artemisia-Eriogonum/Poa* community; rare in *Artemisia/Sedum* and *Artemisia/Stipa* communities.

Eriogonum douglasii Benth. var. *douglasii,* Douglas' buckwheat—abundant in *Artemisia-Eriogonum/Poa* community; occasional in *Artemisia/Sedum* and *Artemisia/Stipa* communities.

Eriogonum elatum Dougl., tall buckwheat—rare in *Artemisia/Stipa* community.

Eriogonum umbellatum Torr. var. *umbellatum,* sulfur buckwheat—rare in shallow soil along east end of Meeks Table.

Polygonum aviculare L., doorweed—rare along ridge access trail and within old fire pit.

Polygonum kelloggii Greene, Kellogg's knotweed—occasional in *Artemisia/Sedum* and *Artemisia/Stipa* communities; rare in *Artemisia-Eriogonum/Poa* community.

Polypodiaceae

Cystopteris fragilis (L.) Bernh., brittle bladder-fern—occasional in *Artemisia/Sedum* community and in rock crevices and ledges immediately below ridge crest of Meeks Table.

Portulacaceae

Claytonia lanceolata Pursh var. *lanceolata,* western springbeauty—occasional in *Artemisia/Sedum* community.

Lewisia rediviva Pursh, bitterroot—occasional to common in *Artemisia-Eriogonum/Poa* community.

Primulaceae

Dodecatheon cf *conjugens* Greene, slimpod shooting star—rare in transition area between *Pseudotsuga/Calamagrostis* and *Artemisia/Sedum* communities.

Ranunculaceae

Delphinium nuttallianum Pritz. var. *nuttallianum,* upland larkspur—occasional in *Artemisia-Eriogonum/Poa* community.

Ranunculus glaberrimus Hook. var. *ellipticus* Greene, sagebrush buttercup—occasional along transition areas between forest communities and *Artemisia* communities.

Ranunculus glaberrimus Hook. var. *glaberrimus,* sagebrush buttercup—occasional along transition areas between forest communities and *Artemisia* communities.

Rhamnaceae

Ceanothus velutinus Dougl. var. *velutinus,* sticky laurel—rare in openings within *Pinus/Calamagrostis* community.

Rosaceae

Amelanchier alnifolia Nutt. var. *cusickii* (Fern.) Hitchc., western serviceberry—rare in *Pseudotsuga/Calamagrostis* community.

Geum triflorum Pursh var. *ciliatum* (Pursh) Fassett, old man's whiskers—common in *Artemisia/Sedum* and *Artemisia/Stipa* communities; occasional in *Pinus/Calamagrostis* community.

Holodiscus discolor (Pursh) Maxim., creambush oceanspray—common in *Pseudotsuga/Calamagrostis* community; rare in *Pinus/Calamagrostis* community.

Potentilla arguta Pursh var. *convallaria* (Rydb.) Wolf, tall cinquefoil—occasional in *Artemisia-Eriogonum/Poa* community; rare in *Pinus/Calamagrostis* community.

Potentilla fruticosa L., shrubby cinquefoil—occasional in *Artemisia/Stipa* community and in nonforested areas along east end of Meeks Table.

Potentilla gracilis Dougl. var. *flabelliformis* (Lehm.) Nutt., cinquefoil—rare in *Artemisia/Sedum* community and on north-facing slope immediately below summit of Meeks Table.

Prunus virginiana L. var. *melanocarpa* (Nels.) Sarg., chokecherry—rare in openings within forest communities.

Purshia tridentata (Pursh) DC., bitterbrush—common along east end of Meeks Table; occasional to common in *Artemisia-Eriogonum/Poa* community; rare in *Artemisia/Stipa* community.

Rosa gymnocarpa Nutt., baldhip rose—rare in openings within *Pseudotsuga/Calamagrostis* community.

Spiraea betulifolia Pall. var. *lucida* (Dougl.) Hitchc., shiny-leaf spiraea—occasional in *Pseudotsuga/Calamagrostis* community.

Rubiaceae

Galium multiflorum Kell., shrubby bedstraw—occasional in *Artemisia-Eriogonum/Poa* community and along south-facing slope immediately below ridge crest of Meeks Table.

Salicaceae

Salix scouleriana Barrett, Scouler willow—rare in *Pseudotsuga/Calamagrostis* community.

Saxifragaceae

Heuchera cylindrica Dougl., roundleaf alumroot—occasional in *Artemisia/Sedum* and *Artemisia/Stipa* communities and along north-facing slopes immediately below ridge crest of Meeks Table.

Lithophragma bulbifera Rydb., rocketstar—rare in all *Artemisia* communities.

Mitella pentandra Hook., alpine mitrewort—occasional in *Pseudotsuga/Calamagrostis* communities.

Scrophulariaceae

Castilleja miniata Dougl. var. *miniata,* common paintbrush—occasional in *Artemisia/Stipa* community.

Castilleja thompsonii Pennell, Thompson's paintbrush—occasional in all *Artemisia* communities.

Collinsia parviflora Lindl., small-flowered blue-eyed Mary—occasional in *Artemisia/Sedum* and *Artemisia/Stipa* communities; rare in *Artemisia-Eriogonum/Poa* and forest communities.

Cordylanthus capitatus Nutt., Yakima birdbeak—occasional in *Artemisia/Stipa* community; rare in *Artemisia-Eriogonum/Poa* community; population abundance fluctuates greatly from year to year.

Pedicularis racemosa Dougl. var. *alba* (Pennell) Cronq., sickletop lousewort—rare in *Artemisia/Sedum* community.

Pedicularis racemosa Dougl. var *racemosa,* sickletop lousewort—rare in openings within forest communities.

Penstemon attenuatus Dougl. var. *attenuatus,* sulfur penstemon—occasional in *Pseudotsuga/Calamagrostis* communities.

Penstemon fruiticosus (Pursh) Greene var. *fruiticosus,* shrubby penstemon—rare in *Pseudotsuga/Calamagrostis* community.

Penstemon gairdneri Hook. var. *gairdneri,* Gairdner's penstemon—occasional to common in *Artemisia-Eriogonum/Poa* community; rare in *Artemisia/Stipa* community.

Penstemon richardsonii Dougl. var. *richardsonii,* Richard's penstemon—rare in unforested areas along east end of Meeks Table.

Violaceae

Viola nuttallii Pursh var. cf *bakeri* (Greene) Hitchc., Baker violet—rare along transition areas between *Pinus/Calamagrostis* community and *Artemisia* communities.

Viola trinervata Howell, sagebrush violet—rare to occasional in all *Artemisia* communities.

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Effects of Site Preparation on Seedling Growth: A Preliminary Comparison of Broadcast Burning and Pile Burning

Don Minore

Abstract

Site preparation is often necessary to obtain adequate forest regeneration, but inappropriate treatment may reduce subsequent growth. Broadcast-burned and piled-and-burned plantations were studied in southwestern Oregon to determine if burning method affected the growth of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*). The measured and potential heights of 5-year-old seedlings were about equal where broadcast burning occurred, but measured heights were less than potential heights on most of the piled-and-burned plantations. Site quality probably is damaged by piling and burning.

Keywords: Site preparation (-regeneration, seedling growth, plantations.

Introduction

Site preparation is desirable and necessary to establish conifer regeneration on most sites in Oregon (Stewart 1978). The environmental modification resulting from that site preparation usually benefits seedling survival, and higher stocking levels usually are achieved (Wilhite 1981). The environmental conditions that favor high stocking levels are not necessarily the same as the conditions that favor vigorous seedling growth, however, and seedling growth may be reduced if inappropriate site-preparation treatments are applied.

Windrowing of slash is sometimes an inappropriate site-preparation treatment. It reduced the growth of loblolly pine between windrows where topsoil had been removed by rootraking in North Carolina (Glass 1976). A similar windrowing effect occurred in northern California with white fir (*Abies concolor* var. *lowiana* (Gord.) Lemm.), despite attempts to respread the windrows, and even though brush competition was greater in the windrows than between them, where topsoil had been removed (Nakamura 1985). The removal of topsoil, litter, and humus is a major loss to the site that can have long-term negative effects on productivity (Austin and Baisinger 1955, Terry and Campbell 1981). Such loss is not limited to windrowing; it also occurs during several other site-preparation treatments.

Soil compaction occurs during several site-preparation treatments. Compaction may sometimes be beneficial where moisture is limiting and aeration is adequate (Lull 1959), and moderate compaction may not seriously affect plant nutrient status where moisture conditions remain satisfactory in fertile soils (Kemper and others 1971). Soil compaction is detrimental under most conditions, however, and the compaction that occurs during logging and slash disposal has a negative effect on

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most sites. It reduces water infiltration (Tackle 1962), increases soil strength, and impedes root penetration (Heilman 1981, Minore and others 1969, Taylor and Burnett 1964), and reduces seedling growth (Foil and Ralston 1967, Steinbrenner and Gessel 1956). The major effect of compaction on tree growth appears to occur during the first 10 to 30 years (Power 1974), but severely affected soils may not recover for 30 to 40 years or longer (Perry 1964, Power 1974, Wert and Thomas 1981).

The effects of slash burning do not seem to last as long as the effects of soil compaction. Severely burned areas are difficult to regenerate (Stewart 1978), however, and poor seedling growth has been associated with heavily burned soils (Baker 1968). Burning decreases the subsequent number of mycorrhizae on Douglas-fir seedlings (Wright 1971), but the resulting ash acts like a slow-release fertilizer on deep soils with sufficient cation-exchange capacity to absorb the nutrients that are released (Stark 1979). The direct effects of burning logging slash are usually confined to the top 5 cm (2 in) of soil depth (Austin and Baisinger 1955). Fertile, usually moist soils are less damaged by fire than infertile, dry soils (Jablanczy 1964).

Soil fertility, moisture, and drainage influence the effects of site preparation, and differences among site preparation treatments are often obscured by differences in site quality when those treatments are compared. For example, plant response to soil compaction varies with soil type, plant species, and climate (Rosenberg 1964), and the effects of compaction on nutrient uptake vary with fertility, root distribution, and moisture and aeration regimes (Parish 1971). Harvest intensity and slash removal tend to have greater effects on seedling growth and mortality where productivity is low than they do where productivity is high (Bigger and Cole 1983). Variation within a given treatment is also influenced by productivity of the site because among-plot variability in soil properties tends to be higher on high sites than it is on low sites (Courtin and others 1983).

Commonly used site-preparation treatments are almost as variable as the sites on which they are applied. Most clearcut areas are yarded by cable or tractor, but these yarding methods are combined with subsequent slash treatments that include broadcast burning, piling and burning on site, and piling and burning off site. Soil compaction is sometimes ameliorated by tilling (disking or ripping). High-intensity treatments accomplished with heavy equipment are more costly than low-intensity treatments (Mills and others 1985), and whether the extra money spent to obtain better seedling survival also results in better seedling growth is important to determine. If intensive site preparation degrades the site and results in poorer growth, the investment in site preparation may be buying initial stocking at the cost of subsequent growth.

I am conducting a long-term study to determine the effects of various site preparation treatments—yarding, slash disposal, and tilling (when present)—on seedling growth in southwestern Oregon. Many plantations on many different sites will be measured to obtain replicates of each treatment-combination on several sites, and each combination will be analyzed to determine its effect on growth. Data will be collected for several years to obtain the requisite number of plantations for these detailed analyses.

Presently available data do not permit detailed analyses of each treatment combination, but they do allow a preliminary comparison of two commonly used slash-burning treatments. That comparison is presented here. My objective is to determine if broadcast burning and piling and burning have different effects on the growth of seedlings planted in clearcut areas.

Methods

Data were collected on 57 progeny test plantations in Coos, Curry, and Douglas Counties, Oregon, during 1984. Plantation selection was based on the availability of 5-year seedling-height data. Federal and private members of the Coquille, Gold Beach, and Roseburg Tree Improvement Cooperatives owned the plantations, which were fenced to keep out browsing mammals and carefully tended to control brush competition. Each plantation was about 4 ha (10 ac), and each contained several thousand carefully planted, individually identified Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) seedlings of known female parentage. Heights were measured when the seedlings were 5 years old from seed. The average 5-year seedling height measured on each plantation was obtained from records stored at the Forestry Sciences Laboratory in Corvallis, Oregon.

A potential 5-year seedling height was determined for each plantation by using the method described by Minore (1986). Stumps of the best-growing trees from the previous stand were measured on each plantation and used in a regression equation to estimate the potential seedling height that would be obtained on the site after minimal disturbance. This potential seedling-height estimate was a function of site quality, not site preparation or slash burning technique. It was used to reduce the confounding effect of site quality when slash burning techniques were compared among plantations.

Slash was treated by broadcast burning on 23 of the progeny-test plantations (fig. 1). On the other 34 plantations (fig. 2), slash was piled and burned. The two burning treatments were not uniform or consistent, however, and burning was only one factor in site preparation. Plantations in the broadcast-burned category included some that were cable-yarded and some that were tractor-yarded. The piled-and-burned category also included both cable- and tractor-yarding and included some plantations where burning was done off site and some where piles were burned on the plantation. Most of the piling was done by machine, but a few plantations were hand piled. The number of plantations measured in 1984 was insufficient to differentiate these more detailed categories in this preliminary comparison.

Seedling heights after broadcast burning were compared with seedling heights after piling and burning by comparing potential heights with measured heights in each burning category, by two methods:

- A potential-minus-measured-height difference was determined for each plantation, and the average difference was calculated for each burning treatment. These average differences were then compared to see which treatment was associated with the largest difference.

- Potential height was plotted against measured height on a set of coordinates. A separate graph was used for each burning treatment, and the resulting plots were compared to see which treatment was associated with the greatest divergence from a 45° line that expressed axis equality (potential height = measured height).

Soil compaction was measured indirectly by sampling with a proving ring penetrometer to determine the average soil-penetration resistance on each plantation. Penetration resistance in the top 20 cm (8 in) was determined at 100 to 400 systematically located points on each plantation. A grating sound and harsh feel were produced when the penetrometer probe was pushed against rocks, and penetrometer readings influenced by rocks in the soil profile were discarded. Rock-free and rocky measurements were not differentiated at first, however, and the

Figure 1—A progeny-test plantation established after slash had been broadcast burned. Note the scattered debris and charred stumps. Most plantations were not this steep.

Figure 2—A progeny-test plantation established after slash had been piled and burned. Note the dense grass cover and absence of debris.

presence of rocks was not recorded until June 1984. Therefore, penetrometer measurements recorded before June were not used in comparing soil-penetration resistance among plantations. Penetrometer readings below 3.5 kg per cm^2 (50 lb per in^2) were judged to be the result of hidden holes or animal burrows.

Soil structure, texture, and moisture influence soil-penetration resistance measured with a penetrometer (Lutz 1952). The plantations occurred on soils of various structure and texture, and because they were measured throughout the summer under various moisture conditions, I adjusted the penetrometer measurements for these differences. I assumed that 1 percent of every plantation remained unaffected by the soil compaction associated with logging or site preparation and calculated a mean soil-resistance value for the lowest 1 percent of the rock- and hole-free penetrometer measurements obtained on each plantation. This low mean value was used as an adjustment factor by subtracting it from the mean of all the rock-free penetrometer measurements on that plantation:

$$\text{Adjusted resistance} = (\text{mean of all } P_{rf}) - (\text{mean of lowest 1\% } P_{rhf}),$$

where P_{rf} = rock-free penetrometer measurements, and

P_{rhf} = rock- and hole-free penetrometer measurements.

Penetrometer measurements were higher on dry sites than on moist sites, but the mean value of the lowest 1 percent of the rock- and hole-free measurements was also higher on dry than on moist sites. Subtracting the low mean from the total mean provided an internal soil calibration for each plantation that resulted in a soil-penetration resistance value that was assumed to be corrected for soil structure, texture, and moisture.

The presence or absence of humus in the top 20 cm (8 in) of soil was determined at every penetrometer sampling point by examining the soil on the flat top of the penetrometer cone after each soil resistance measurement. Humus frequency was calculated for each plantation by summing the number of sample points containing humus and dividing that sum by the total number of points. The result was multiplied by 100 to convert to a percentage:

$$\text{Humus frequency \%} = \frac{\text{number of points with humus}}{\text{total number of points}} \times 100.$$

Results and Discussion

Seedling heights varied greatly among plantations, both within site-preparation treatments and between treatments. This variation occurred with potential heights as well as with seedling heights actually measured on those plantations. Differences were apparent between the two site-preparation treatments, however, in spite of the variation within each treatment (tables 1 and 2).

Table 1—Potential seedling height, measured seedling height, soil-humus frequency, and soil-penetration resistance on plantations where slash was broadcast burned

Plantation	Potential seedling height [1]	Measured seedling height [2]	Potential-measured height difference [3]	Soil-humus frequency [4]	Soil-penetration resistance [5]
	Centimeters [6]			Percent	Kilograms/ square centimeter [7]
I	148.5	152.6	-4.1	100 0	—
II	185.4	198.8	-13.4	52.5	14.2
III	79.8	62.8	+ 17.0	81.9	7.7
IV	89 1	67.9	+21 2	69.3	15.0
V	106.2	97.9	+ 8.3	48 8	13.8
VI	122.0	119.9	+ 2.1	84.6	—
VII	105.2	89.5	+ 15.7	39 4	10 2
VIII	64.4	69.0	-4.6	52.6	12.2
IX	94.8	98.6	-3.8	98.9	10.3
X	73.0	98.9	-25.9	90.0	10.0
XI	73.0	91.6	-18.6	63 7	13.6
XII	89.8	76.0	+ 13.8	88 5	7.6
XIII	59.0	56.4	+2.6	68 2	4.7
XIV	66.2	57.3	+8.9	79.5	4.4
XV	163.9	144.9	+ 19.0	34.7	—
XVI	112.3	111.7	+0.6	—	—
XVII	128.4	180.0	-51.6	59.8	8.8
XVIII	136.3	136.2	+0.1	60.6	—
XIX	119.9	99.1	+20.8	53.8	—
XX	73.3	50.4	+22.9	26.7	—
XXI	98.7	106.1	-7.4	85.7	—
XXII	81.6	58.1	+23.5	76.9	11.3
XXIII	93.7	95.0	-1.3	77.1	—
Average, all plantations:	102.80	100.81	+ 1.99	67.87	10.27
n	23	23	23	22	14
standard error	6.90	8.31	3.74	4.36	0.90

[1] Potential seedling height at 5 years was estimated by using a regression equation and measurements of stumps from the previous stand

[2] The average of several thousand measurements of 5-year-old seedlings

[3] Potential height minus measured height.

[4] $\frac{\text{Number of sample points with humus in the top 20 cm}}{\text{Total number of sample points}} \times 100$

[5] Penetration resistance was adjusted for soil-moisture differences among plantations by using the average of all rock-free penetrometer measurements on each plantation minus the average of the lowest 1 percent of the rock-free, hole-free measurements. Dashes indicate plantations where rock-free penetrometer measurements were not differentiated from measurements influenced by rocks.

[6] To convert to inches, multiply by 0.394

[7] To convert to pounds per square inch, multiply by 14 223.

Table 2—Potential seedling height, measured seedling height, soil-humus frequency, and soil-penetration resistance on plantations where slash was piled and burned

Plantation	Potential seedling height[1]	Measured seedling height[2]	Potential-measured height difference[3]	Soil-humus frequency[4]	Soil-penetration resistance[5]
	Centimeters[6]			*Percent*	*Kilograms/ square centimeter*[7]
XXIV	126.3	76.1	+50.2	67.5	12.5
XXV	110.2	94.9	+15.3	61.0	11.2
XXVI	89.1	95.4	-6.3	76.6	14.6
XXVII	111.3	95.3	+16.0	53.7	15.2
XXVIII	94.8	90.4	+4.4	68.1	13.8
XXIX	103.8	75.7	+28.1	35.5	14.0
XXX	139.9	53.7	+86.2	44.3	12.4
XXXI	86.2	78.5	+7.7	92.2	12.2
XXXII	89.1	73.1	+16.0	85.2	12.2
XXXIII	139.2	65.7	+73.5	27.8	14.0
XXXIV	117.4	59.4	+58.0	89.7	9.1
XXXV	117.4	72.3	+45.1	100.0	15.6
XXXVI	100.9	67.3	+33.6	57.4	16.3
XXXVII	90.5	72.7	+17.8	96.2	7.9
XXXVIII	177.1	99.7	+77.4	36.5	13.1
XXXIX	196.8	119.1	+77.7	40.5	14.2
XL	130.6	108.8	+21.8	79.1	—
XLI	122.7	116.1	+6.6	41.0	13.3
XLII	140.3	110.7	+29.6	82.6	12.6
XLIII	103.4	103.9	-0.5	69.2	—
XLIV	90.5	123.8	-33.3	68.4	—
XLV	119.9	75.9	+44.0	83.2	—
XLVI	105.9	92.9	+13.0	64.6	—
XLVII	88.0	94.8	-6.8	68.3	—
XLVIII	90.1	78.2	+11.9	50.0	—
IL	137.4	70.3	+67.1	19.6	10.6
L	103.4	83.1	+20.3	51.0	13.9
LI	147.1	63.2	+83.9	92.7	10.9
LII	81.6	62.0	+19.6	66.0	8.2
LIII	82.3	63.1	+19.2	87.6	8.0
LIV	100.5	72.0	+28.5	40.6	15.4
LV	118.1	91.9	+26.2	89.9	—
LVI	90.9	85.4	+5.5	59.5	12.9
LVII	96.2	60.9	+35.3	68.1	16.0
Average, all plantations:	112.91	83.71	+29.19	65.10	12.70
n	34	34	34	34	26
standard error	4.57	3.20	4.92	3.64	0.48

[1]Potential seedling height at 5 years was estimated by using a regression equation and measurements of stumps from the previous stand.

[2]The average of several thousand measurements of 5-year-old seedlings.

[3]Potential height minus measured height.

[4]$\frac{\text{Number of sample points with humus in the top 20 cm}}{\text{Total number of sample points}} \times 100.$

[5]Penetration resistance was adjusted for soil-moisture differences among plantations by using the average of all rock-free penetrometer measurements on each plantation minus the average of the lowest 1 percent of the rock-free, hole-free measurements. Dashes indicate plantations where rock-free penetrometer measurements were not differentiated from measurements influenced by rocks.

[6]To convert to inches, multiply by 0.394.

[7]To convert to pounds per square inch, multiply by 14.223.

Potential seedling heights ranged from 59 to 185 cm (23 to 73 in) on the broadcast-burned plantations, averaging 102.8 cm (40.5 in). Potential heights ranged from 81 to 197 cm (32 to 78 in) on the piled-and-burned plantations, averaging 112.1 cm (44.1 in).

Actual seedling heights measured in the field ranged from 50 to 199 cm (20 to 78 in) on the broadcast-burned plantations, averaging 100.8 cm (39.7 in). Field-measured heights ranged from 53 to 124 cm (21 to 49 in) on the piled-and-burned plantations, averaging 83.7 cm (33.0 in).

The differences between potential and measured heights also varied greatly among plantations, but those differences tended to be much larger on the piled-and-burned plantations than on the broadcast-burned plantations. By chance, inherent site quality (expressed here as potential seedling height at 5 years) tended to be higher on the piled-and-burned plantations than on the plantations that were broadcast burned. Actual growth in seedling height measured on the piled-and-burned plantations was less than growth measured on broadcast-burned plantations, however, indicating that piling and burning may be more detrimental to seedling height growth than broadcast burning.

Detrimental effects associated with piling and burning are also indicated when potential and measured heights are compared on each plantation. Measured and potential seedling heights were about equal on the broadcast-burned plantations, and the plotted data points are uniformly scattered around the 45° line of equality (fig. 3). In contrast, measured heights were less than potential heights on most of the piled-and-burned plantations, and most of the data points are below the 45° line (fig. 4).

The frequency of soil humus in the top 20 cm (8 in) was extremely variable, and little difference in humus was found between burning treatments. Soil-penetration resistance also varied in both burning treatments, and the higher average resistance measured on piled-and-burned plantations may be a sampling artifact (tables 1 and 2).

When more plantation data become available, the yarding and slash treatment procedures included in the two slash-burning categories discussed here will be analyzed and compared in six separate site-preparation categories:

- cable-yarded and broadcast burned
- cable-yarded and piled and burned on site
- cable-yarded and piled and burned off site
- tractor-yarded and broadcast burned
- tractor-yarded and piled and burned on site
- tractor-yarded and piled and burned off site

Less variation within treatments and greater differences among treatments should result.

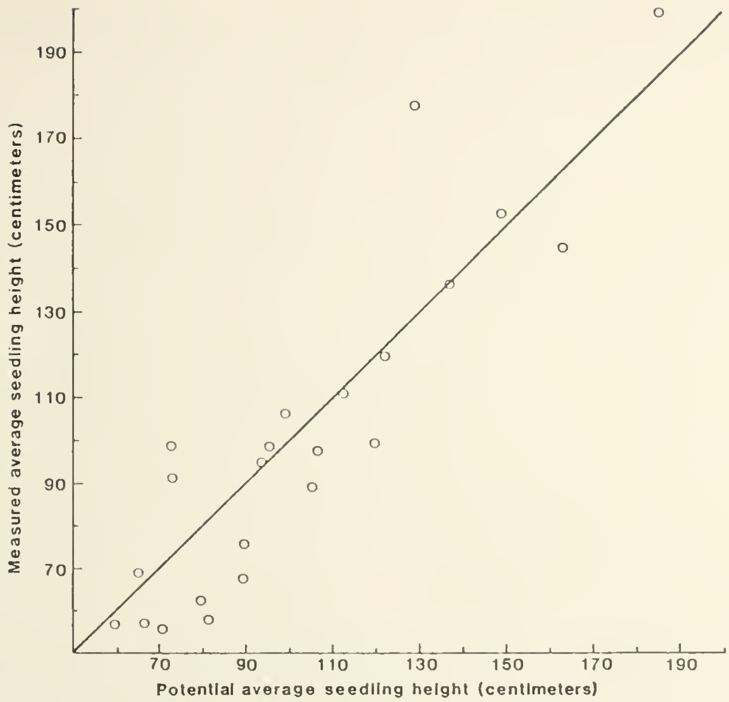

Figure 3—A comparison of measured seedling heights and potential seedling heights on plantations where slash was broadcast burned. Points below the diagonal line indicate measured heights shorter than potential heights at age 5. Points above the line indicate measured heights taller than potential heights.

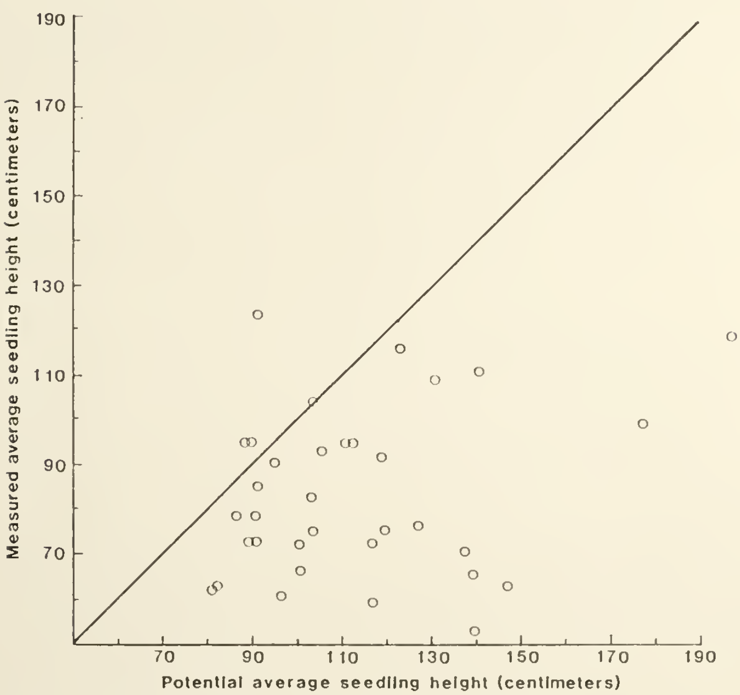

Figure 4—A comparison of measured seedling heights and potential seedling heights on plantations where slash was piled and burned. Points below the diagonal line indicate measured heights shorter than potential heights at age 5. Points above the line indicate measured heights taller than potential heights.

The data presented here indicate that piling and burning slash tends to be associated with less seedling height growth than does broadcast burning in southwestern Oregon. Burning treatments are not isolated, however, and other factors (e.g., yarding equipment and season) may be responsible for the observed differences in seedling growth. I did not measure those factors; instead, I considered them to have random effects that increased variation among plantations without obscuring the effects of the two burning treatments being compared. If that is true, piling and burning slash tends to be damaging, and it probably degrades site quality as expressed in 5-year seedling height. Broadcast burning seems to be less damaging, and it may not adversely affect site quality.

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Effects of *Arceuthobium americanum* on Twig Growth of *Pinus contorta*

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Abstract

Patterns of branch growth in *Pinus contorta* Dougl. ex Loud. (lodgepole pine) on the east side of the Cascade Range in Oregon were significantly altered by *Arceuthobium americanum* (lodgepole pine dwarf mistletoe). There were decreases in the number, length, and mass of needles, as well as in the length and mass of twigs. These reductions were correlated with the infection status of individual branches. Generally, twigs from uninfected branches supported the greatest number, size, and mass of needles, as well as the greatest twig mass. Twigs from branches having localized infections were intermediate for these same characteristics, whereas twigs from systemically infected branches were lowest. These differences suggest that changes in metabolic function of the host result from infection by dwarf mistletoe. The changes are probably among the factors that contribute to host decline correlated with increases in severity of infection.

Keywords: Parasites (plant) (-forest damage, dwarf mistletoe, *Arceuthobium americanum,* lodgepole pine, *Pinus contorta*.

Introduction

Arceuthobium[1/] is a genus of flowering plants comprised of approximately 40 taxa. Members of this genus parasitize all of the genera of the family Pinaceae that occur in the Pacific Northwest (Hawksworth and Weins 1972). Because the members of the genus *Arceuthobium* cannot obtain water and nutrients directly from abiotic sources and because they can provide only 25 to 30 percent of their own energy requirements through photosynthesis (Hull and Leonard 1964, Miller and Tocher 1975), essentially all their metabolic needs must be provided by their host. This contributes to changed growth patterns and to increased mortality rates for the host (Hawksworth and Weins 1972).

Most coniferous species are valuable for timber, so the effects of *Arceuthobium* spp. are usually assessed in terms of damage to, or loss of, fiber or lumber. Although *Arceuthobium* spp. measurably reduce productivity of forests, little information is available about specific alterations of branch structure of the host (the sites of photosynthesis) that are caused by infection. Tinnin and Knutson (1980) reported that branches of *Pseudotsuga menziesii,* when heavily infected with

[1/]Common names are listed under "Scientific and Common Names."

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A. douglasii, supported twigs that were longer and needles that were more numerous but had a lower individual biomass than similar parts from healthy branches.

More detailed information about changes in branch structure resulting from infection by *Arceuthobium* is needed to thoroughly describe the causes of decline in host trees. Hence, our purpose was to quantify changes in the branch structure of *Pinus contorta* associated with infection by *Arceuthobium americanum,* as correlated with local and systemic infection. We worked with *P. contorta* because it shows the same general response to infection by *Arceuthobium* as do other host species, a loss of growth and an increased rate of mortality (Baranyay 1970, Baranyay and Safranyik 1970, Gill and Hawksworth 1964, Johnson and others 1980); because it is of convenient size for detailed work with crown parts; and because it typically supports both local and systemic infections of *A. americanum.*

Methods

Two sample sites were chosen in which almost all the trees present were *Pinus contorta* and in which *Arceuthobium americanum* was found. Both sites were on the east side of the Cascade Range in Oregon. The Sisters site is 21 km (13 mi) south of the town of Sisters on USFS Road 16 (R. 9 E., T. 16 S., sec. 34, 35) at an elevation of about 2000 m (6,550 ft). The Crescent site is southeast of Crescent Lake and about 1.5 km (0.9 mi) south of highway 58 along USFS road 243-I (R. 7 E., T. 24 S., sec. 29) at an elevation of about 1750 m (5,750 ft).

Each site was divided into nine 1-ha (2.47-acre) plots, from which three plots were randomly chosen. Within these plots, study trees were randomly chosen from among the dominant and codominant individuals, excluding spike-topped and double-trunked trees. Each tree was given a dwarf mistletoe rating (d.m.r.) according to its level of infection by *A. americanum*—zero for no infection and six for heavy infection (Hawksworth 1977). An increment core was taken from each tree 1.4 m (4.5 ft) above ground level—diameter at breast height (d.b.h.)—to determine stand age and growth characteristics, and tree height was determined with a clinometer.

The trees at the Sisters site were moderately to heavily infected (d.m.r. 3-6) by *A. americanum.* The density of *P. contorta,* all ages included, was 1.2 trees/m^2 (4,850 trees/acre) with a density of 0.3 mature tree/m^2 (1,225 mature trees/acre). A random sample of mature trees exhibited an average age of 84 years, a d.b.h. of 25 cm (9.8 in), a height of 13 m (42.5 ft), and an estimated lateral growth rate of 0.6 cm (0.24 in) per year averaged over the 1977-81 period.

The trees at the Crescent site were uninfected to moderately infected (d.m.r. 0-4) by *A. americanum.* The density of all age classes of *P. contorta* was 1.8 trees/m^2 (7,275 trees/acre) with a density of 0.2 mature tree/m^2 (800 mature trees/acre). A random sample of mature trees at this site had an average age of 88 years, a d.b.h. of 26 cm (10.2 in), a height of 14 m (46.0 ft), and an estimated lateral growth rate of 0.5 cm (0.20 in) per year averaged over the 1977-81 period. These stand data are summarized in tables 1 and 2.

Table 1—Mean growth characteristics of sample trees from the Sisters, Oregon, site (± standard error)

Dwarf mistletoe rating	Trees	Mean age at breast height, 1981	Mean d.b.h., 1982	Mean height, 1982	Mean lateral growth, 1977-81
	no.	yr	cm 1/	m 2/	cm/yr 1/
3	6	53±12	22±2	11±1	0.7±0.09
4	8	83± 8	25±2	13±1	.5± .06
5	23	81± 5	26±1	13±1	.6± .05
6	16	102± 4	24±1	12±1	.4± .07
Total (mean)	53	84	25	13	.6

1/ 1 cm = 0.39 in.

2/ 1 m = 3.28 ft.

Table 2—Mean growth characteristics of sample trees from the Crescent, Oregon, site (± standard error)

Dwarf mistletoe rating	Trees	Mean age at breast height, 1981	Mean d.b.h., 1982	Mean height, 1982	Mean lateral growth, 1977-81
	no.	yr	cm 1/	m 2/	cm/yr 1/
0	3	64± 8	21±2	12±0.3	0.8±0.10
1	6	93±12	25±4	14±2	.6± .05
2	6	84± 6	25±2	14±2	.5± .07
3	7	95±10	28±2	15±1	.6± .16
4	8	91± 3	28±2	16±1	.4± .04
Total (mean)	30	88	26	14	.5

1/ 1 cm = 0.39 in.

2/ 1 m = 3.28 ft.

Twig samples were obtained from three branches on the southwest side of each study tree at a height of 6 m (20 ft) or less from the ground. Each sample was classified as being taken from an uninfected, a locally infected, or a systemically infected branch. A branch was considered locally infected when the infections were confined to a small portion of the branch, whereas a systemically infected branch had dwarf mistletoe growing throughout many or all of the twigs. Aerial shoots of *A. americanum* distributed over some distance along a twig was evidence of the latter condition.

Samples were collected in 1981. Data on twig growth were recorded for the 1979 annual growth segment. This age class was selected because the segments were fully developed and vigorous at the time of collection. For each sample we measured twig length, twig dry mass, needle number, needle length, and needle dry mass. Twig and needle lengths were measured to the nearest millimeter. Segment dry mass was recorded to the nearest 0.1 mg after the tissues were dried at 80 °C for 48 h.

The data were analyzed by means of a two-level nested analysis of variance in which sample replicates were nested under source branch and source branch under branch infection class (Sokal and Rohlf 1969).

Results and Discussion

For the growth segments sampled, we found a significant decrease in mean number, length, and biomass of needles and in the mean length and biomass of twigs from *Pinus contorta* infected with *Arceuthobium americanum* (table 3). In most cases our measures showed the greatest growth for needles and twigs from uninfected branches, less growth for locally infected branches, and the least growth for systemically infected branches. Twig length is an exception to this pattern because locally infected branches show the least twig elongation.

The trees at the Sisters site showed greater growth for each variable measured. The two sites are different in several ecologically important ways, so the difference in growth of branch parts from the two sites is not surprising.

The data in table 3 imply the action of certain mechanisms leading to host decline after infection. Although the data are not consistent for both sites, a reduction in the numbers and sizes of needles at either site, when correlated with infection, implies that infection affects the photosynthetic efficiency of branches. We presently have no reason to assume that the changed structure of infected branches compensates for the observed reduction in photosynthetic tissue on individual twigs.

Table 3—Mean growth of branch parts of *Pinus contorta* in response to infection by *Arceuthobium americanum* 1/

Site and branch classification	Needles: Number		Needles: Length	Needles: Dry mass	Dry mass per needle	Twigs: Length		Twigs: Dry mass	Dry mass per cm
			cm	g	g	cm		g	g
Crescent Lake:									
Uninfected	58.1	n=6	3.5	0.7818	0.131	2.4	n=7	0.1773	0.0730
Local	41.5	n=11	2.9	.3902	.0091	1.5	n=11	.0857	.0561
Systemic	[55.0]	n=2	[1.7]	[.2730]	[.0048]	[4.0]	n=2	[.1771]	[.0441]
Probability 2/	.05		NS	.05	.05	.001		.001	.05
Sisters:									
Uninfected	[84.5]	n=2	[4.1]	[1.5884]	[.0202]	[3.6]	n=2	[.4260]	[.1234]
Local	52.6	n=20	3.4	.6840	.0130	1.9	n=20	.1726	.0852
Systemic	46.9	n=9	2.1	.3224	.0065	2.7	n=9	.1626	.0583
Probability 2/	NS		.001	.01	.001	NS		NS	.01

1/ Each element is the mean of all samples for a given classification; "n" is the number of trees sampled. Data in brackets were not considered during statistical evaluation because of small sample size. 1 cm = 0.39 in; 1 g = 0.04 oz.

2/ NS = not significant.

Tinnin and Knutson (1980) reported similar data for the growth of branches of *Pseudotsuga menziesii* infected by *Arceuthobium douglasii* (table 4). They found no significant difference in total needle mass between healthy and infected twigs, but they did find that infected branches were much more massive than uninfected branches. In short, the equivalence of the photosynthetic potential of uninfected and infected branches is in question. Detailed comparative work is needed to elucidate the physiological response to infection by various host species.

In addition to the significant changes in branch structure that result from the infection of *P. contorta* by *A. americanum*, it is known that the starch content of needles increases (Broshot and Tinnin 1986), respiratory rates decrease (Wanner and Tinnin 1986), and patterns of carbon allocation change (Leonard and Hull 1965). The many changes in structure and function that occur after infection are at least related to, if not part of, the mechanisms that cause host decline.

Table 4—Comparison of branch characteristics for *Pinus contorta* and *Pseudotsuga menziesii* infected with *Arceuthobium* 1/

Characteristic	P. contorta 2/	P. menziesii 3/
Needle number	4/<	>
Needle length	4/<	NA
Total needle mass	<	ns
Mass per needle	<	<
Twig length	4/<	>
Twig mass	4/<	ns
Twig mass per cm	<	<

1/< indicates significant decrease; >, significant increase; ns, no difference; NA, data not available--compared with twigs from uninfected branches.
2/ Data from current study.
3/ From Tinnin and Knutson (1980).
4/ The differences at only 1 sample site were significant.

Acknowledgments

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Scientific and Common Names

Arceuthobium americanum Nutt. ex Engl.	Lodgepole pine dwarf mistletoe
Arceuthobium douglasii Engl.	Douglas-fir dwarf mistletoe
Pinus contorta Dougl. ex Loud.	Lodgepole pine
Pseudotsuga menziesii (Mirb.) Franco	Douglas-fir

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Research Note PNW-RN-454

January 1987

Temperature Changes in an Initially Frozen Wood Chip Pile

George R. Sampson and Jenifer H. McBeath

Abstract

White spruce trees and tops were chipped and placed in a pile near Fairbanks, Alaska, in February 1983. The pile was 6 meters in diameter and 6 meters high in a cylindrical shape. Thermocouples were placed at 25 locations within the pile so that temperatures could be tracked over time. Gypsum blocks were placed at 10 locations to determine changes in moisture content.

The first evidence that the pile was generating heat appeared at the end of May 1983. This heat accelerated the warming and thawing of the pile. By early August, all thermocouple points were above freezing. The highest temperature recorded was 61 °C near the core of the pile. The chip pile did not freeze at all points the second winter, and all points in the pile were above freezing by early July 1984. The highest temperature recorded inside the pile during the second summer was 41 °C.

Keywords: Chip fuels, energy, white spruce, Alaska (interior), interior Alaska.

Potential for Wood Chips for Energy in Interior Alaska

Since 1978, the State of Alaska has sold 63 932 hectares of uncleared, forested agricultural land (Drew 1984). Large-scale clearing of land for farming will likely occur in the next decade in interior Alaska as it did in Delta I, Delta II, and the Point MacKenzie projects. In the past, most of the biomass from clearing activity was burned after it was chained down and pushed into berm rows. Much of the burning has been done in the winter to prevent escape of fire, and as a result, the berm rows do not completely burn. Repiling with repetitive burning is necessary, making the process expensive. Using the woody part of the biomass for fuel would undoubtedly require storing it as chips in piles for up to a year. Storing the residue in its natural form (tree length or long length) is impractical because of stacking, piling, and handling problems. The most practical and economical method for harvesting residual biomass is the whole tree chipper (McKnight 1983).

Some remote villages are interested in using wood as a substitute for expensive oil for generating electricity. Also, farmers could use wood as a fuel for drying grain. For both uses, the users would benefit if the wood could be stored for long periods. Chippers and chipping crews could be shared more easily among several users if a 2-year or more supply of chips could be produced at one time.

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If chipping is done during the late spring or summer in interior Alaska, biological activity will probably proceed at a rate similar to that in warmer climates with self-heating and significant temperature increases (Allen 1968, Bergman and Nilsson 1979, Springer and Hajney 1970). Information is not available on temperature changes and subsequent deterioration that may occur in chips that are produced and placed in piles while temperatures are below freezing. One possibility we wished to explore was whether the core of a large pile of wood chips would remain frozen throughout the year in a climate such as that of Fairbanks, Alaska. If they would remain frozen, wood chips could be stored for years without significant deterioration.

Purpose of Study

The purpose of this pilot study was to determine changes in temperature, moisture content, and energy that occur during a 2-year period in a large pile of wood chips in a subarctic climate such as Fairbanks, if chipping is done in the winter.

Methods

The wood chips for this study included whole-tree white spruce (*Picea glauca* (Moench) Voss) thinnings from the University of Alaska aboretum near Fairbanks (about 10 percent of the total volume) and white spruce tops from a commercial timber sale along the Tanana River west of Fairbanks. The trees and tops were chipped with a portable chipper on the site where they were to be stored. The chips were blown into a circular pile 6 meters in diameter and 6 meters high. Most chipping was done while the temperature was -12 to -18 °C. The chip pile was maintained in a circular shape by use of a snow fence anchored by four poles (fig. 1).

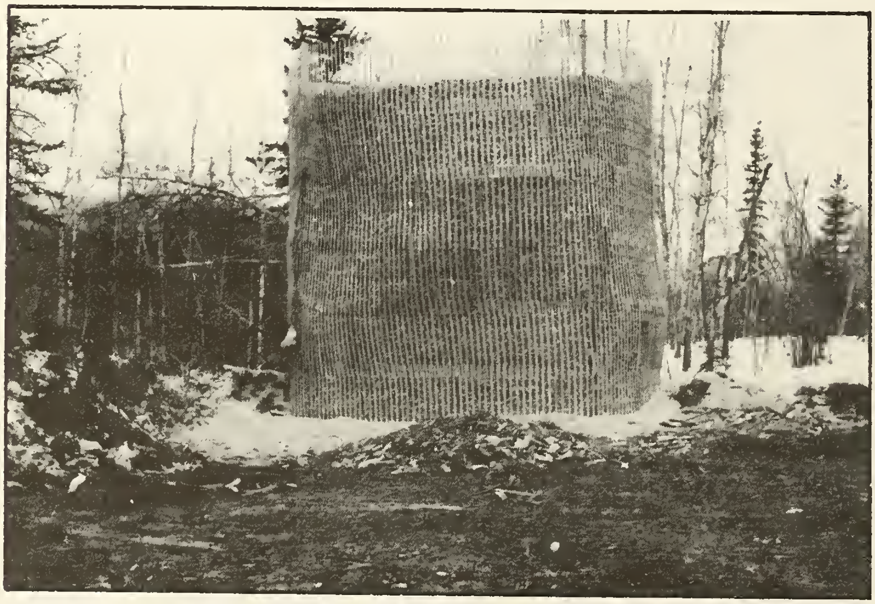

Figure 1—Snow fence keeps chip pile circular.

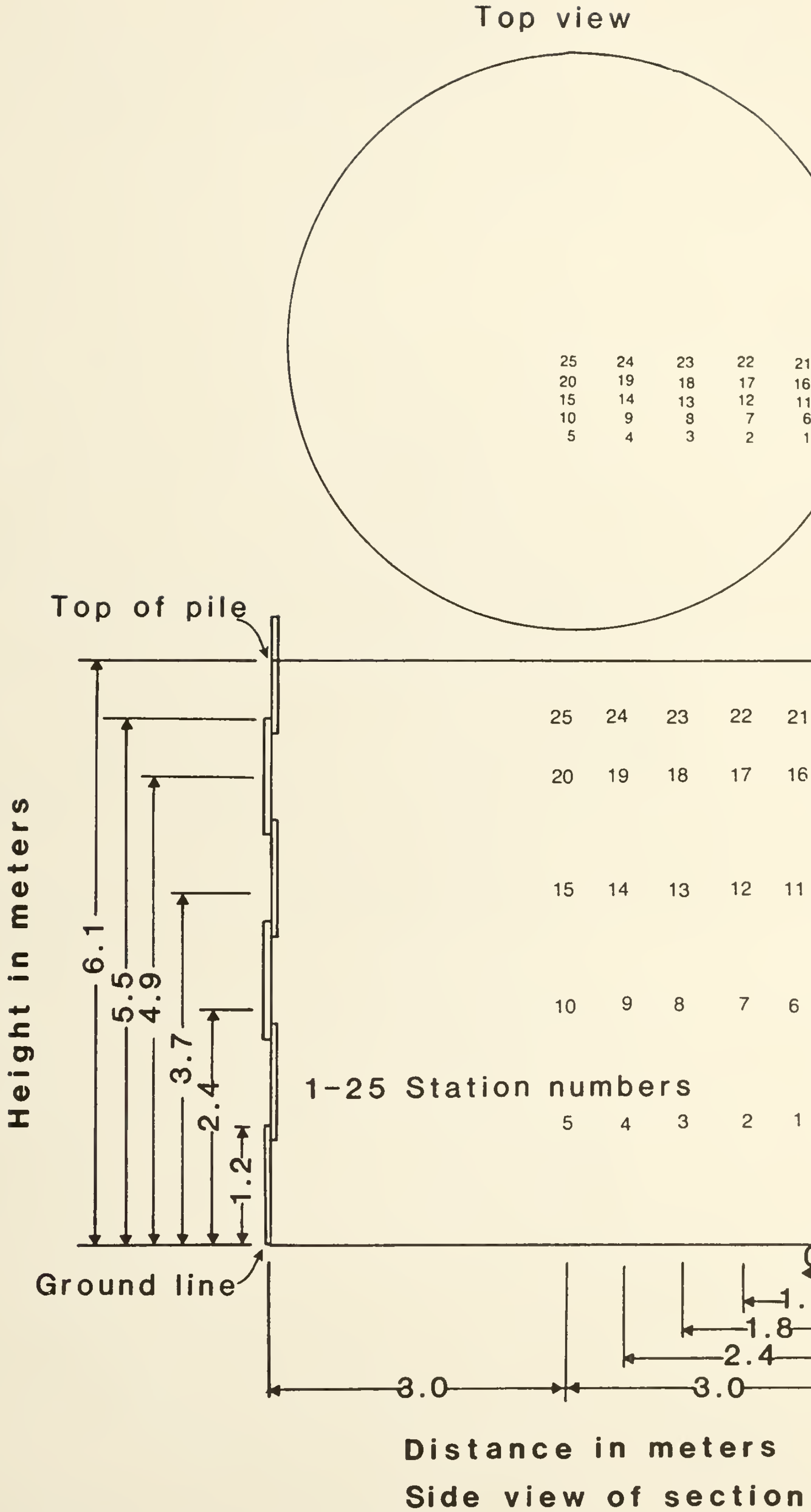

Figure 2—Location of stations, thermocouples, mesh bags, and gypsum-block moisture probes within the study pile.

Temperatures within the pile were monitored over time by 25 thermocouples placed in the pile. These 25 locations or stations are shown on figure 2. Ten gypsum blocks were placed in the pile so that changes in moisture content could be determined. Nylon mesh bags, each containing about 14 liters of chips, were placed in 15 locations. These bags will be removed at the time the pile is broken up, and the extent of chip deterioration will be determined for each location by comparison with chips removed from these same locations while the pile was being built. Solubility of wood samples in sodium hydroxide solution will be used as an indication of decay. Higher heating value will be determined through use of an adiabatic calorimeter.

Chip samples were taken at the mesh-bag locations when the pile was constructed to determine initial moisture content and chip size. Moisture content was determined by drying each sample in an oven at 103 °C until weighings at intervals of several hours revealed no further weight loss. Moisture content was calculated on an ovendry basis.

In the analysis, a set of four sieves with square openings of 38.1, 19.0, 9.5, and 4.0 millimeters was used; each sample was shaken about 3 minutes. Particles passing through the 4.0 millimeter sieve were caught in a pan. The percentage of chips retained on each sieve and in the pan and the mean size of the chips were calculated as follows:

$$X = \frac{\Sigma W_i x_i}{100};$$

where:

X = mean size of chips or particles in millimeters,
W_i = weight of chips or particles collected on the ith sieve as a percentage of the total sample weight, and
x_i = size of opening in ith sieve in millimeters.

The losses and gains in the energy of the core of the chip pile resulting from conductance were estimated. These estimates helped us determine the overall energy loss resulting from storage. Heat losses and gains were estimated from the average ambient temperature between readings and the temperature readings at stations 1, 6, 11, 16, 21, 22, 23, 24, and 25. Temperatures at these nine stations were extrapolated to similar locations around the core surface above ground. The outer and upper 61-centimeter shell of the pile was treated as if it were inert insulation material. The resistivity factor used was based on data for sawdust or wood shavings reported in "Wood Handbook" (U.S. Forest Products Laboratory 1974).

Estimates of energy loss or gain for the chip pile were calculated as follows:

$$L_{im} = C(S_{im} - O_m)Tm\ A_i;$$

where:

L_{im} = energy loss or gain for the part of the pile represented by station i during time period m;
C = the constant 0.033593, which represents heat loss or gain for a layer of wood chips 61 centimeters thick in kilojoules per square meter per hour for each degree (Celsius) difference in temperature on the two sides of the chip layer;
S_{im} = average temperature (°C) of the ith station during time period m;
O_m = average outside temperature (°C) during time period m;
T_m = hours in time period m; and
A_i = surface area (m^2) represented by station i.

Calorific value per unit of dry weight of chips will be determined at the time the pile is broken up for comparison with calorific values for fresh white spruce chips. Time of pile breakup is planned to coincide with a study at a local powerplant in 1986 on the feasibility of burning wood chips mixed with coal.

Results

Late in the summer of 1985, chip samples were taken from the half of the pile cylinder without instruments. Samples were taken from positions analogous to stations 1, 3, 4, 11, 13, 14, 21, 23, and 24. The chips were analyzed for moisture content. Sampling was done with an auger designed to allow sampling at specific locations within a chip pile (White and others 1980).

Temperature changes in the pile over time are indicated by figure 3. Self-heating accelerated if rate of heat diffusion was less than rate of heating; however, no thermocouple station was ever higher than 61 °C.

Plots of temperatures for stations 1, 15, and 21 are shown in figure 4. For each date that chip pile temperatures are reported, a plot of the average ambient temperature for the preceding 5 days is also provided.

Self-heating began near the outer top of the pile because this part of the pile has greatest exposure to solar radiation, and it therefore thawed first. Until self-heating began, the pile was in a general state of net heat gain; however, after self-heating began, the pile was in a state of net heat loss through the summer and fall until midwinter. Warming of the upper part of the pile the second spring was probably retarded by the snow layer on top of the pile, which was allowed to melt in place.

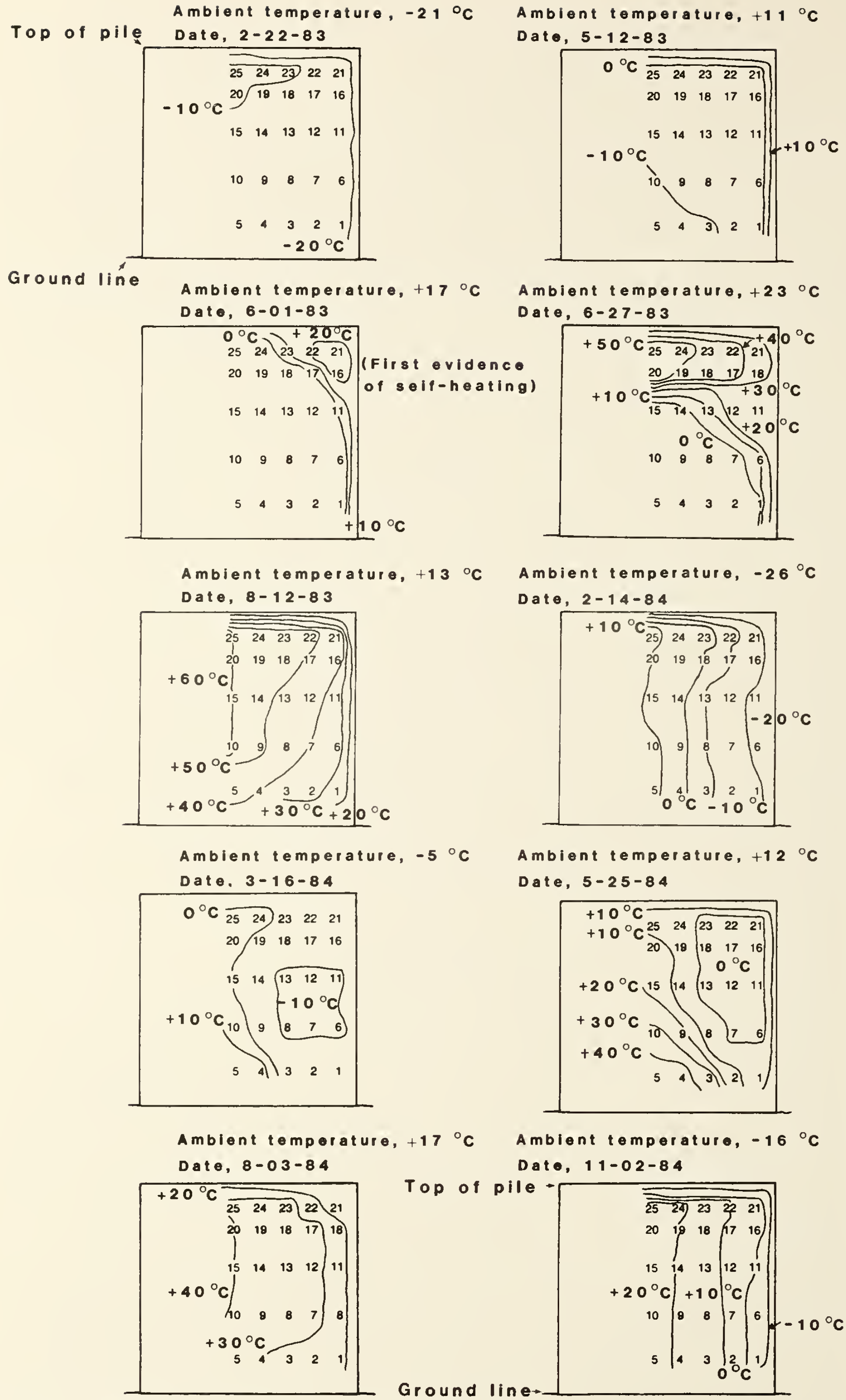

Figure 3—Isotherms on 10 dates during the storage period and average ambient temperature for the preceding 5 days.

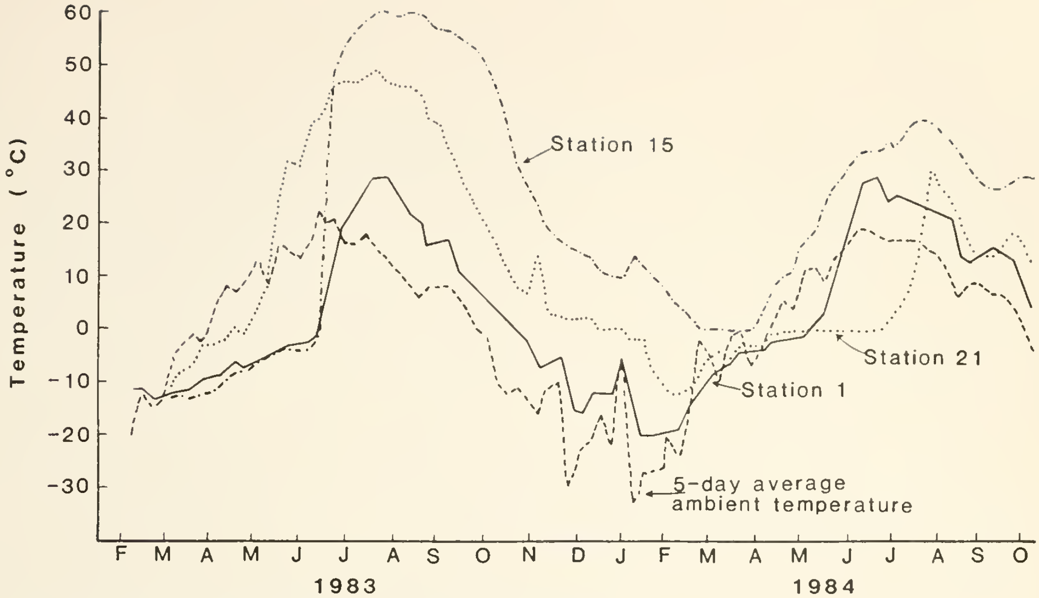

Figure 4—Temperatures for stations 1, 15, and 21 during the storage period and corresponding average ambient temperature for the preceding 5 days.

Mean moisture content of the wood chips at the time of pile construction was 89 percent. Range of individual samples was 64 to 103 percent. The gypsum blocks buried within the pile at 10 locations used in conjunction with an electronic moisture detector are not capable of detecting moisture content changes except at low ranges. Concurrent laboratory experiments showed that moisture content of wood chips may drop as low as 30 percent before moisture detector readings for gypsum blocks buried within the wood chips drop below the maximum. Readings are affected by below freezing temperatures for either the moisture detector or the gypsum blocks. Therefore, the gypsum blocks indicate changes in relative moisture content only when the wood chips are below 30 percent. The only clear indication of moisture content decreasing is for station 6 located 2.4 meters high and 0.6 meter from the outside of the pile. Moisture content for auger samples taken in mid-September 1985 are shown by table 1.

Table 1—Moisture content of samples from selected stations in the back half of the chip pile, mid-September 1985

Station number	Moisture content (dry weight basis)
	Percent
1	26
3	28
4	27
11	121
13	195
14	74
21	197
23	228
24	233

Table 2—Chips retained by each sieve and the mean size of the chips

Sieve opening	Proportion of chips retained
Millimeters	*Percent*
38.1	0.7
19.0	17.5
9.5	57.1
4.0	22.1
Pan	2.6
	Millimeters
Mean size of chips	9.9

The proportion of chips retained on the various sieves and the mean size of the chips are shown in table 2.

The estimated energy losses and gains of the core of the chip pile resulting from conductance are shown in figure 5. Some daily heat loss resulted from the pile absorbing heat when ambient temperature was higher than the temperatures in the chip pile, then releasing heat when the ambient temperature dropped below the internal temperatures of the chip pile. Over the course of a year, energy gains in the chip pile should offset such losses. The daily rate of heat loss was considerably less the second summer than the first summer.

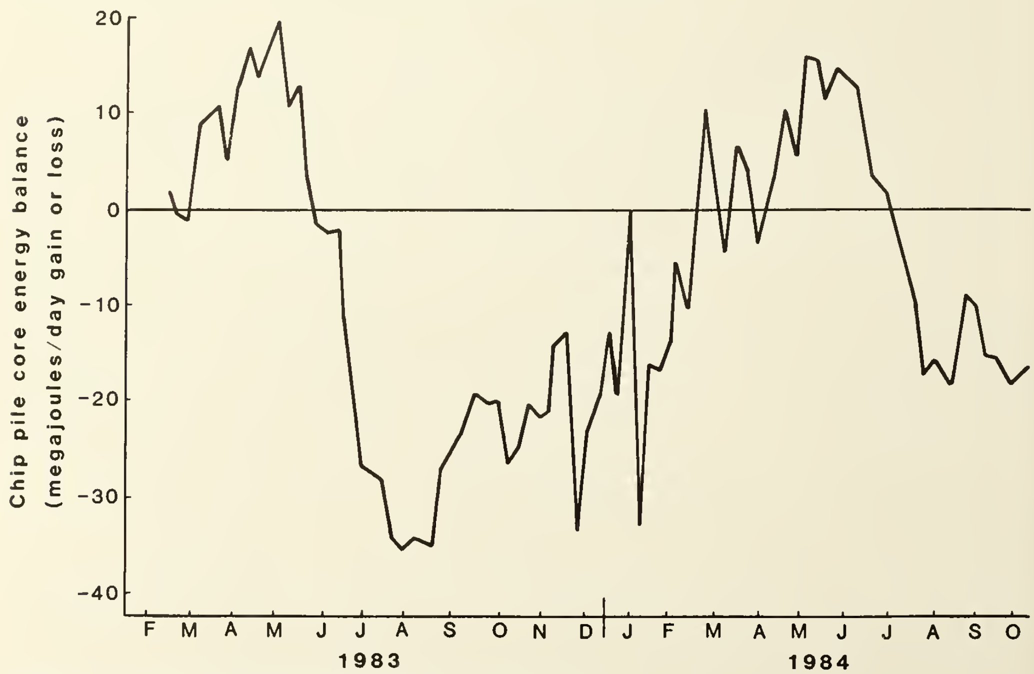

Figure 5—Chip pile energy balance based on outer pile temperatures, average ambient temperatures, and conductance.

Discussion

There was no lasting insulation effect from the outer layers of chips in the frozen chip pile. As the outer layers of chips warmed to about 5 °C, thermogenesis (the chip pile generating heat) began, and temperatures in these outer areas rose far above ambient temperatures, accelerating thawing and the subsequent thermogenesis of the core of the pile. The lower center of the pile remained frozen until early August of the first summer. The pile did not completely refreeze the second winter, and no part of it remained frozen after early July of the second summer, although it began to refreeze again by early November.

The maximum temperatures reached within the pile probably result from the interaction of the rates of thermogenesis and heat diffusion. The major buildup of heat results from the metabolism of the mixed saprophytic, microbial flora that develops in green chips. As the temperature rises, the thermophiles can multiply rapidly and increase the temperature to 70 °C or slightly higher (Unligil 1982). The upper limit for growth of fungi is about 60 °C (Cooney and Emerson 1964). Subsequent heating results from autocatalytic processes which can begin to operate at this temperature. In studies of large (6000 m^3) pulpwood chip piles of Scotch pine (*Pinus silvestris* L.) and spruce (*Picea abies* (L.) Karst.), the highest temperatures remained below 70 °C (Bergman and Nilsson 1971). The Fairbanks chip pile contains about 178 m^3, but the cylindrical shape may cause it to react differently from conical piles.

The energy losses and gains suggested by figure 5 are only an approximation of changes resulting from conductance for ambient temperature and temperatures within the chip pile. At temperatures above 50 °C, heat lost through diffusing vapor may approach heat lost through conduction (Kubler 1984). Significant heat may also be lost by convection of hot air at high temperatures. Loss of potential energy from the entire pile will be estimated after the pile is broken up.

Plans

The chip pile will be broken up late in 1986. If the chips are still suitable as fuel, they will be mixed with coal and burned at a local powerplant in conjunction with an experiment on the technical and economic feasibility of harvesting wood chips and burning them as fuel supplement for coal at a large powerplants.

Conversion Factors

centimeter = 393.7008 mils or 0.3937 inch
meter = 3.2808 feet
hectare = 0.4047 acre
cubic meter = 35.31 cubic feet or 0.2759 cord
liter = 0.353 cubic foot
kilojoule = 0.9479 British thermal unit
megajoule = 947.9 British thermal units
degrees Celsius (°C) = 0.5556 (°F-32)

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Research Note PNW-RN-455
November 1986

Growth and Yield of Western Larch in Response to Several Density Levels and Two Thinning Methods: 15-Year Results

K.W. Seidel

Abstract

The 15-year growth response from a levels-of-growing-stock study in an even-aged western larch (*Larix occidentalis* Nutt.) stand, first thinned from above and below at age 55, was measured in northeastern Oregon. Basal area and volume growth increased with stand density for both thinning methods, whereas diameter growth decreased. Attacks of the larch casebearer (*Coleophora laricella* (Hübner)) for about 3 years reduced height growth because of top dieback, but diameter and volume growth were not severely impacted. Thinning from above reduced net volume growth because of considerable mortality caused by windthrow and snow or ice damage, although surviving trees responded well to increased growing space. Thinning from below is recommended in previously unmanaged larch stands.

Keywords: Increment (stand volume), even-aged stands, stand density, thinning effects, growing stock (-increment/yield, western larch, *Larix occidentalis*.

Introduction

Long-term levels-of-growing-stock and spacing studies provide information needed to design thinning regimes to attain desired rates of diameter or volume growth to meet timber production and multiple use objectives. They also are needed to supply growth and yield data for the development of managed yield tables and to verify simulation models designed to predict growth and yield for various management alternatives. Western larch (*Larix occidentalis* Nutt.) is an important species in the mixed-conifer forests of eastern Oregon, and many stands require thinning to produce salable trees in a reasonable time.

This paper reports 15-year results from a levels-of-growing-stock study begun in 1970 in the Blue Mountains of northeastern Oregon.[1] The purpose of the study was to obtain information on the growth and mortality of even-aged larch stands thinned to several density levels by two methods. It supplements earlier reports of results for the first 5 and 10 years (Seidel 1975, 1980).

Study Area and Methods

The study site is on Boise-Cascade land about 6 miles northwest of Elgin, Oregon; the site and the timber stand are described in an earlier report (Seidel 1980). Study results are applicable to larch stands of similar site quality throughout northeastern Oregon and southeastern Washington.

[1] A cooperative research effort between the Boise-Cascade Corporation and Pacific Northwest Research Station.

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The study consists of a 2 by 4 factorial randomized complete block design replicated two times for a total of sixteen 0.286-acre plots. It is designed for thinning at 10-year intervals, with remeasurement every 5 years. The first factor, density, consists of four levels: 50, 90, 130, and 170 square feet of basal area per acre. These levels correspond to 21, 38, 55, and 72 percent of the basal area of normal (fully stocked) larch stands at age 55 and site index 80 given by Schmidt and others (1976).[2] The second factor is the thinning method: from above (cutting the largest trees—dominants and codominants) and from below (cutting the smallest trees—suppressed, intermediate, and small codominants). Split-plot analyses of variance were used to test significance of treatment effects for three 5-year periods (1970-74, 1975-79, and 1980-84). Tukey's test was used to determine significant differences among treatment means. Regression analyses related diameter, basal area, and volume growth to residual basal area for each period.

All plots were well stocked, ranging from 191 to 226 square feet of basal area per acre before treatment (table 1). Trees were spaced from 8.5 to 10.3 feet apart; average d.b.h. (diameter at breast height) ranged from 8.2 to 9.8 inches before thinning. After thinning from above, all plots contained 2 to 8 percent of Rocky Mountain Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco), grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.), or Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), except one plot where 22 percent of the residual basal area was grand fir and Douglas-fir. All plots thinned from below were pure larch.

Plots were thinned with a Drott "feller-buncher"[3] before growth began in 1970. This machine uses shears and a grapple mounted on a 25-foot boom with a crawler tractor undercarriage. Operation of this equipment required prior removal of all trees (clearcut) in swaths 20 feet wide. Swaths were spaced 50 feet apart and oriented east and west through the stand. The feller-buncher moved along these clearcut strips, reaching 25 feet into the thinning strips to cut and remove the entire tree. Some variation in residual stocking levels between replications and between thinning methods for a given density level existed because a few trees marked for cutting were missed and some leave trees were accidentally pushed over by the feller-buncher. In plots thinned from above, the variation in residual basal area levels in 1970 ranged from a 4-percent undercut to a 10-percent overcut, whereas in plots thinned from below, variation from desired levels was only +1 to -3 percent.

[2] Site index of plots (83 feet at age 50) is based on curves in "Ecology and Silviculture of Western Larch Forests" (Schmidt and others 1976). These curves use total age (age at ground line).

[3] Mention of companies or products is for the convenience of the reader. Such mention does not imply endorsement by the U.S. Department of Agriculture to the exclusion of other products or services that may be suitable.

Table 1—Stand characteristics per acre of western larch before and after the 1970 and 1980 thinnings and in 1975 and 1985[1]

Density level 2/	Basal area	Number of trees	Average spacing	Quadratic mean diameter	Average height 3/	Volume 4/ Total	Merchantable, including ingrowth	
	Square feet		Feet	Inches	Feet	Cubic feet	Cubic feet	Board feet
				BEFORE INITIAL (1970) THINNING				
Thinned from above:								
1	221.5	420	10.2	9.8	85.1	7,177	6,635	26,816
2	191.5	495	9.4	8.4	80.3	6,032	5,331	18,540
3	213.7	408	10.3	9.8	90.1	6,883	6,164	27,020
4	202.0	513	9.2	8.5	82.0	6,285	5,311	18,045
Thinned from below:								
1	211.0	490	9.4	8.9	95.3	6,892	6,202	24,555
2	205.5	557	8.8	8.2	91.8	6,688	5,942	20,898
3	221.5	596	8.5	8.3	93.7	7,192	6,366	19,479
4	226.0	525	9.1	8.9	92.4	7,402	6,689	26,446
				AFTER 1970 THINNING 5/				
Thinned from above:								
1	50.6	133	18.1	8.4	85.1	1,647	1,439	2,816
2	93.8	257	13.0	8.2	80.3	2,906	2,506	5,687
3	126.0	231	13.7	10.0	90.1	4,091	3,792	13,990
4	153.0	400	10.3	8.4	82.0	4,670	4,080	10,054
Thinned from below:								
1	48.9	58	27.4	12.4	94.8	1,686	1,593	8,331
2	87.7	115	19.5	11.9	91.8	2,974	2,796	13,503
3	131.8	196	14.9	11.1	93.7	4,448	4,161	16,790
4	169.0	219	14.1	11.9	92.0	5,801	5,459	24,440
				1975 5/				
Thinned from above:								
1	50.4	111	19.8	9.1	88.3	1,668	1,492	4,309
2	9.2	239	13.5	8.7	84.0	3,105	2,742	7,273
3	132.9	220	14.1	10.5	94.5	4,346	4,051	15,880
4	158.2	378	10.7	8.8	86.0	4,876	4,335	13,260
Thinned from below:								
1	55.5	58	27.4	13.3	99.1	1,925	1,825	10,005
2	96.5	115	19.5	12.5	95.1	3,312	3,125	16,141
3	141.4	196	14.9	11.5	96.9	4,775	4,480	19,732
4	183.6	219	14.1	12.4	96.4	6,274	5,914	28,440
				BEFORE 1980 THINNING 5/				
Thinned from above:								
1	59.3	110	19.9	9.9	83.4	1,919	1,819	5,382
2	105.3	221	14.2	9.5	81.7	3,333	3,120	8,868
3	152.1	220	14.1	11.3	88.5	5,022	4,712	19,103
4	161.9	348	11.2	9.2	84.4	5,002	4,586	15,294

See footnotes at end of table.

Table 1—Stand characteristics per acre of western larch before and after the 1970 and 1980 thinnings and in 1975 and 1985[1] (continued)

Density level 2/	Basal area	Number of trees	Average spacing	Quadratic mean diameter	Average height 3/	Volume 4/ Total	Merchantable, including ingrowth	
	Square feet		Feet	Inches	Feet	Cubic feet	Cubic feet	Board feet
				BEFORE 1980 THINNING 5/ (continued)				
Thinned from below:								
1	64.3	58	27.4	14.3	101.7	2,288	2,218	11,636
2	107.2	115	19.5	13.2	96.8	3,729	3,591	18,869
3	151.5	196	14.9	11.9	96.9	5,136	4,998	21,478
4	196.3	219	14.1	12.9	97.3	6,740	6,493	32,225
				AFTER 1980 THINNING 5/				
Thinned from above:								
1	53.3	98	21.1	10.0	80.4	1,726	1,636	4,921
2	96.2	214	14.5	9.2	78.1	3,050	2,841	7,361
3	140.0	209	14.4	11.1	85.3	4,623	4,336	17,118
4	160.6	347	11.2	9.2	84.0	4,958	4,543	15,082
Thinned from below:								
1	54.9	46	30.8	14.8	102.4	1,955	1,895	10,171
2	99.2	102	21.2	13.7	98.3	3,409	3,290	17,425
3	139.7	175	16.0	12.3	98.3	4,782	4,659	20,402
4	183.6	190	15.3	13.4	100.4	6,327	6,112	31,991
				1985 5/				
Thinned from above:								
1	58.4	82	23.1	11.4	81.5	1,998	1,894	8,311
2	99.2	168	16.1	10.4	81.5	3,328	3,098	11,986
3	157.0	189	15.2	12.3	86.5	5,527	5,184	24,773
4	156.3	278	12.7	10.1	87.2	5,315	4,869	20,086
Thinned from below:								
1	65.6	46	31.0	16.3	105.4	2,366	2,293	13,782
2	109.6	98	21.5	14.6	99.2	4,015	3,874	21,946
3	140.0	149	17.1	13.2	100.3	4,913	4,785	23,252
4	203.2	182	15.6	14.4	103.0	7,396	7,145	40,107

1/ Based on plots without clearcut strips.

2/ 1 is lowest; 4, highest.

3/ Measured with a dendrometer (about 15 trees per plot).

4/ Total cubic-foot volume--entire stem, inside bark, all trees. Merchantable cubic-foot volume--trees 5.0-inch d.b.h. and larger to a 4-inch top d.i.b. Board-foot volume--International 1/4-inch rule, trees 10.0-inch d.b.h. and larger to a 6-inch top d.i.b.

5/ Basal area, number of trees, and volume per acre should be reduced by 29 percent if clearcut strips are included in plot area.

In April 1980, 10 years after the first thinning, plots were thinned for the second time with chain saws. Plots were not thinned to the original density levels after the 1970 thinning but were marked to allow an 8-percent increase in basal area, approximately the normal increase in stand density with age for fully stocked stands. The adjusted density levels after the second thinning were 54, 97, 140, and 184 square feet of basal area per acre, again corresponding to 21, 38, 55, and 72 percent of the density of normal stands at age 65.

Diameter at breast height of all plot trees was measured to the nearest one-tenth inch in the spring of 1970 and in the fall of 1974, 1979, and 1984. In addition, about 15 trees per plot covering the range of diameters were measured with an optical dendrometer in 1970, 1974, 1979, and 1984 to derive an equation expressing volume of the entire stem inside bark as a function of diameter for each plot. The volume equations developed from the 1970 measurements were used to compute plot volumes (cubic feet and board feet, International 1/4-inch rule) at the beginning and end of the first 5-year period. New equations developed from the 1979 measurement were used to compute plot volumes at the end of the second and third 5-year periods. Height growth was measured by dendrometer only on trees chosen to provide data for volume equations.

Because of the mechanized thinning equipment used in this stand, 29 percent of the total area was occupied by clearcut strips, which resulted in a reduction in volume growth compared with a thinned area completely occupied by trees. Therefore, growth per acre is presented two ways—based on the 0.286-acre plot completely occupied by trees and on a larger 0.4-acre plot that includes the clearcut strips.

Examination of data on basal area and volume growth for the plot containing 22 percent of the basal area in fir revealed an unusually high growth rate because of the more rapid growth of the fir. Therefore, data from this plot were not used in the growth and statistical analyses.

Results

Mortality and Damage

Considerable mortality and damage occurred during the 15 years of this study because of wind, snow, and ice damage and attacks of the larch casebearer (*Coleophora laricella* (Hübner)). During the first 10 years of the study, all mortality occurred in plots thinned from above and was caused by either windthrow or shock after release. Of the 570 trees in these plots, 12 percent died—7 percent during the first 5-year period and 5 percent during the second. Most of these trees were in the intermediate and suppressed crown classes and thus had not developed sufficient windfirmness or large enough crowns to keep pace with the increased respiratory rate after release. During the third period, an additional 15 percent of the trees in plots thinned from above died as the result of a severe ice storm in January 1984 that broke tree boles below the live crown. Also, 6 percent of the 377 trees in plots thinned from below died during the third period from storm damage. To summarize, 20 percent or 167 of the 855 trees present at the beginning of the study in all plots died during the 15 years of this study. Eight-five percent of the mortality (142 trees) occurred in plots thinned from above but only 15 percent (25 trees) in plots thinned from below.

Wind or ice also damaged 12 percent of the trees in plots thinned from above compared with 3 percent in plots thinned from below during the 15 years. This damage consisted of trees leaning from 10 to 35 degrees from the vertical or several feet of the top broken off. In 1976, the larch casebearer moved into the study area and attacked larch in all plots. Dieback of terminals occurred on many trees during the second period from 1976 to 1979. No casebearer damage was observed during the third period.

Diameter Growth

Diameter growth from 1970 through 1984 was greatest at the lowest density level for both thinning methods (table 2). As stand density increased, diameter growth generally decreased, although this trend was not completely consistent. The growth rate at the lowest density was about twice that at the highest density (0.2 vs. 0.1 inch per year) when averaged over all periods and thinning methods. Diameter growth was significantly greater ($P < 0.01$) at the lowest density level, but no statistical differences were found among the other three levels (0.14, 0.11, and 0.10 inch per year).

Diameter growth rates also changed over time. Significant diameter growth differences ($P < 0.01$) were found among all periods (fig. I). Only small differences in growth existed between the first and second periods, but during the third period growth accelerated considerably. Averaged over all density levels and thinning methods, diameter growth was 0.10 inch per year in the first period and 0.13 inch in the second, but growth increased to 0.20 inch per year in the third period. The more rapid diameter growth during the third period can be attributed to the combined effects of the second thinning in 1980 and the decline in larch casebearer populations about that time. A significant ($P < 0.01$) period-density interaction occurred because of the relatively greater growth differences among periods at the lowest density level than at the other levels.

The thinning method did not affect diameter growth. Differences in diameter growth between thinning methods were not significant; they averaged 0.13 inch per year in plots thinned from above and 0.15 inch in those thinned from below.

After 15 years of growth and two thinnings, the average stand diameter in plots thinned from below at the lowest density level was 16.3 inches compared with 11.4 inches in plots thinned from above (table 1). This difference of almost 5 inches is caused primarily by removal of larger trees in plots thinned from above versus removal of smaller trees in plots thinned from below. Annual diameter growth in these plots during the 15-year period was 0.13 inch (above) and 0.15 inch (below).

Table 2—Periodic annual increment and mortality per acre of western larch by age, density level, and thinning method after thinning at ages 55 and 65

Density level 1/	Residual basal area	Diameter growth 2/	Basal area growth: Net	Basal area growth: Mortality	Basal area growth: Gross	Total volume growth: Net	Total volume growth: Mortality	Total volume growth: Gross	Merchantable volume growth, including ingrowth: Net	Merchantable volume growth, including ingrowth: Mortality	Merchantable volume growth, including ingrowth: Gross	Ingrowth	Ingrowth
	Square feet	Inches	- - - Square feet - - -			- - - Cubic feet - - -			- - - Board feet - - -			Board feet	Percent
			AREA WITHOUT CLEARCUT STRIPS, AGE 55-60 (1ST PERIOD)										
Thinned from above:													
1	51	0.10	-0.04	1.12	1.08	4	34	38	299	0	299	225	75.2
2	94	.08	1.08	.85	1.93	40	25	65	317	0	317	163	51.4
3	126	.08	1.38	1.12	2.50	51	37	88	378	132	510	202	39.6
4	153	.05	1.04	.91	1.95	41	24	65	641	0	641	456	71.2
Thinned from below:													
1	49	.16	1.32	0	1.32	48	0	48	335	0	335	33	9.8
2	88	.12	1.76	0	1.76	68	0	68	528	0	528	109	20.6
3	132	.08	1.92	0	1.92	65	0	65	588	0	588	278	47.2
4	169	.09	2.92	0	2.92	95	0	95	800	0	800	248	31.0
			AREA WITH CLEARCUT STRIPS, AGE 55-60 (1ST PERIOD)										
Thinned from above:													
1	36	.10	-0.03	.81	.78	3	24	27	213	0	213	161	75.6
2	67	.08	.78	.61	1.39	29	18	47	227	0	227	116	49.8
3	89	.08	.98	.80	1.78	36	26	62	268	94	362	143	39.6
4	109	.05	.74	.65	1.39	29	18	47	458	0	458	326	71.2
Thinned from below:													
1	35	.16	.94	0	.94	34	0	34	239	0	239	24	10.0
2	63	.12	1.25	0	1.25	48	0	48	377	0	377	78	20.7
3	94	.08	1.36	0	1.36	47	0	47	420	0	420	198	47.1
4	121	.09	2.07	0	2.07	68	0	68	571	0	571	177	31.0
			AREA WITHOUT CLEARCUT STRIPS, AGE 60-65 (2D PERIOD)										
Thinned from above:													
1	50	.17	1.78	.06	1.84	50	2	52	215	0	215	83	38.6
2	99	.10	1.22	1.10	2.32	46	33	79	319	32	351	188	53.6
3	133	.14	3.84	0	3.84	135	0	135	645	0	645	267	41.4
4	158	.06	.75	1.72	2.47	25	50	75	407	84	491	295	60.1
Thinned from below:													
1	56	.20	1.76	0	1.76	73	0	73	326	0	326	0	0
2	97	.12	2.13	0	2.13	83	0	83	545	0	545	28	5.1
3	141	.08	2.03	0	2.03	72	0	72	350	0	350	96	27.4
4	184	.09	2.55	0	2.55	93	0	93	757	0	757	113	14.9
			AREA WITH CLEARCUT STRIPS, AGE 60-65 (2D PERIOD)										
Thinned from above:													
1	36	.17	1.27	.05	1.32	36	1	37	153	0	153	59	38.6
2	71	.10	.86	.78	1.64	33	23	56	228	23	251	133	53.0
3	95	.14	2.73	0	2.73	96	0	96	458	0	458	190	41.5
4	113	.06	.53	1.22	1.75	18	36	54	289	60	349	209	59.9
Thinned from below:													
1	40	.20	1.25	0	1.25	52	0	52	233	0	233	0	0
2	69	.12	1.52	0	1.52	60	0	60	390	0	390	20	5.1
3	101	.08	1.45	0	1.45	52	0	52	250	0	250	69	27.6
4	131	.09	1.83	0	1.83	66	0	66	541	0	541	81	15.0
			AREA WITHOUT CLEARCUT STRIPS, AGE 65-70 (3D PERIOD)										
Thinned from above:													
1	53	.27	1.02	1.54	2.56	55	49	104	678	109	787	401	51.0
2	96	.19	.59	2.90	3.49	56	87	143	926	54	980	370	37.8
3	140	.20	3.40	1.56	4.96	159	45	204	1,531	0	1,531	510	33.3
4	161	.12	-.86	4.37	3.51	26	131	157	1,071	84	1,155	326	28.2
Thinned from below:													
1	55	.29	2.13	0	2.13	82	0	82	722	0	722	0	0
2	99	.20	2.08	.31	2.39	121	10	131	1,094	0	1,094	63	5.8
3	140	.15	0.06	2.59	2.65	26	98	124	746	226	972	96	9.9
4	184	.18	3.91	.86	4.77	168	31	199	1,623	102	1,725	343	19.9
			AREA WITH CLEARCUT STRIPS, AGE 65-70 (3D PERIOD)										
Thinned from above:													
1	38	.27	.72	1.09	1.81	39	35	74	481	77	558	285	51.0
2	68	.19	.42	2.06	2.48	40	62	102	657	38	695	263	37.8
3	99	.20	2.41	1.11	3.52	113	32	145	1,087	0	1,087	362	33.3
4	114	.12	.61	3.10	2.49	18	93	111	760	60	820	231	28.2
Thinned from below:													
1	39	.29	1.51	0	1.51	58	0	58	513	0	513	0	0
2	70	.20	1.48	.22	1.70	86	7	93	777	0	777	45	5.8
3	99	.15	.04	1.84	1.88	18	70	88	530	160	690	68	9.9
4	131	.18	2.78	.61	3.39	119	22	141	1,152	72	1,224	244	19.9

1/ 1 is lowest; 4, highest.

2/ Arithmetic diameter growth of trees living through three 5-year periods (1970-74, 1975-79, 1980-84).

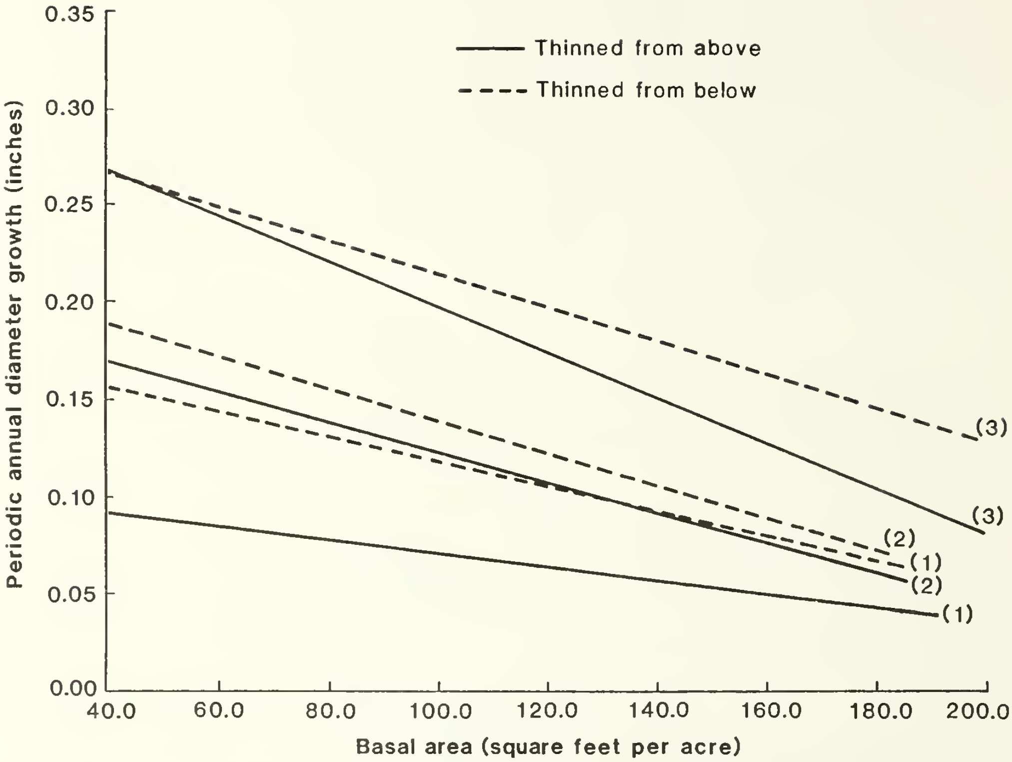

Figure 1—Periodic annual diameter growth by thinning method and growth period as a function of stand density; number in parentheses are growth periods.

Height Growth

Height growth was not affected by changes in stand density, but significant ($P < 0.05$) growth differences were found among periods and thinning methods. Increment ranged from a high of 0.88 foot per year during the first period to a low of -0.15 foot during the third period (fig. 2). Averaged over all density levels and thinning methods, height growth decreased significantly from 0.76 foot per year in the first period to 0.13 foot in the second period because of dieback caused by the larch casebearer. Height growth recovered slightly during the third period to 0.32 foot per year but was still significantly less than first period growth because of ice damage. Average annual height growth for the 15 years in plots thinned from above was about 0.30 foot per year compared with 0.51 foot in plots thinned from below, a significant difference.

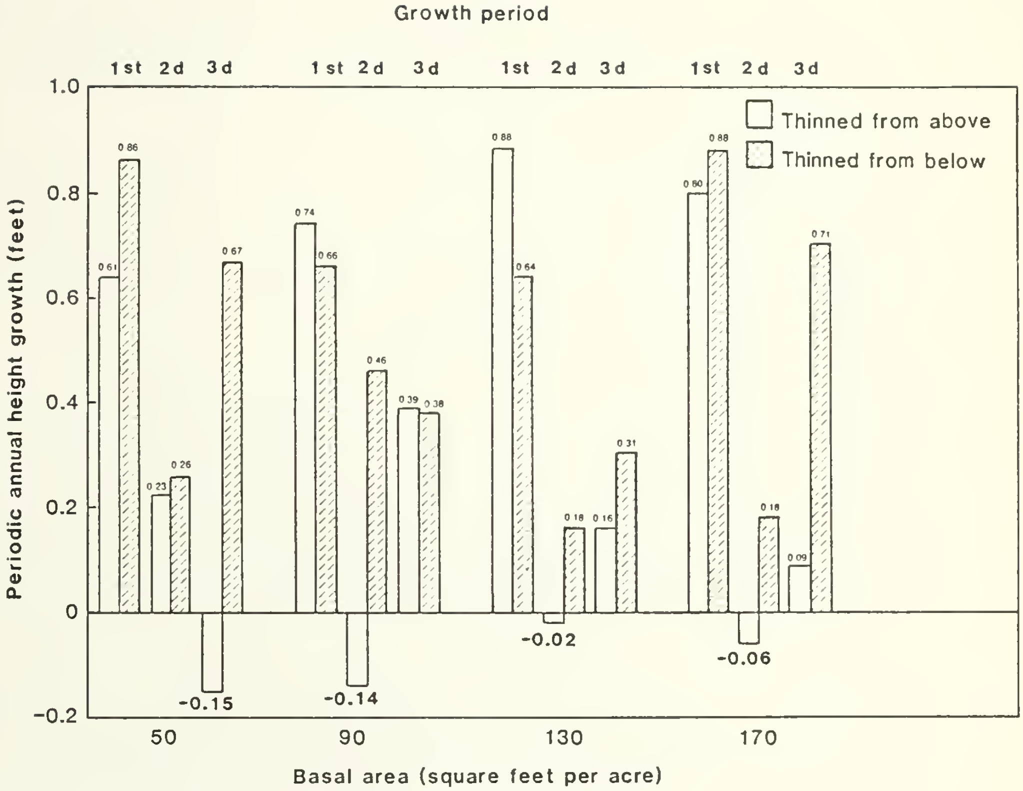

Figure 2—Periodic annual height growth by density level, thinning method, and growth period.

Basal Area Growth

Periodic gross annual basal area increment showed a linear upward trend for both thinning methods and all periods as stand density increased (table 2, fig. 3). Trees in plots thinned from above to the lowest density level in the first period grew 0.78 square foot per acre compared with a maximum growth rate of about 3.5 square feet in high density plots in the third period.

Significant differences ($P < 0.01$) in basal area growth were found among density levels and periods (table 3). The growth rate at the highest level was significantly greater than that at the lowest level (3.03 vs. 1.78 square feet per acre), but all other comparisons were nonsignificant. Average gross basal area growth increasd from 1.92 to 3.20 square feet per acre from the first to the third period, and all differences were significant.

Because of considerable mortality which tended to minimize differences in net growth (table 3), no significant differences were found in net basal area growth among density levels, periods, or thinning methods. For example, mortality offset 54 percent of the gross basal area growth during the third period compared with only 15 to 20 percent during the first two periods. This resulted in a net growth rate during the third period about equal to that of the first period. Mortality in plots thinned from above amounted to 55 percent of the gross growth compared with only a 15-percent loss in plots thinned from below.

Volume Growth

Total gross cubic volume increment showed a positive linear relationship to stand density similar to the basal area stand density relationship (table 2, fig. 4). Gross annual increment varied greatly, ranging from a low of 27 cubic feet per acre during the first period to a high of 204 cubic feet during the third period. The relationship of volume growth to stand density was similar during the first two periods, but during the third period the slope of the curves increased, which suggested greater volume production per square foot of basal area (fig. 4).

Gross cubic volume growth increased significantly ($P < 0.01$) with increasing stand density from 66 cubic feet per acre annually at the lowest level to 114 cubic feet at the highest (table 3). The growth rate at the lowest level was significantly less than that at the other three levels, and level 2 was also significantly less than level 4. Net cubic volume growth was considerably less than gross growth because of the mortality, which ranged from 21 to 34 percent among density levels, and all differences in net growth were nonsignificant.

Gross cubic volume growth increased from the first through the third period, but differences between the first and second period were not significant (table 3). The greatest increase occurred during the third period when the average annual growth rate rose to 141 cubic feet per acre. A 40-percent mortality rate, however, reduced net growth to 84 cubic feet per acre, which was not significantly different from the first two periods. Gross growth in plots thinned from above was not significantly different from growth in plots thinned from below, but the much greater mortality in the plots thinned from above resulted in a significant net growth advantage for the plots thinned from below.

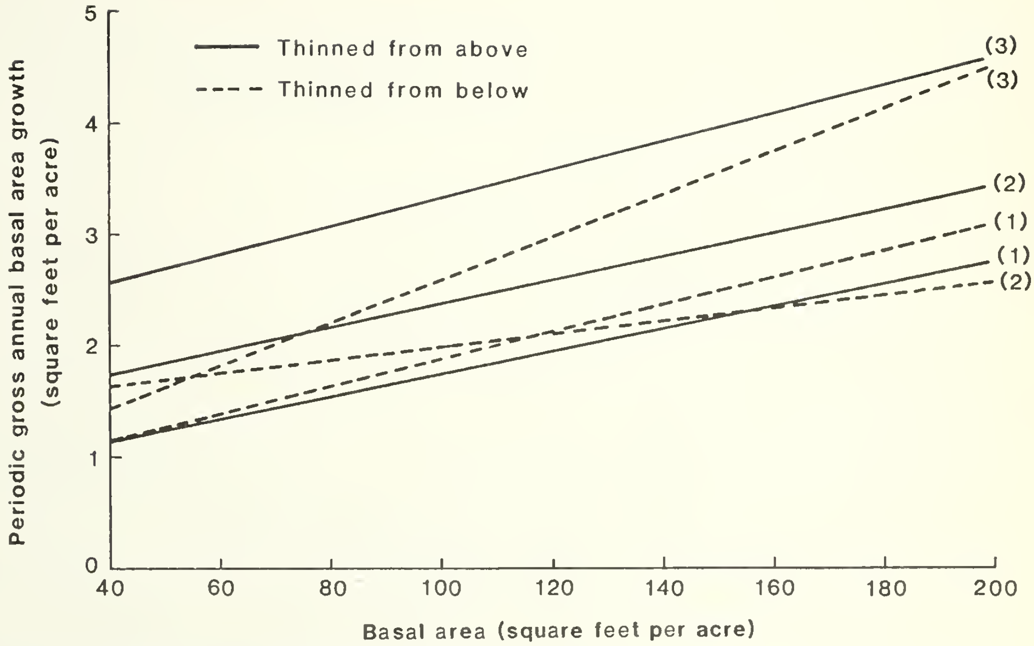

Figure 3—Periodic annual gross basal area growth by thinning method and growth period as a function of stand density; numbers in parentheses are growth periods.

Table 3—Average annual net and gross basal area, total cubic volume and board-foot volume growth and mortality per acre, by density level, growth period, and thinning method[1/]

Item	Basal area growth				Total volume growth				Merchantable volume growth			
	Net	Gross	Mortality		Net	Gross	Mortality		Net	Gross	Mortality	
	- - - Square feet - - -			Percent	- - Cubic feet - -			Percent	- - Board feet - - -			Percent
By density level averaged over all periods and thinning methods:												
1 (low)	1.40a	1.78a	0.38a	21	52a	66a	14a	21	429a	448a	19a	4
2	1.41a	2.34ab	.93a	40	69a	94b	25a	27	622b	627ab	5a	1
3	1.98a	2.73ab	.75a	27	77a	107bc	30a	28	625b	690b	65a	9
4 (high)	1.75a	3.03b	1.28a	42	75a	114c	39a	34	883c	928c	45a	5
By periods averaged over all density levels and thinning methods:												
1970-74	1.50a	1.92a	.42a	22	51a	66a	15a	23	482a	502a	20ab	4
1975-79	1.95a	2.30b	.35a	15	69a	80a	11a	14	430a	444a	14a	3
1980-84	1.47a	3.20c	1.73b	54	84a	141b	57b	40	1,008b	1,073b	65b	6
By thinning methods averaged over all density levels and periods:												
Above	1.27a	2.38a	1.31a	55	54a	96a	42a	44	579a	618a	39a	6
Below	2.01a	2.36a	.35b	15	83b	94a	11b	12	701b	729b	28a	4

1/ Based on plots without clearcut strips. Means followed by the same letter are not significantly different.

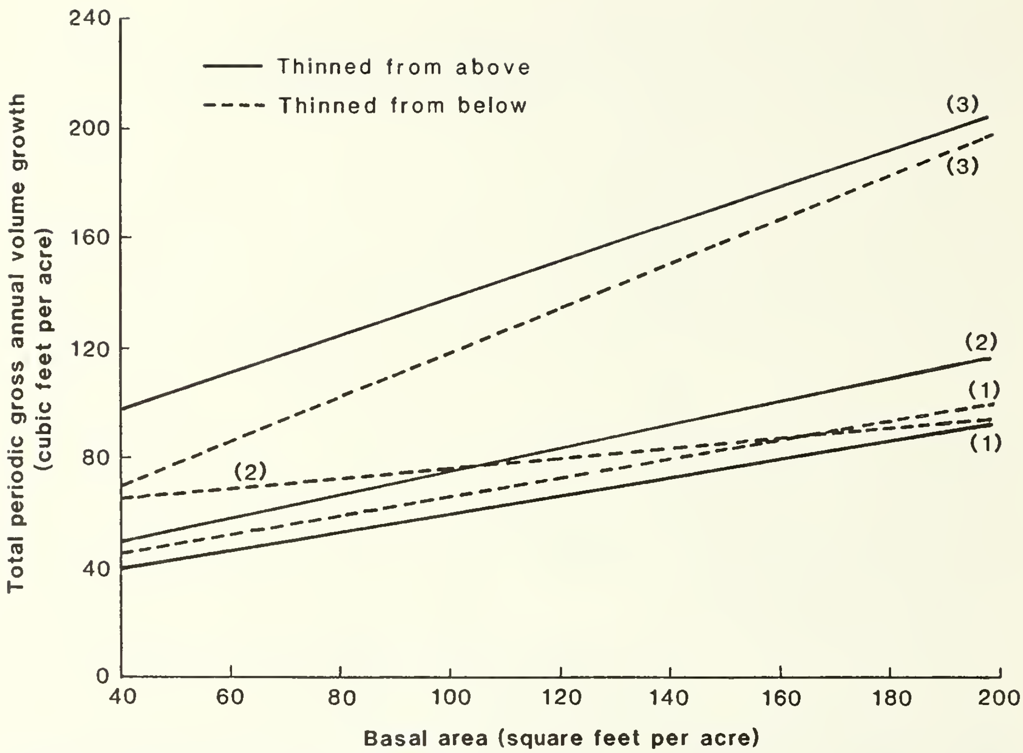

Figure 4—Total periodic gross annual cubic volume growth by thinning method and growth period as a function of stand density; numbers in parentheses are growth periods.

At high stand densities, volume increment is generally greater but is distributed over a large number of trees, many of which are smaller and slow growing. Thinning transfers growth to fewer but faster growing trees in addition to utilizing potential mortality. For example, during the second period, in plots thinned from below, 58 trees per acre at the low density produced 78 percent of the cubic volume grown by 219 trees per acre at the high level.

Gross board-foot volume increment increased linearly with greater stand density during all periods (fig. 5). Annual growth at the lowest level averaged 448 board feet per acre over all periods and thinning methods and increased to 928 board feet at the highest density; significant differences existed among levels (table 3). Board-foot mortality was less than 10 percent of gross growth, so significant differences in net growth are similar to those of gross growth. Both gross and net growth decreased nonsignificantly from the first to the second period but more than doubled during the third period to about 1,000 board feet per acre annually (table 3). The board-foot growth rate was significantly greater in plots thinned from below for both gross and net increment. Ingrowth accounted for a considerable amount (up to 75 percent) of the volume during the first two periods but decreased during the third period as fewer trees remained to enter board-foot size (table 2).

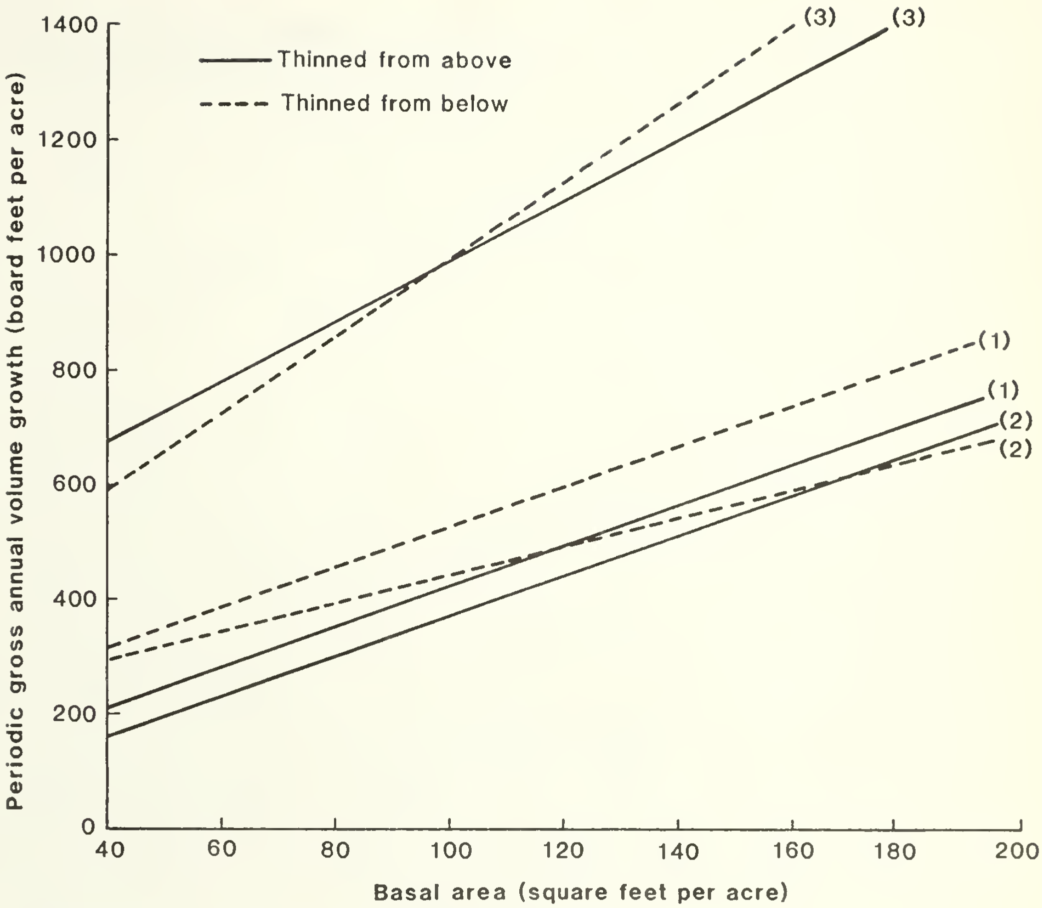

Figure 5—Perioic annual gross board-foot (International 1/4-inch rule) volume growth by thinning method and growth period as a function of stand density; numbers in parentheses are growth periods.

Culmination of mean annual cubic increment appears to have occurred at about age 55; as expected, board-foot increment is still increasing (table 4). Cubic-and board-foot volume growth rates measured in this study from age 55 to 70 agree well with data from yield tables developed for larch in Montana (Schmidt and others 1976). Based on the Montana data, mean annual cubic increment in this study could be expected to decline slowly to about 100 cubic feet per acre at age 140 while mean annual board-foot increment increases to about 650 board feet per acre at the same age.

Thinning with the feller-buncher caused about 29 percent of the total area to be occupied by clearcut strips, with a corresponding 29-percent reduction in volume growth compared with a thinned area completely occupied by trees. The growth and mortality data on an area that includes the clearcut strips are shown in table 2.

Table 4—Net mean annual increment of western larch per acre

Basal area per acre	Age				Age			
	55	60	65	70	55	60	65	70
Square feet	Cubic feet				Board feet			
AREA WITHOUT CLEARCUT STRIPS								
Thinned from above:								
50	130	120	115	110	488	472	452	468
90	110	104	99	96	337	335	334	376
130	125	119	120	125	491	482	494	568
170	114	108	102	100	328	354	358	409
Average	120	113	109	108	411	411	410	455
Thinned from below:								
50	125	119	115	113	446	437	429	450
90	122	117	115	116	380	392	363	453
130	131	125	121	120	354	374	372	473
170	135	131	128	134	481	507	527	605
Average	128	123	120	121	415	428	423	495
AREA WITH CLEARCUT STRIPS								
Thinned from above:								
50	93	85	82	78	347	335	321	332
90	78	74	70	68	239	238	237	267
130	89	84	85	89	349	342	351	403
170	81	77	72	71	233	251	254	285
Average	85	80	77	77	292	292	291	322
Thinned from below:								
50	89	84	82	80	317	310	305	320
90	87	83	82	82	270	278	258	312
130	93	89	86	85	251	266	264	336
170	96	93	91	95	342	360	374	430
Average	91	87	85	86	295	304	300	350

Total Yield and Tree Size

Total net yield in plots thinned from below increased as stand density became greater. Cubic-foot yield ranged from about 7,900 cubic feet per acre at the lowest density level to about 9,400 cubic feet at the highest level in 1985 (table 5). Board-foot yield was greatest at the highest level (42,000 feet per acre) in plots thinned from below, but only small differences were found between the other three levels (31,000 to 33,000 board feet per acre). Total yield in plots thinned from above did not show a consistent relationship to stand density but varied from about 6,700 to 8,600 cubic feet per acre. Averaged over all density levels, total net cubic-foot yield 15 years after the initial thinning was about 12 percent greater in plots thinned from below than in those thinned from above. In terms of board feet, plots thinned from below have a 9-percent advantage in yield.

Table 5—Total net growth and yield of western larch per acre, by density level and thinning method[1]

Item	Residual basal area level (square feet) and thinning method							
	50		90		130		170	
	Above	Below	Above	Below	Above	Below	Above	Below
	Number of trees							
Total trees, 1970	420	490	495	557	408	596	513	525
Cut, 1970	287	432	238	442	177	400	113	306
Left, 1970	133	58	257	115	231	196	400	219
Cut, 1980	35	12	43	13	22	21	53	29
Left, 1980	98	46	214	102	209	175	347	190
Total trees, 1985	82	46	168	98	189	149	278	182
15-year mortality	37	--	82	3	31	26	121	7
	Inches							
Quadratic mean diameter, 1985	11.4	16.3	10.4	14.6	12.3	13.2	10.1	14.4
	Percent							
Trees, 10 inches in d.b.h. and larger, 1985	57.0	100	45.7	100	72.2	88.8	49.0	100
	Cubic feet							
Total volume:								
Total stand, 1970	7,177	6,892	6,032	6,688	6,883	7,192	6,285	7,402
Cut, 1970	5,530	5,206	3,126	3,714	2,792	2,744	1,615	1,601
Left, 1970	1,647	1,686	2,906	2,974	4,091	4,448	4,670	5,801
Cut, 1980	193	333	283	320	399	354	44	413
Left, 1980	1,726	1,955	3,050	3,409	4,623	4,782	4,958	6,327
Net 15-year growth	545	1,015	710	1,360	1,725	1,208	715	1,978
Total net yield, 1985	7,722	7,907	6,742	8,048	8,608	8,400	7,000	9,380
	Board feet (International 1/4-inch rule)							
Merchantable volume:								
Total stand, 1970	26,816	24,555	18,540	20,898	27,020	19,479	18,045	26,446
Cut, 1970	24,000	16,224	12,853	7,395	13,030	2,689	7,991	2,006
Left, 1970	2,816	8,331	5,687	13,503	13,990	16,790	10,054	24,440
Cut, 1980	461	1,465	1,507	1,444	1,985	1,076	212	234
Left, 1980	4,921	10,171	7,361	17,425	17,118	20,402	15,082	31,991
Net 15-year growth	5,960	6,915	7,810	10,835	12,770	13,631	10,595	15,900
Total net yield, 1985	32,776	31,470	26,350	31,733	39,790	33,110	28,640	42,346

1/ Based on plots without clearcut strips.

In plots thinned from below, quadratic mean diameter in 1985 ranged from 13.2 to 16.3 inches (table 5). Although stand diameter was not greatly different among density levels, plots at the highest density contained more unmerchantable trees, which resulted in less merchantable volume when the second thinning was made. For example, at the 90-square-foot density level, 13 trees per acre removed in the second thinning from below yielded 1,444 board feet. In contrast, 29 trees per acre cut from the 170-square-foot level yielded only 234 board feet.

Discussion

It is evident that western larch stands have considerable ability to maintain diameter and volume growth despite attacks by the larch casebearer. In spite of heavy infestation of the casebearer during part of the second period, growth increased. Prolonged attacks, however, may have a more negative effect on growth. It is also encouraging to observe the excellent growth response during the third period after the second thinning when the casebearer was no longer present. Although the casebearer did not impact diameter growth at breast height[4/] or volume growth, it did have an adverse effect on height growth. In young stands a sustained reduction in height growth caused by insect damage can make the shade-intolerant larch lose its competitive advantage to its more shade-tolerant associates and eventually be eliminated from the stand.

Gross cubic volume growth in plots thinned from above was about equal to growth in plots thinned from below, but because of much greater mortality in plots thinned from above net growth was considerably less in these plots. The smaller trees remaining are not able to withstand wind, snow, and ice after the protection of the larger dominant and codominant trees is removed. Therefore, thinning from below is recommended in previously unmanaged larch stands.

Selecting a suitable stocking level after thinning is a compromise between high stand densities that produce the most wood volume and low densities that result in greater diameter growth. In this study, net periodic cubic volume increment and yield did not differ greatly among density levels; and diameter growth was also relatively uniform, except at the lowest level. Therefore, the land manager has considerable latitude in selecting an appropriate growing stock level to attain desirable product characteristics. In terms of timber management, stands should be thinned from below to a level that will maintain acceptable tree vigor and diameter growth and will minimize mortality without sustaining unacceptable volume losses.

Comparisons of the stand density levels in this study with stocking-level curves for larch prepared by Cochran (1985) show that plots initially thinned to 130 square feet of basal area per acre (level 3) fall between the lower (minimum) and upper (maximum) curves for site index 80 stands. The 50- and 90-square-foot levels are below the minimum stocking curve, whereas the 170 level is near the maximum curve. To reduce stand density to correspond to the minimum curve, a residual basal area of about 110 square feet per acre is indicated if the average stand diameter is about 12 inches.[5/]

[4/]Although diameter growth at breast height was not affected by defoliation, the effects of defoliation are usually greatest in the live crown and therefore diameter growth may have been reduced in the upper portions of the bole (Kulman 1971).

[5/]The lower and upper stocking-level curves given by Cochran (1985) are based on 45 and 75 percent of normal stocking, respectively.

In a shade-intolerant species such as western larch, early thinning is necessary. Although thinning in older stands can increase diameter and volume growth of residual trees, the greatest gain from thinning seral species (such as larch) is obtained when thinning is begun much earlier. Schmidt (1966) suggests that the ideal time for precommercial thinning of larch is when trees are about 10 years old and 10 to 15 feet tall. Such early thinning maintains vigorous, full-crowned trees and concentrates the rapid growth during the sapling and pole stages on crop trees. In addition, trees in stands thinned early develop greater resistance to wind, snow, and ice damage than trees growing in dense stands.

To summarize, early precommercial thinnings when trees are about 10 years old and 10 to 15 feet tall are recommended in overstocked young larch stands. The spacing selected should result in a diameter growth rate that will allow merchantable trees to be cut in the next (commercial) thinning. A range in spacings of 13 to 19 feet after the precommercial thinning should meet this objective. Using a closer spacing assumes that smaller trees will be salable at the time of the commercial thinning, whereas a wider spacing implies that larger trees are needed for the commercial thinning. After the stand reaches merchantable size, thinnings from below to reduce basal area to the minimum curve (Cochran 1985) are recommended.

Metric Conversions

1 mile = 1.61 kilometers
1 foot = 0.3048 meter
1 inch = 2.54 centimeters
1 acre = 0.4047 hectare
1 square foot/acre = 0.2296 square meter/hectare
1 cubic foot/acre = 0.0700 cubic meter/hectare
1 tree/acre = 2.47 trees/hectare

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Madrone Duff and the Natural Regeneration of Douglas-fir

Don Minore

Abstract

Excellent natural regeneration of Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) often occurs under canopies of Pacific madrone (*Arbutus menziesii* Pursh), but the effects of madrone duff on regeneration are poorly understood. A field experiment was conducted in a thinned Douglas-fir stand in southwestern Oregon to see if madrone duff benefits natural regeneration or reduces the cover of species that compete with Douglas-fir. No significant differences in conifer regeneration and growth or in the cover of competing species occurred among seedbeds of madrone duff, conifer duff, and mineral soil during 10 growing seasons. Douglas-fir regeneration may be affected less by madrone duff than by other influences of madrone trees.

Keywords: Duff, regeneration (natural), Douglas-fir, madrone.

Introduction

Pacific madrone (*Arbutus menziesii* Pursh) often competes with Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco). Several components of that competition have been studied: madrone growth rates (Roy 1955, Tappeiner and others 1984); leaf area and biomass (Harrington and others 1984); transpiration (Bentson 1983); and effects of madrone sprouts on light, moisture, and temperature (Minore 1986). The allelopathic effects of madrone are inconsistent, however, and the influence of madrone duff on the natural regeneration of Douglas-fir is poorly understood.

Del Moral and Cates (1971) used extracts of leaves and litter to show that madrone produces allelopathic chemicals capable of inhibiting the radical elongation of germinating Douglas-fir seeds on extract-soaked sponges in the laboratory. They compared the number and cover of species beneath madrone canopies with the number and cover of species beyond the canopies and concluded that madrone reduces subordinate vegetation in the field.

Tinnin and Kirkpatrick (1985) also examined the allelopathic effect of madrone on early seedling growth of Douglas-fir. Their leaf extracts did not significantly reduce the radical elongation of germinating Douglas-fir seeds on extract-soaked sponges. Tinnin and Kirkpatrick germinated and grew Douglas-fir for 4 weeks in a mixture of sponge rock and vermiculite; mean seed germination time nearly doubled and root growth time was halved when leaf material was added to the artificial soil mixture. Madrone leaf material had no significant effect on Douglas-fir growth when it was added to soils collected from the field, however, and germination was slowed in only one of three soil trials. Tinnin and Kirkpatrick concluded that allelopathy is not the primary factor affecting the regeneration of Douglas-fir in southwestern Oregon.

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Rose and others (1983) found that madrone litter extracts stimulate the growth of some mycorrhizal fungi and inhibit others when applied to pure cultures in the laboratory. Inhibition varies with the concentration of the extract. They found that madrone litter leachate reduces the mycorrhizae formed on roots of Douglas-fir seedlings grown in the greenhouse on forest soil from southern Oregon, but it does not reduce root growth or shoot weight.

Laboratory experiments using extracts of ground leaves or leaf litter and artificial substrates are useful in isolating the effects of allelopathic chemicals, but they do not indicate the importance of those effects in the field. Similarly, laboratory and greenhouse experiments that use soils collected from the field for short-term bioassays of allelopathic effects neither prove nor disprove the importance of allelopathy in nature. If allelopathic effects occur, their cause or causes may be very difficult to isolate. Nevertheless, it is important to determine the presence or absence of those effects under natural conditions.

Alvarez and others (1979) determined that white fir (*Abies concolor* [Gord. & Glend.] Lindl. ex Hildebr.) seedlings survive and grow better in mineral soil alone than in mineral soil with organic layers in the north-central Sierra Nevada. They concluded that both seedling growth and the presence of mycorrhizae are favored by the absence of organic layers.

Organic layers derived from madrone litter are present under most madrone trees, and these local areas of madrone duff may affect the survival and growth of naturally established Douglas-fir seedlings. Pacific madrone competes for light, moisture, and nutrients, but it often forms a nurse cover for Douglas-fir in southwestern Oregon (Gratkowski 1961). Excellent natural regeneration of Douglas-fir sometimes occurs under madrone canopies (fig. 1).

I conducted an experiment in the field to determine if madrone duff benefits the natural regeneration of Douglas-fir or reduces the cover of species that compete with Douglas-fir seedlings. I conducted another experiment in the laboratory to determine if madrone duff affects Douglas-fir seed germination. There were three null hypotheses:

- Madrone duff does not affect the natural regeneration of Douglas-fir.
- Madrone duff does not affect the cover of competing species.
- Madrone duff does not affect the germination of Douglas-fir seeds.

Figure 1—Natural regeneration of Douglas-fir under a madrone canopy.

Methods

Field Experiment

The field experiment was established in a Douglas-fir stand at an elevation of 945 meters (3,100 ft) in the Tiller Ranger District, Umpqua National Forest. Similar stands are common in the Cascade Range of southwestern Oregon. This stand was thinned in 1974. Average light intensity under the thinned stand at noon on September 12 was 410 microeinsteins meter^{-2} second^{-1}—about 25 percent of full sunlight.[1/] Soil under the stand was a well-drained sandy loam in the Straight series. The site had a west aspect and was on a 40-percent slope. An array of 12 seedbed plots was established in May 1975. Each plot was a 2- by 1-meter (6.6- by 3.3-ft) rectangle, and the plots were spaced about 3 meters (9.8 ft) apart.

[1/] A Li-Cor model LI-185A quantum/radiometer/photometer and quantum sensor registering in the 400 to 700 nm waveband were used to measure radiation at 1 meter (3.3 ft) above the soil surface at 120 systematically located points. (The use of trade names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product to the exclusion of others that may be suitable.)

Three treatments were randomly assigned to these 12 plots. In the first treatment, all duff was removed from four plots. In the second treatment, all duff was removed from four plots and immediately replaced. In the third treatment, all duff was removed from four plots and replaced with madrone duff. Four 2- by 1-meter (6.6- by 3.3-ft) areas under a nearby madrone stand were scraped bare to provide the duff for this third treatment. Thus, there were four replications of three seedbeds: mineral soil, conifer duff, and madrone duff. Sides of 1.3-centimeter (0.5-in) hardware cloth were constructed around each plot to reduce litter movement and raveling. The sides were 15 centimeters (6 in) high and supported by length of 1.3-centimeter (0.5-in) diameter aluminum tubing driven into the soil at regular intervals.

I revisited the plots in June 1976, May 1977, July 1978, September 1979, September 1980, and September 1984. Fresh litter from the previously scraped areas under the madrone stand was removed and scattered on the madrone duff plots in 1976, 1977, 1978, and 1979. Douglas-fir seedlings of natural origin were counted and measured on each of the 12 plots at each visit. Vegetative cover was measured in 1976, 1977, 1978, 1979, and 1984 by recording the length occupied by each species present along two systematically located, 2-meter (6.6-ft) line intercepts on each plot. Numbers of seedlings, heights of the tallest seedling on each plot, and total vegetative cover were evaluated in split-plot analyses of variance by treating seedbed treatments as the whole plots and measurement periods as the subplots.

Laboratory Experiment

Surface material was collected from each of the 12 field plots and brought to the laboratory in September 1984. The field samples were moistened and placed in 12 plastic sandwich boxes. Sixty Douglas-fir seeds were sown on the surface in each box, and the boxes were closed and placed in random order in a cooler at 1 °C (34 °F). After an 8-week stratification period, the closed boxes were removed from the cooler and placed in random order in a growth chamber at 10 °C (47 °F) with a 12-hour photoperiod. Germinating seeds were counted and removed daily. I used the techniques described by Campbell and Sorensen (1979) to calculate days to peak germination, mean germination rate, and the standard deviation of mean germination rate. Germination percentages were transformed to arc sines. Completely random analyses of variance were used to examine all differences associated with seedbed substrates.

Results

Field Experiment

Douglas-fir regeneration was slow at first, but there was an average of 2.7 seedlings/square meter (0.25 seedlings/ft^2) after the first six growing seasons (table 1). Regeneration continued during the last four growing seasons to produce an average of 10 seedlings/square meter (0.93 seedlings/ft^2) in September 1984 at the end of the 10th growing season. This is equivalent to 100,000 seedlings/hectare (40,469 seedlings/acre). Variation among seedbed replicates was large, however, and the conifer duff, mineral soil, and madrone duff averages were not significantly different.

The Douglas-fir seedlings grew slowly. Seedling heights increased with every measurement, but the increases were small and not significantly different among seedbeds (table 2).

Table 1—Average number of naturally established Douglas-fir seedlings on conifer duff, mineral soil, and madrone duff seedbeds in the field, by measurement date [1/]

Seedbed	June 1976 [2/]	May 1977 [2/]	July 1978 [2/]	September 1979 [2/]	September 1980 [2/]	September 1984 [2/]
			Seedlings per square meter [3/]			
Conifer duff	0.1	1.1	2.0	3.1	2.8	7.1
Mineral soil	.1	1.1	1.9	2.5	2.5	9.8
Madrone duff	.1	.4	2.8	3.1	2.9	13.2

[1/]Each value is the average obtained from 4 randomly located, 2- by 1-meter rectangular plots under a thinned Douglas-fir stand. The plots were established in May 1975.

[2/]The seedbed values do not differ significantly ($\underline{P}<0.05$).

[3/]To obtain number of seedlings per square foot, multiply by 0.0929.

Table 2—Average height of naturally established Douglas-fir seedlings on conifer duff, mineral soil, and madrone duff seedbeds in the field, by measurement date [1/]

Seedbed	May 1977 [2/]	July 1978 [2/]	September 1979 [2/]	September 1980 [2/]	September 1984 [2/]
			Centimeters [3/]		
Conifer duff	2.0	4.1	5.2	6.5	11.9
Mineral soil	2.3	4.8	6.4	7.6	11.8
Madrone duff	1.5	5.3	6.7	8.2	9.1

[1/]Each value is the average obtained from the tallest seedling on each of 4 randomly located, 2- by 1-meter rectangular plots under a thinned Douglas-fir stand. The plots were established in 1975, but absence of seedlings on most replicates made height analysis impractical in 1976.

[2/]The seedbed values do not differ significantly ($\underline{P}<0.05$).

[3/]To obtain height in inches, multiply by 0.3937.

Competing vegetation was not a serious problem on any of the seedbed plots. Indeed, seedling establishment seemed to be more common under competing plants than it was in the open. Snowberry (*Symphoricarpos albus* [L.] Blake) was the most abundant species, and it accounted for about half of the vegetative cover after 10 growing seasons. Species composition was similar on the three seedbeds, and the average cover of competing vegetation did not differ significantly on conifer duff, mineral soil, and madrone duff (table 3).

Table 3—Average cover of competing vegetation on conifer duff, mineral soil, and madrone seedbeds in the field, by measurement date [1]

Seedbed	June 1976 [2]	May 1977 [2]	July 1978 [2]	September 1979 [2]	September 1984 [2]
			Percent		
Conifer duff	23.2	7.2	21.8	24.0	36.0
Mineral soil	25.5	7.5	17.5	15.2	34.8
Madrone duff	21.8	3.8	13.5	12.0	32.2

[1]Each value is the average obtained from line intercepts on 4 randomly located, 2- by 1-meter rectangular plots. Snowberry (*Symphoricarpus albus* [L.] Blake) was the dominant species on all 3 seedbeds.

[2]The seedbed values do not differ significantly ($\underline{P}<0.05$).

Table 4—Average germination percentages, days to peak germination, and mean germination rates of Douglas-fir seeds stratified and germinated in the laboratory on conifer duff, mineral soil, and madrone duff [1]

Seedbed substrate	Germination [2]	Peak germination [2]	Mean germination rate and standard deviation [2] [3]
	Percent	*Days*	
Conifer duff	57.1	12.8	0.0643 ± 0.0231
Mineral soil	68.3	12.6	.0656 ± .0231
Madrone duff	72.5	12.4	.0666 ± .0237

[1]Each value is the average of 4 replicates.

[2]Determined by the method of Campbell and Sorensen (1979). The substrates do not differ significantly ($\underline{P}<0.05$).

[3]Mean germination rate equals 1/(mean germination time in days).

Laboratory Experiment

Germination began 8 days after seeds were placed in the growth chamber; the last viable seed germinated 7 weeks later. A few more Douglas-fir seeds germinated on madrone duff than on conifer duff or mineral soil, but the differences among seedbed substrates were not significant (table 4). Differences among substrates were also small and not significant with respect to peak germination and mean germination rate. I did not observe any substrate-related germination abnormalities.

Conclusions

None of the three null hypotheses were rejected. Failure to reject a null hypothesis does not prove that null hypothesis (Parkhurst 1985), however, and the lack of significant differences among the seedbed substrates does not prove that the substrates were similar. I have not shown that madrone duff failed to affect natural regeneration, competing vegetation, or seed germination. It may have done so, but any effects of the duff were obscured by variation among seedbed replicates. That variation indicates that other factors were more important than madrone duff.

If madrone duff benefits the natural regeneration of Douglas-fir, reduces competing vegetation, or affects the germination of Douglas-fir seeds, its effects probably are not very important. Douglas-fir regeneration may be affected less by madrone duff than by the influences of madrone trees on microclimate, soil moisture, seed fall, animal predation, and other unmeasured variables.

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Pecky Rot in Incense-Cedar: Evaluation of Five Scaling Methods

James M. Cahill, W.Y. Pong, and
D.L. Weyermann

Abstract

A sample of 58 logs was used to evaluate five methods of making scale deductions for pecky rot in incense-cedar (*Libocedrus decurrens* Torr.) logs. Bias and accuracy were computed for three Scribner and two cubic scaling methods. The lumber yield of sound incense-cedar logs, as measured in a product recovery study, was used as the basis for comparison. Results showed that the most biased and least accurate scaling systems deducted the greatest percentage of log volume.

Keywords: Log scaling, defect deduction (-merchantable volume, pecky rot, lumber recovery, incense-cedar, *Libocedrus decurrens*.

Introduction

Incense-cedar (*Libocedrus decurrens* Torr.) is an important commercial softwood species in the Western United States. Currently, there are about 14 billion board feet of commercial size incense-cedar in the West; a majority of this volume is in northern California and southern Oregon (USDA Forest Service 1973b). Incense-cedar is manufactured into a variety of products including lumber, pencil stock, fenceposts, and shakes.

Although wood products manufactured from incense-cedar are recognized as extremely resistant to decay, standing sawtimber is highly defective. Pecky or dry rot (*Polyporus amarus* Hedgc.) causes extensive heart rot in trees throughout the range of this species (Boyce 1920, Wagener and others 1958). In the early stages of decay, pecky rot occurs in small scattered pockets confined to the heartwood (fig. 1a). As the decay intensifies, the number and size of the decay pockets increase and eventually coalesce (fig. 1b). The varying amount and scattered occurrence of pecky rot create problems for scalers trying to estimate the net volume of wood available for lumber production. Scalers often ask whether the scaling rules used to deduct for pecky rot are accurate: Do specific scaling rules deduct too much or too little for the presence of peck?

The purpose of this paper is to report the results of an analysis of five ways to make deductions for pecky rot. Three methods of Scribner deductions and two methods of cubic log scale deductions were analyzed for their ability to estimate the volume of wood available for lumber production. The scaling systems were compared by ranking the estimates of bias and accuracy.

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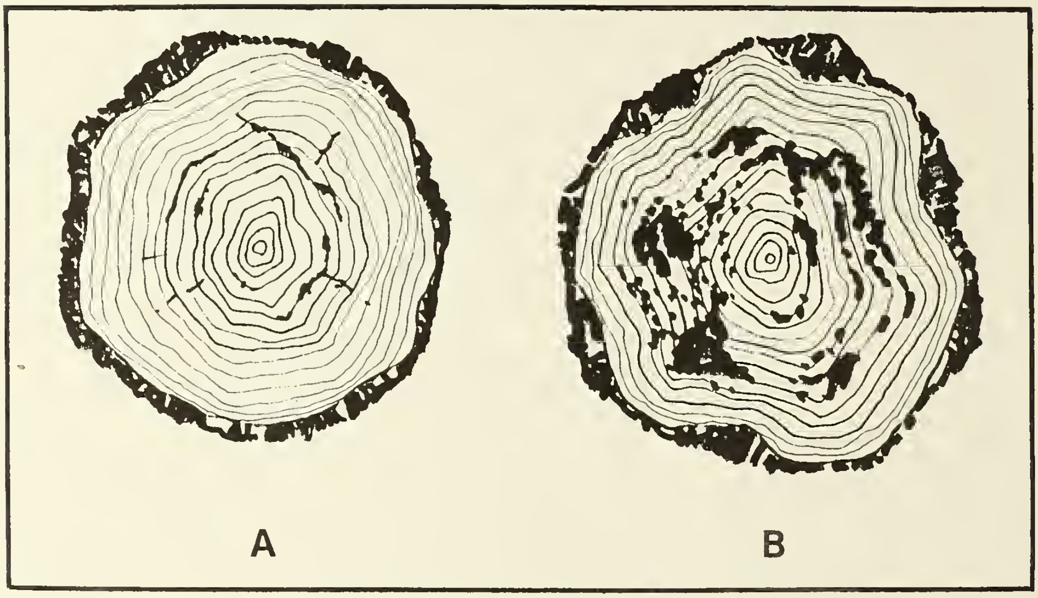

Figure 1—Incense-cedar log ends: **(A)** Scattered pockets typical of the early stages of decay. **(B)** Large, numerous decay pockets typical of advanced decay.

Methods

The general approach used to analyze the scaling options was to compare the lumber yield of logs containing pecky rot to the lumber yield of sound logs. Lumber yield and log scale data measured at a product recovery study were used. Fahey and others (1981) and Cahill (1983) used the same approach to analyze other scaling problems. Log scale deductions are considered accurate if the lumber yield based on the net volume of a log with peck in it is the same as the lumber yield of a sound log of equivalent volume.

Data Base

The data used to conduct this analysis were collected during a product recovery study in 1982. A total of 130 incense-cedar trees were selected from six areas in the Eldorado National Forest in California. Trees were selected to capture the range of quality and sizes that exists in incense-cedar. Diameter at breast height (d.b.h.) for the sample ranged from 16 to 54 inches. The pecky rot included in the sample represented the range of severity that would be seen in normal scaling operations.

Certified USDA Forest Service scalers recorded Scribner (USDA Forest Service 1973a) and cubic (USDA Forest Service 1978) scales on the woods-length logs prior to sawing. Deductions by scaling defect were recorded for each log and were based on all scaling methods. The logs were processed in a sawmill where moulding, shop, and board items were cut. Study lumber was tallied for individual logs after drying and surfacing. The percentage of lumber manufactured by grade group is shown:

Lumber grade	Percent
Moulding	10
Shop grades	36
3 & Better Common	29
4 Common	15
5 Common	10

Alternative Scaling Techniques

Deductions for pecky rot were made using the following Scribner and cubic scaling rules:

1. *Scribner standard scale.* Scale was taken using the standard National Forest log scaling handbook rules for Scribner scale (USDA Forest Service 1973a). All peck, regardless of the arrangement on the log ends, is deducted. Since this study was completed, Forest Service scaling practices have changed. Handbook rules now state that only pockets of peck less than 5 inches apart are considered as a scaling defect.

2. *Scribner 1¾-inch rule.* A deduction for pecky rot is made only when there is less than 1¾ inches of solid wood between pockets of rot as the pockets appear on the log end. For example, deductions would be made on a log where the pockets of peck were 1 inch apart. No deductions would be made if the peck holes were 2 inches apart.

3. *Scribner 4-inch rule.* A deduction for pecky rot is made only when there is less than 4 inches of solid wood between pockets of rot.

4. *Cubic, total deduction.* The cubic volume of rot is estimated using Smalian's formula. Diameters of the column containing the scattered peck are measured on both ends if possible. If peck shows on only one end, length of the rot column is estimated by the scaler.

Example: If a rot column of 10 inches shows only on the large end of a 33-foot log, the scaler would estimate that the rot extends 8 feet into the log and the peck deduction would be:

$$\text{Peck volume} = (10^2 + 10^2) \times 8 \times (0.0027274) = 4.4 \text{ cubic feet (CF)};$$

where:

10 and 10 = the diameters (in inches) of the rot column,
8 = the estimated length of the rot column (in feet), and
0.0027274 = a constant used to convert to cubic feet.

5. *Cubic, soft deduction.* Under this method the scaler estimates the volume of wood fiber that is decayed and not available for lumber production. If the scaler estimates that only 50 percent of the rot column of the log in the example above is in soft, unusable wood, then the cubic soft deduction would be 2.2 cubic feet (4.4 × 0.50).

Analysis Procedure

The first step in analyzing the scaling options was to sort the logs into two groups: Sound logs and logs with only peck as a scalable defect (pecky logs). Logs with defects other than pecky rot or logs with multiple defects were not included in the analysis. The following tabulation shows the number of logs, the average scaling diameter, and the range in diameters for the two groups of logs:

	Number of logs	Average diameter	Range in diameters
		(Inches)	(Inches)
Sound logs	185	12	6-31
Pecky logs	58	19	8-33

The second step in the analysis established the yield of lumber from sound incense-cedar logs. This provided a basis for comparing the different scaling options. Lumber yield of the sound logs is represented by the regression of rough green lumber tally in cubic feet over gross Scribner and gross cubic scales (figs. 2 and 3). The relation for gross cubic scale volume was simple linear function (fig. 3); a segmented regression was needed to adequately describe the relation between Scribner scale and cubic lumber tally (fig. 2). The segmented regression was necessary because Scribner scale underestimates the volume in small logs; hence, the rate of lumber recovery varies depending on log size. The regression was segmented at 240 board feet after we examined summary statistics (R^2 and standard error of the regression) for several models with different break points.

The final step in the procedure compared the actual lumber tally of a pecky log, after scale deductions, to the recovery of a sound log of the same net scale. The closer the lumber recovery of a defective log is to a sound log of equivalent volume, the better. Lumber yield for sound logs was estimated from the regression of lumber tally over scale volume (figs. 2 and 3).

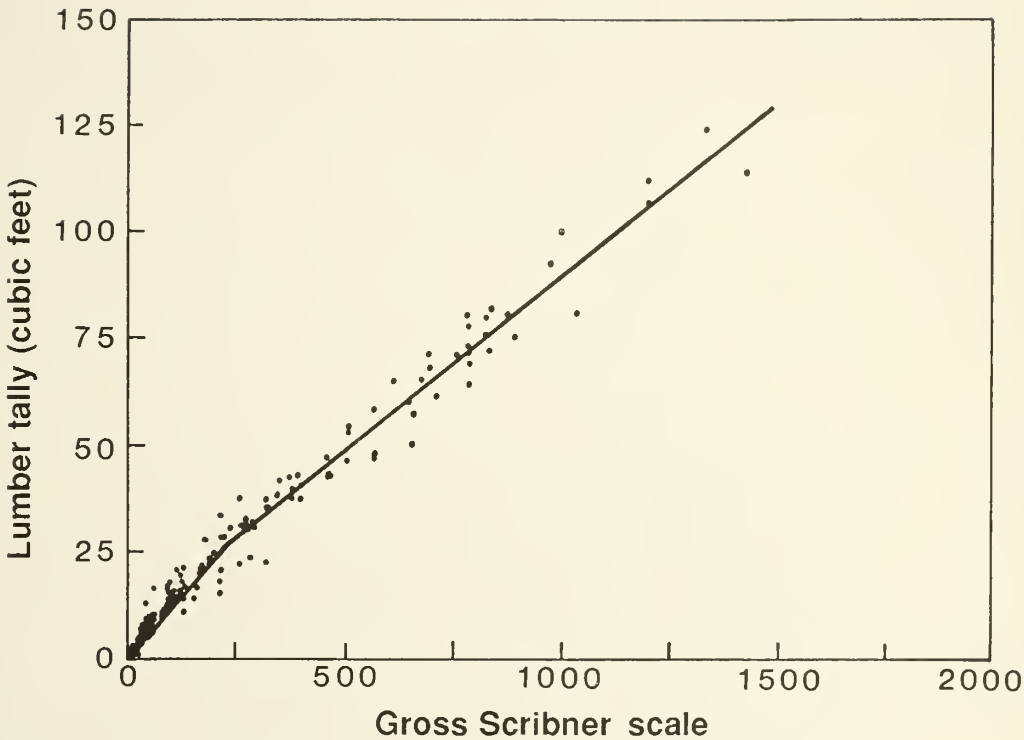

Figure 2—Regression line and data scatter of lumber tally (cubic feet) versus gross Scribner scale for sound incense-cedar logs. The regression equation is:

$$LT = 8.19 + 0.0807 * S - 0.0282 * I * (240 - S) ;$$

where:

LT = lumber tally,
S = Scribner log scale, and
I = an indicator variable (I = 1 when $S \leq 240$ and I = 0 when $s > 240$).

$R^2 = 0.98$; N = 185.

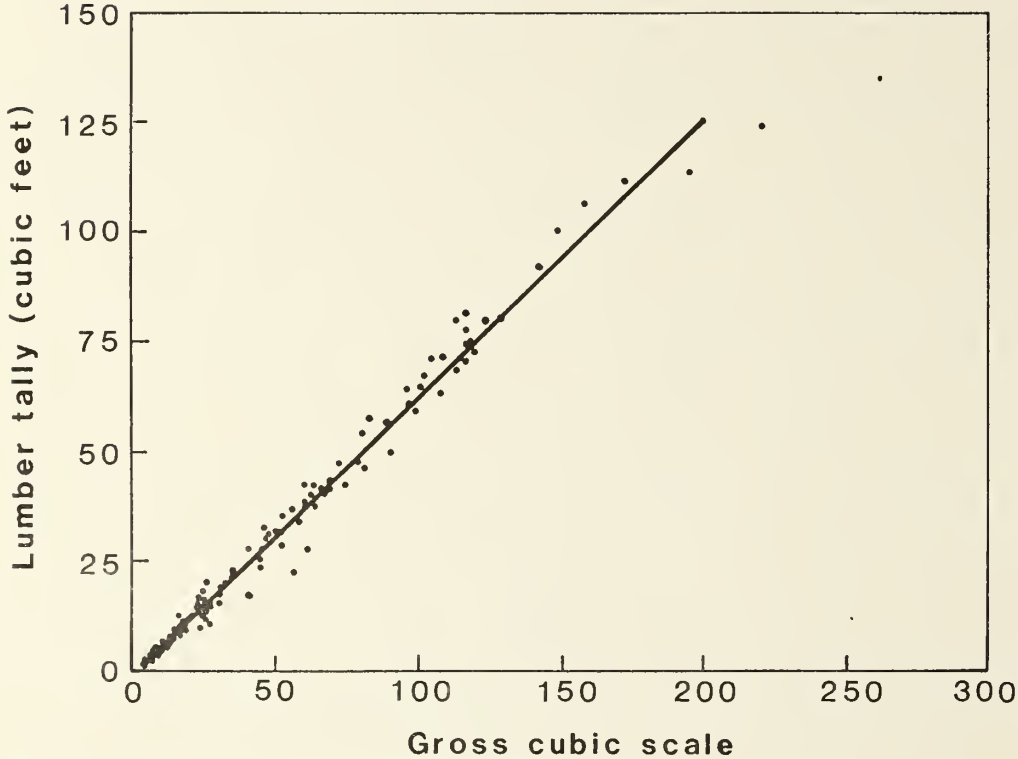

Figure 3—Regression line and data scatter of lumber tally (cubic feet) versus gross cubic log scale for sound incense-cedar logs. The regression equation is:

$$LT = -1.526 + 0.635 * CS ;$$

where:

LT = the lumber tally, and
CS = the cubic log scale.

$R^2 = 0.99$; N = 185.

An objective evaluation of the scaling options was made by comparing the average bias and accuracy for the 58 pecky logs and by using the lumber recovery of the sound logs as a base for comparison. Bias is defined as the average deviation of the actual lumber tally of a pecky log from the predicted tally of a sound log of the same net volume.[1] A system with little bias (bias close to zero) indicates that, on the average, the deduction is placing pecky logs on the same lumber yield basis as a sound log. Accuracy is defined as the square root of the average squared deviations[2] and is a measure of the variability of the yield of lumber from the pecky logs around the sound regression line. The larger the number associated with accuracy, the greater the variability. When the scaling options are evaluated, both bias and accuracy should be considered because a system that is both unbiased (a number close to zero) and accurate (a small number) is desirable.

Table 1 shows an example of the calculation of bias for a hypothetical incense-cedar log. It was assumed that pecky rot is the only defect in the log. Only the three Scribner scaling options are used in this example. The net log scales are different because each scaling option used different rules to estimate the amount of defect. The yield of lumber from a sound log for each net scale estimate was taken from the regression line in figure 2. Actual lumber tally would be the cubic feet of lumber measured at a product recovery study. Bias is the actual yield of lumber subtracted from the estimated yield of a sound log. In this example, the Scribner 4-inch rule worked best because that bias was closest to zero (+2.6). Accuracy was not computed in this example. The average bias and accuracy are used for large samples of defective logs to make comparisons among scaling systems.

---

[1] Estimate of bias is the average deviation where the deviation is actual recovery from a defective log (y_i) minus the predicted recovery of a sound log of the same volume $(\hat{y}_i)$; that is, $\Sigma(y_i - \hat{y}_i)/n$.

[2] Estimate of accuracy is the square root of the average squared deviation; that is, $(\Sigma(y_i - \hat{y}_i)^2/n)^{1/2}$.

Table 1—Example of bias calculation for a hypothetical incense-cedar log

Scaling option	Net scale	Lumber yield[1] from a sound log	Actual lumber tally[2]	Bias[3]
	Board feet	- - - - - - - -	*Cubic feet*	- - - - - - - -
Net 1¾-inch rule	350	36.4	33.0	33.0-36.4 = −3.4
Net 4-inch rule	275	30.4	33.0	33.0-30.4 = +2.6
Standard Forest Service scale	200	23.2	33.0	33.0-23.2 = +9.8

[1] Lumber yield for a sound log was estimated from the regression equations in figures 2 and 3.

[2] Actual lumber tally is the cubic feet of lumber measured at a product recovery study.

[3] Bias is the actual lumber tally, in cubic feet, minus the predicted lumber tally from a sound log.

Results

Table 2 shows the average bias and accuracy and the percentage of log volume deducted for the Scribner and cubic scaling options.

The 1¾-inch rule deducted the smallest amount of volume (28 percent) for the Scribner options and had the least bias and greatest accuracy. The positive sign associated with the bias (+4.95) indicated that, on the average, the deductions were still excessive. The standard Forest Service scale deducted the greatest volume (46 percent) and was the most biased and least accurate. A better estimate of net scale can be made by making no deductions for peck than by using the current, standard Forest Service scale.

Bias and accuracy for the cubic scales were best for the deduction that adjusted the volume of rot by the amount of wood actually decayed (cubic soft). This option also deducted the least amount of log volume. Making no deductions would have provided a better estimate of usable wood than the cubic total deduction.

The 58 pecky logs were then divided into two groups: (1) Logs with rot showing on one end (ROT1 logs, N = 25) and (2) logs with rot showing on both ends (ROT2 logs, N = 33). Rot occurred along the entire length of the woods-length, ROT2 log; the decay in the ROT1 logs ended at some intermediate point. The average bias, accuracy, and percentage of log scale deduction are shown for both groups in table 3.

We expected the logs in the ROT2 group to have a greater lumber loss than the ROT1 logs because they had decay scattered throughout the entire log length. This was confirmed by the data in table 3 that compares the average bias for gross Scribner and gross cubic scales. ROT2 logs, on the average, were more negatively biased than were ROT1 logs.

Table 3 also shows that all the scaling systems were more biased and less accurate for ROT2 logs than for ROT1 logs. The Scribner systems, for instance, tended to overdeduct when pecky rot occurred on both log ends, as compared with logs with rot showing on one end.

Greater bias and less accuracy were also present in the ROT2 logs when the cubic systems were used. The cubic soft method had a small bias on the ROT1 logs (bias = +0.79) but underdeducted (bias = -3.60) on the ROT2 logs.

Table 2—Average bias, accuracy, and percentage of scaling defect for incense-cedar logs with pecky rot as the only scaling defect [1]

Scaling option	Bias	Accuracy	Average amount of defect
	- - - *Cubic feet*	- - -	*Percent*
Scribner:			
Scribner gross	− 5.73	13.81	—
1¾-inch rule	+ 4.95	11.42	28
4-inch rule	+ 8.88	14.20	36
Standard Forest Service scale	+13.99	18.25	46
Cubic:			
Cubic gross	− 4.37	13.63	—
Cubic soft	− 1.71	11.37	5
Cubic all	+ 9.02	13.87	28

[1]Number of logs equals 58.

Table 3—Average bias, accuracy, and percentage of defect for logs with pecky rot showing on one end (ROT1) and logs with pecky rot showing on both ends (ROT2)

	ROT1			ROT2		
Scaling option	Bias	Accuracy	Average amount of defect	Bias	Accuracy	Average amount of defect
	-- *Cubic feet*	--	*Percent*	-- *Cubic feet*	--	*Percent*
Scribner:						
Gross Scribner	−2.79	6.54	—	− 7.96	17.40	—
1¾-inch rule	+2.67	7.79	19	+ 6.68	13.53	34
4-inch rule	+5.34	8.92	28	+11.56	17.14	43
Standard Forest Service scale	+9.14	12.91	36	17.66	21.43	54
Cubic:						
Gross cubic	−1.10	5.06	—	− 6.85	17.53	—
Cubic soft	+ .79	4.75	4	− 3.60	14.50	6
Cubic all	+5.86	11.96	18	+11.41	15.17	36

Conclusions

All Scribner scaling options overdeducted for the presence of pecky rot. The magnitude of bias was greater for logs with pecky rot showing on both log ends versus logs with rot showing on one end. The 1¾-inch rule performed best of the Scribner systems tested; it had the least amount of bias and the greatest degree of accuracy. Future efforts to revise the Scribner scaling rules for pecky rot should note that the scaling options that performed the worst were those that deducted the greatest percentage of log volume.

Of the cubic systems, the cubic soft method was superior to the cubic total method. The cubic soft method slightly overdeducted for logs with rot showing on one end and underdeducted for logs with rot showing on both ends.

Acknowledgment

We thank Larry Knecht, regional check scaler, USDA Forest Service, Pacific Southwest Region, for his assistance in defining the scaling systems and for his leadership during the scaling of the study logs.

Metric Equivalents

1 inch	=	2.540 centimeters
1 foot	=	0.305 meter
1 cubic foot	=	0.028 cubic meter

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February 1987

Fifteen-Year Results From a Grand Fir-Shasta Red Fir Spacing Study

K.W. Seidel

Abstract

A 43-year-old, even-aged stand of advance reproduction of grand fir and Shasta red fir in central Oregon responded to release and thinning with diameter and height growth two to three times the prerelease rate. The response began the first growing season after the overstory was killed with 2,4-D. Diameter growth during the second and third 5-year periods after release increased significantly over that of the first 5 years. Differences in spacing had no effect on diameter growth during the first 5 years, but growth at the wider spacings increased considerably during the second and third periods. Increased growth after release suggested that saving true fir advance reproduction can be a desirable option, but the potential for losses from heart-rot should also be considered.

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

Introduction

Long-term growth and yield data from permanent plots are essential for developing yield tables for managed stands or for verifying stand simulation models. True firs are an important component of many mixed conifer forests in eastern Oregon and Washington, and many stands consist of a mature or overmature overstory with a suppressed understory of true fir saplings or poles. Little information is available on the growth potential of the fir understory after removal of the overstory and thinning to various spacings.

In 1970, a study was begun in a suppressed, even-aged stand of grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.) and Shasta red fir (*A. magnifica* var. *shastensis* Lemm.) in central Oregon. The purpose was to obtain long-term data on growth of the two species at several initial spacings and under a progressive thinning schedule. This paper reports study results after 15 years. It supplements earlier reports of results for the first 10 years (Seidel 1977, 1983).

Study Area and Methods

The study site is in the Pringle Falls Experimental Forest in the Deschutes National Forest near Bend, Oregon, on a north-facing, 13-percent slope at an elevation of about 5,600 feet. The soil is a well-drained Typic Cryorthent (Shukash series) developing in dacite pumice that orginated from the eruption of Mount Mazama about 6,500 years ago. It has an A1, AC, C1, C2 horizon sequence that is about 3 feet deep over the buried soil.

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Before study installation, the timber stand had an overstory of 75-year-old lodgepole pine (*Pinus contorta* Dougl. ex Loud.) with a 43-year-old grand fir-Shasta red fir seedling and sapling understory averaging about 4.5 feet in height. About 70 percent of the understory was less than 0.6 inch in diameter at breast height (d.b.h.), and average d.b.h. of measurable trees was about 1 inch. Site index of older red fir in the area, based on Schumacher's (1928) curves, indicates a height of 65 feet at age 50. Site index based on curves of DeMars and others (1970) shows a height of 120 feet at age 100. The lodgepole basal area averaged about 150 square feet per acre, and there were about 3,000 fir trees per acre in the understory.

The study area is in an *Abies shastensis/Chimaphila umbellata* plant community (Franklin and Dyrness 1973, p. 155). Ground vegetation is sparse and is primarily prince's pine (*Chimaphila umbellata* (L.) Bart.). Small amounts of other genera, such as *Arctostaphylos, Stipa, Carex,* and *Epilobium,* are also present.

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

The second part of the study is a progressive thinning experiment with fixed-area plots similar to O'Conner's design (1935). Eight 0.25-acre plots were thinned to 6-foot spacing in 1970. The study plan calls for subsequent thinning based on diameter growth. When diameter growth of 10 percent of trees on all eight plots is at least 0.1 inch less than growth the previous year, six of the eight plots will be thinned to 12-foot spacing. When growth on the plots with 12-foot spacing slows to the same degree, four plots of the six will be thinned to 18-foot spacing. Thinning will continue in this pattern until there are two plots at each of the four spacings as in the variable-area plots. A completely randomized design is also used for these plots. Eventually volume growth and yield will be compared between the initially spaced, variable-area plots and the progressively thinned, fixed-area plots. None of the fixed-area plots have been thinned since 1970 so they retain the 6-foot spacing.

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

Height of all plot trees was measured to the nearest 0.1 foot, and d.b.h. of trees 0.6 inch or larger was measured to the nearest 0.05 inch in 1971, 1975, 1980, and 1985. Diameter was measured annually on a 10-percent sample of trees on the fixed-area plots. In 1976, 50 trees of each species were randomly chosen from the buffer strips and cut at ground level for measurements of diameter growth during the 5 years before release and the 5 years after release. In 1976, the 5-year prerelease height growth was measured by counting whorls of all trees in the variable-area plots and whorls of the 10-percent sample in the fixed-area plots. In 1975, the total height and diameter at 4-foot intervals up the stem were measured on 15 trees per plot to calculate an equation expressing cubic volume of the entire stem inside bark as a function of diameter and height. This equation was used to compute plot volumes from the measurements taken in 1971, 1975, 1980, and 1985.

Table 1—Characteristics of grand fir-Shasta red fir plots after thinning in 1970 and in 1975, 1980, and 1985

Year, plot, and spacing	Species composition: Grand fir	Species composition: Red fir	Total trees	Trees less than 0.6 inch d.b.h.		Quadratic mean diameter 1/	Average height	Basal area	Total volume
	Percent		Number per acre		Percent	Inches	Feet	Square feet per acre	Cubic feet per acre
After thinning, 1970:									
Fixed-area plots—									
6 by 6 feet	59	41	1,169	817	70	1.2	4.8	2.8	20.6
Variable-area plots—									
6 by 6 feet	81	19	1,200	975	81	1.2	3.8	1.7	11.5
12 by 12 feet	79	21	304	158	52	1.2	5.6	1.2	7.7
18 by 18 feet	92	8	134	103	77	.9	4.3	.2	1.1
24 by 24 feet	71	29	78	63	83	1.0	4.1	.1	.5
1975:									
Fixed-area plots—									
6 by 6 feet	59	41	1,114	498	45	1.5	6.7	8.5	65.4
Variable-area plots—									
6 by 6 feet	81	19	1,200	800	67	1.5	5.3	5.4	38.3
12 by 12 feet	79	21	304	95	31	1.8	8.0	3.6	25.4
18 by 18 feet	92	8	134	61	46	1.4	6.5	.8	5.6
24 by 24 feet	71	29	78	33	43	1.3	6.0	.4	2.5
1980:									
Fixed-area plots—									
6 by 6 feet	60	40	1,039	280	27	2.2	8.4	19.9	173.6
Variable-area plots—									
6 by 6 feet	81	19	1,200	550	46	1.9	8.5	12.8	100.5
12 by 12 feet	80	20	298	44	15	2.6	10.1	9.3	81.8
18 by 18 feet	92	8	132	11	8	2.1	9.1	3.0	24.8
24 by 24 feet	69	31	76	11	15	2.0	8.3	1.4	10.2
1985:									
Fixed-area plots—									
6 by 6 feet	60	40	1,003	115	11	2.7	10.9	37.1	386.7
Variable-area plots—									
6 by 6 feet	81	19	1,200	450	38	2.1	7.8	22.5	195.4
12 by 12 feet	80	20	291	19	7	3.2	12.6	16.2	175.5
18 by 18 feet	92	8	131	0	0	3.3	12.7	7.8	85.4
24 by 24 feet	68	32	75	5	7	3.0	11.5	3.5	33.7

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

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

Differences in diameter and height growth among species, periods, and initial spacings were analyzed for the variable-area plots using split-split plot analyses of variance in a completely randomized design at the 0.05 probability level. Whole plot treatments were spacings, split-plot treatments were species, and time periods were the split-split plot factor. Tukey's test was used to determine significant differences among treatment means. Height growth was also subjected to analysis; height before release and thinning and 5-year prerelease height growth were used as covariates. No analyses were applied to data from the fixed-area plots because those plots all have the same 6-foot spacing.

Table 2—Periodic annual increment and mortality of grand fir and Shasta red fir saplings during 3 5-year measurement periods after release and thinning in 1970 when trees were 43 years old

		Basal area growth			Total volume growth		
Age, plot, and spacing	Diameter growth 1/	Net	Mortality	Gross	Net	Mortality	Gross
	Inches 2/	—Square feet per acre 2/—			—Cubic feet per acre 2/—		
From age 43 to 48 (1971-75):							
Fixed-area plots—							
6 by 6 feet	0.15±0.01	1.13±0.18	0.01±0.001	1.14±0.18	8.9±1.7	0.1±0.01	9.0±1.7
Variable-area plots—							
6 by 6 feet	.15±.05	.74±.69	0	.74±.69	5.4±4.9	0	5.4±4.9
12 by 12 feet	.16±.01	.50±.09	0	.50±.09	3.6±1.0	0	3.6±1.0
18 by 18 feet	.16±.05	.14±.07	0	.14±.07	.9± .5	0	.9± .5
24 by 24 feet	.16±.01	.06±.01	0	.06±.01	.4± .1	0	.4± .1
From age 48 to 53 (1976-80):							
Fixed-area plots—							
6 by 6 feet	.17±.01	2.28±.29	.08±.01	2.36± .30	21.6±3.8	.7±.2	22.3±4.0
Variable-area plots—							
6 by 6 feet	.18±.01	1.47±1.02	0	1.47±1.02	12.4±9.4	0	12.4±9.4
12 by 12 feet	.22±.03	1.14± .33	.03±.01	1.17± .34	11.3±4.6	.2±.08	11.5±4.8
18 by 18 feet	.23±.01	.44± .14	0	.44± .14	3.9±1.8	0	3.9±1.8
24 by 24 feet	.20±.02	.20± .07	0	.20± .07	1.6± .6	0	1.6± .6
From age 53 to 58 (1981-85):							
Fixed-area plots—							
6 by 6 feet	.16±.01	3.43± .27	.05±.01	3.48± .27	42.6±5.9	.3±.09	42.9±5.9
Variable-area plots—							
6 by 6 feet	.12±.01	1.95±1.15	0	1.95±1.15	19.0±14.1	0	19.0±14.1
12 by 12 feet	.18±.01	1.46± .31	.03±.01	1.49± .32	18.8± 6.3	.1±.01	18.9± 6.3
18 by 18 feet	.27±.03	.96± .26	0	.96± .26	12.1± 5.1	0	12.1± 5.1
24 by 24 feet	.24±.01	.42± .09	0	.42± .09	4.7± 1.6	0	4.7± 1.6

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

2/ Mean ± standard error.

Results

Diameter Growth

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

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

During the second 5-year period, diameter growth increased significantly ($P < 0.05$) above that of the first period. Increases ranged from 20 percent at the 6-foot spacing to 44 percent at the 18-foot spacing. Differences among spacings were still not significant, although growth at the 12- and 18-foot spacings was 0.22 to 0.23 inch per year compared with 0.18 inch at the 6-foot spacing (table 2).

During the third 5-year period, diameter growth averaged over all spacings was about the same as during the second period (0.20 vs. 0.21 inch per year). Although overall growth was similar among periods, growth at the 6- and 12-foot spacings decreased 16 to 33 percent; growth at the 18- and 24-foot spacings increased 15 to 20 percent compared with the second period. Differences among spacings were significant ($P < 0.01$). Growth at the 6-foot spacing (0.12 inch per year) was significantly less than growth at the 18- or 24-foot spacing (0.27 and 0.24 inch per year)(table 2). Diameter growth of trees on the fixed-area plots (all at the 6-foot spacing) was essentially constant during all three periods (0.15 to 0.17 inch per year). As during the first two periods, no significant differences in diameter growth were found between grand fir and red fir. Diameter growth shown in table 2 may not agree with differences between mean diameters at the beginning and end of growth periods shown in table 1 because average diameters at each measurement are based on trees 0.6 inch d.b.h. or larger at the time, but growth is based only on trees of measurable size in 1970, 1975, and 1980.

Height Growth

Height growth did not differ significantly between the first two periods, but increased significantly ($P < 0.05$) during the third period. Although statistically significant, the change in the rate of height growth was small; it increased from about 0.41 foot per year during the first two periods to 0.52 foot per year during the third (averaged over the four spacings). No significant differences in height growth were found among spacings or between species during any of the three periods. During the third period, however, growth differences approached significance at the 5-percent level because of the faster growth at the 18- and 24-foot spacings. Average annual growth was slowest at the 6-foot spacing during all periods and fastest at the 12- and 18-foot spacings during the first two periods (table 3). During the third period, height growth at the two widest spacings increased considerably to about 0.7 foot annually.

The trees responded to release the first growing season after release, in contrast to a delay of 5 years for suppressed red firs in California (Gordon 1973). The height growth rate doubled from about 0.2 foot annually before release to about 0.4 foot per year after release. Even after release, however, the rate of height growth (0.4 foot per year) did not increase greatly during the first 10 years and was comparable to the growth rate of 5-year-old grand fir planted in the same general area (Seidel 1985a). Although the rate of height growth is still relatively slow, growth appears to be accelerating during the third period at the two widest spacings and on the fixed-area plots at the 6-foot spacing.

Basal Area and Volume Growth

Growth in both basal area and total cubic volume on the fixed-area plots was small during the first 5 years but increased significantly ($P < 0.05$) from the first to the second period and again from the second to the third period as more trees reached measurable size (table 2). Annual volume increment more than doubled during the second period, from 9.0 to 22.3 cubic feet per acre, and nearly doubled again during the third period to 42.9 cubic feet per acre. Basal area and volume growth on the variable-area plots showed the expected response to spacing—progressively less growth as spacing increased because of fewer trees per unit area. Even though the growth rate differed widely, possibly because on one variable-area plot at a 6-foot spacing only one-third of the trees were of measurable size in 1980 compared to about three-fourths of the trees on the other plot, differences in growth rates among spacings were not significant. At this time, growth on the fixed-area plots is therefore more representative of the true growth potential at the 6-foot spacing than is growth on the 6-foot-spaced variable-area plots. This disparity should decrease in the future when all trees on all plots are measured for basal area and volume growth.

Table 3—Periodic annual diameter and height growth after release, by species, spacing, and growth period

Time period, plot, and spacing	Diameter growth 1/ Grand fir	Diameter growth 1/ Red fir	Diameter growth 1/ Both species	Height growth 2/ Grand fir	Height growth 2/ Red fir	Height growth 2/ Both species
	Inches 3/			Feet 3/		
First period (1971-75):						
Fixed-area plots--						
6 by 6 feet	0.14±0.01	0.16±0.01	0.15±0.01	0.41±0.03	0.35±0.03	0.38±0.03
Variable-area plots—						
6 by 6 feet	.15±.01	.22±.01	.15±.005	.33±.08	.24±.12	.30±.08
12 by 12 feet	.16±.01	.19±.01	.16±.005	.47±.06	.51±.09	.48±.03
18 by 18 feet	.16±.05	.20± 0	.16±.05	.45±.05	.50±.03	.45±.04
24 by 24 feet	.16±.01	.18± 0	.16±.005	.40±.06	.33±.12	.38±.07
Second period (1976-80):						
Fixed-area plots--						
6 by 6 feet	.16±.01	.18±.01	.17±.01	.35±.02	.33±.02	.33±.02
Variable-area plots--						
6 by 6 feet	.16±.01	.19±.01	.18±.01	.20±.06	.28±.04	.24±.07
12 by 12 feet	.21±.04	.27±.05	.22±.03	.48±.02	.42±.16	.48±.04
18 by 18 feet	.22±.03	.25±.04	.23±.01	.50±.05	.65±.05	.51±.05
24 by 24 feet	.20±.01	.19±.08	.20±.02	.46±.06	.45±.09	.46±.08
Third period (1981-85):						
Fixed-area plots—						
6 by 6 feet	.16±.01	.17±.01	.16±.01	.48±.05	.51±.03	.49±.04
Variable-area plots—						
6 by 6 feet	.12±.02	.13±.01	.12±.01	.23±.11	.40±.08	.26±.10
12 by 12 feet	.18±.01	.18±.01	.18±.01	.45±.01	.54±.06	.46± 0
18 by 18 feet	.26±.02	.27±.07	.27±.03	.73±.07	.68±.22	.73±.08
24 by 24 feet	.23±.01	.27±.02	.24±.01	.60±.09	.72±.19	.65±.13

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

2/ Based on growth of all trees living through each 5-year period.

3/ Mean ± standard error.

The effects of some 40 years of suppression on growth and yield can be estimated by comparison of the basal area and volume data obtained in this study with yield estimates for unsuppressed grand or white fir given by Cochran (1979). For example, when the study was established (age 43), the fixed-area plots at the 6-foot spacing had about 1.2 percent of the net basal area and 0.5 percent of the net cubic volume of unsuppressed stands of the same age and site index. The basal area growth rate of these plots during the first 5-year period after release was 25 percent of the growth rate of unsuppressed stands, while volume growth was 5 percent of the unsuppressed rate. After 15 years, in 1985, net basal area on these study plots was about 15 percent of the unsuppressed stands and net cubic volume was about 6 percent. During the third period after release, basal area growth was equal to that of the unsuppressed stands and volume growth increased to 25 percent of unsuppressed stands.

Mortality

During the 15 years of this study, 255 trees died; 11 during the first period, 70 during the second, and 74 during the third. All but 8 of the 111 that died during the first 5 years were transplanted seedlings. During the second and third periods, about 25 percent of the mortality appeared to be caused by *Armillaria* sp. Most of the remaining mortality was in trees less than 3 feet tall with very small crowns. No snow damage was observed after release and thinning, except for a few trees with small crowns that were growing in dense clumps before thinning.

Discussion

After 15 years, the results of this study give land managers an estimate of the growth rates that can be expected after suppressed true fir sapling stands are released from overstory competition and thinned to various spacings. After release, the increase in diameter and height growth rates of two to four times the prerelease rate is typical of other studies in the Western United States (Ferguson and Adams 1979, Gordon 1973, McCaughey and Schmidt 1982, Seidel 1985b). Increased growth rates sometimes occur the first year after release; sometimes they are delayed several years. In either case, silviculturists can be confident of an accelerated growth rate within 5 years after release if the trees are vigorous and live crown ratios are at least 50 percent.

The diameter growth response to spacing is now typical of such studies—greater growth as spacing between trees increases. This relation was not present during the first 5-year period after release, when diameter growth at all spacings was about the same, but became evident during the second period and was more pronounced during the third period. The basal area and cubic volume growth data after 15 years showed the potential of sapling-size true fir stands to respond to release quickly even though suppressed for 40 or more years.

Although there is now ample evidence that suppressed true fir advance reproduction has the capacity to considerably increase diameter, height, and volume growth rates after release and thinning, the possibility of future volume losses caused by Indian paint fungus (*Echinodontium tinctorium* E & E) should also be considered by managers when evaluating the potential of suppressed true fir for future crop trees. This fungus is responsible for most of the heartrot decay in old-growth grand fir stands. Aho (1977) found that this fungus alone causes about 70 percent of the board-foot decay volume in the Blue Mountains of eastern Oregon and Washington. Guidelines for reducing losses from heartrot based on tree vigor, number of wounds, degree of suppression, and presence of the disease in the overstory have been prepared by Filip and Aho (1978) and Filip and others (1983).

A decision to save and manage the advance reproduction requires the use of logging methods and slash-disposal techniques designed to reduce loss and damage to the understory. Procedures to accomplish this objective that have proved successful are given by Aho and others (1983), Barrett and others (1976), Gottfried and Jones (1975), and Gravelle (1977).

Metric Equivalents

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

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Influence of Overstory on Snow Depth and Density in Hemlock-Spruce Stands: Implications for Management of Deer Habitat in Southeastern Alaska

Thomas A. Hanley and Cathy L. Rose

Abstract

Snow depth and density were measured in 33 stands of western hemlock-Sitka spruce (*Tsuga heterophylla* [Raf.] Sarg.-*Picea sitchensis* [Bong.] Carr.) over a 3-year period. The stands, near Juneau, Alaska, provided broad ranges of species composition, age, overstory canopy coverage, tree density, and wood volume. Stepwise multiple regression analyses indicated that both overstory canopy coverage and gross wood volume were negatively related to snow depth in the forest, which was expressed as a proportion of the depth in a nearby open area. Multiple regression equations accounted for 53-79 percent of the variance in snow depth, but relationships were not consistent from one sampling period to another. Density of snow under the forest canopy, expressed as a proportion of the density of snow in the open, was less influenced by forest overstory than was snow depth. Regression equations accounted for 18-70 percent of the variance in snow density but, as with snow depth, were inconsistent from one sampling period to another. The following criteria are suggested in selecting stands for winter range for deer where snow accumulation is a problem: (1) topographic setting; (2) overstory canopy coverage at least 95 percent, as measured with a spherical densiometer; (3) timber volume class at least 20,000 board feet per acre, net volume; and (4) an understory of relatively abundant, high-quality forage.

Keywords: Wildlife habitat management, deer, winter range, overstory layer, southeastern Alaska, Alaska (southeastern), deer, *Odocoileus hemionus sitkensis*.

Introduction

Forest overstories influence snowpacks by intercepting snow and modifying the radiation environment (Hoover and Leaf 1967, Miller 1964). As a result, snow accumulates in response to overstory structure (Cline and others 1977, Ffolliot and Thorud 1972, Fitzharris 1975, Golding and Harlan 1972, Harestad and Bunnell 1981). Most studies of the influence of forest overstories on snowpacks have focused on the hydrologic aspects of snow-water equivalent and have been conducted in areas of deep snow. Generally, overstory canopy coverage is a good predictor of the effects of coniferous forests on snow-water equivalent (Harestad and Bunnell 1981).

Much less information is available on the influence of forests on snow depth and density, especially in areas of shallow or transient snow. For many ecological applications, snow depth and density are more important than snow-water equivalent. Snow is an important factor affecting the movement and energy requirements of animals. Energy expended by

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deer to move in snow is a function of both snow depth and density but not snow-water equivalent (Parker and others 1984). Snow also buries forage and makes it unavailable to deer. The combined effect of increasing costs of locomotion and decreasing availability of food make snow a major determinant of habitat quality for black-tailed deer (*Odocoileus hemionus columbianus* and *O. h. sitkensis*) (Hanley 1984, Harestad and others 1982).

The objective of this study was to determine relationships between variables of western hemlock-Sitka spruce (*Tsuga heterophylla* [Raf.] Sarg.-*Picea sitchensis* [Bong.] Carr.) overstory and snow depth and density in the low-elevation, transient-snow zone of southeastern Alaska. We sought to develop predictive equations useful for comparing the effects of any given forest stand with those of any other.

Methods

Snow depth and density were measured for 3 years in 33 stands near Juneau, Alaska. Overstory in each stand was measured once, and the snow in each stand was measured on five different occasions (sampling periods). Stands were selected to provide a broad range of species composition (exclusively spruce to nearly exclusively hemlock), age (40 to more than 400 years), canopy coverage (9.1-100 percent), tree density (16-2,803 trees/ha), and gross wood volume (6-1338 m^3/ha). All stands were on level or nearly level ground (slope gradients less than 10 percent) and were close to a large open (nonforest) area where snow could be measured at distances greater than two tree-heights from the forest. All stands were low elevation (less than 100 m), unmanaged hemlock-spruce forest. Snow measurements were made when a wide range of depths and densities could be obtained.

Each stand was selected for homogeneity. All measuring and sampling were done within circular plots 30-70 m in diameter. The sizes of the plots varied in proportion to the variation in basal area and canopy coverage of the stand. Basal area and canopy coverage were estimated at the center of the circle and at 5-m intervals along transect lines running in each of the four cardinal directions from the center. Basal area was estimated with a relaskop and the variable plot method (Dilworth 1977). Overstory canopy coverage was estimated with a spherical densiometer (Lemmon 1956). The number of sample points required to obtain a standard error less than or equal to 10 percent of the mean was calculated for both basal area and canopy coverage. The larger of these two numbers determined the size of the circular plot to be sampled.

The diameter at breast height (d.b.h) and total height of each tree with a d.b.h. greater than 2 cm was estimated with a relaskop. The species of each tree was identified, and signs of wood defect were noted. These measurements provided the following data for each forest stand: tree density (trees per hectare), percentage of spruce (by density), mean d.b.h., coefficient of variation of d.b.h., mean tree height, coefficient of variation of tree height, gross wood volume (cubic meters per hectare), net wood volume, basal area (square meters per hectare), and mean overstory canopy coverage (percentage). Additionally, each stand was categorized as even-aged or uneven-aged.

Snow measurements were made at 3-m intervals within the circular plot in each stand (a 5-m buffer zone was left at the edge of the plot) and in the nearby open area. Fifty measurements of snow depth were made in each stand and open area at each sampling. Snow density was measured with a standard U.S. Soil Conservation Service snow measuring tube. The number of samples, which varied in proportion to the variation in the measurements, was sufficient to obtain a standard error less than or equal to 10 percent of the mean. All stands were sampled as close to one another as possible—within 3 to 6 days. Snow data were obtained from February 1982 through January 1984. Only 27 stands were sampled in 1982; 6 more were added for the 1983 samples; and 4 were deleted from the 1984 sample because of disturbance to the overstory.

Data were analyzed with the SPSS statistical programs (Nie and others 1975). A correlation matrix for all variables was calculated, and scatterplots of each variable against snow depth and against snow density were examined separately for each snow sampling period and for all periods combined. Distinctly nonlinear relationships were transformed. Four overstory variables were selected for further analysis on the basis of their having an interpretable functional relation to snowpack and having minimum intercorrelations among themselves. These variables, along with mean snow depth or density in the open area, were treated as independent variables in stepwise regression analyses with proportional depth (mean snow depth in the forest divided by mean snow depth in the open area) and proportional density as dependent variables. Data from each snow measuring period were analyzed separately and then were combined into one analysis.

Results and Discussion

Mean snow depths in the open ranged from 23 to 94 cm (table 1). Mean snow densities in the open ranged from 0.09 to 0.18 g/ cm^3. Snow in the forest stands was, on average, only 62 percent as deep as that in the open but was of very similar density. Mean snow depths in the open areas and the forest stands were most similar under the deepest conditions and least similar under medium to low depths. Disparities between densities in open areas and forest stands were important only under the wettest, densest conditions, when density was greater in the forest than the open.

Table 1—Summary of mean snow depths and densities from measurements in forest stands and open areas on 5 sampling dates

Sampling period	Date	Depth: Open areas	Depth: Forest stands	Density: Open areas	Density: Forest stands	Number of stands
		——cm——		——g/cm^3——		
1	21-26 Feb. 1982	94	71	0.12	0.12	27
2	14-19 Jan. 1983	49	31	.12	.12	33
3	14-18 Feb. 1983	57	26	.11	.10	33
4	21-26 Dec. 1983	23	11	.09	.09	33
5	26-28 Jan. 1984	59	37	.18	.23	29

We selected overstory canopy coverage, gross wood volume, percentage of spruce, forest type (even-aged versus uneven-aged), and mean snow depth in the open as independent variables in the multiple regression analysis for predicting proportional depth of snow in the forest. We reasoned that overstory canopy coverage provided our best measure of the horizontal distribution of forest canopy; gross wood volume provided our best measure of overstory mass; percentage of spruce accounted for differences in species composition of the stand; forest type accounted for potential differences in the amount of snow intercepted by old-growth stands compared to even-aged stands; and mean snow depth in the open accounted for differences in total amount of snow. Only the relation between overstory canopy coverage and proportional depth of snow was distinctly nonlinear. Canopy coverage was transformed with an exponential transformation: $e^{x \div 10}$.

Table 2—Results of stepwise multiple regression analysis with proportional depth (depth of snow in the forest divided by depth of snow in the open) as the dependent variable

		Regression coefficients of independent variables1/				
Sampling period	Constant	Depth in open2/	Canopy coverage3/	Wood volume4/	Forest type5/	R^2
1	1.079	6/—	-2.284 (0.70)	—	—	0.70
2	.678	0.168 (.16)	-1.313 (.11)	-3.415 (.44)	—	.71
3	.669	—	-2.990 (.45)	—	0.178 (.08)	.53
4	1.115	—	-3.188 (.68)	-3.190 (.05)	—	.74
5	2.068	-.447 (.13)	-2.842 (.66)	—	—	.79
1-57/	0.809	.094 (.11)	-2.126 (.48)	-2.192 (.04)	—	.63

1/Values listed for independent variables are their regression coefficient and their contribution to the multiple R^2 (in parentheses). Percentage of spruce also was included in the analysis but was never significant enough to enter the multiple regression equations (see footnote 6).

2/Depth in open area (centimeters), times 10^{-1}

3/Overstory canopy coverage (percentage) transformed by $e^{x \div 10}$, times 10^{-5}

4/Gross wood volume (cubic meters per hectare), times 10^{-4}.

5/Forest type = 1 for uneven- aged; 2 for even- aged.

6/Dash indicates that the variable accounted for an insignificant amount of variation and was not included in the regression equation (that is, F to enter was <0.01 and/or tolerance was <0.001).

7/All data combined.

Stepwise multiple regression analyses indicated (1) that of the five independent variables, only canopy coverage consistently accounted for a significant proportion of the variance in proportional depth of snow; (2) that gross wood volume was the next best predictor of proportional depth; (3) that the species composition and even-aged versus uneven-aged structure of the forest were irrelevant; and (4) that although 53 to 79 percent of the total variance in proportional depth was accounted for with only one to three independent variables, the equations were not consistent from one sampling period to another (table 2). The most consistent pattern was that proportional depth was negatively correlated with both overstory canopy coverage and (to a lesser degree) gross wood volume. The effect of canopy coverage was pronounced only at high levels of coverage (at least 95 percent, fig. 1), however; the effect of wood volume was most pronounced at low levels of volume (less than 400 m^3/ha, fig. 2).

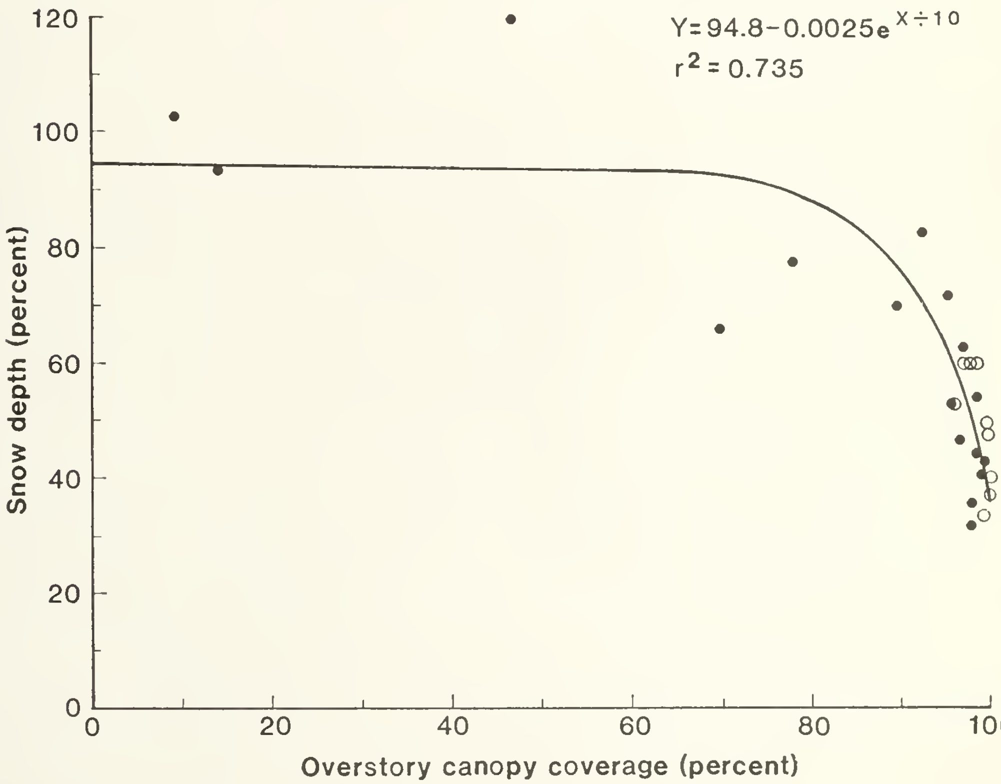

Figure 1—Mean snow depth in the forest (as a percentage of depth in the open) as a function of overstory canopy coverage. Each point is the mean of five sampling periods. Only stands that were measured in all five periods are included. Solid circles represent uneven-aged stands; open circles represent even-aged stands.

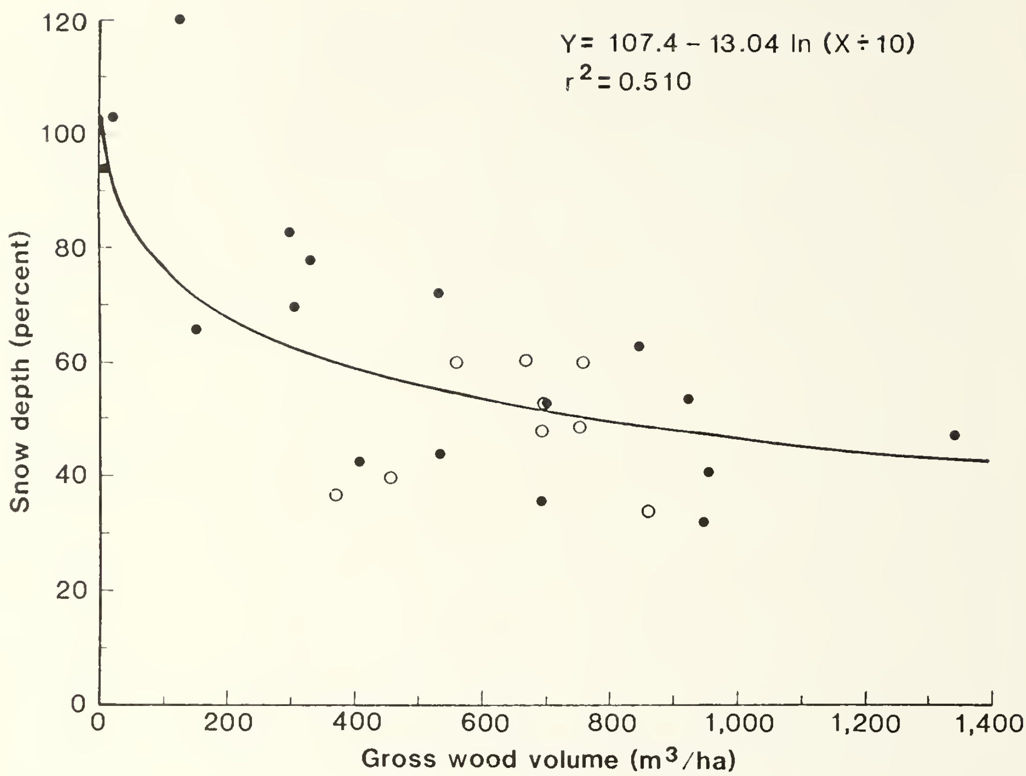

Figure 2—Mean snow depth in the forest (as a percentage of depth in the open) as a function of gross wood volume. Each point is the mean of five sampling periods. Only stands that were measured in all five periods are included. Solid circles represent uneven-aged stands; open circles represent even-aged stands.

The relations between overstory variables and proportional density of the snowpack were much less clear than those for proportional depth of snow. Of all the overstory variables, only tree density was significantly correlated (negatively) with proportional density of the snow. Multiple regression analyses with snow density in the open, overstory canopy coverage, and tree density as independent variables indicated that 18-70 percent of the variance in proportional density was accounted for by snow density in the open area and by tree density (table 3). Snow density in the open area was the most important variable for predicting proportional density of the snow. As with proportional depth, though, the equations were not consistent from one sampling period to another. Although proportional density was negatively correlated with density in the open for any one sampling period, it was positively correlated in the combined data set. This reflected the small differences in snow density encountered between stands during any one sampling period relative to the large difference in snow density encountered in period 5 versus all other periods (table 1).

These results indicated that in western hemlock-Sitka spruce stands varying across broad ranges of species composition, age, canopy coverage, tree density, and wood volume, overstory canopy structure exerts a significant influence on snow depth but much less influence on snow density. Overstory canopy coverage and gross wood volume are the best predictors of the influence on snow depth, but the relations change with snow conditions. Forest overstory, for example, may exert a greater or lesser influence depending on whether the snow falls during cold, windy conditions or warm, still conditions, or whether it falls in one intense storm or in several intermittent storms. Although our relations account for a reasonable amount of variation over broad ranges of forest structure, the data are much too variable to be satisfactory over shorter ranges (that is, in comparisons of fairly similar stands). This problem was apparent when we made the snow measurements. We could always be certain the snow would be deepest in the most open stands and shallowest in the most closed stands, but intermediate stands varied in their relative depths from one sampling period to another. Our study focused on the effects of stand and tree stem characteristics on snowpack. Greater resolution would require focusing on individual trees and their crown characteristics and on weather conditions.

Table 3—Results of stepwise multiple regression analysis with proportional density (density of snow in the forest divided by density of snow in the open) as the dependent variable

Sampling period[1]	Constant	Regression coefficients of independent variables[2]: Density in open[3]	Tree density[4]	R^2
1	2.817	-15.070 (.47)	[5]—	0.47
2	.906	—	1.112 (.18)	.18
3	1.253	-4.274 (.30)	1.139 (.10)	.41
5	1.881	-4.178 (.56)	2.018 (.14)	.70
[6]1-5	.801	.908 (.98)	1.411 (.01)	.99

[1]Snow depths and densities were too low to measure density accurately in period 4.
[2]Values listed for independent variables are their regression coefficient and their contribution to the multiple R^2 (in parentheses). Overstory canopy coverage also was included in the analysis but was never significant enough to enter the multiple regression equations (see footnote 5).
[3]Density in open area (grams per cubic centimeter).
[4]Number of trees per hectare, times 10^{-4}.
[5]Dash indicates that the variable accounted for an insignificant amount of variation and was not included in the regression equation (that is, F to enter was <0.01 and/or tolerance was <0.001).
[6]All data combined, except period 4.

Implications for Research

The transient-snow zone poses technical problems that differ from those of areas with deep and persistent snowpacks. We encountered several major problems while conducting this study. Because our stands were relatively large and widely dispersed, we needed 3 to 6 days to sample them during the short days of winter. Snow depths can change greatly in 3 to 6 days in transient-snow zones (Berris 1984). Although each of our plots was paired with an adjacent open area, the differences from day 1 through day 6 undoubtedly contributed to the variation in our data. This should be true especially for shallow snow, where a given change in depth is proportionally greater than it is for deep snow. Shallow snow also created problems in measuring density with the Soil Conservation Service snow tube, a device designed for measuring deep snow. The difficulties of accurately measuring density compounded the problem of sampling stands rapidly. And density, like snow depth, can change rapidly, especially if rainfall is a factor (Berris 1984).

Our results indicated that overstory canopy coverage was potentially the most useful factor for predicting the influence of overstory on snow. This is consistent with the results of most studies of forest influences on snowpacks (reviewed by Bunnell and others 1985, Harestad and Bunnell 1981). Of the variables we considered, however, overstory canopy coverage was the most difficult to measure. Indeed, it cannot be measured directly but must be estimated. We used a spherical densiometer because it has high precision (Vales and Bunnell 1985). Its accuracy is low, however, because it projects a wide angle of view toward the canopy and, therefore, overestimates canopy coverage directly overhead (vertical) (Vales and Bunnell 1985). The result was that 23 of our 33 stands had canopy coverage values greater than 95 percent. These also were the stands that had a pronounced effect on snowpack.

We encountered a high degree of variability between stands and between sampling periods. Part of the variability may be attributed to the problems above, but most is more likely because of vagaries of weather and their effect on the processes controlling snow interception, sublimation, and melt. Weather conditions during a snowstorm (including air temperature, wind speed, wind turbulence, rate of snowfall, duration of snowfall, and amount of snowfall) and following a storm (including air temperature, precipitation, solar insolation, wind speed, and vapor pressure deficit) play major roles in affecting forest influences on snowpacks (Bunnell and others 1985). Additionally, tree characteristics such as branch size and load capacity, leaf or needle configuration, leaf area, crown architecture, and spacing between neighboring trees are very important (Bunnell and others 1985). These variables were essentially unaccounted for in our analysis. High precision in predicting the effects of forests on snowpacks undoubtedly requires modeling of processes that control snow interception, sublimation, and melt. Regressions based on stand attributes from forest inventory data will undoubtedly yield low levels of precision, especially over time (variety of snowfall events). This is most likely in the transient-snow zone, where cycles of snow deposition and melting alternate throughout the winter.

Implications for Management of Deer Habitat

Our results indicated that over very broad ranges of canopy coverage and wood volume these two variables can serve as useful indices of the effects of forest overstories on snowpacks. In general, open-canopied stands accumulate and retain more snow than do closed-canopied stands. But over narrow ranges of canopy coverage and wood volume, these two variables are poor predictors of the effect of overstory on snowpack.

Our results indicated, for example, that canopy coverage exerts essentially no influence on snowpack at values less than about 60 percent coverage, a moderate effect at values between 60 and 95 percent, and a substantial but highly variable effect at values greater than 95 percent (measured with the spherical densiometer). Similarly, our results indicated that stands with less than 100 m^3/ha gross wood volume (about 1,200 net board feet per acre) have essentially no effect on snowpack, stands with 100-400 m^3/ha gross wood volume (about 1,200-17,000 net board feet per acre) have a moderate effect, and stands with more than 400 m^3/ha gross wood volume have a substantial but highly variable effect on snowpack. Most questions about commercial-sized stands are for those with more than 20,000 board feet per acre net volume (about 550 m^3/ha gross volume). Therefore, within most of the commercial-sized stands, neither canopy coverage nor wood volume are very useful predictors of the effects of forest overstory on snowpack.

These results are similar to the patterns observed by Kirchhoff and Schoen (1985), who measured snowpack and overstory variables in a study area near Juneau, Alaska. Their method of measuring overstory canopy coverage differed from ours and yielded a more linear relation, but the implications for both canopy coverage and wood volume are qualitatively the same as those above.

Our data also indicated no differences related to the species composition or to whether stands were even-aged or uneven-aged. These might be important variables at a finer scale of resolution, but given the variation we encountered, they were unimportant.

Within commercial-sized stands (at least 20,000 board feet per acre, net volume), the most important factors affecting snowpack are apparently related to weather rather than to forest overstory. This was particularly evident in the relative differences we encountered between stands on different dates: relative depths differed greatly, yet the overstories remained the same. Furthermore, as total snowfall increases, forest overstories tend to have a decreasing influence on snowpack (Harestad and Bunnell 1981). Weather, of course, is strongly influenced by climate and topography. Snow is most likely to occur and accumulate in cold climates, at high elevations, on northern exposures, on level ground, on shaded slopes, in valley bottoms subjected to cold-air drainage, at heads of narrow inlets, and in areas distant from the relatively warm (in winter) salt water of the Alexander Archipelago. For commercial-sized stands, topography is probably a better indicator of snowpack than is forest overstory.

The following criteria should be helpful in selecting stands for winter range for deer where snow accumulation is a problem: (1) topographic setting (for example, unshaded, low-elevation, moderate to steep, southerly slopes on a point or peninsula projecting into salt water); (2) overstory canopy coverage at least 95 percent, as measured with a spherical densiometer; (3) timber volume class of at least 20,000 board feet per acre, net volume; and (4) an understory of relatively abundant, high-quality forage (for example, a *Vaccinium* spp./*Cornus canadensis-Rubus pedatus* understory) (Hanley and McKendrick 1985). The effects of snow on deer are greater for food (energy intake) than for locomotion (energy expenditure) at the depths usually encountered in the transient-snow zone (less than 50 cm) (Wickstrom and others 1984). At depths greater than 50-60 cm (brisket height), however, energy costs for locomotion become especially great as deer are forced to jump while traveling through the snow (Parker and others 1984). Maximum interception of snow may be expected for stands with high levels of both overstory canopy coverage and wood volume. Such stands could provide important refuge for deer when snow is deep, but if the understory is sparse, few deer could be supported for long.

Acknowledgments

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English Equivalents

1 centimeter (cm) = 0.39 inch
1 cubic centimeter (cm^3) = 0.06 cubic inch
1 meter (m) = 39.4 inches
1 square meter (m^2) = 10.76 square feet
1 cubic meter (m^3) = 35.31 cubic feet
1 hectare (ha) = 2.47 acres
1 gram (g) = 0.04 ounce

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Appendix

Correlation Matrix of Overstory Variables

Variables	Percentage of spruce	Mean d.b.h.	Mean height	Canopy coverage	Basal area	Gross wood volume
Tree density	0.266	-0.653	-0.157	0.386	0.359	-0.001
Percentage spruce		-.241	-.027	.231	.197	-.018
Mean d.b.h.			.728	.188	.151	.450
Mean height				.649	.572	.657
Canopy coverage					.773	.644
Basal area						.738

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Seven Chemicals Fail To Protect Ponderosa Pine From Armillaria Root Disease in Central Washington

Gregory M. Filip and Lewis F. Roth

Abstract

Chemicals were applied once to the root collars of small-diameter ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) to prevent mortality caused by *Armillaria obscura* (Pers.) Herink Roll-Hansen (=*A. mellea* sensu lato). After 10 years, none of the 15 treatments appeared to reduce mortality in treated trees vs. untreated trees. Diameter growth of surviving trees averaged 3.0 millimeters per year, and the spread rate of the fungus averaged 0.6 meter per year.

Keywords: Root rot, *Armillaria*, fungus control/prevention, ponderosa pine.

Introduction

Damage in commercial conifer forests caused by *Armillaria* is widespread and can be severe in western North America (Wargo and Shaw 1985). Near Glenwood, Washington, root disease in ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) stands has been under study for the past 20 years. Research to date has concentrated on epidemiology and damage reduction (Filip and Roth 1977; Roth and others 1977, 1980; Roth and Rolph 1978; Shaw 1980; Shaw and Roth 1976; Shaw and others 1976). These and other studies show that *Armillaria* infection at the root collar of ponderosa pine, a principal host, results in mortality and that lateral root infections are much less lethal (Adams 1972, Shaw 1980).

At least two chemicals, copper sulfate (Reitsma 1932, Thomas and Raphael 1935) and iron sulfate (Gard 1925, Thomas and Raphael 1935), applied as root collar drenches, are effective in protecting trees from *Armillaria* attack. Also, several fumigants eliminate *Armillaria* from woody inoculum: these include chloropicrin (Filip and Roth 1977, Godfrey 1936), carbon disulfide (Fawcett 1925, Filip and Roth 1977), and methyl bromide (Filip and Roth 1977, Larue and others 1962). The objective of our study was to test the effectiveness of benomyl, captan, copper sulfate, iron sulfate, copper wire, vorlex, and chloropicrin in protecting the root collars of living and presumably uninfected ponderosa pine in central Washington from mortality caused by *Armillaria*.

Materials and Methods

The study area is near Glenwood, Washington, in a young-growth pine forest. The topography is flat to rolling, elevation varies from 750 to 1050 meters, and precipitation is 65 to 90 centimeters per year (table 1). Plant communities range from *Pinus ponderosa*/*Purshia tridentata* at the lower elevations to *Pinus ponderosa*/*Pseudotsuga menziesii*/*Carex geyeri* at the higher elevations (Franklin and Dyrness 1973). Density of understory trees more than 2.5 centimeters in diameter at 1.4 meters above ground (DBH) ranges

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from 2,500 to 5,000 trees per hectare. Site index at 100 years is moderate to good and ranges from 27 to 34 meters. Stands in the study area have been selectively harvested for the past 35 years by the Champion International (formerly St. Regis) Paper Company and the Washington State Department of Natural Resources.

A total of 180 ponderosa pine trees from 7 to 15 centimeters DBH were selected at seven locations within the study area on the basis of high exposure to infection by *Armillaria*. Probability of infection was regulated by distance from apparently advancing margins of

Table 1—Site and stand characteristics of 7 locations treated with chemical protectants, Glenwood, Washington

Location designation	Elevation	Plant community	Trees/ha > 2.5 cm DBH	Side index at 100 years
	Meters			*Meters*
A	760	*Pinus ponderosa* *Ceanothus velutinus* *Purshia tridentata*	4,940	34
B	760	*Pinus ponderosa* *Purshia tridentata*	4,075	29
C	990	*Pinus ponderosa* *Pseudotsuga menziesii* *Carex geyeri*	3,210	32
D	850	*Pinus ponderosa* *Ceanothus velutinus*	2,965	27
E	790	*Pinus ponderosa* *Ceanothus velutinus* *Purshia tridentata*	3,950	31
F	990	*Pinus ponderosa* *Pseudotsuga menziesii* *Carex geyeri*	2,470	28
G	850	*Pinus ponderosa* *Ceanothus velutinus*	3,705	27

disease centers (Shaw 1980). All selected trees were within 6.1 meters of the nearest tree showing signs of *Armillaria* infection (mycelial fans at the root collar). We selected a tree only if the total basal area of infected trees within 6.1 meters of it was between 0.009 and 0.084 square meter. This was done to standardize exposure to inoculum.

One of seven chemicals was applied once in August 1973 to each tree selected. Four of the seven chemicals (iron sulfate, copper sulfate, captan, and benomyl) were applied to a small moat (0.3 meter wide) around the root collar of each tree as a 19-liter drench. Nineteen liters of water were then added to increase percolation. Three concentrations of each material were tested (25, 50, and 100 grams of active ingredient per tree for captan and benomyl; 193, 580, and 963 grams per tree for iron and copper sulfate). Each tree treated with copper wire received 1,135 grams of wire bits (1-2 centimeters long) sprinkled around its base at the root collar zone. Chloropicrin and vorlex (80 percent chlorinated hydrocarbon, 20 percent methyl isothiocyanate) were applied to each appropriate tree in four filled and capped 132-millimeter polyethylene bottles buried 20 centimeters at cardinal points around the root collar. (Cooper (1973) demonstrated the slow release of these fumigants from such polyethylene vials.) Control trees received 38 liters of water. Treatments were assigned randomly to the trees. Each location contained some of the treatments, but not all, because of an insufficient number of candidate trees at each location. Tree mortality was monitored yearly, and diameter growth was measured on surviving trees after 10 years.

Results and Discussion

The species of *Armillaria* causing mortality within the study area was *A. obscura* (Pers.) Herink Roll-Hansen (=*A. mellea* sensu lato) or intersterility group I of Anderson and Ullrich (1979); identification was based on pairings of single-spore isolates collected within the study area (Anderson and others 1979). *A. obscura* is considered to be the most destructive species in western North America (Wargo and Shaw 1985). Ten years after application, none of the 15 treatments appeared to reduce or increase mortality in treated trees as compared to untreated trees (table 2). Differences among treatments were not tested statistically because an insufficient number of trees at all locations precluded performing a balanced, replicated design. Enhancement of *Armillaria* infection has been reported in inoculated *P. ponderosa* and *P. radiata* D. Don seedlings that were treated chemically (Filip 1976, Shaw and others 1980). Except for the first 2 years of the study, when infected trees were probably selected inadvertently, the mortality rate among the 180 trees was fairly constant at about five or six trees per year.

The diameter growth rate of trees surviving after 10 years averaged 3.0 millimeters per year (table 3). This rate is much less than the 5.0-millimeters per year diameter growth of dominant trees on each site and probably reflects the overstocked condition of the understory in many locations. Also, the growth rates of infected trees prior to being killed may have been even less, although these rates were not measured.

The spread rate of the fungus, measured annually by recording the distance of recently killed trees from apparent infection sources, averaged 0.6 meter per year (table 4). This rate is less than that reported by Shaw and Roth (1976) in the same general area, but they studied the spread of disease over several decades and among much larger trees (70-130 centimeters DBH). Chemical treatments probably did not affect the spread rate in our study because none of the treatments greatly affected tree mortality. The experimental design did not allow statistical testing of this relation.

Table 2—Incidence of ponderosa pine mortality caused by *Armillaria obscura* 10 years after treatment with chemical protectants, Glenwood, Washington

	Location designation							
Treatment	A	B	C	D	E	F	G	All locations
	Number of dead trees							
Control	6(14)[1]	1(3)	2(2)	1(2)	1(1)	0(4)	4(4)	15(30)
Benomyl:								
25 g	2(2)	1(2)	1(2)	1(1)	0(0)	1(1)	2(2)	8(10)
50 g	1(5)	0(0)	2(2)	0(1)	1(1)	0(0)	1(1)	5(10)
100 g	1(2)	0(1)	1(2)	1(3)	0(1)	0(0)	0(1)	3(10)
Captan:								
25 g	1(4)	1(1)	0(2)	1(2)	0(0)	0(0)	1(1)	4(10)
50 g	0(2)	0(1)	0(0)	2(4)	0(0)	0(2)	1(1)	3(10)
100 g	0(3)	0(0)	0(1)	0(1)	1(2)	1(1)	0(2)	2(10)
Copper sulfate:								
193 g	0(0)	2(4)	3(4)	0(2)	0(0)	0(0)	0(0)	5(10)
580 g	1(3)	0(0)	0(0)	2(5)	1(1)	1(1)	0(0)	5(10)
963 g	3(5)	1(2)	0(0)	0(1)	0(0)	0(1)	0(1)	4(10)
Iron sulfate:								
193 g	0(0)	0(2)	3(3)	1(3)	0(0)	1(2)	0(0)	5(10)
580 g	2(4)	0(1)	0(0)	1(1)	1(1)	1(1)	2(2)	7(10)
963 g	1(4)	0(1)	1(1)	2(2)	0(0)	0(0)	1(2)	5(10)
Copper wire	0(2)	0(2)	0(0)	2(3)	0(0)	1(2)	1(1)	4(10)
Vorlex	0(3)	0(0)	1(2)	3(4)	0(0)	0(0)	1(1)	5(10)
Chloropicrin	1(2)	1(1)	2(2)	1(2)	2(3)	0(0)	0(0)	7(10)
Total	19(55)	7(21)	16(23)	18(37)	7(10)	6(15)	14(19)	87(180)

[1]Number in parentheses is the total number of trees treated.

Single applications of chemicals to protect small-diameter pines from lethal infections of *A. obscura* generally are not effective, but some of the chemicals may protect pines from lethal attack in high-value areas, such as seed orchards, recreation sites, or ornamental plantings, where economics may justify more than one chemical application. More promising in commercial forests is the use of chemicals as eradicators of inoculum rather than as protectors. *A. obscura* can be eliminated from small stumps by injecting the stump with choloropicrin, volvex, vapam, methyl bromide, or carbon disulfide (Filip and Roth 1977).

Precommercial thinning rather then chemical barriers may be a better method of protecting small-diameter pines from mortality caused by *Armillaria*. Precommercial thinning on certain sites in Oregon has significantly reduced crop-tree mortality caused by *Armillaria* (Johnson and Thompson 1975). Density of the understory on many of the Glenwood, Washington, sites is high and growth rates are low. This may predispose understory trees to infection and subsequent mortality, which could be mitigated by precommercial thinning. Current methods of control in the Glenwood area include commercial thinning with stump removal of infected pines (Roth and others 1977) and conversion to Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), which is more tolerant of *Armillaria* root disease.

Table 3—Mean annual diameter increment of surviving ponderosa pine 10 years after treatment with chemical protectants, Glenwood, Washington

	Location designation							
Treatment	A	B	C	D	E	F	G	All locations
				Millimeters per year				
Control	2.8(8)[1]	1.9(2)	—	4.4(1)	—	2.3(4)	—	2.5(15)
Benomyl:								
25 g	—	8.8(1)	6.2(1)	—	—	—	—	7.5(2)
50 g	3.2(4)	—	—	4.6(1)	—	—	—	3.5(5)
100 g	3.0(1)	.9(1)	2.5(1)	8.3(2)	2.5(1)	—	4.2(1)	4.2(7)
Captan:								
25 g	3.7(3)	—	5.5(2)	.7(1)	—	—	—	3.9(6)
50 g	4.9(2)	—	—	2.3(1)	—	2.1(1)	—	3.5(4)
100 g	5.1(3)	—	2.8(1)	4.4(1)	3.9(1)	6.2(1)	1.4(2)	3.9(9)
Copper sulfate:								
193 g	—	1.2(2)	1.4(1)	3.9(3)	—	—	—	2.5(6)
580 g	1.4(2)	1.6(1)	—	4.9(3)	—	—	—	3.2(6)
963 g	.7(3)	.9(1)	—	1.4(1)	—	6.2(1)	2.1(1)	1.9(7)
Iron sulfate:								
193 g	—	1.4(3)	—	6.7(1)	—	2.3(1)	—	2.5(5)
580 g	2.5(2)	—	—	—	2.8(1)	—	1.4(1)	2.3(4)
963 g	4.2(3)	1.6(2)	—	—	—	—	2.9(1)	3.2(6)
Copper wire	3.2(2)	1.4(1)	—	4.4(1)	—	3.5(1)	—	3.2(5)
Vorlex	3.5(2)	—	—	2.5(1)	—	—	—	3.2(3)
Chloropicrin	1.6(1)	—	—	3.5(1)	3.7(1)	—	—	3.0(3)
Total	3.0(36)	2.1(14)	3.9(6)	3.7(18)	3.2(4)	2.8(9)	2.3(6)	3.0(93)

— = no living trees remaining at that location.
[1]Numbers in parentheses are the number of trees measured.

Table 4—Spread rate of *Armillaria obscura* as determined by annually recording the distance of recently killed ponderosa pine from apparent infection sources, Glenwood, Washington

Year	Location designation							Mean
	A	B	C	D	E	F	G	
	Meters per year							
1974	1.1	1.4	0.9	1.0	0.6	1.5	—	1.1
1975	.4	.9	.3	2.0	—	.8	0.9	.9
1976	.3	—	.2	—	—	—	.6	.4
1977	—	.8	.6	.5	—	—	—	.6
1978	.4	.7	.3	.1	1.1	.6	.2	.5
1979	.7	—	—	.2	—	—	1.0	.6
1980	.5	—	—	.8	—	—	.8	.7
1981	—	—	.6	.2	—	.5	.5	.5
1982	.5	—	—	.1	.5	—	.5	.4
1983	.3	—	—	.2	.4	.6	.4	.4
1984	.3	—	. .4	—	.5	—	.5	.4
Mean	.5	.9	.5	.6	.6	.8	.6	.6

— = no mortality at that location for that year.

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English Equivalents

1 meter = 39.37 inches
1 square meter = 10.7639 square feet
1 centimeter = 0.3937 inch
1 millimeter = 0.0394 inch
1 hectare = 2.4710 acres
1 gram = 0.03527 ounce

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Research Note PNW-RN-461

Bud Characteristics of Unrooted Stem Cuttings Affect Establishment Success of Cottonwood

M.A. Radwan, J.M. Kraft, and D.S. DeBell

Abstract

Experimental plantings of different genotypes of cottonwood were examined. The four clones tested were: a *Populus* hybrid (Dula, D-01), a *P. trichocarpa* x *P. deltoides* hybrid (Hybrid 11), and two native *P. trichocarpa* clones (Nisqually 1 and Orting 5). Establishment success and characteristics of hardwood cuttings or resulting plants that might be related to success were determined. Establishment success varied significantly ($P < 0.01$) among the four clones in the order, Orting = Dula > Hybrid 11 > Nisqually. Also, there was much variation among the clones in the relative proportion of internodal shoots, dead buds, and "spent" buds. Results suggest that best establishment and growth are achieved when cuttings have healthy axillary buds at planting. Establishment success from such cuttings would be fairly high, and resulting experimental plantings would permit valid comparisons of productivity of different genotypes of cottonwood.

Keywords: Stem cuttings, genotypes, black cottonwood, *Populus trichocarpa*.

Introduction

Stem cuttings of black cottonwood (*Populus trichocarpa* Torr. & Gray) root easily, and unrooted cuttings (or whips) have frequently been used to establish new plantations in the Pacific Northwest. As with other species, however, different sources of cottonwood can differ considerably in their ability to root, and this, in turn, can affect establishment success. An example of such variation has been reported among different clones of *P. trichocarpa* and hybrids of *P. trichocarpa* x *P. deltoides* (Heilman and Stettler 1985). Additional factors such as quality of cuttings used, soil conditions, and weather during and after planting can also influence development of both roots and shoots.

In 1985, we attempted to establish from cuttings an experimental plantation containing two *Populus* hybrid clones and two native *P. trichocarpa* clones near Yelm in western Washington. From the start, sprouting varied considerably among clones, and differences persisted through the growing season. Performance was particularly poor with two of the clones, and attempts to replace dead cuttings were not very successful. Variation in both establishment success and growth were clearly large enough to preclude fair assessment of biomass production of the different clones, which was the primary objective of the study.

Preliminary examination of a few cuttings and plants in midsummer 1985 suggested that the quality of cuttings may have been a factor in the variable performance of the different clones. This study, therefore, was conducted in late summer 1985 to test this hypothesis before another attempt at establishing the same clones was made in 1986.

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Methods

A total of four clones were studied as follows:

1. *Dula, D-01:* A *Populus* hybrid (taxonomic identity unknown) developed by the University of Idaho and Dula's Nursery of Canby, Oregon.
2. *Hybrid 11:* A *P. trichocarpa* x *P. deltoides* hybrid developed by the University of Washington and Washington State University.
3. *Nisqually 1:* A clone of *Populus trichocarpa.*
4. *Orting 5:* A clone of *Populus trichocarpa.*

The Dula cuttings were purchased from a private nursery, and cuttings of the other clones were provided by a forest products company. All cuttings were made in January and stored moist in plastic bags at 2-3 °C until planted.

Cuttings were planted in March 1985 at a fenced field, on State of Washington land, near Yelm. On the average, cuttings were about 30 cm long and were planted 20 cm deep; diameters varied by genotype and ranged from 5 to 30 mm. Before being planted plots were fertilized with a 16-16-16 commercial fertilizer at a rate of 100 kg each of nitrogen, phosphorus, and potassium per hectare. Plots also received a pre-emergent herbicide treatment (Goal + Kerb)[1/] after planting. Overhead irrigation was begun in July 1985. There were three replications per treatment.

Establishment success was determined by examining 100 cuttings or resulting plants from each of three replications of the same spacing treatment per clone. Percentage success was calculated from the number of living plants and dead cuttings found. No distinction by amount or quality of growth was made among living plants.

Characteristics of cuttings or plants that might be related to establishment success were determined on 30 cuttings or plants from each of three replications of the same spacing treatment of each clone. The 30 cuttings or plants examined included 10 dead cuttings, 10 weak plants, and 10 vigorously growing plants, all selected at random within each category. Characteristics studied were "spent" and dead buds on cuttings, nodes above ground, live and dead shoots (normal and adventitious), and live roots. Spent buds were represented on the cuttings by old branch stubs; the original axillary buds had sprouted during the previous year, and resulting branches had been cut when cuttings were made from the stem. Dead buds were at the nodes; they were dark brown and clearly rotten. Normal shoots originated from the axillary buds present at the nodes at time of planting. Adventitious shoots were initiated in the internodes after planting.

1/ The use of brand names is for the convenience of the reader and does not constitute endorsement by the U.S. Department of Agriculture to the exclusion of other products that may be suitable.

Figure 1 shows an example of the three cutting and plant categories (that is, dead cuttings, weak plants, and vigorous plants) used in the study. Spent buds are contrasted with axillary buds in figure 2. All data were collected in late August 1985. Values for establishment success were treated by analysis of variance and means were separated by Tukey's test (Snedecor 1961).

Figure 1—Example of the three cutting and plant categories studied. From left to right: dead cutting, weak plant, and vigorous plant.

Figure 2—Cuttings with healthy axillary buds (left) and spent buds (right).

Results and Discussion

Establishment success varied greatly between the four clones in the order, Orting = Dula > Hybrid 11 > Nisqually (table 1). Throughout the plantation, propagation by cuttings was obviously much more successful for Dula and Orting than for Hybrid 11 and Nisqually. This contrast is illustrated in figure 3, which shows the Orting and Nisqually clones in adjacent plots planted at the 1- by 1-m spacing.

Data in table 1 and figure 4 also show much variation among the clones in the characteristics of the cuttings or plants determined. Spent buds accounted for a greater percentage of total buds in the less successful clones (Hybrid 11 and Nisqually) than in the more successful ones (Dula and Orting). Also, within clones, spent buds were generally highest in dead cuttings, intermediate in weak plants, and lowest in vigorous plants. Unlike other clones, the Dula cuttings were prepared from plants grown in very dense ("wood grass") stool beds. This very high density limits light penetration and presumably discourages branching which, in turn, decreases the number of spent buds per cutting. Even at wider spacing, branching may vary by genotype. This is illustrated in figure 5 where Dula (minimal branching) and Hybrid 11 (much branching) plants from the same spacing treatment are shown.

Establishment success, therefore, seems to be correlated with the relative proportion of spent buds on the cuttings at planting which, in effect, reflects the lack of axillary buds.

Table 1—Selected characteristics of black cottonwood clones[1]

	Clone			
Item	Dula	Hybrid 11	Nisqually	Orting
Establishment success (percent of total cuttings)	76a	54b	34c	88a
"Spent" buds on cuttings (percent of total buds)	9	84	80	57
Dead buds on cuttings (percent of total buds)	55	2	6	19
Live nodal shoots per plant (percent of all shoots)	83	72	69	90
Live internodal shoots per plant (percent of all shoots)	0	28	31	8
Dead shoots (percent of all shoots)	17	0	0	2
Number of live shoots per plant	1.8	1.5	2.5	2.1

[1] Values are averages of 3 replications. Establishment success is based on 100 cuttings or plants from each of 3 replications per clone. Other items are based on 30 cuttings or plants from each of 3 replications per clone. Means in a horizontal sequence followed by different letter are statistically different at $p < 0.01$ by Tukey's test (Snedecor 1961).

Axillary buds burst early in the spring and produce the normal shoots. When these buds are absent, as when only spent and dead buds are present, establishment success depends on adventitious or suppressed buds. Initiation or development of these buds or both require much energy and time, and that would at least delay shoot development and growth. Our survey showed that vigorous shoots were formed consistently at the nodes from axillary buds, whereas weak shoots almost always resulted from adventitious buds in the internodes below the ground surface. This may not hold true for different genetic stock or environmental conditions. For example, a

A

B

Figure 3—Nisqually (A) and Orting (B) plots at 1- by 1-m spacing. Note the much greater success of establishment from Orting.

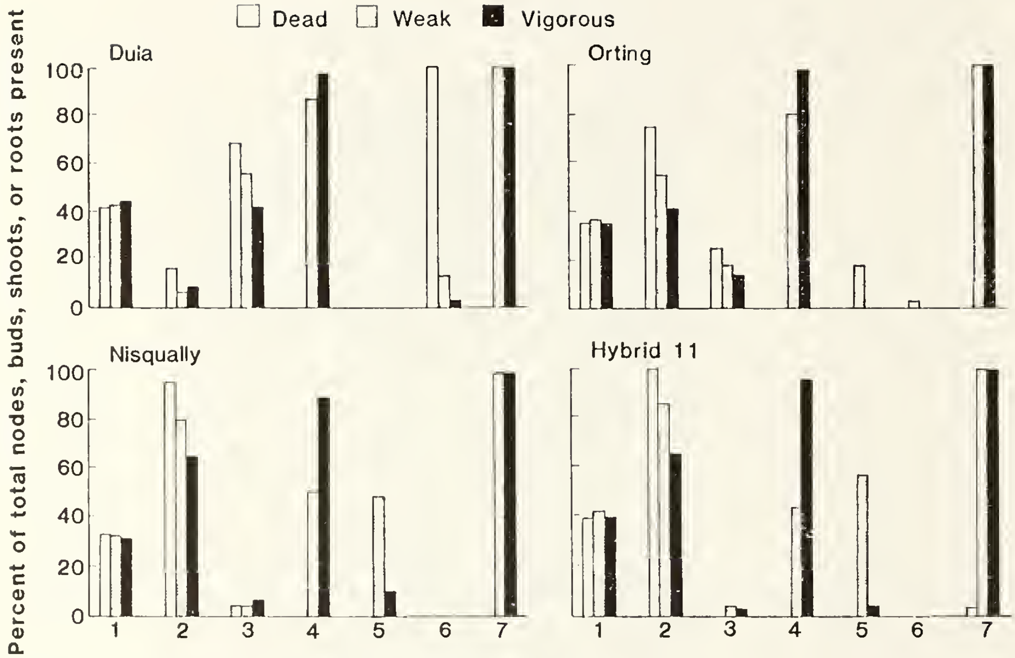

Figure 4—Selected characteristics of black cottonwood clones by cutting or plant category. 1 = nodes above ground, 2 = spent buds, 3 = dead buds, 4 = live nodal shoots, 5 = live internodal shoots, 6 = dead shoots, 7 = live roots.

Figure 5—Dula (left) and Hybrid 11 (right) plants taken from the same spacing treatment. Note much more branching with Hybrid 11 than with Dula.

followup test established at our laboratory in spring 1986 showed that some shoots developed above ground on or near the base of the branch stubs of the spent buds. By the middle of the growing season, however, these shoots were weak and they were less than one-tenth the length of shoots that had developed from axillary buds of other cuttings.

Dead buds and shoots were most prevalent on the most successful clones (Dula and Orting) and least common on the least successful (Hybrid 11 and Nisqually). To some degree, the higher percentage of dead buds and shoots probably reflects more original axillary buds on cuttings of the more successful clones. Most dead buds and shoots were associated with the very thin cuttings, which were most common with Dula. Also, within clones, dead buds and shoots generally occurred in the order: dead cuttings > weak plants > vigorous plants.

All clones had considerably more live nodal shoots than live internodal shoots. Also, within clones, there were more nodal shoots on the vigorous plants than on the weak ones; the opposite was true for internodal shoots. For all clones, therefore, most shoots originated from axillary buds at the nodes. Live internodal shoots occurred mostly in Hybrid 11 and Nisqually (about 30 percent). Those two clones were also highest in spent buds, and success of their cuttings depended, to a large extent, on initiation and development of adventitious buds from the internodes, as explained above. The tendency for shoots to produce branches from axillary buds during the same year in which shoots develop on cuttings appears to be common among native deciduous angiosperms in the Pacific Northwest.

As expected, all successful cuttings had live roots, regardless of clone or plant vigor. In contrast, the two native *Populus* clones (Nisqually and Orting) had more live shoots per plant than did the two hybrid clones (Dula and Hybrid 11); the opposite was true for percentage of nodes above the ground. Apparently, these characteristics were not related to clonal differences in establishment success.

Conclusions

At present, the literature contains no specifications for cuttings of black cottonwood for maximum success of establishment. As with other *Populus* species (Hansen and others 1982), however, the importance of minimum length and diameter of cuttings and depth of planting has been recognized in some publications and in conventional practice. Our results indicate that establishment success and 1st-year growth will be greatest if cuttings also have healthy axillary buds. Cuttings, therefore, should not be made from the part of stems where maximum branching has occurred. Also, as with other species, cuttings should not be made from tip portions of shoots that are usually low in stored foods (Hartman and Kester 1983) and where axillary buds may not be fully developed. We believe establishment success from the recommended high-grade cuttings will be high and that the resulting experimental plantings will permit valid comparisons of productivity of different genotypes. Indeed, cuttings made using the recommended criteria resulted in establishment successes of nearly 100 percent for each of the four clones in our 1986 plantings. Furthermore, early growth is much more uniform and will thus provide a more sensitive test of differences among and within clones for cultural treatments such as fertilizing and spacing.

Acknowledgments

This work was supported in part by a grant from the U.S. Department of Energy.

English Equivalents

1 millimeter (mm) = 0.039 inch
1 centimeter (cm) = 0.39 inch
1 kilogram (kg) = 2.2046 pounds
°C = (°F-32)/1.8

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Research Note PNW-RN-462

Fungi From Foliage of *Arctostaphylos patula*, *Castanopsis chrysophylla*, and *Ceanothus velutinus*

Ralph H. Crawford, Steven E. Carpenter, John Mayfield, and Robert E. Martin

Abstract

Twelve fungus species were isolated from three shrubs—*Arctostaphylos patula*, *Ceanothus velutinus*, and *Castanopsis chrysophylla*—in ponderosa pine stands in central Oregon. *Hormonema dematioides* was most frequently isolated and was recovered from all three shrubs. *Penicillium frequentans* was most frequently isolated from the single shrub, *Arctostaphylos patula*, at all but one location. Three potential plant pathogens, *Alternaria alternata*, *Drechslera* sp., and *Truncatella angustata*, should be further investigated as possible biological control agents.

Keywords: Woody plants, brush control, competition (plant), fungi, biological control.

Introduction

Greenleaf manzanita (*Arctostaphylos patula* Greene), golden chinkapin (*Castanopsis chrysophylla* (Dougl.) A. DC.), and snowbrush ceanothus (*Ceanothus velutinus* Dougl.) are major shrub competitors in commercial seedling stands of young ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) in central Oregon (Zavitkovski and others 1969). These shrubs cover about 27 percent of the Deschutes National Forest and are pioneers in forest lands after fire. Snowbrush and chinkapin easily regenerate after fire via sprouts from buried rootstock; manzanita has hard seeds that can remain dormant in the soil for up to 300 years (Hayes 1959). Competition from snowbrush can reduce growth of western white pine (*P. monticola* Dougl. ex D. Don) and ponderosa pine seedlings by more than 50 percent. Snowbrush can also enhance animal populations; animal browsing is often a major cause of seedling mortality (Zavitkovski 1966).

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Snowbrush dominates thousands of acres of logged or burned forest lands in the Pacific Northwest, and its dominance is likely to increase with the present methods of logging and prescribed burning. The role of snowbrush in the regeneration of conifers has been studied primarily for its potential as a nurse crop and as a fixer of nitrogen. Shrub and brush control can also promote growth of young seedlings (Bentley and others 1971). Bulldozing is an effective method for initial shrub and brush control (Buck 1959); but within 2 years after bulldozing, a dense stand of competitive shrub and brush plants commonly reestablishes (Bentley and others 1970). Since 1962, control practices have included spraying with herbicides, such as 2,4-D (2,4-dichlorophenoxyacetic acid) and 2,4,5-T (2,4,5-trichlorophenoxyacetic acid), the first or second year after bulldozing. Spraying can be repeated as needed to maintain an open shrub or brush stand. Gratkowski (1959) has shown, however, that greenleaf manzanita and snowbrush are only moderately susceptible to 2,4-D and 2,4,5-T, whereas golden chinkapin is resistant. In addition, these herbicides must be carefully timed to prevent damage to pine seedlings (Gratkowski 1977).

This paper reports results of initial searches for previously unstudied endemic foliar fungi that might serve as biological control agents of these competing shrubs.

Materials and Methods

Leaves exhibiting necrotic spots or lesions were collected from shrubs on randomly selected, widely spaced areas on Lookout Mountain, Benham Butte, Bessie Butte, Black Butte, and China Hat in the Deschutes National Forest, Deschutes County, Oregon. Necrotic (with lesions) and nonnecrotic leaves from *Arctostaphylos patula, Castanopsis chrysophylla,* and *Ceanothus velutinus* in forest areas containing a high density of these shrubs were severed, placed in individual plastic containers, labeled, and dated. All collections were made between June and August.

Necrotic and nonnecrotic portions of each leaf were aseptically cut into 5- to 10-mm squares; necrotized leaf-squares also included areas with green tissue. The squares were surface sterilized in a 5.75-percent solution of sodium hypochlorite for 30, 60, 90, and 120 seconds; aseptically removed with sterile forceps; and rinsed in sterile distilled water. The tissue squares were blotted on sterile filter paper to remove excess water and transferred immediately to sterile 100- by 15-mm plastic petri dishes containing ca 20 mL potato dextrose agar (PDA) (Difco).[1]

Cultures were maintained at ambient temperature (25 °C) and lighting. The tissue squares on agar plates were examined daily for fungal growth. Mycelia growing from the plant tissues onto the agar medium was subcultured and subsequently maintained on PDA agar plates and slant tubes. Samples were prepared for microscopic observation by making wet slide mounts and slide cultures.

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[1]/Use of trade names does not imply endorsement or approval of any product by the USDA Forest Service to the exclusion of others that may be suitable.

Results and Discussion

Twelve fungus species were isolated from necrotic tissue of greenleaf manzanita, snowbrush ceanothus, and golden chinkapin (tables 1-3). The majority of fungal isolates were weak saprobes or parasites and varied greatly in their occurrence both on the three shrub species and by site. *Hormonema dematioides* was most frequently isolated from all three shrub species (frequency refers to the number of sites from which the isolates originated) (tables 1-3). *Penicillium frequentans* was most frequently isolated from a single shurb species (*A. patula*). Three of the isolated species (*Alternaria alternata, Drechslera* sp., and *Truncatella angustata)* are important as potential plant pathogens. *Alternaria alternata* was isolated from *Arctostaphylos patula* on Bessie Butte and *C. velutinus* on China Hat; *Drechslera* sp. and *T. angustata* were isolated from *C. velutinus* on Bessie Butte and *Castanopsis chrysophylla* on Black Butte, respectively. None of these fungi were isolated from nonnecrotic shrub structures.

Table 1—Fungal species isolated from *Arctostaphylos patula* at 5 locations in Deschutes National Forest, Oregon

	Location				
Isolated fungal species	Black Butte	Benham Butte	Bessie Butte	China Hat	Lookout Mountain
Acremonium chrysogenum (Thirum. & Sukap) W. Gams					
Agyriella sp.					
Alternaria alternata (Fr.) Keissler			+		
Alternaria tenuissima (Kunze ex Pers.) Wilts.					
Aspergillus sp.	+				
Cladosporium cladosporioides (Fres.) de Vries					
Drechslera sp.					
Hormonema dematioides Lagerb. & Melin		+	+		
Penicillium frequentans Westling	+	+	+		+
Penicillium sp.					
Trichoderma viride Pers. ex Gray	+			+	
Truncatella angustata (Pers. ex Lk.) Hughes					
Total number of species by location	3	2	3	1	1
Total number of fungi/shrub		5			

Table 2—Fungal species isolated from *Ceanothus velutinus* at 5 locations in Deschutes National Forest, Oregon

Isolated fungal species	Location: Black Butte	Benham Butte	Bessie Butte	China Hat	Lookout Mountain
Acremonium chrysogenum					
Agyriella sp.					
Alternaria alternata	+				
Alternaria tenuissima					
Aspergillus sp.				+	
Cladosporium cladosporioides				+	
Drechslera sp.			+		
Hormonema dematioides	+			+	
Penicillium frequentans					
Penicillium sp.			+		+
Trichoderma viride					+
Truncatella angustata					
Total number of species by location	1	0	2	4	3
Total number of fungi/shrub		8			

Table 3—Fungal species isolated from *Castanopsis chrysophylla* at 5 locations in Deschutes National Forest, Oregon

Isolated fungal species	Location: Black Butte	Benham Butte	Bessie Butte	China Hat	Lookout Mountain
Acremonium chrysogenum					+
Agyriella sp.					+
Alternaria alternata					
Alternaria tenuissima	+				
Aspergillus sp.	+				
Cladosporium cladosporioides					
Drechslera sp.					
Hormonema dematioides					+
Penicillium frequentans					
Penicillium sp.	+				
Trichoderma viride					
Truncatella angustata	+				
Total number of species by location	4	0	0	0	3
Total number of fungi/shrub		7			

For the most part, no consistent distribution pattern of fungus species with particular shrub species or locations was observed (tables 1-3). One exception, however, was the occurrence of *P. frequentans* only with *A. patula* and isolated from all locations except China Hat. All fungi associated with *C. chrysophylla* were isolated from two locations, Black Butte and Lookout Mountain.

The results reported here suggest that finding a common pathogen that will effectively control all three shrub species is unlikely. Because *Alternaria alternata, Drechslera* sp., and *T. angustata* are the most probable pathogen forms, they should be further investigated for their ability to induce disease symptoms in healthy shrubs. Caution must also be taken in such a research program to assure that the biological control agents are not pathogenic to desired crop species.

English Equivalents

1 millimeter (mm) = 0.0394 inch
°C = (°F-32) 5/9
1 milliliter (mL) = 0.001056 quart

Acknowledgment

This paper is adapted from a thesis submitted by Ralph Crawford for a master's degree in biology, Atlanta University. The authors thank the employees at the Pacific Northwest Research Station, Silviculture Laboratory, Bend, OR, for their assistance and advice.

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Research Note PNW-RN-463

Water Quality and Streamflow in the Caribou-Poker Creeks Research Watershed, Central Alaska, 1979

Jerry W. Hilgert and Charles W. Slaughter

Abstract

Baseline data from 1979 are presented on precipitation, streamflow, occurrence of permafrost, and physical and chemical water quality in a subarctic, tiaga watershed. First- to third-order streams drain catchments embracing permafrost-underlain and permafrost-free landscapes in the undisturbed research watershed. The data are compared to those from a fourth-order stream impacted by placer mining; streams in the research watershed drain into the fourth-order stream slightly beyond the watershed border. These and subsequent baseline data sets will be used to compare natural conditions in undisturbed streams of the subarctic to conditions in streams impacted by resource management activities and to evaluate the impacts of such activities on stream ecosystems.

Keyword: Baseline data, water quality, streamflow, subarctic environment, Alaska (Caribou-Poker Creeks research watershed).

Introduction

The Caribou-Poker Creeks research watershed was established in 1969. Research in the watershed is directed toward understanding of environmental characteristics and processes in an undisturbed subarctic setting, and toward evaluating resource management techniques and their impacts on stream ecosystems. Water quality data were collected from 1971 through 1974 (Jinkinson and others 1973, Lotspeich and others 1976) and were reinitiated in 1978 (Hilgert and Slaughter 1983). Collection of baseline data has continued through 1986 with the purpose of accumulating a comprehensive data set against which post-treatment characteristics will be assessed.

Baseline water quality data are presented from eight sampling stations on Caribou and Poker Creeks and from a station recently established an the Chatanika River above its confluence with Poker Creek. The Caribou-Poker Creeks research watershed, located 49 km north of Fairbanks, encompasses 106 km² of the subarctic taiga of central Alaska (fig. 1). The setting and climate of this catchment are described by Koutz and Slaughter (1972), Reiger and others (1972), Slaughter and Long (1974), and Troth and others (1975).

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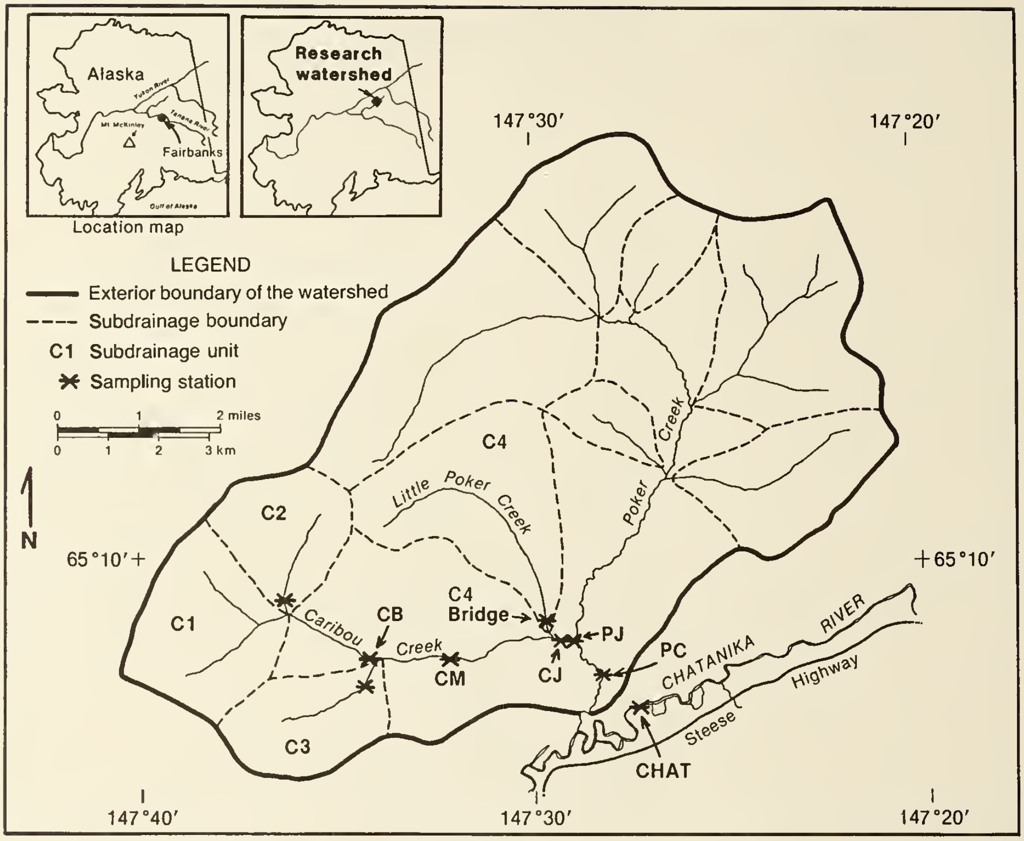

Figure 1—Caribou-Poker Creeks research watershed.

Subdrainages C2 and C3 were chosen for detailed monitoring because of their dissimilarity in the occurrence of permafrost. The C2 catchment has a relatively small percentage of area underlain by permafrost (3 percent) and is characterized by south-facing slopes with relatively deep soils. Approximately 52 percent of the area is dominated by quaking aspen (*Populus tremuloides* Michx.), paper birch (*Betula papyrifera* Marsh.), and white spruce (*Picea glauca* (Moench) Voss); the remaining area is characterized by a black spruce (*Picea mariana* (Mill.) B.S.P.) and moss community. The C3 subdrainage has a greater percentage of area underlain by permafrost (53 percent) because of its generally northeast aspect. Soils are shallow with approximately 99 percent of the area overlain with a moss/lichen ground cover and a generally open, black spruce-dominated overstory. Striking dissimilarities between the two subdrainages have been documented on local climate (Slaughter and Long 1974) and hydrological response (Slaughter and Kane 1979). First comprehensive samples of water quality characteristics, taken in 1978, indicated possible variation in turbidity, temperature, and sediment production (Hilgert and Slaughter 1983).

The sampling site on the Chatanika River was chosen because it had been subjected to sedimentation and increased turbidity from placer mining on upstream tributaries during summer and fall 1979. By comparing higher order stations within the undisturbed research watershed to the Chatanika River station, we can determine whether sediment and turbidity are results of natural storm events or mining activities.

Characteristics of all subdrainages sampled are shown in table 1.

Table 1—Characteristics of subdrainages in Caribou-Poker Creeks research watershed and Chatanika River

Subdrainage	Area	Stream order at station	Dominant aspect	Permafrost	Stream length
	Square kilometer			Percent	Kilometer
C2	5.2	1	S	3.5	2.2
C3	5.7	1	NE	53.2	2.6
C4	11.4	1	SSE	18.8	5.0
CB	15.7	2	E	28.0	9.7
CM	23.1	2	E	28.0	11.3
CJ	43.8	2	E	28.0	19.0
PJ	61.3	3	S	30.5	29.6
PC	110	3	S	30.7	48.4
CHAT	738	5	W	40.0	1/113

1/ Estimated length of main channel; does not include tributaries.

Methods used in acquisition of samples and analysis of data are described in the first report presenting baseline data on Caribou-Poker Creeks (Hilgert and Slaughter 1983). The current report is built upon the first and upon work reported by Jinkinson and others (1973) and Lotspeich and others (1976).

Methods

Chemical and physical properties of the water and biological constituents were sampled throughout 1979 at eight stations: three first-order sites in separate streams (C2, C3, and C4), three second-order sites in Caribou Creek (CB, CM, CJ), a third-order site in Poker Creek (PJ), and a fourth-order site in the Chatanika River (CHAT) (table 2). Midway through the summer of 1979, we established a ninth station, below the confluence of Caribou and Poker Creeks (PC); that station completed a hypothetical "river continuum" (Vannote and others 1980).

Table 2—Water properties and biological constituents sampled in Caribou-Poker research watershed and Chatanika River, 1979

Chemical properties	Physical properties	Biological constituents
Alkalinity	Discharge	Periphyton:
pH	Temperature	Natural populations
Filterable:	Turbidity	Artificial substrates
NO_3-N, NH_3-N	Nonfilterable residue	Macroinvertebrates:
Kjeldahl-N	Specific conductance	Standing crop
ortho-P, total-P		Drift
Ca, Mg, Na, K, Mn, Fe, As, Cl, Si		

Samples of water quality were taken from April through November 1979. We attempted to take grab samples once each calendar week, but conditions often necessitated a change in sampling day. Ambient air and water temperatures at each site were measured with calibrated thermometers near midday while water quality was being sampled. Water samples for turbidity, pH, alkalinity, and specific conductance were kept cool and dark while being transported to the laboratory for measurement and for filtering for chemical determinations (American Public Health Association 1975). Two 125-ml samples were filtered through a rinsed Gelman MicroQuartz[1/] glass fiber filter (0.45 μm). One of the two 125-ml samples was then acidified to a pH of 2 and stored in the dark at 5°C until analyzed by atomic absorption spectrophotometry for dissolved sodium, potassium, calcium, magnesium, arsenic, iron, and manganese (American Public Health Association 1975). The other 125-ml sample was filtered as above, stored frozen, and analyzed for filterable nitrate, ammonia, Kjeldahl nitrogen, ortho-phosphorus, total phosphorus, chloride, and silica by the U.S. Environmental Protection Agency (Corvallis, Oregon) Chemical Lab using a Technicon Auto-Analyzer (U.S. Environmental Protection Agency 1976). A 500-ml grab sample was collected from each station and filtered through a tared Gelman MicroQuartz glass fiber filter (0.45 μm) for quantification of nonfilterable residue (total suspended sediment). Grab samples were collected because of the shallow nature (less than 30 cm) of the stream sites. Grab samples were collected at well-mixed sites from the center of each stream or from the mouth of each flume.

Results and Discussion

Streamflow

Discharge measurements at three stations are summarized in figure 2. Peak flows in C3 and CM occurred on July 6, and minor storms increased discharge on June 12 and July 27. Malfunction of the C2 water level recorder permitted only instantaneous discharge measurements, which were taken in the C2 flume when grab samples were taken. The instantaneous discharge measurements are plotted as "•" in figure 2. The relationship of C2 to C3 appears to be consistent with results from the 1978 field season (Hilgert and Slaughter 1983), when peak storm flows were much higher and more pronounced in C3 than in C2, and when base flow tended to be greater in C2 than C3. In the 1979 field season, C2 had much less flow than did C3 during the storm of July 6 but had higher base flow during the relatively dry months of August and September.

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

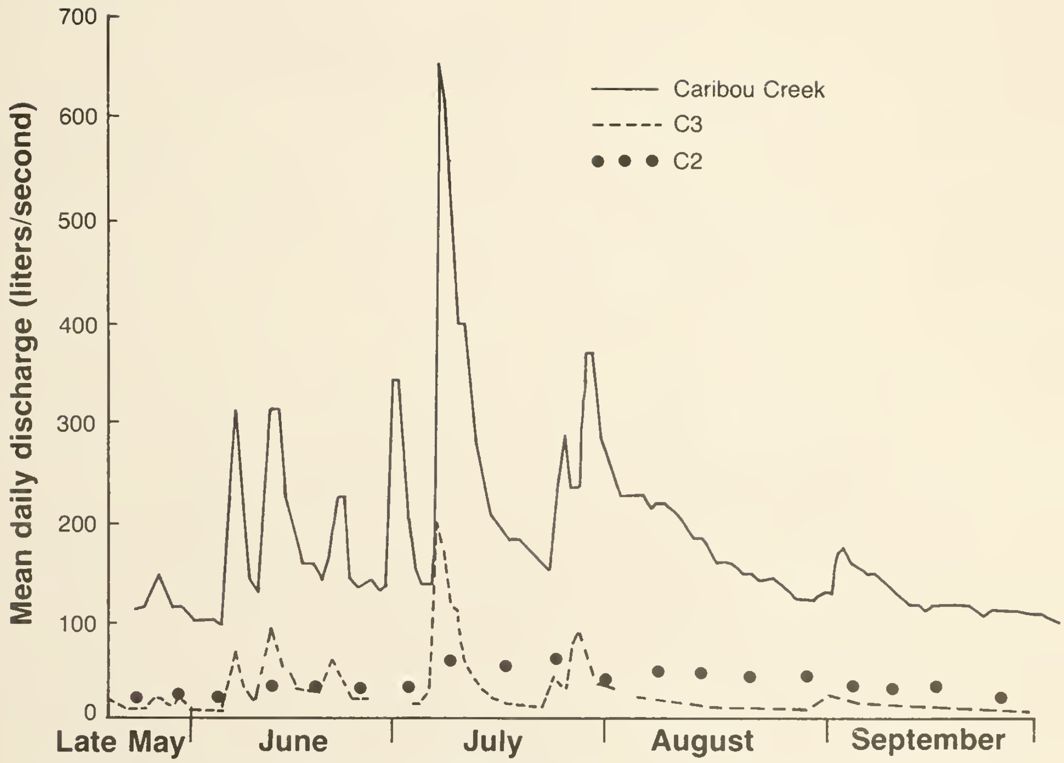

Figure 2—Mean daily discharge at C3 and Caribou Creek, and instantaneous point discharge at C2, May-September 1979.

Discharge during spring breakup[2] at C3 was estimated hourly with time lapse photography (fig. 3). Breakup occurred from April 25 through May 15, 1979, with an estimated discharge of 3.16 x 10^8 liters in 23 days. This amount compares to a measured discharge of 3.67 x 10^8 liters during the ice-free season of May 16 through September 30, or 138 days. Kane and Slaughter (1972) estimated the discharge from C3 as 2.8 liters per second during the winter, when streams were covered with ice.

Discharge from C3 was estimated as 5.04 x 10^7 liters during the ice-covered season and 7.33 x 10^8 liters for the entire year. Approximately 50 percent of the annual discharge runs off during the ice-free season, 43 percent during breakup, and 7 percent during the winter. Future research efforts will strive to determine annual yields from each basin within the watershed and to determine a sediment budget for basins with gaged sampling stations.

[2] The term "breakup" refers to melting of ice cover and associated increase of discharge.

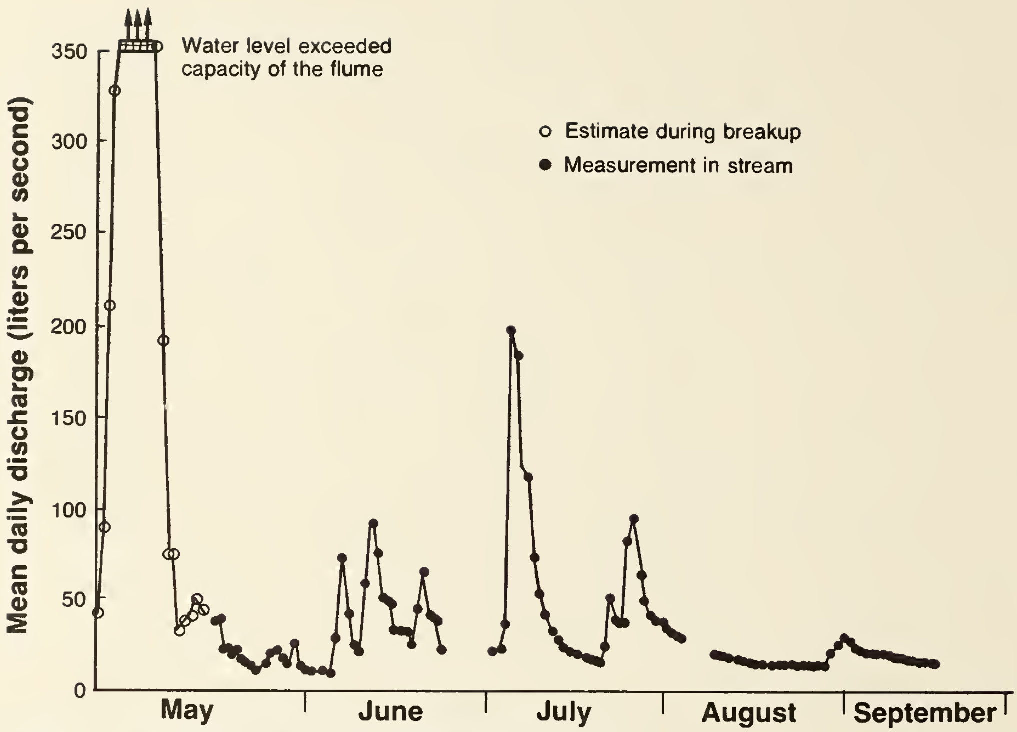

Figure 3—Mean daily discharge at C3 from measurements taken in the stream and from estimates during breakup, 1979

Temperature

Water and air temperatures measured at sampling stations throughout the season are shown in figure 4. Median water temperatures were lowest in streams draining C2 and C3 (table 3 and fig. 5). Water temperature appears to increase with higher stream order and larger basin area. Median water temperatures were greater in the downstream reaches of Caribou Creek than in the first-order streams of C2 and C3. In the first-order stream at C4-bridge,[3] however, they appeared to be the same as in the second-order streams of CB and CM. The C4 basin has about twice the area as C2 and C3, and, although smaller than the CB or CM basin, has a lower percentage of its area (18 percent) underlain by permafrost. The stream reach is also longer (5.0 km in C4 as opposed to 2.2 km for C2 and 2.6 km for C3) and drains in a generally southeast direction (Lotspeich and Slaughter 1981). Poker Creek (third order) was warmer than Caribou Creek (second order), and the Chatanika River had the highest water temperature of the streams measured.

[3] The only sampling station within C4 during the 1979 monitoring period was located at the bridge over Little Poker Creek. Since that time additional stations have been established within C4. To help the reader compare data for C4 in this report with data for C4 in subsequent reports, locations of the C4 sampling stations will be identified.

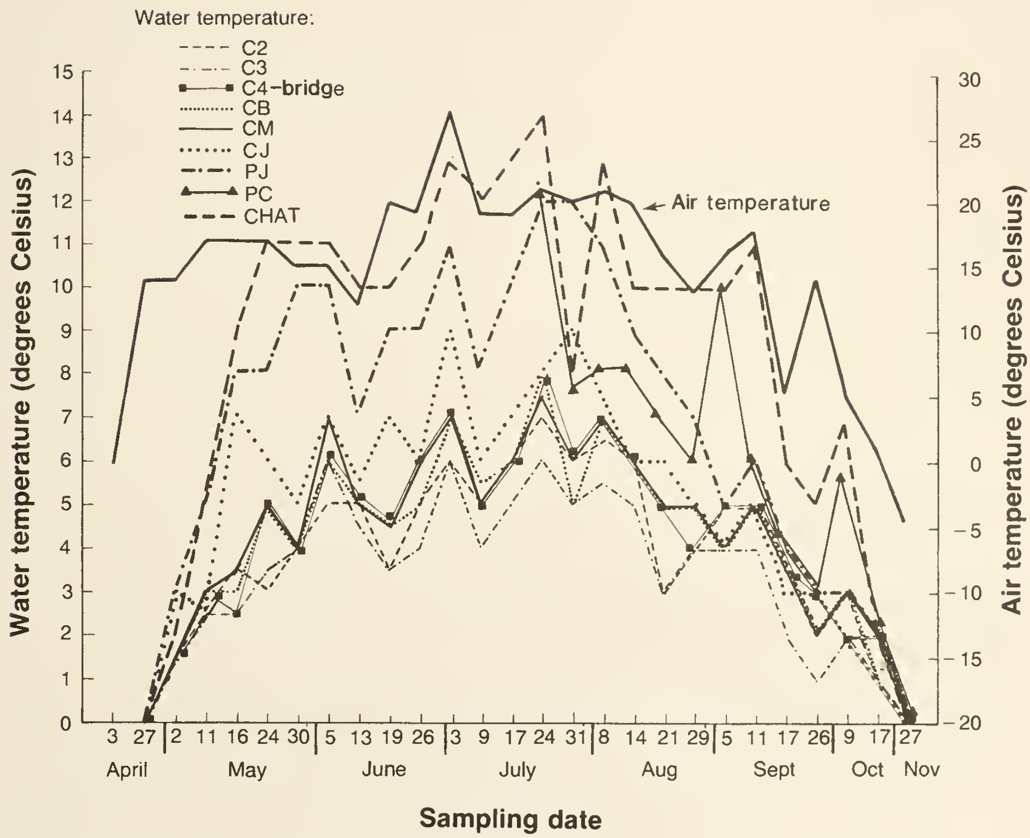

Figure 4—Median water temperature measured at sampling stations in Caribou-Poker Creeks research watershed and Chatanika River, and air temperature measured at the confluence of Caribou and Poker Creeks, 1979.

Table 3—Mean and median water temperature at sampling stations in Caribou-Poker Creeks research watershed and Chatanika River, 1979

Station	Number of observations	Mean	Median	Standard deviation
		- - - - - - Degrees Celsius - - - - - -		
C2	27	3.8	4.0	2.0
C3	26	3.4	4.0	1.8
C4-bridge	26	4.3	5.0	2.0
CB	27	4.1	5.0	2.2
CM	26	4.3	5.0	2.0
CJ	26	5.1	5.8	2.5
PJ	26	6.9	8.0	3.5
PC	13·	6.1	6.0	3.3
CHAT	27	8.3	10.0	4.3

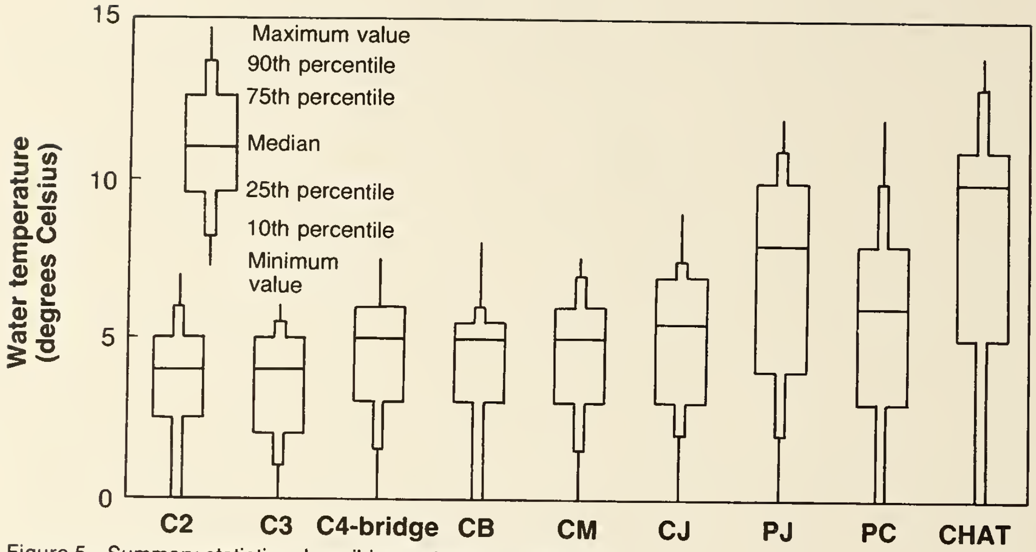

Figure 5—Summary statistics describing water temperature at sampling stations in Caribou-Poker Creeks research watershed and Chatanika River, 1979

Relationships of interest are basin area to water temperature, and basin area underlain by permafrost to water temperature. When median water temperatures were correlated with basin area (fig. 6), there was a significant positive correlation ($P < 0.05$, $r = 0.95$, $N = 7$) . This correlation is consistent with the "river continuum hypothesis" (Vannote and others 1980). The PC and CHAT sites were not included in this analysis. Measurements from PC represented only a portion of the season and were excluded. When the larger basin area of the Chatanika River was included, its warmer temperatures drove the correlation in a positive direction ($P < 0.05$, $r = 0.84$, $N = 8$), resulting in a curvilinear function instead of the linear function seemingly more typical of sites within the research watershed.

A greater proportion of area underlain by permafrost may coincide with lower water temperatures. The C2 and C3 basins have nearly equal drainage areas, yet C3 has a higher proportion of permafrost (53.2 percent) than C2 (3.5 percent). There was no apparent difference in the median water temperatures between the two sites (4.0 °C at both sites), but mean water temperatures during the ice-free season were lower in C3 than in C2. Median water temperature in Poker Creek (8.0 °C), however, appeared consistently higher than Caribou Creek (5.8 °C). The higher temperatures may reflect both the longer length of stream in Poker Creek (29.6 km) and its generally southerly-flowing direction as opposed to the shorter stream length (19.0 km) and easterly (more topographically shaded) flow of Caribou Creek (Bredthauer and Hoch 1979). Areas underlain by permafrost are nearly equal in Caribou Creek (28.0 percent) and Poker Creek (30.5 percent).

When water temperatures in low-order subarctic basins are modeled, components of the river continuum hypothesis are accounted for: stream length, width, direction of flow, and shading by riparian vegetation. Characteristics of permafrost should also be considered.

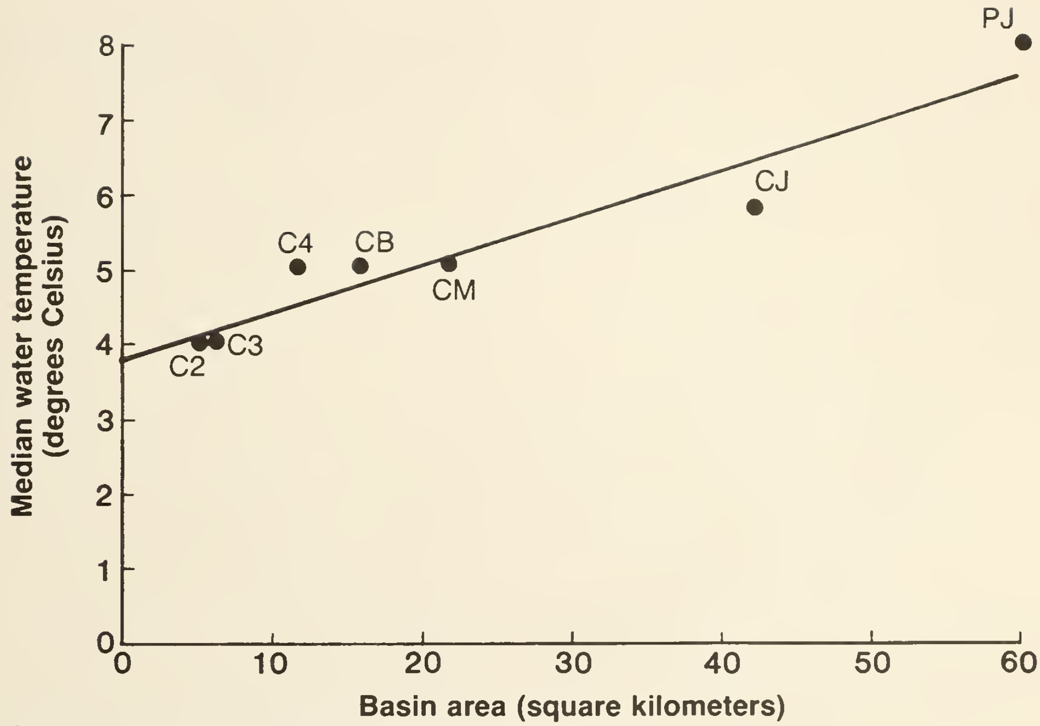

Figure 6—Correlation of median water temperatures for 1979 at some sampling stations in Caribou-Poker Creeks research watershed and basin area.

Turbidity

Mean and median turbidities for the 1979 sampling season presented in table 4 and summary statistics on turbidity are shown in figure 7. During spring breakup, melting and flushing do not occur simultaneously at all sites. The sites were in differing stages of breakup on April 27 and May 2: some locations were covered with thick ice and were not sampled, while other sites had substantial over-ice flow. The median rather than the mean is used as the comparative measure of central tendency. The median incorporates ice-free measurements but does not overemphasize the high breakup values from some sites. The mean values of some sites are much larger than the median, because of occasional high values during the breakup period, but are included for comparison. This procedure is followed for most water quality characteristics presented in this paper.

The Chatanika River had the highest median turbidity followed in descending order by the CJ, C3, C4-bridge, and PJ sites. Other sites had median turbidities near zero. First-order streams C3 and C4 appeared to have nearly equal median turbidities, whereas C2 had the same median turbidity (near zero) as second-order sites CB and CM. The PC site (below the confluence of Poker and Caribou Creeks) also had median turbidity of near zero; however, samples were collected only in the late summer and fall.

Because of the relatively higher proportion of basin underlain by permafrost in C3 than in C2, we assumed turbidity would be greater in C3 as a result of high humic staining from flows through the extensive moss cover (Hilgert 1979). Mean and median turbidities from C3 were indeed much higher in C3 than in C2, confirming observations from the 1978 sampling season.

Table 4—Mean and median turbidity at sampling stations in Caribou-Poker Creeks research watershed and Chatanika River, 1979

Station	Number of observations	Mean	Median	Standard deviation
		- - - Formazin turbidity units - - -		
C2	27	5.4	<0.1	11.7
C3	26	13.5	5.0	17.6
C4-bridge	26	4.4	5.0	2.0
CB	27	6.8	<.1	13.4
CM	25	7.9	<.1	14.7
CJ	26	10.5	8.0	12.5
PJ	26	9.3	3.0	13.8
PC	14	3.1	<.1	5.6
CHAT	27	18.4	18.0	21.9

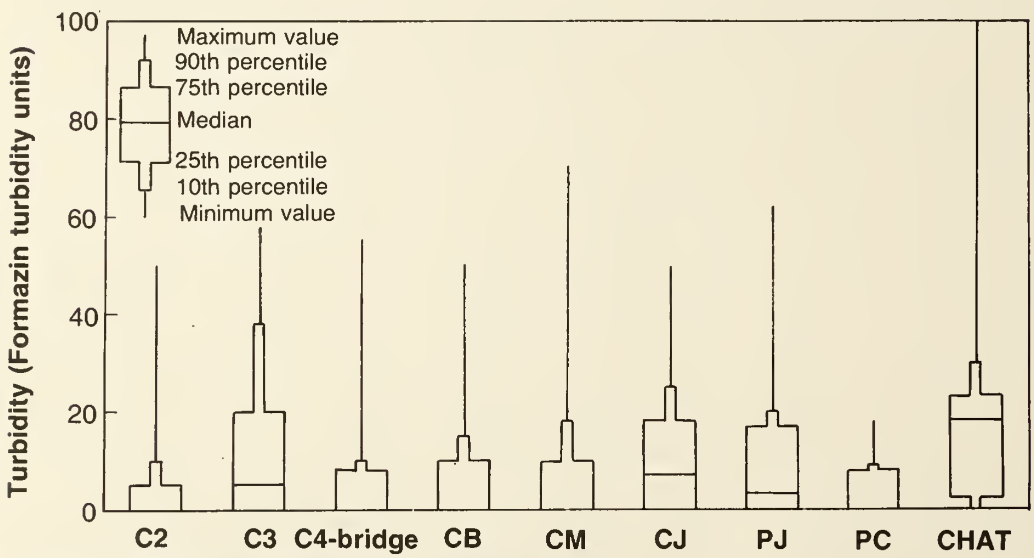

Figure 7—Summary statistics describing turbidity at sampling stations in Caribou-Poker Creeks research watershed and Chatanika River, 1979.

There is an apparent significant positive correlation ($P < 0.05$, $r = 0.85$, $N = 9$) of median turbidity to basin area. The Chatanika River, however, is impacted 50 km upstream of the research watershed by placer mining activities and cannot be considered an undisturbed system. The high turbidity values from CHAT and the large basin area tend to drive the correlation in a positive direction. When CHAT and partial-season data from PC are excluded from the analysis, the correlation coefficient becomes nonsignificant ($P > 0.05$, $r = -0.29$, $N = 7$).

When percent basin area underlain by permafrost is compared to median turbidity, a nonsignificant correlation coefficient ($P > 0.05$, $r = 0.42$, $N = 9$) results. When CHAT is excluded from the analysis, the correlation coefficient remains nonsignificant ($P > 0.05$, $r = 0.32$, $N = 8$). Comparison of first-order streams C2 and C3 draining basins of nearly equal size shows that the C3 site has consistently higher turbidity than C2, suggesting that turbidity in smaller streams may be related to proportion of permafrost and associated moss cover rather than to basin area. If substantiated by data from other subarctic watersheds, this concept could be valuable in comparing and predicting turbidities of similar-sized streams for impacts of pipeline, road, and trail construction.

Figure 8 shows turbidities by stream order. Turbidity was highest during spring breakup but also increased during storm events on June 13, July 9, and July 24. Turbidities were low in late August and September in the undisturbed (CJ and PJ) creeks. Fluctuations in turbidity of the Chatanika River reflect intermittent placer mining activity upstream. Water quality trends can be evaluated by comparing “background” turbidities of undisturbed Caribou and Poker Creeks to nearby streams.

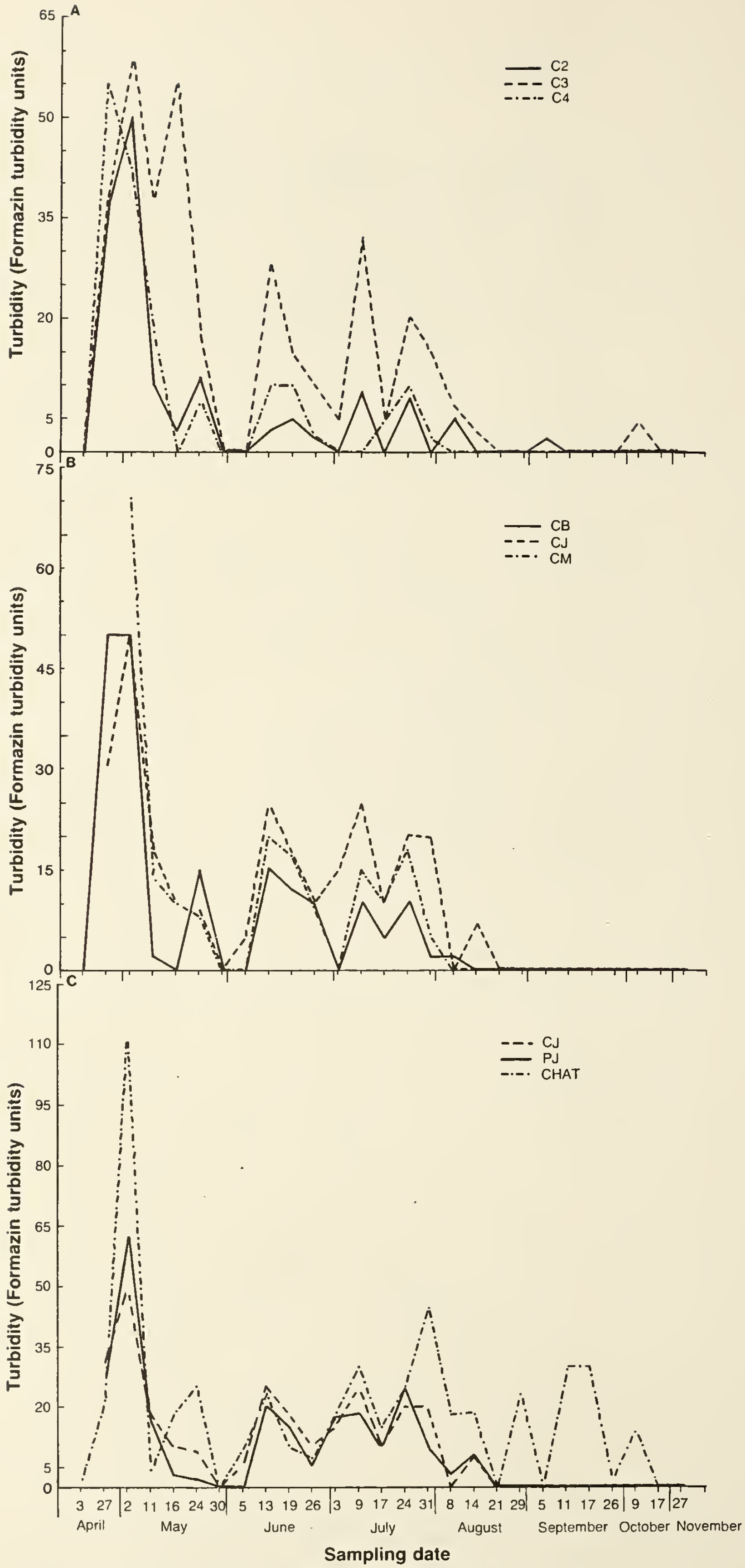

Figure 8—Turbidity, 1979: **A,** Of first-order streams; **B,** second-order streams; **C,** second-order (CJ), third-order (PJ), and fourth-order (CHAT), streams.

Nonfilterable Residue

Median concentrations of nonfilterable residue for the 1979 sampling season including residues collected from C2 and C3 by automated sampling[4] are presented in table 5. Among the first-order streams (C2, C3, and C4), C3 appeared to have the lowest median concentration (0.80 mg/liter). Concentrations of residue tended to increase slightly in a downstream direction toward CJ (1.20 mg/liter) and PJ (2.00 mg/liter), with the Chatanika River having the highest median value of 3.80 (fig. 9).

Because of the higher turbidities found in C3, we assumed C3 would have correspondingly higher concentrations of nonfilterable residue than C2. That was not the case, however: median concentration from C2 was only slightly higher than from C3. Because Caribou Creek had a higher mean turbidity than Poker Creek, we assumed CJ would have higher concentrations of nonfilterable residue. The CJ site, however, had lower concentrations than did PJ.

Subarctic systems having substantial variation in the occurrence of permafrost may lack an evident causal relationship of turbidity to concentration of nonfilterable residue during periods without storms. The dark-stained leachates from the thick moss layers on north-facing permafrost slopes may mask a direct turbidity-to-sediment relationship under the comparatively storm-free and low-discharge conditions sampled during 1979. Future monitoring may include more storm events, which would allow interbasin comparisons of water quality characteristics during periods of high discharge.

Table 5—Mean and median concentration of nonfilterable residue at sampling stations in Caribou-Poker Creeks research watershed and Chatanika River, 1979

Station	Number of obervations	Mean	Median	Standard deviation
		- - - -Milligrams per liter- - - -		
C2	189	1.71	1.00	2.30
C3	105	1.28	0.80	1.57
C4-bridge	26	2.01	1.60	1.97
CB	26	6.15	1.00	14.18
CM	24	1.25	1.10	1.11
CJ	26	1.90	1.20	2.58
PJ	26	3.25	2.00	4.17
PC	11	.67	0	1.01
CHAT	27	10.03	3.80	24.56

[4] Automated sampling is explained in the following section.

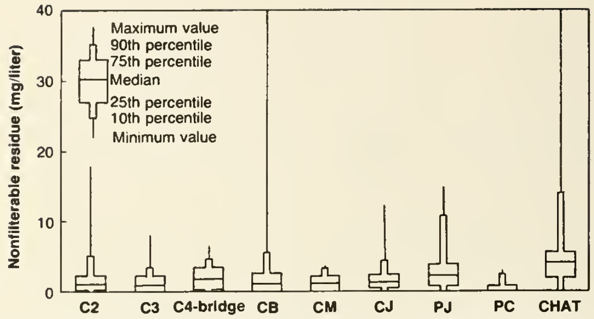

Figure 9—Summary statistics describing nonfilterable residue at sampling stations in Caribou-Poker Creeks research watershed and Chatanika River, 1979.

Concentrations of nonfilterable residue for first- and second-order streams are shown in figure 10 A and 10 B. Concentrations were highest during spring breakup. Concentrations in CB reached maximum on April 27, then appeared to respond in a manner similar to CM and CJ for the remainder of the 1979 season (fig. 10 B).

Concentrations of nonfilterable residue at higher order sites PJ, PC, and CJ are shown in figure 10 C. Concentrations during breakup peaked sooner in Poker Creek (May 2) than in Caribou Creek (May 11); however, the peak values appear similar. The earlier peak may be related to greater basin area and higher discharge in Poker Creek. Concentrations of residue in Poker Creek peaked again on July 9, September 17, and October 17 and were higher than in Caribou Creek. Concentrations appeared to be consistently higher in Poker Creek than in Caribou Creek from June 19 through July 24.

The Chatanika River site is not included on these figures. It tended to have much higher concentrations of residue than sites within the research watershed. The greater concentrations of nonfilterable residue taken in the fall at CHAT may have resulted from increased placer mining activity upstream combined with low streamflow.

These and previous data (Hilgert and Slaughter 1983) indicate that periods of highest sediment transport within the watershed occur during breakup and storm events. Future efforts to monitor concentrations of sediment should include these high-flow events.

Automated Sampling of Nonfilterable Residue

Automated sampling of nonfilterable residue from C2 and C3 began in summer 1979 to evaluate a wastewater sampler[5/] for use in subarctic conditions. The advantage of an automated sampler is its battery-power capability, allowing continuous functioning in remote subarctic regions where electric line power is unavailable. Concentrations of nonfilterable residue were obtained from collections in up to 28 prewashed 500-ml bottles in the sampler. Samples can be composited up to 4 per bottle, or 4 bottles per sample. During periods of spring breakup, the devices were set to collect a single 500-ml water sample at 12-hour intervals. Later in the season, 2 samples taken 12 hours apart were composited into a "daily" sample.

[5/] Model 1680 manufactured by Instrument Specialties Co. (ISCO), Lincoln Nebraska.

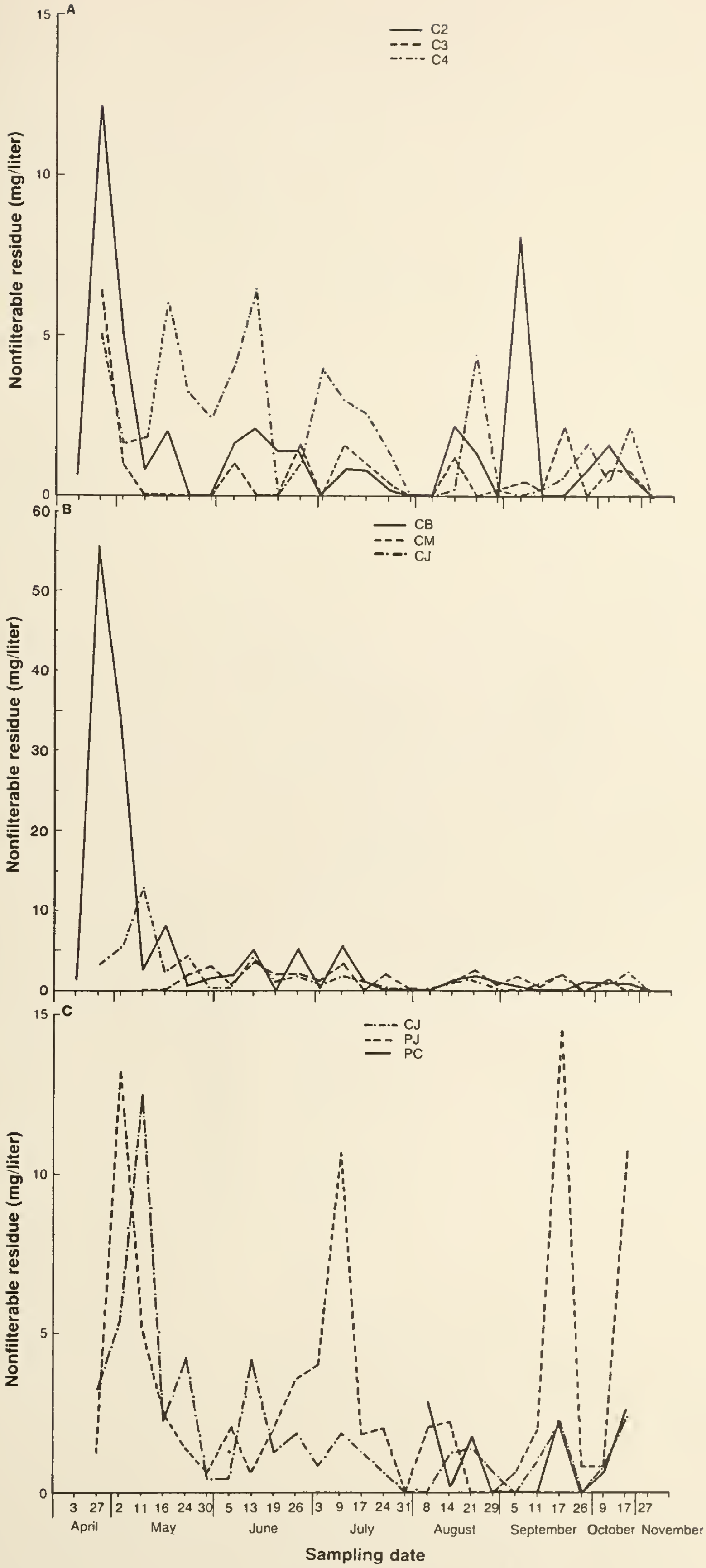

Figure 10—Concentration of nonfilterable residue, 1979: **A,** In first-order streams; **B,** second-order streams; **C,** second-order (CJ) and third-order (PJ and PC) streams.

Concentrations of nonfilterable residue taken from C2 by automated sampling are compared in figure 11 to those taken by grab sampling; a comparison for C3 is shown in figure 12. Generally, the residue level was low (< 10 mg/l) except for a few samples collected at breakup and during minor storms. Relationship of sediment to discharge for C3 is also shown in figure 12; the absence of high-discharge storm events throughout the season, however, precluded development of such relationships at high flows.

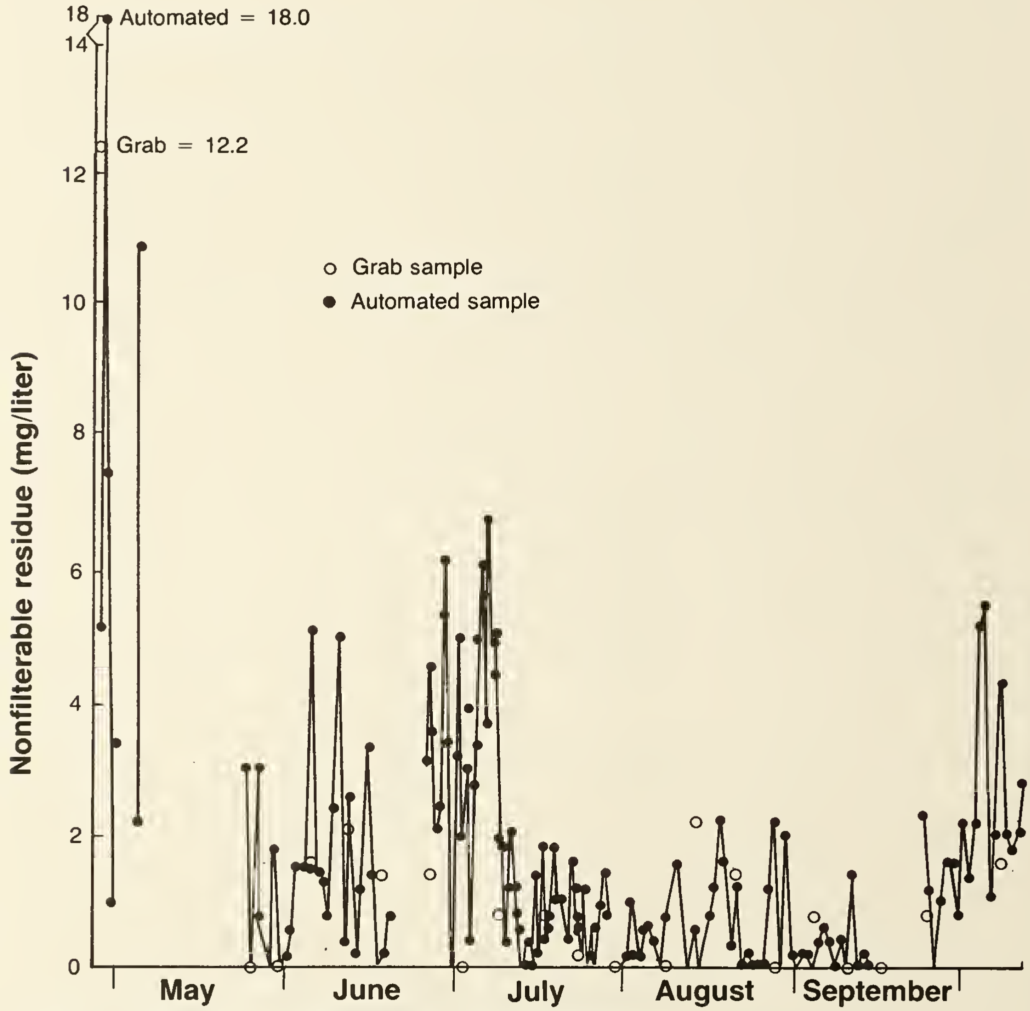

Figure 11—Concentration of nonfilterable residue from automated and grab sampling in C2, 1979. Values for grab samples duplicate those shown for C2 in figure 10A; they are repeated here for comparison with values from automated sampling.

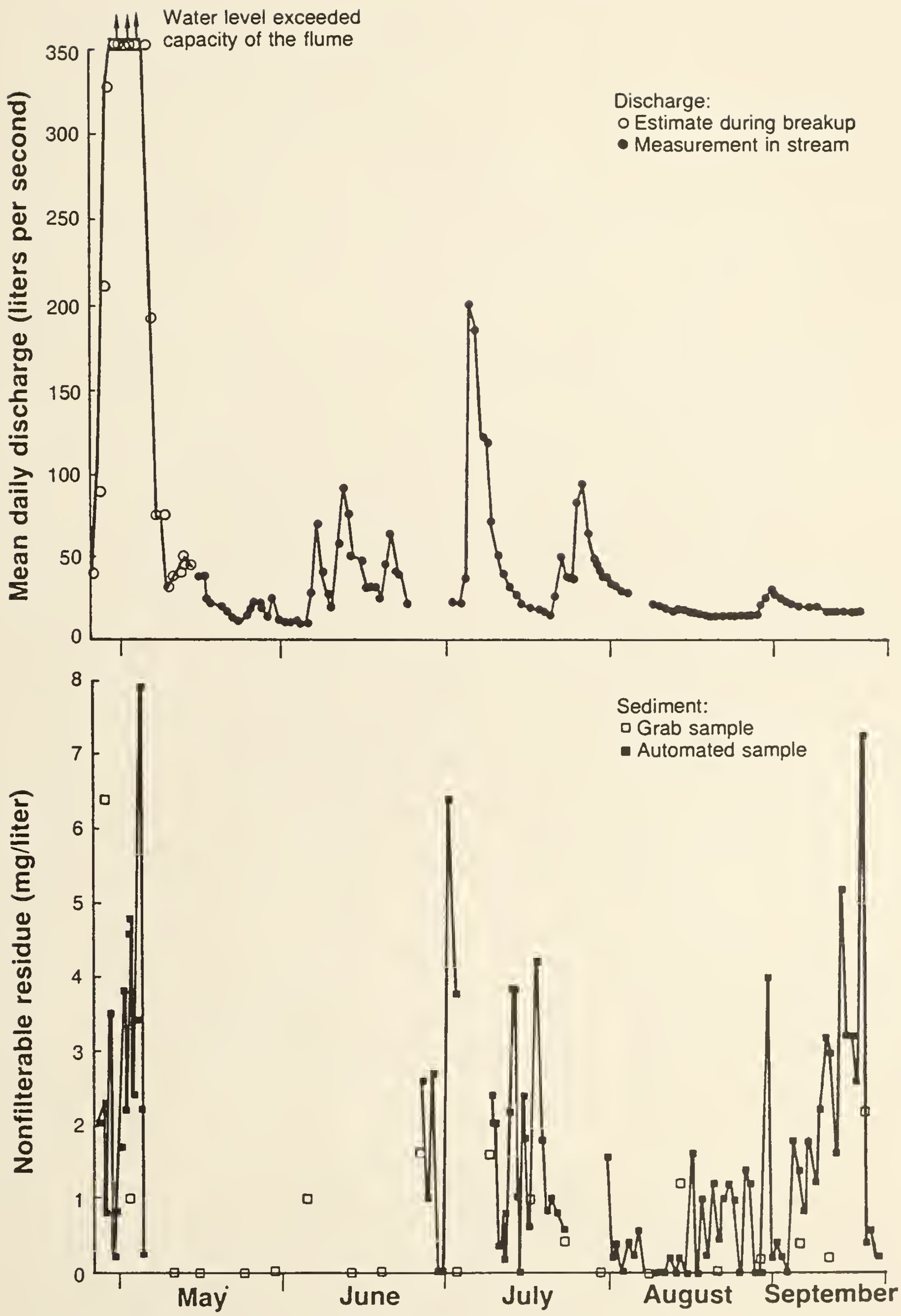

Figure 12—Concentration of nonfilterable residue from automated and grab sampling in C3, and relationship of discharge to sediment, 1979.

Automated sampling at C3 continued for 9 days during spring breakup, until a mechanical malfunction necessitated repair of the device. Samples were taken at 1 a.m. and 1 p.m. each day. Concentrations of nonfilterable residue appeared generally higher at the afternoon sampling times than at early morning (fig. 13). Time lapse photography taken at the flume (Slaughter and Hilgert 1979, Slaughter 1982) revealed that flow increased during the afternoon and decreased at night. Peak flows could not be determined because light levels in late afternoon were too low for photography. It appears that higher flows were accompanied by greater concentrations of residue. After April 29, discharge exceeded the capacity of the flume. A comparison of grab samples to automated samples taken throughout breakup would have been useful for evaluating techniques. Unfortunately, concurrent samples were not collected so that the devices could continue on the preprogrammed sampling schedule. In the future, automated samples will be taken at the same time as grab samples.

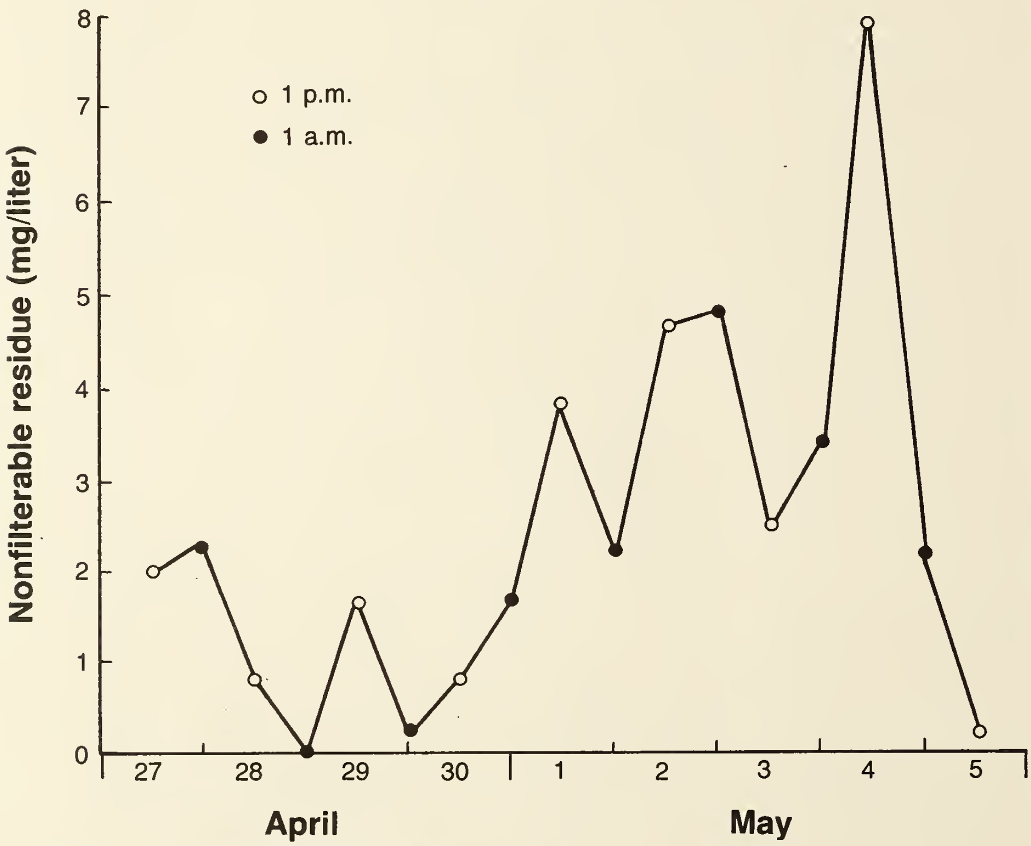

Figure 13—Concentration of nonfilterable residue taken by automated sampling in C3 during spring breakup, 1979.

A daily yield of residue at gaged stations at C3 can be estimated with the product of mean daily discharge and mean concentrations of nonfilterable residue, collected with automated samplers. This highest yield of residue occurred on July 10 and 11, following peak discharge on July 6. Unfortunately, the automated sampler failed during part of the storms on July 6 and on July 26; mean daily yield of nonfilterable residue for those days was 2.2 kg. Estimates of peak daily yields for storm events sampled throughout the season are given in table 6. To our knowledge, this is the first attempt to quantify residue on a continuous basis in subarctic headwaters.

Future efforts in the research watershed will be aimed toward achieving greater resolution of the relationships between discharge and residue concentration, particularly on the rising portion of the hydrograph, and expanding the coverage of baseline data to additional sites in the stream continuum. The use of a network of automated samplers coupled with continuous discharge measurement using flumes and water level recorders has the potential for obtaining accurate sediment loadings during breakup and high-discharge storm events.

Table 6—Estimated peak daily yield of nonfilterable residue collected with automated samplers at C3 during storm events

(In kilograms per day)

Date (1979)	Yield
7-11	13.7
7-18	7.2
8-1	5.2
8-31	8.9
9-14	7.5

Specific Conductance

Specific conductance appears to increase with stream order and basin size (fig. 14). Among the first-order streams, C4 had the highest median conductance (88 µmhos/cm) (table 7). Specific conductance of first-order streams declined during breakup (May 2) but then increased gradually until freeze-over (fig. 15 A). The C4 site had consistently greater specific conductance than C2, whereas lowest values occurred in C3.

In higher order streams, conductance was relatively low during breakup and gradually increased throughout the summer into winter (fig. 15 B and 15 C). Specific conductance increased from CB to CM to CJ and was highest in PJ and CHAT. Second-order (CB, CM, and CJ) and third-order (PJ) streams exhibited an apparent increase in specific conductance with increasing distance downstream.

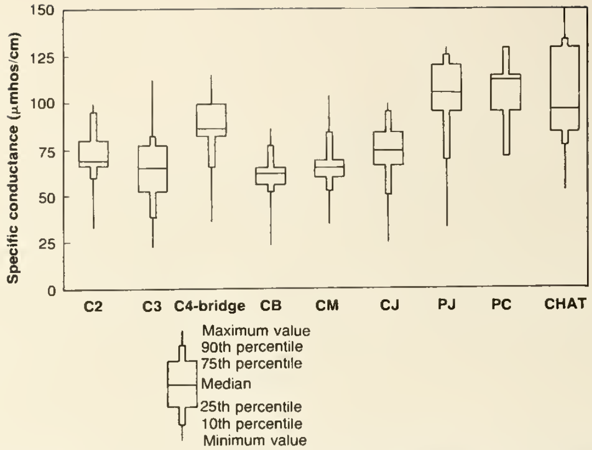

Figure 14—Summary statistics describing specific conductance at sampling stations in Caribou-Poker Creeks research watershed and Chatanika River, 1979.

Table 7—Mean and median specific conductance at sampling stations in Caribou-Poker Creeks research watershed and Chatanika River, 1979

Station	Number of observations	Mean	Median	Standard deviation
		µmhos/cm		
C2	27	73.3	69.0	14.3
C3	26	65.1	66.0	19.0
C4-bridge	26	86.7	88.0	16.6
CB	27	62.0	62.0	12.2
CM	25	65.8	65.0	13.6
CJ	26	74.3	75.5	17.1
PJ	26	104.2	108.5	21.8
PC	13	107.8	112.0	15.5
CHAT	26	103.8	97.5	25.1

Increasing discharge was apparently accompanied by a reduction in specific conductance. The C3 stream had a significant negative correlation ($P < 0.05$, $r = -0.59$, $N = 23$) of specific conductance to discharge; CM had a slightly less significant negative correlation ($P < 0.05$, $r = -0.45$, $N = 23$), and C2 had a nonsignificant negative correlation ($P > 0.05$, $r = -0.26$, $N = 23$). This apparent inverse relationship of specific conductance to discharge is consistent with dilution as discharge increases.

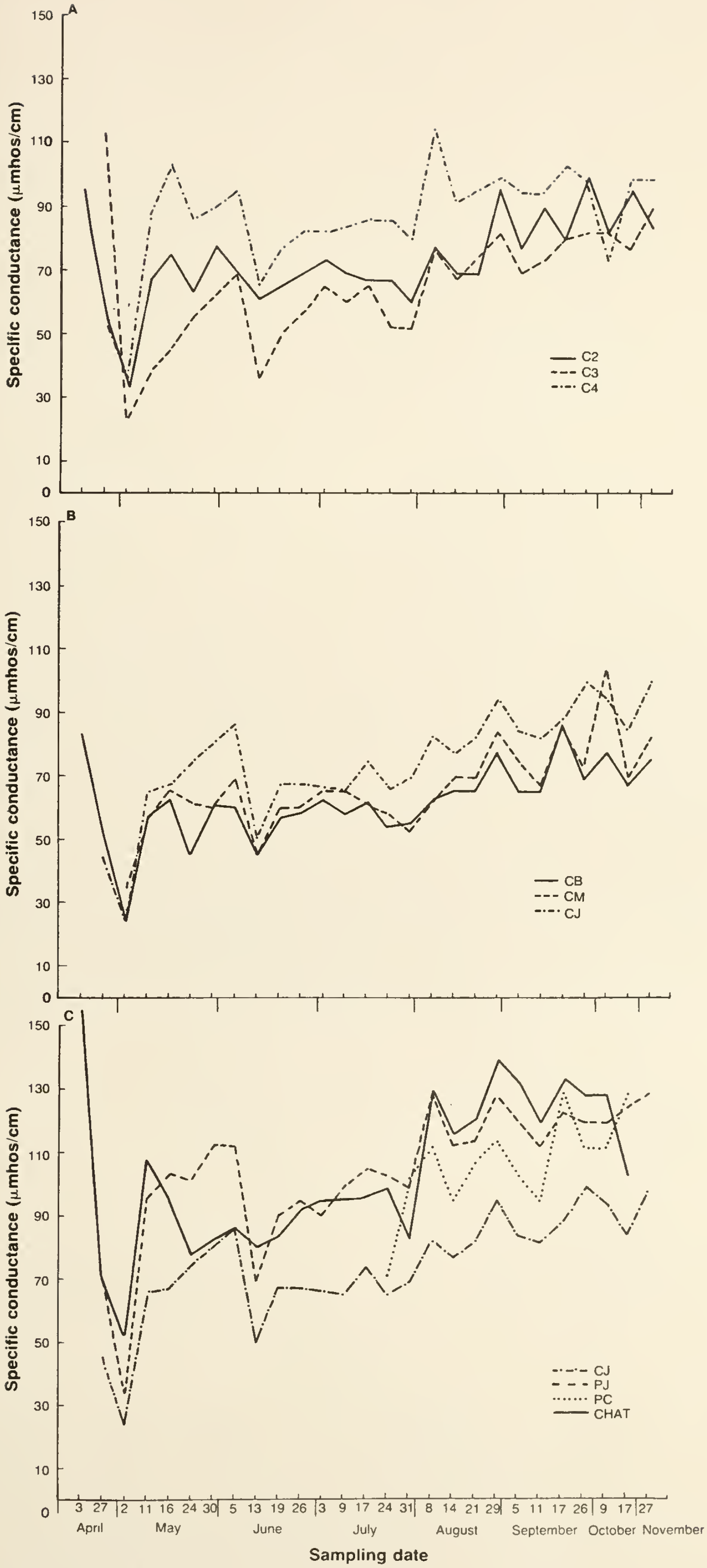

Figure 15—Specific conductance, 1979: **A,** Of first-order streams; **B,** second-order streams; **C,** second-order (CJ), third-order (PJ and PC), and fourth-order (CHAT) streams.

Figure 16 shows the specific conductance at several sites on a day with low discharge, September 11. The only sample taken from a thawing pingo (an ice-cored mound) in the north-facing area of Caribou Creek, near the CM station, had a specific conductance of 387 µmhos/cm, a much higher value than at any other station within the watershed. Although the discharge contribution to Caribou Creek is small, the pingo runoff and several associated seeps from the surrounding slope may slightly increase stream conductivity.

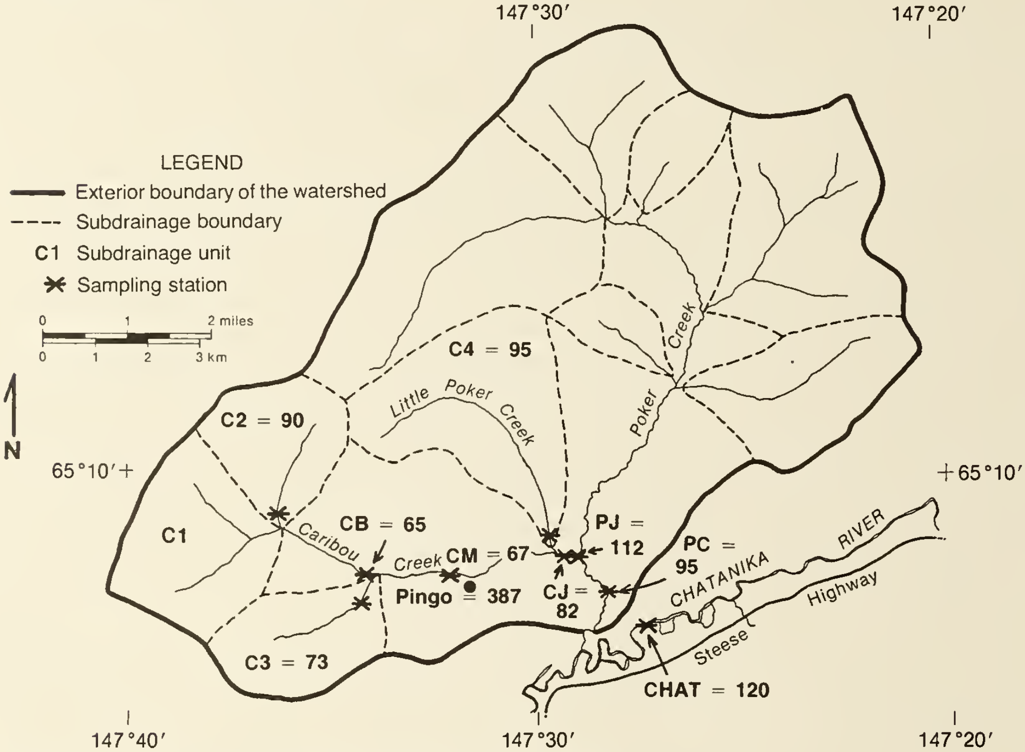

Figure 16—Specific conductance at selected sites on September 11, 1979.

Water Chemistry

pH and alkalinity. — The pH and alkalinity for CM is shown in fig. 17. Median pH at all sites was similar, ranging from 7.3 to 7.6 (table 8, fig. 18). The similarity was expected because of relatively homogeneous parent material and lack of any terrestrial disturbance that could alter pH. The C3 stream, however, was expected to have a slightly lower pH than C2 because its basin has a greater *Sphagnum*-dominated moss cover, which can increase soil and runoff acidity. A difference in pH between C2 and C3, however, was not apparent from these data.

Median bicarbonate alkalinity was highest in PJ, PC, and C4, and was lowest in C3. In the three stations having concurrent measurements of discharge and alkalinity, significant negative correlations ($P < 0.05$, $N = 23$) were observed: $r = -0.473$ for C2, -0.732 for C3 and -0.624 for CM. The inverse relationship of alkalinity to discharge is consistent with a dilution effect with increasing discharge.

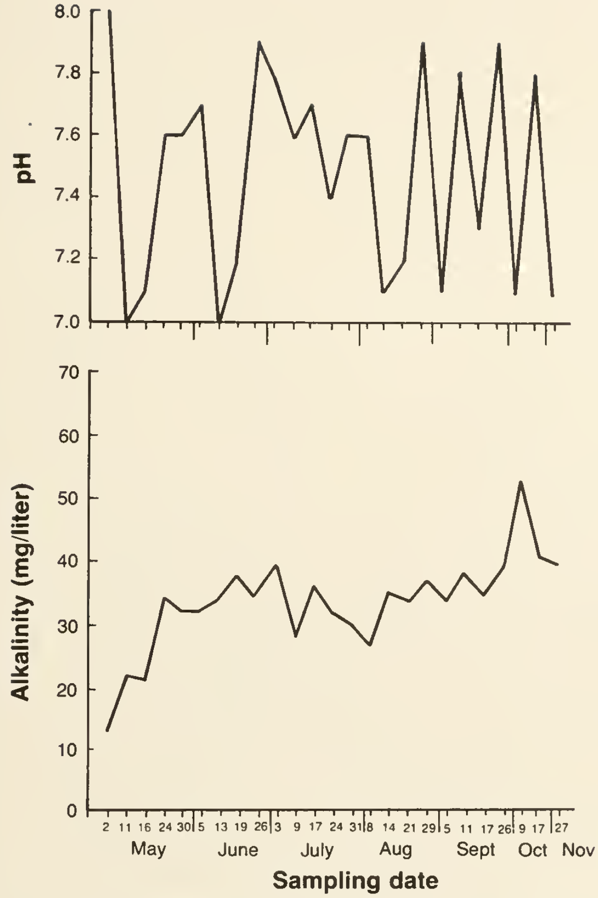

Figure 17—Measurements of pH and alkalinity at CM, 1979.

Table 8—Mean and median pH and alkalinity at sampling stations in Caribou-Poker Creeks research watershed and Chatanika River, 1979

		pH			Alkalinity		
Station	Number of observations	Mean	Median	Standard deviation	Mean	Median	Standard deviation
					- - - - -mg/liter - - - -		
C2	27	7.5	7.6	0.4	30.9	34.0	7.7
C3	26	7.4	7.3	.4	28.2	31.0	8.4
C4-bridge	26	7.4	7.5	.3	43.8	47.0	9.7
CB	27	7.4	7.3	.4	31.9	34.0	7.7
CM	26	7.4	7.3	.4	33.0	34.0	8.0
CJ	26	7.4	7.3	.4	39.4	42.0	10.2
PJ	26	7.4	7.4	.3	51.6	54.0	12.2
PC	13	7.5	7.4	.2	52.7	52.0	4.3
CHAT	26	7.4	7.4	.4	43.4	47.0	11.8

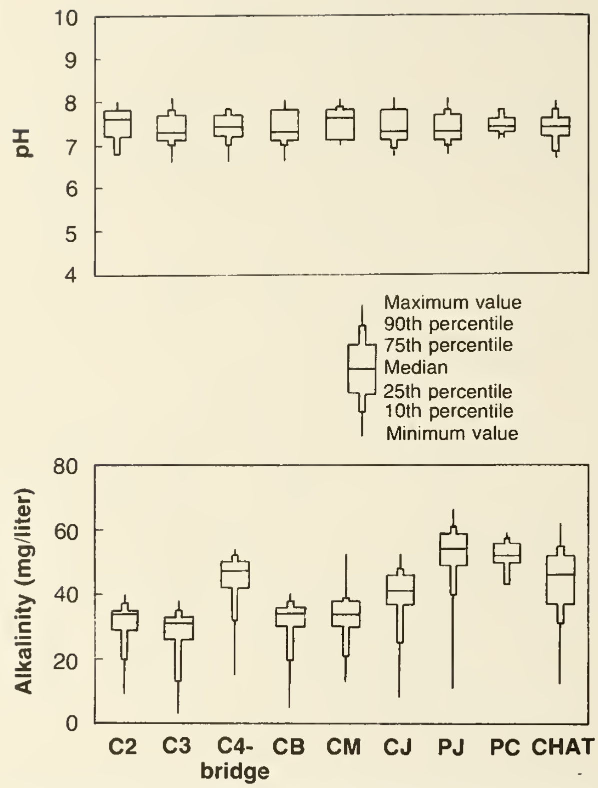

Figure 18—Summary statistics describing pH and alkalinity at sampling stations in Caribou-Poker Creeks research watershed and Chatanika River, 1979.

Nitrogen and phosphorus.—Median concentrations of dissolved Kjeldahl nitrogen, NH_3-N, NO_3-N, and phosphorus compounds are summarized in table 9 and figure 19.

Table 9—Median concentrations of dissolved Kjeldahl nitrogen and phosphorus compounds at sampling stations in Caribou-Poker Creeks research watershed and Chatanika River, 1979[1/]

Station and sample size	Kjeldahl-N		NH_3-N		NO_3-N		Total P		Available P	
C2, N=27	1.650	(0.306)	0.156	(0.086)	0.929	(0.543)	0.068	(0.174)	0.011	(0.176)
C3, N=26	1.715	(.310)	.146	(.063)	.744	(.439)	.067	(0.167)	.008	(.167)
C4-bridge, N=25	1.640	(.316)	.120	(.068)	.882	(.484)	.068	(0.120)	.000	(.125)
CB, N=27	1.590	(.319)	.085	(.072)	.738	(.416)	.062	(0.152)	.017	(.153)
CM, N=25	1.660	(.289)	.128	(.064)	.620	(.444)	.066	(0.123)	.000	(.126)
CJ, N=26	1.630	(.248)	.104	(.072)	.650	(.410)	.071	(0.142)	.013	(.147)
PJ, N=26	1.600	(.301)	.095	(.077)	.831	(.401)	.064	(0.149)	.004	(.149)
PC, N=13	1.720	(.349)	.189	(.074)	1.130	(.441)	.062	(0.010)	.000	(.015)
CHAT, N=26	1.625	(.309)	.111	(.069)	.607	(.447)	.068	(0.134)	.017	(.132)

1/ Standard deviations are shown in parentheses.

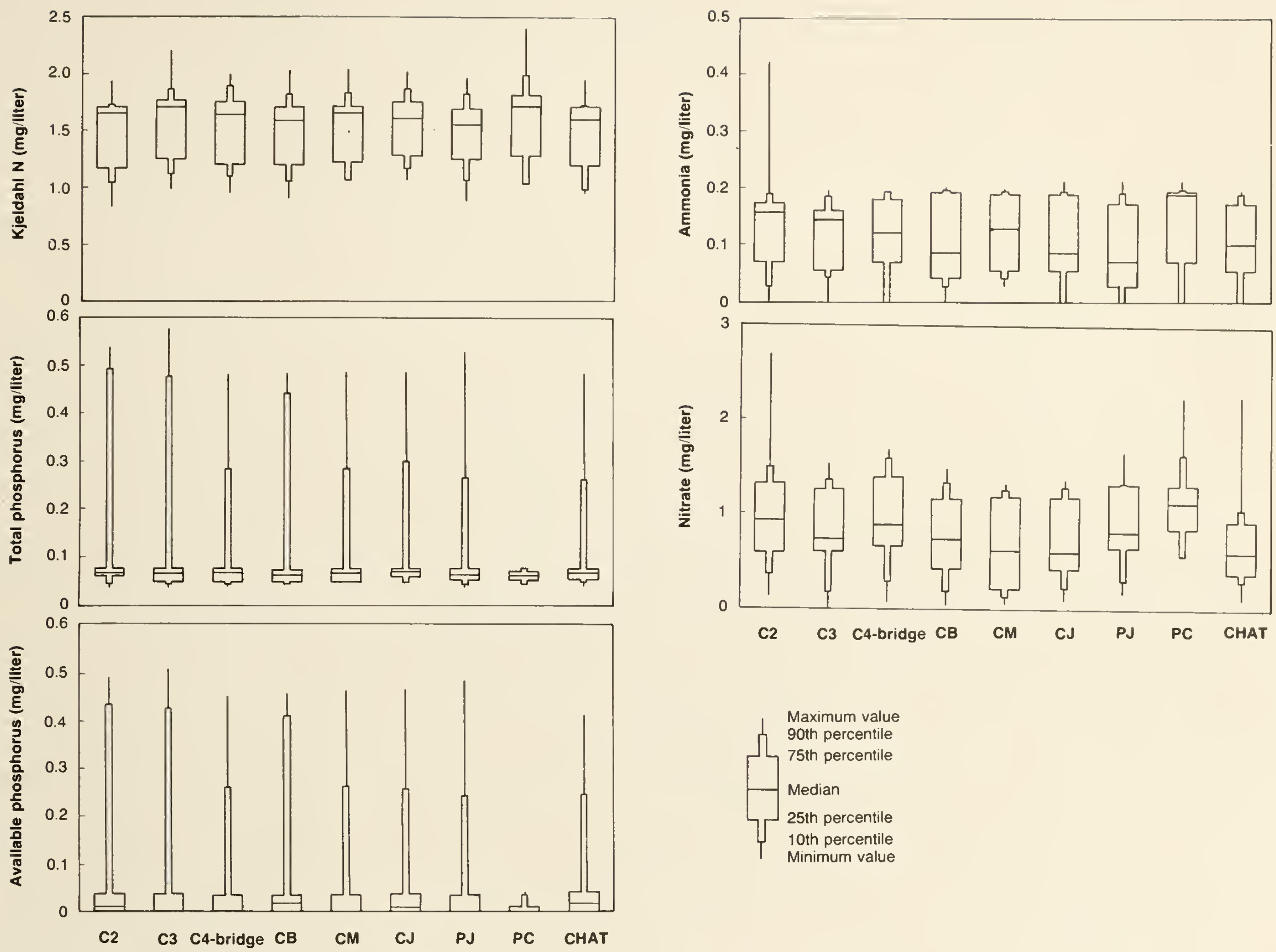

Figure 19—Summary statistics describing dissolved nitrogen and phosphorus compounds at sampling stations in Caribou-Poker Creeks research watershed and Chatanika River, 1979.

The CM site is used in this report as a representative sampling point within the research watershed from which to examine the seasonality of chemical constituents. A historical data base of its chemical constituents and the continuous discharge record make CM a useful site for monitoring hydrochemical changes over the ice-free season. Median concentrations of Kjeldahl nitrogen in 1979 were highest during breakup (fig. 20). From a low of about 1 mg/liter in the spring, concentrations increased slightly, to 1.6 mg/liter, until just prior to freeze-up. A seasonal change is more pronounced in concentrations of NO_3-N and NH_3-N.

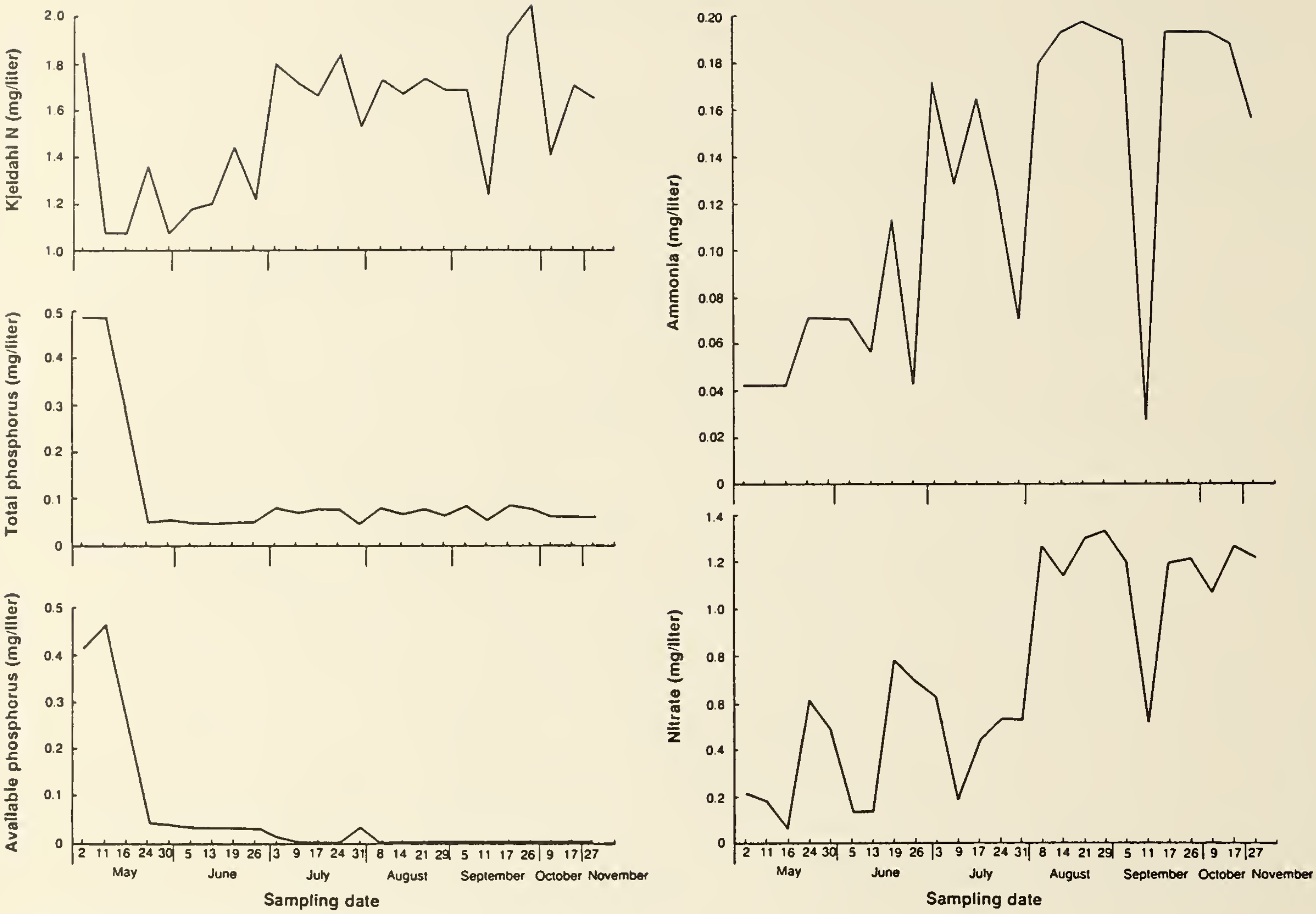

Figure 20—Concentrations of dissolved nitrogen and phosphorus compounds at CM, 1979.

Median concentrations of dissolved total phosphorus and Kjeldahl nitrogen appear similar at all sites sampled. There are slight variations in levels of nitrate, ammonia, and available phosphorus. Interpretation of these data is aided by ranking the sites from highest to lowest median concentration (table 10). Because sampling at PC did not begin until late summer, we did not include PC in the ranking. Its much lower number of observations and seasonal bias would be misleading in comparisons for the entire season. First-order sites C2, C3, and C4-bridge generally had higher concentrations of nitrogen compounds than did higher order sites. There was no apparent relationship of phosphorus to stream order. Ranking of sites by type of compound (table 11) suggest that dissolved phosphorus compounds are present in very low concentrations throughout the watershed. Dissolved nitrogen compounds are also present in relatively low concentrations and exhibit a very weak but apparent relationship of decreasing levels with increased distance downstream.

Table 10—Ranking of sampling stations in Caribou-Poker Creeks research watershed and Chatanika River by median concentration of dissolved nitrogen and phosphorus compounds, 1979[1]

Station	Kjeldahl-N	NH_3-N	NO_3-N	Total P	Available P
C2	3	1	1	3	4
C3	1	2	4	5	5
C4-bridge	4	4	2	4	7
CB	8	8	5	8	1
CM	2	3	7	6	8
CJ	5	6	6	1	3
PJ	7	7	3	7	6
CHAT	6	5	8	2	2

1/ 1 = highest concentration, 8 = lowest.

Table 11—Ranking of sampling stations in Caribou-Poker Creeks research watershed and Chatanika River by median concentration of dissolved nitrogen compounds, dissolved phosphorus compounds, and dissolved nitrogen and phosphorus compounds combined, 1979[1]

Station	All nitrogen and phosphorus compounds	All nitrogen compounds	All phosphorus compounds
C2	1	1	1
C3	2	2	5
C4-bridge	3.5	3	6
CB	7.5	8	4
CM	6	4	8
CJ	3.5	5.5	1.5
PJ	7.5	5.5	7
CHAT	5	7	1.5

1/ 1=highest concentration, 8=lowest.

Growths of periphyton (attached algae) in the streams tend to be higher in sites further downstream in the research watershed (Hilgert 1984), especially in August and September. Uptake and incorporation of nitrogen and phosphorus compounds into the algal population, often described as a component process of "nutrient spiraling," can result in a decrease in dissolved nutrient levels along a river continuum. This relationship appears weak, however, at the sites sampled in the Caribou-Poker Creeks continuum.

Nitrogen-to-phosphorus ratios calculated from the 1978 field season (Hilgert and Slaughter 1983) were found to be overwhelmingly nitrogen dominated (phosphorus-limited). Values from the 1979 season also show consistent N-to-P ratios of approximately 25 to 1, verifying the observation from 1978 data that the Caribou-Poker Creeks river continuum is phosphorus-limited with respect to algal and aquatic plant production.

Dissolved ionic constituents.—Median concentrations of dissolved ionic consistuents are given in table 12 and sites are ranked by concentration in table 13; summary statistics are shown in figure 21. An increase of median ionic concentrations apparently occurs from low-order to high-order streams, especially for dissolved calcium, magnesium, sodium, and manganese. The rank of C4, however, appears more representative of higher order sites. This position has been consistent with most of its other water quality characteristics, suggesting that C4 may represent a higher position in a hypothetical river continuum than just its basin area or relative discharge would suggest. Concentrations of silica, arsenic, and chloride appeared similar at all sites in the watershed, whereas iron levels tended to increase with stream order. When the ranks of all ionic constituents are totaled by site, sites can be ordered from highest to lowest concentrations: PJ > CHAT > CJ > C4-bridge > CB > C2 > CM > C3.

Table 12—Median concentration of dissolved ionic constituents at sampling stations in Caribou-Poker Creeks research watershed and Chatanika River, 1979[1]

Station	Ca	Mg	Na	Si	Fe	K	Mn	As	Cl
	mg/liter							µg/liter	mg/liter
C2, N=27	17.30 (2.59)	2.80 (0.64)	1.38 (0.25)	11.70 (3.78)	0.037 (0.040)	0.50 (0.15)	1.00 (0.84)	2.00 (1.16)	0.88 (0.42)
C3, N=26	18.95 (5.19)	1.50 (.60)	1.57 (.34)	10.65 (2.62)	.074 (.102)	.49 (0.24)	1.00 (7.84)	1.50 (1.72)	.72 (.43)
C4-bridge, N=25	28.50 (5.60)	2.70 (.49)	1.75 (.39)	11.70 (1.46)	.049 (.048)	.76 (0.12)	2.00 (1.12)	1.00 (1.26)	.81 (.33)
CB, N=27	17.00 (2.78)	2.10 (.44)	1.44 (.27)	12.15 (2.37)	.073 (.055)	.51 (0.14)	6.00 (4.45)	2.00 (1.63)	.75 (.90)
CM, N=25	18.40 (3.70)	2.00 (.44)	1.57 (.35)	12.70 (2.63)	.089 (.052)	.51 (0.15)	5.00 (1.98)	1.00 (1.51)	.70 (.36)
CJ, N=26	22.25 (5.45)	2.35 (.59)	1.62 (.35)	10.80 (1.88)	.121 (.062)	.64 (0.17)	6.00 (2.05)	2.00 (2.24)	.88 (.51)
PJ, N=26	31.15 (6.88)	3.60 (.81)	1.72 (.38)	11.45 (1.85)	.102 (.068)	.76 (0.15)	11.00 (6.08)	2.00 (2.19)	.86 (.43)
PC, N=13	28.90 (2.18)	3.50 (.27)	2.05 (.30)	12.30 (1.35)	.100 (.054)	.77 (0.41)	8.00 (1.66)	2.00 (1.03)	.75 (.30)
CHAT, N=26	28.65 (6.66)	4.35 (1.40)	1.69 (.36)	9.95 (2.41)	.241 (.135)	.75 (0.25)	9.00 (6.29)	1.50 (1.65)	1.05 (.51)

1/ Standard deviations are shown in parentheses.

Table 13—Ranking of sampling stations in Caribou-Poker Creeks research watershed and Chatanika River by median concentration of dissolved ionic constituents, 1979[1]

Station	Ca	Mg	Na	Si	Fe	K	Mn	As	Cl	Total
C2	7	3	8	3.5	8	7	7.5	2.5	2.5	49
C3	5	8	5.5	7	5	8	7.5	5.5	7	58.5
C4-bridge	2	4	1	3.5	7	1.5	6	7.5	5	37.5
CB	8	6	7	2	6	5.5	3.5	2.5	6	46.5
CM	6	7	5.5	1	4	5.5	5	7.5	8	49.5
CJ	4	5	4	6	2	4	3.5	2.5	2.5	33.5
PJ	1	2	2	5	3	1.5	1	2.5	4	22
CHAT	3	1	3	8	1	3	2	5.5	1	27.5

1/ 1 = highest concentration, 8 = lowest.

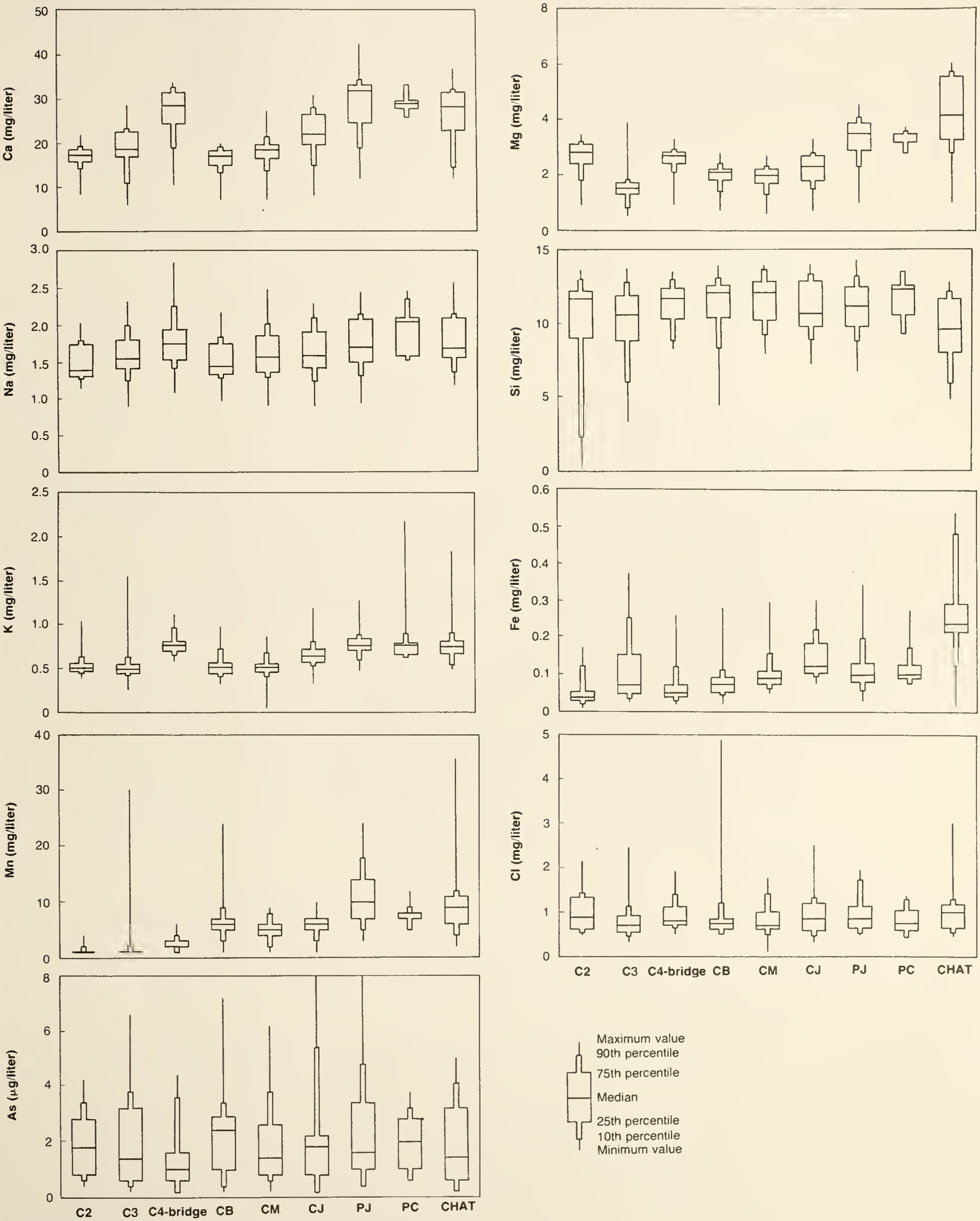

Figure 21—Summary statistics describing dissolved ionic constituents at sampling stations in Caribou-Poker Creeks research watershed and Chatanika River, 1979.

Concentrations of dissolved calcium, magnesium, sodium, and silica tended to increase from summer to freeze-up at CM (fig. 22). Potassium, manganese, chloride, and arsenic showed no apparent seasonal trends, whereas iron tended to decrease from summer to fall. Comparing rankings from these baseline data to rankings after treatment will aid in the assessment of water quality changes resulting from landscape manipulation. Logging or prescribed fire could change the rank relative to the pretreatment period. Comparing rankings of undisturbed basins to treated basins for the same year will also aid interpretation. Water quality characteristics most sensitive to landscape manipulation should exhibit the greatest change in ranking. Data from several years will be required to fully assess annual differences in relationships.

Conclusions

Physical and chemical water quality characteristics in samples collected in 1979 exhibited tendencies that appear consistent with those in a hypothetical river continuum. There appears to be a relationship of many water quality characteristics to basin size (or stream order), season, and the occurrence of underlying permafrost. When paired watersheds in this region of discontinuous permafrost are compared, the basins can yield drastically different results, evident in basins C2 and C3. Hydrologic response was much more pronounced in the permafrost-dominated C3 stream, as hypothesized in a previous study (Hilgert and Slaughter 1983). The difference in response of precipitation to discharge can impact the monitoring and interpretation of water quality characteristics related to discharge.

Annual discharge was estimated from gaged stream C3: approximately 43 percent occurred during the spring breakup, 7 percent during winter, and 50 percent during the ice-free season June through October.

Water temperature generally increased with basin size, consistent with a hypothetical stream continuum . Mean water temperature was slightly lower during the ice-free season in the C3 stream than in C2, possibly indicating a slight effect of permafrost dominance in the C3 basin.

Turbidity tended to increase with basin size; however, the C3 site had a much higher median turbidity than did C2. Highest turbidities occurred during breakup and storm flows, corresponding to increased concentrations of nonfilterable residue. Concentrations of residue increased slightly with basin area and were highest in the Chatanika River, just outside the research watershed; the river is impacted by placer mining activities upstream from the sampling site. Data indicate that concentrations of nonfilterable residue within the research watershed are typically very low, except during breakup and storm events.

Specific conductance tended to increase with basin area and stream order, having low values during breakup and high discharge periods and gradually increasing through the summer. Runoff from a pingo within the watershed had higher specific conductance than did other sites but did not appear to have a substantial effect on specific conductance in Caribou Creek, into which it drains.

Among sites, pH appeared to be fairly consistent; however, alkalinity increased with stream order. Higher discharges were accompanied by lower alkalinity. Highest concentrations of nitrogen compounds tended to occur during the breakup period, were lowest in the summer, and increased slightly as the streams froze in the fall. Concentrations of total dissolved nitrogen and phosphorus did not appear related to stream order, and N-to-P ratios were generally 25 to 1, designated as phosphorus-limited with respect to aquatic plant growth.

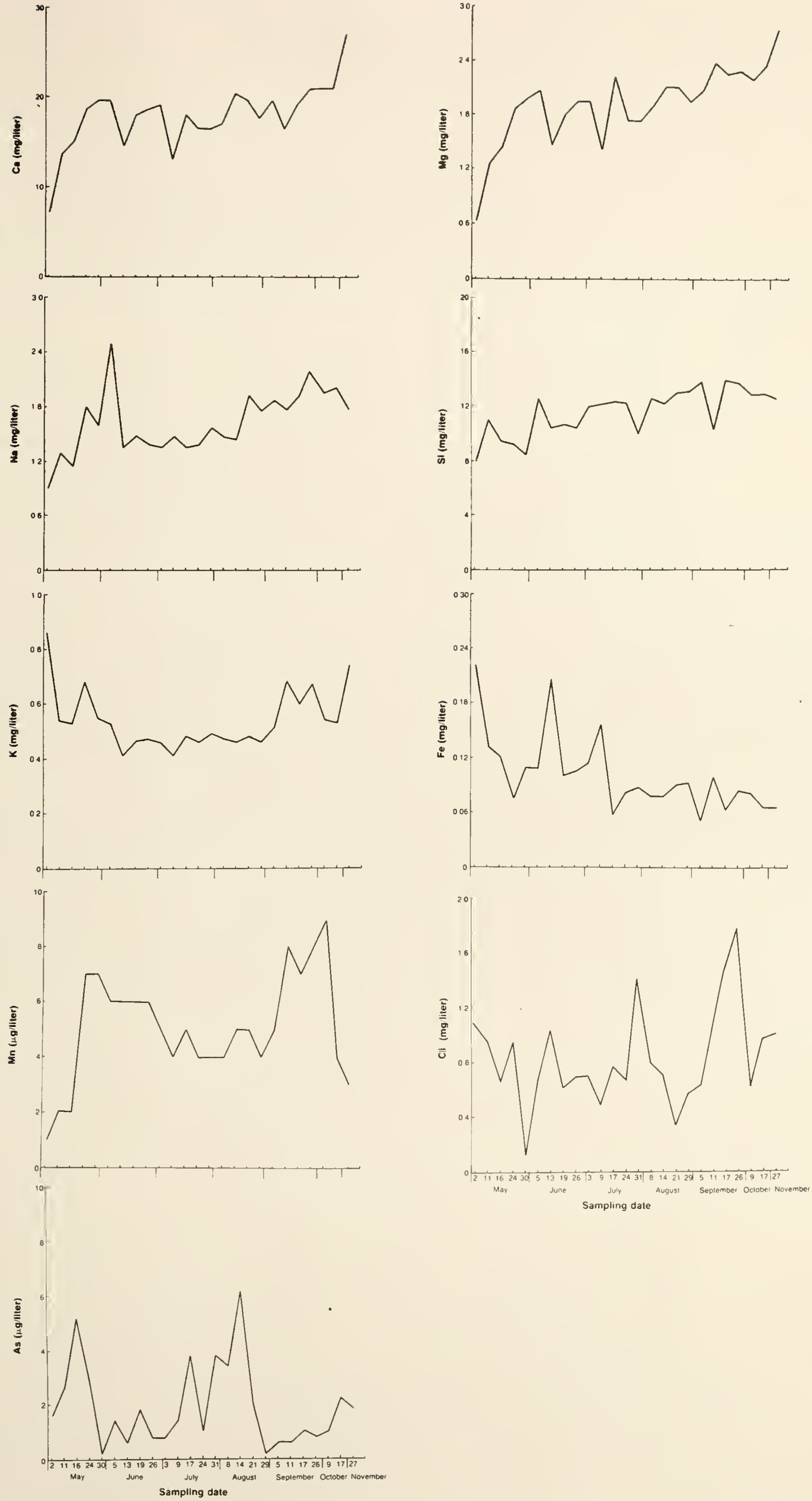

Figure 22—Median concentration of dissolved ionic constituents at CM, 1979.

There was an apparent increase in concentrations of dissolved calcium, magnesium, sodium, manganese, and iron with increasing stream order. Concentrations of dissolved calcium, magnesium, sodium, and silica tended to increase from summer months to freeze-up. A series of rankings of elements by site was developed for 1979.

Continuing efforts to monitor water quality characteristics should intensify sampling of storm events and spring breakup to better estimate sediment and chemical loadings, and should utilize an array of sites within the river continuum. Comparing rankings of sites by water quality characteristics described in baseline data to rankings after treatment will be valuable in assessing effects of landscape manipulation in the subarctic. Basins treated by logging or prescribed burning will likely change ranking because those treatments will change certain water quality characteristics. Several years of comprehensive data will be required to assess differences between years, differences that can result from annual variation in magnitude and timing of precipitation and in general climate.

Comparison of undisturbed sites within the Caribou-Poker Creeks research watershed to the Chatanika River and streams impacted by placer mining, road building, and timber harvesting will help resource managers assess and understand impacts of increased turbidity and concentration of sediment in the region. Thus, immediate benefits can be realized by continuing and expanding water quality monitoring, and long-term benefits will derive from studying effects of experimental landscape manipulations in the subarctic region.

Acknowledgments

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English Conversions

Multiply	By	To obtain
kilometer (km)	0.621	mile
centimeter (cm)	.394	inch
meter (m)	3.281	foot
square kilometer (km^2)	.386	square mile
cubic meter (m^3)	35.320	cubic foot
kilogram (kg)	2.205	pound
milliliter (ml)	.338	fluid ounce
liter	.264	gallon
liter per second	.353	cubic feet per second
°C	$(\frac{9}{5}\,°C) + 32$	°F

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Research Note PNW-RN-464

Variation in Damage from Growing-Season Frosts Among Open-Pollinated Families of Red Alder

Kevin C. Peeler and Dean S. DeBell

Abstract

Repeated growing-season frosts during late April and early May 1985 caused extensive damage to red alder (*Alnus rubra* Bong.) seedlings in a newly planted research trial in western Washington. About two-thirds of the seedlings were severely damaged (entire stem damaged or necrotic). Such damage varied by family, from 50 percent of seedlings in the least affected family to nearly 90 percent of seedlings in the most sensitive family. Seedlings planted in plots fertilized with triple superphosphate suffered greater damage than those in unfertilized plots.

Introduction

Red alder (*Alnus rubra* Bong.) exhibits rapid juvenile growth, fixes atmospheric nitrogen in its root nodules, and occurs naturally over a wide range of soil and site conditions. Such traits make it well-suited for use in intensive cultural systems designed to produce energy and/or fiber in short (10- to 15-year) rotations. In recent years, many research and pilot plantations of red alder have been established successfully throughout western Oregon and Washington.

In spring 1985, we established a field experiment to test effects of several cultural practices on productivity of red alder plantations. The experimental plots were planted with container-grown seedlings from 18 open-pollinated families. Buds began to swell in mid-March and most trees leafed out during the next 2 weeks. Several frosts occurred during late April and early May, causing extensive damage to the newly planted alder. By late May, at least 50 percent of the alder seedlings had been severely damaged. Although the damage necessitated replanting the experiment in spring 1986, the loss did provide an opportunity to observe variation in frost damage to newly planted red alder seedlings. This note discusses the temperature patterns that led to the severe frost damage in spring 1985 and examines the variation in damage among red alder families included in our study.

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Study Area and Methods

The site is located 12 km east of Olympia, Washington, on land managed by the Washington State Department of Natural Resources (DNR) as a Douglas-fir seed orchard. Topography is level to very gently rolling, and the soil is a Nisqually sandy loam. The site was prepared by plowing and disking in early January 1985.

The study involved an examination of effects of family, spacing, irrigation, and phosphorus fertilizer on early growth of red alder. The experimental design was a split plot, with spacing, irrigation, and fertilizer treatments applied to whole plots and families randomly assigned to subplots. The experiment was replicated in three blocks. Triple superphosphate was applied in late January at 300 kg P per ha to plots designated for fertilizer treatment.

The seedlings had been grown in Styro-8[1] containers, using a 50:50 mix of peat and vermiculite, at DNR's Mike Webster Nursery near Olympia. Seeds were sown in mid-May, and seedlings were grown to 10 cm height in greenhouses; in mid-June, they were moved outside to complete their growth and to harden off under partially shaded conditions. Seedlings from 18 open-pollinated families were removed from the Styro blocks and planted in late February 1985 when they were 20 to 30 cm tall. The family identity of each seedling was recorded on plot maps. Characteristics of the parental sites for the 18 families are given in table 1.

Frost damage data were collected in July 1985 on all plots that had been planted at 1- by 1-m spacing. Each plot contained a total of 324 trees (16-20 trees of each of the 18 alder families). Irrigation treatments had not been applied. Thus, two fertilized and two unfertilized plots were examined in each of three blocks. The assessment involved nearly 3,900 trees and included at least 200 observations for each family.

Each seedling was examined for frost damage and scored according to the following categories:

Severe—100 percent of stem damaged or necrotic (may or may not be resprouting from base).
Moderate to Heavy—50 to 99 percent of stem damaged or necrotic.
Light or None—0 to 49 percent of stem damaged or necrotic.

Data were compiled to provide the percentage of trees scored in each category in each family-fertilizer subplot. After transformation to arcsin values, the data were analyzed statistically as a randomized complete block design with fertilizer as the main plot treatment and family as the subplot treatment (table 2). Means were separated by Tukey's test using $P < 0.05$ as the level of significance.

Temperature data were obtained from the official weather station at the Olympia airport, located about 15 km southwest of the site. The data were examined for patterns that might explain the severe damage encountered in spring 1985 and summarized as the number of frosts and minimum temperature (below freezing) by 10-day periods from March 1 through May 31.

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

Table 1—Characteristics of parental sites for red alder families planted in the Department of Natural Resources seed orchard

Family		Elevation	Latitude	Approximate distance from saltwater	Temperature[1] Mean January minimum	Mean July maximum
No.	Name	m		km	-Degrees Celsius-	
1	Vancouver Island #1	50	50° 20' N	<5	2.2	17.6
2	Vancouver Island #2	50	50° 20' N	<5	2.2	17.6
3	Capital Forest #1	150	46° 50' N	10	-1.1	25.3
4	McCleary W-10	500	46° 50' N	15	-1.1	25.3
5	McCleary SP-28	100	47° 10' N	20	-0.4	24.6
6	McCleary SP-36	100	47° 10' N	20	-0.4	24.6
7	McCleary RC-42	250	46° 50' N	10	-0.2	25.3
8	McCleary Mc-62	75	47° 00' N	15	-0.4	24.6
9	McCleary Mc-71	75	47° 00' N	15	-0.4	24.6
10	Nisqually Delta 402	50	47° 00' N	<5	1.3	23.5
11	Nisqually Delta 404	50	47° 00' N	<5	1.3	23.5
12	Nisqually Delta 405	50	47° 00' N	<5	1.3	23.5
13	Nisqually Delta 407	50	47° 00' N	<5	1.3	23.5
14	Elbe 420	400	46° 40' N	30	0.9	25.6
15	Forks 9	50	47° 50' N	20	0.5	21.3
16	Forks 15	50	47° 50' N	20	0.5	21.3
17	Johns River J-1	150	46° 50' N	10	1 1	20.9
18	Johns River I-2	150	46° 50' N	10	1.1	20.9

1/ From nearest weather station listed in Climatological Handbook (Meteorology Committee, Pacific Northwest River Basins Commission 1969).

Table 2—Analysis of variance for categories of frost damage

Source of variation	Degree of freedom	Severe: Mean square	Severe: F	Moderate to heavy: Mean square	Moderate to heavy: F	Light or none: Mean square	Light or none: F
Blocks (B)	2	351	2.7	50	0.8	1115	1.4
Phosphorus (P)	1	2172	17.0*	1873	29.6**	128	0.2
BxP ($Error_a$)	2	128		63		807	
Families (Fa)	17	1012	11.0***	598	5.2**	592	6.9***
PxFa	17	134	1.5	142	1.2	75	0.9
BxPxFa + BxFa($Error_b$)	68	92		116		86	

* = P <0.10; ** = P <0.05; *** = P <0.01.

Results and Discussion

The frost damage in spring 1985 occurred in a spring that, at first glance, appeared mild and warm. This damage was the first reported to red alder plantations since 1969 (DeBell and Wilson 1978). Similar damage also occurred in other newly established red alder plantations in Oregon and Washington, and local farmers reported one of the worst years on record for frost damage to berry crops. Temperature patterns in spring 1985 differed from those of the past 20 years in several ways (table 3). No frosts occurred from March 29 until April 19, a period normally having frequent and hard frosts. The mild weather was followed by several frosts, including one of -3.3 °C on April 26. The last frost of -2.2 °C occurred on May 12, the coldest since 1966. Thus, it appears that the extensive frost damage to newly planted alder and other crops in spring 1985 can be attributed primarily to unusually mild temperatures in late March and early April followed by repeated and sustained freezing temperatures from late April to mid-May.

Table 3—Comparison of temperature patterns near study site for spring 1985 and 20-year average1/

Time period	Number of frosts during time period		Temperature of coldest frost	
	1985	20-year average	1985	20-year average
			°C	°C
March:				
1-10	9	5.4	-3.8	-2.8
11-20	6	4.3	-3.0	-2.3
21-31	4	4.1	-1.5	-2.4
April:				
1-10	0	3.8	2/ N.F.	-1.4
11-20	2	3.9	-0.8	-1.3
21-30	5	2.7	-1.0	-1.2
May:				
1-10	1	1.1	0.0	-0.8
11-20	1	.5	-2.2	-0.8
21-31	0	.4	N.F.	-0.6

1/ Data obtained from records kept at official weather station, Olympia, Washington, airport.

2/ No frost occurred during time period.

About two-thirds of the containerized seedlings planted at the study site showed evidence of frost damage to the entire stem, and some had begun to resprout from the base. Although few container-grown seedlings were undamaged, field-collected wildlings (1 to 2 years old) planted in a few border rows were not visibly damaged.

Frost damage varied significantly among families and, to a lesser degree, by fertilizer treatment (table 2). Family differences were significant in all three damage categories (severe, moderate to heavy, and light or none). Of the trees in 9 families, 75 percent or more experienced severe damage (fig. 1). On the other hand, 6 families had a sizable portion of trees (15 percent or more) with little or no damage (fig. 2). If the two figures are compared, certain families lie at opposite ends in both categories. Thus, we might regard families 8, 9, and 15 as particularly sensitive to growing-season frosts because they had not only high percentages of stems severely damaged but also very low percentages of stems with little or no damage. Conversely, families 1, 5, 6, 14, and 16 might be regarded as somewhat tolerant of growing-season frosts because they had low percentages of stems severely damaged and the greatest percentages of stems that escaped with little or no damage.

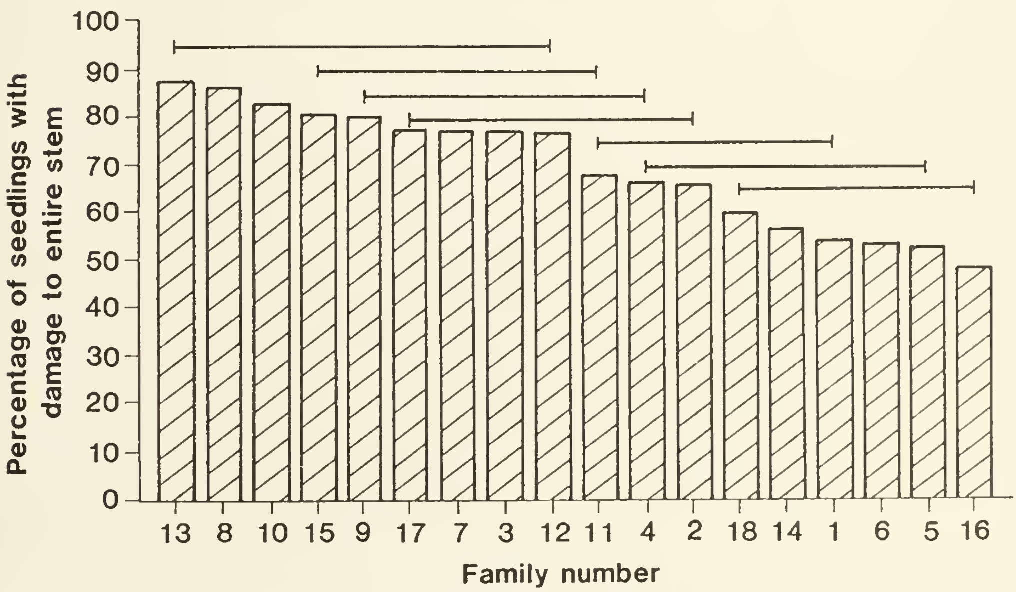

Figure 1.—Ranking of families according to percentage of seedlings with severe frost damage. Families joined by a common bar do not differ significantly at $P < 0.05$.

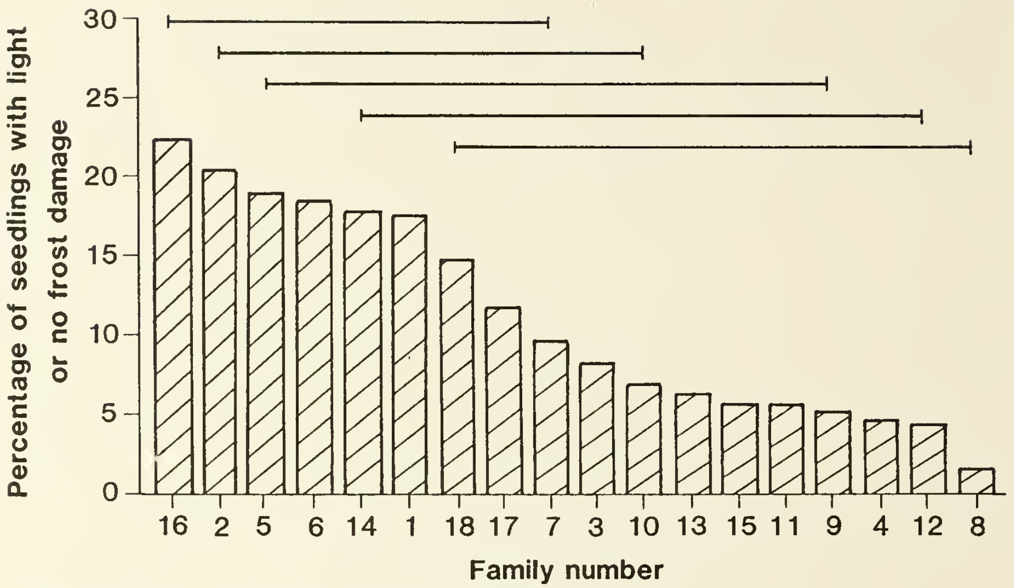

Figure 2.—Ranking of families according to percentage of seedlings with light or no frost damage. Families joined by a common bar do not differ significantly at $P < 0.05$.

Much of the variation in cold-hardiness or general frost tolerance of temperate zone species is related to geographic source (location and climatic characteristics of parent sites), primarily because of long-term natural selection associated with phenological differences (Wright 1976). Such relationships, however, were not apparent in our plantation. For example, families 15 and 16 originated from the same parent stand near Forks, Washington, and they varied greatly in frost damage. In contrast, families 5 and 6 suffered less damage than most other families and came from the same parent site, and families 8 and 9 were heavily damaged and came from another parent site. No climatic differences between these two sites that might explain such differences in frost damage are apparent, however.

The lack of an apparent relation between frost damage of various families and characteristics of parent sites may result simply from insensitivity of the design. Our study was not designed to test differences in population or parent sites; rather, we selected families for outplanting based on seed availability and presumed capacity for good growth at the study site. All families originated from a rather limited area—low elevation sites in western Washington and southern British Columbia. Moreover, methods of propagation may have such an important effect on frost damage or may interact to such degree with family differences that variation associated with parent sites is masked.

On the other hand, damage to unseasonable events (trees had been leaved out for at least 1 month) may not be as strongly related to characteristics of parent sites as is cold-hardiness in general. The fact that families from the same site appear in both sensitive and tolerant groups parallels earlier indications that some phenotypic and genetic traits of red alder may vary as much within a single stand as they do from site to site, at least within a limited area or breeding zone (DeBell and Wilson 1978; DeBell and others 1984; Hook and others, in press). Moreover, work in Scotland shows that red alder provenances from Washington, British Columbia, and Alaska dehardened rapidly in late March, and average date of bud burst of the southerly provenances was only 3 days later than that of Alaskan provenances (Cannell and others, in press).

Effects of phosphorus fertilizer varied with the degree (or category) of frost damage. Seedlings in fertilized plots suffered significantly more heavy frost damage (74 percent of seedlings with entire stem damaged or necrotic) than those in unfertilized plots (65 percent of seedlings). In contrast, the percentage of seedlings with moderate damage was significantly lower in fertilized plots (15 percent) than in unfertilized plots (21 percent); moreover, the percentage of seedlings with little or no damage did not differ significantly with fertilizer treatment.

The increased heavy frost damage to seedlings planted in fertilized plots is puzzling. No apparent differences were found between fertilizer treatments in the development of other vegetation. Excavation of a few seedlings revealed little egress from the root plugs to the surrounding soil. Presumably, differences between fertilizer treatments in P uptake and assimilation by the alder seedlings would still be rather minor at the time of the frosts. The small differences in frost damage are too consistent (fig. 3), however, to be dismissed. Perhaps minor differences in P status caused minute changes in rate of phenological development, which led to corresponding differences in suceptibility to frost damage.

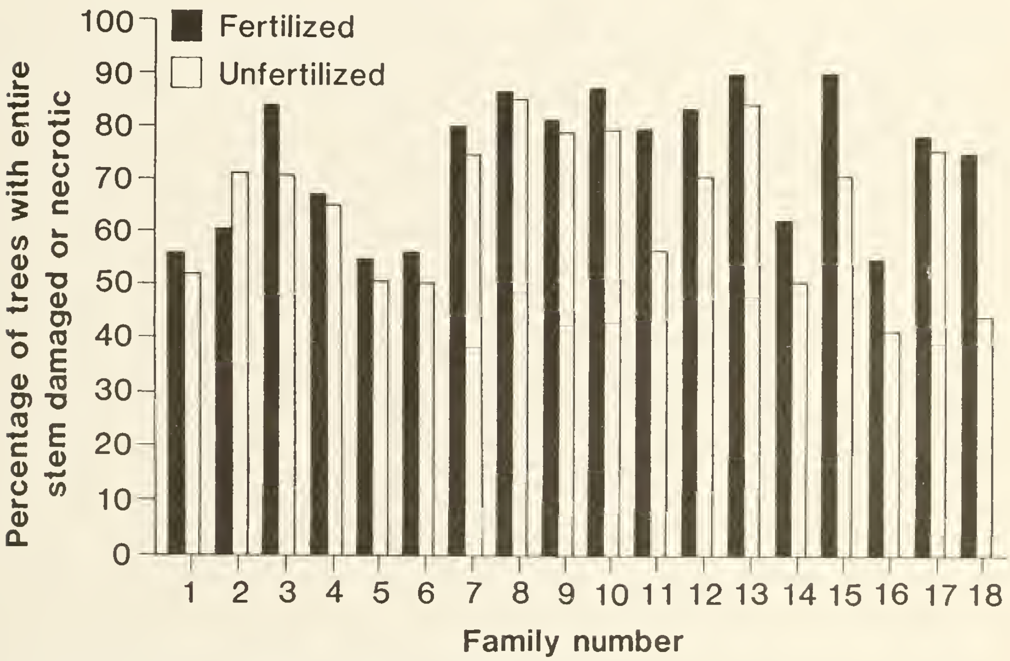

Figure 3.—Influence of fertilizer on heavy frost damage sustained by red alder families.

Differences in phenological development may also help explain the lack of damage in the wildlings planted in the border rows. Root systems of these trees were undoubtedly "shocked" by the transplanting operation, and phenological development (flushing) appeared to be somewhat delayed.

Although such problems have been negligible in recent (after 1970) alder plantings in Oregon and Washington, unseasonable frosts during the 1st year after planting caused considerable damage in two plantings of red alder in earlier years. Tarrant (1961) reported severe frost damage during the fall and spring after planting when alder stock from seed collected near Olympia, Washington (15 m above sea level), was planted in

1933 at 700 m elevation in the Wind River Experimental Forest near Carson, Washington. Moreover, one installation (Olympia, Washington) of a provenance trial established in 1969 was damaged so severely by early fall freezes in the 1st and 2d year after planting that further measurements at the site were abandoned (DeBell and Wilson 1978). Two of the provenances (Juneau, Alaska, and Sandpoint, Idaho) suffered much less damage than other sources from Oregon, Washington, and southern British Columbia, but they also grew much more slowly.

Older red alder stands may also be severely damaged and killed by unseasonable frosts (Duffield 1956), but such occurrences are uncommon. In general, older natural stands and plantations appear to be less susceptible and better able to recover than newly planted seedlings. None of our established alder plantations, aged 3 to 10 years, suffered any observable damage in spring 1985.

To minimize risks of damage from late spring frosts in the 1986 replanting of our study, we held seedlings in a cold room (2 °C) from late February until they were planted in early May. Survival at the end of the first growing season exceeded 98 percent.

Acknowledgments

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English Equivalents

1 kilogram (kg) = 2.2 pounds
1 meter (m) = 3.28 feet
1 kilometer (km) = 0.62 mile
1 hectare (ha) = 2.47 acres
Degrees Celsius (°C) = 5/9 (°F-32)

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Rooting Sitka Spruce From Southeast Alaska

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Abstract

Rooting and shoot growth characteristics of 10-, 15-, and 20-year-old Sitka spruce cuttings were studied. Twigs from three branch orders were tested with or without 5000 parts per million indole-3-butyric acid (IBA) hormone treatment. Rooting success averaged 64 percent. The effect of ortet age on rooting success was not significant. Cuttings from first-order branch positions rooted slightly better than cuttings from second- and third-order positions. Cuttings treated with the IBA hormone had slightly poorer root induction than control cuttings for all ortet age-branch order combinations, except first-order twigs from 15- and 20-year-old trees. Stecklings from 10-year-old ortets had greatest 1st-year shoot growth and lowest cull rate when they were transplanted and less plagiotropic growth than cuttings from 15- and 20-year-old ortets.

Keywords: Rooting ability, Sitka spruce, *Picea sitchensis,* southeast Alaska, Alaska (southeast), vegetative propagation.

Introduction

An opportunity exists for genetically improving new stands in southeast Alaska if positive selection pressure can be exerted during precommercial thinning. Unfortunately, little is known about genetic control of juvenile traits considered important to timber production or wildlife habitat. Ramets of clones of Sitka spruce (*Picea sitchensis* (Bong.) Carr.) are needed as test material from which broad sense heritability values for traits can be calculated. Such estimates can be obtained from measurements of rooted cuttings (Gill 1983) and would be of great help in establishing sound thinning guidelines.

If cloned trees are to be available for measurement, effective means of rooting stem cuttings of Sitka spruce must be found. Considerable information on rooting of *Picea* species has been published (for example, Roulund 1971, van den Driessche 1985). Evaluation of these published techniques and results will assist in selection of rooting methods and procedures most likely to promote favorable rooting.

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Many factors of ortet physiology, cutting treatment, and rooting medium can influence rooting success and steckling performance. Rooting percentage of conifer cuttings is usually affected by age of ortet and original position of the cutting in the crown. Cuttings from older spruce trees have poorer rooting percentage than cuttings from younger ortets (Roulund 1973). Rooting of Norway spruce (*Picea abies* (L.) Karst.) decreases from 65 percent for cuttings from 6-year-old ortets to 9 percent for cuttings from 40- to 60-year-old ortets (Køhn 1976). Considerable variation among ortets is common. Sitka spruce cuttings from the lower crown root better than cuttings from the upper crown (van den Driessche 1983). Rooting of 13-year-old trees is 24 percent from the lower crown and only 10 percent from the upper crown. Norway spruce cuttings show a similar response (Girouard 1971).

Time of collection of cuttings from ortets also influences rooting success. Rooting of Sitka spruce is better when branch tips are collected in January and February than from October through December. They can also be collected in August and rooted in the fall (Roulund 1978). A study of Norway spruce indicates that cuttings may root better when gathered in July and August than from February to April (Bogdanov 1983).

Plagiotropic growth, which is related both to ortet age and cutting position in the crown, is an undesirable trait in stecklings. In Sitka spruce, plagiotropic growth is a greater problem in cuttings from old trees than from young trees (Gill 1983). Cuttings from 12-year-old Norway spruce ortets also exhibit more plagiotropic growth than do cuttings from 2-year-old ortets. Cuttings from the lower crown of Norway spruce are less plagiotropic than cuttings taken from the upper crowns of the same trees (Girouard 1971, Roulund 1979).

Results of hormone treatments of spruce cuttings vary. Two favorable indole-3-butyric acid (IBA) treatments for Sitka spruce are 25 mg/liter in a 24-hour soak and 3000 mg/liter in a 5-second dip. The average of the two treatments is 55-percent rooting for 8- to 11-year-old trees vs. 38 percent for the untreated controls (van den Driessche 1985). When indole-3-acetic acid (IAA) is applied to Norway spruce cuttings in a dilute-soak treatment, rooting percentage improves slightly and the roots appear sooner.

Deneedling the base of cuttings is often done before cuttings are placed in the rooting medium, but removing the needles may damage the stem tissues. In black spruce (*Picea mariana* (Mill.) B.S.P) (Phillion and others 1982) and Norway spruce (Roulund 1971), decreased rooting occurs when the basal 2 to 3 cm of cuttings are deneedled. Basal needles were removed from cuttings in the studies of Sitka spruce by van den Driessche (1983, 1985).

Rooting media can influence rooting percentage and root structure of conifer cuttings (Copes 1977). Successful rooting media for Sitka spruce are mixtures composed of equal parts (by volume) of peat, sand, and perlite (van den Driessche 1983) or of coarse grit and sphagnum peat moss in volume ratios ranging from 1:1 to 4:1 (Mason 1984). Other trials, however, of media with sand, sphagnum peat moss, and perlite indicate that the media do not influence rooting success (Roulund 1971).

This report describes the rooting response and the 1st-year growth of cuttings gathered from 10-, 15-, and 20-year-old ortets in southeast Alaska. The purpose of the experiment was to determine the rooting capacities and growth characteristics of cuttings from trees of three precommercial thinning ages. Cuttings from three different branch orders were tested with and without the IBA rooting hormone.

Methods

In January 1985, cuttings were collected from Sitka spruce trees growing in three clearcuts near Petersburg, Alaska. The ortets were about 10, 15, and 20 years old (±2 years). The trees were representative of trees growing on sites where precommercial thinning had been done or soon would be done. Five trees of each age class were sampled. Selection was solely for age uniformity within each age class. Cuttings were collected from the lower one-third of the crown; 7 first-order, 14 second-order, and 14 third-order branch tips were gathered from each tree and kept separate for each tree by branch order. The cuttings ranged from 50 to 150 mm in length and from 2 to 6 mm in diameter. The newly clipped twigs were placed on ice at collection and shipped by air to Corvallis, Oregon, where they were stored for about 2 weeks at 1° Celsius.

The base of each cutting was cut to expose fresh tissue shortly before it was placed in the rooting bed. The entire cutting was soaked for 1 minute in a saturated solution of Captan-50,[1] and then the basal 2 cm of each cutting was soaked for 5 seconds in either 5000 mg IBA/liter (dissolved in 50 percent ethanol) for hormone treatment, or in just 50 percent ethanol for control treatment. Needles were not removed from the base of the cuttings. The cuttings were planted 1 to 2 cm deep at a 5- by 5-cm spacing.

Rooting was done in a plastic-covered greenhouse at Corvallis. The rooting medium consisted of equal volumes of peat moss and coarse vermiculite. Bottom heat was maintained at 21 °C (±2 °C). A conventional mist system maintained high humidity during daylight hours. Foliage of the cuttings was allowed to be dry at night to retard foliage diseases. A weekly spray program with one of four fungicide sprays (Captan-50, Benlate, Banrot, and Ferban) was used to prevent disease. Weekly application of 20:20:20 (NPK) water-soluble fertilizer was begun when new roots first became visible and was continued through August.

A total of 525 cuttings were placed in the rooting beds (15 trees × 35 cuttings per tree). Seven cuttings of the second-order and seven cuttings of the third-order branch tips from each tree were treated with IBA; an equal number of similar twigs that did not receive the IBA treatment served as controls. Only seven first-order twigs could be obtained from the lower third of each 10-year-old tree, so only seven were collected from each of the 15- and 20-year-old trees. First-order twigs from half of the trees received either the hormone or the control treatment, but there was no reciprocal control or hormone treatment for individual trees. Cuttings of each tree by branch order by hormone treatment combination were placed at random in the rooting beds in rows of seven twigs.

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[1] Use of trade names in this publication is for the information of the reader and does not constitute an endorsement by the U.S. Department of Agriculture of any product to the exclusion of others that may be suitable.

Three growth traits and rooting success were measured or calculated after growth ceased in October 1985. The trait defined as "cull rate" referred to the percentage of cuttings with weakly developed roots that were judged to be too poor to warrant transplanting. The degree of plagiotropism was visually quantified by classifying each rooted cutting that had new shoot growth in 1985 as orthotropic (0), slightly plagiotropic (1), or very plagiotropic (2). Cuttings that did not burst bud in the rooting bed could not be evaluated for plagiotropism. First-year shoot growth was measured from the base of the terminal bud scar to the tip of the 1985 terminal. Growth was measured to the closest millimeter.

Trees were the units of replication for statistical analysis of rooting percentage success; no replication of individual hormone treatment by branch-type combinations was possible because individual trees had only seven first-order cuttings. Replication was increased for analysis of data for plagiotropism, cull rate, and shoot growth by combining data from the two hormone treatments because hormone treatment had little or no effect on growth traits. Growth traits were measured only on rooted cuttings. Percentage data were subjected to arcsin transformation before analysis of variance. Extremely conservative weighted analysis of variance was used to compensate for the unbalanced design of the study.

Results

Rooting success increased with ortet age, but the differences between ages were not significant (tables 1 and 2). Orthogonal comparisons were made for ortet ages—10 vs. (15 + 20) and 15 vs. 20—but results in the tables were combined because of lack of significance of the individual comparisons. None of the main treatments nor interactions for rooting success or growth traits were significant. Reasons for test insensitivity are presented under "Discussion." Lack of significance in rooting success for hormone vs. control treatments was surprising because the controls averaged 70-percent rooted cuttings and only 59-percent hormone-treated cuttings (table 2). The effect of hormone treatment on rooting success of second- and third-order branches from 15- and 20-year-old ortets was also large. The control cuttings rooted much better than the hormone-treated cuttings (67 and 72 percent vs. 55 and 56 percent, respectively).

Most cuttings from all three ages of ortets grew plagiotropically at the end of the 1st year. Cuttings of all 15 ortets exhibited similar degrees of plagiotropic growth, but cuttings from first-order branch tips were slightly more orthotropic than second and third order (tables 2 and 3).

Shoot growth the year of rooting was limited and averaged only 40 mm per tree. Growth of cuttings from 10-year-old ortets was greater than from the 15- and 20-year-old trees (table 3), but again the differences were not significant. Cuttings taken from first-order branches grew slightly longer shoots than cuttings taken from second- and third-order twigs (table 2).

The cull rate at transplanting was directly related to ortet age: Fewer culls were found in rooted cuttings from 10-year-old ortets than from 15- and 20-year-old ortets (1 vs. 11 and 12 percent) (tables 2 and 3). Four of the five 10-year-old ortets had no cull seedlings, even though there were 75 rooted cuttings from those four ortets. Branch order did not appear to influence the percentage of weakly rooted cuttings.

Table 1—Analysis of variance test of rooting success, plagiotropism, cull rate, and shoot growth of Sitka spruce cuttings

Source of variation	Degrees of freedom	Sum of squares	Mean squares	F values	Significance of F values
Rooting success:					
Error 1	12	4.67858	0.38988		
Ortet age (A)	2	.11131	.05566	0.14275	0.87
Error 2	44	2.74123	.06092		
Branch order (B)	2	.03032	.01516	.24890	.78
Hormone treatment (H)	1	.04743	.04743	.77855	.38
A X B	4	.18575	.04644	.76231	.56
A X H	2	.08827	.04414	.72447	.49
B X H	2	.00687	.00343	.05636	.95
A X B X H	4	.07747	.01937	.31792	.86
Plagiotropism:					
Error 1	12	3.83645	.31970		
Ortet age (A)	2	.07531	.03766	.11780	.90
Error 2	20	3.65593	.18280		
Branch order (B)	2	.60160	.30080	1.64551	.22
B X A	2	.12584	.06292	.34420	.71
Cull rate:					
Error 1	12	.49320	.04110		
Ortet age (A)	2	.01445	.00723	.17591	.84
Error 2	22	.37143	.01688		
Branch order	2	.00655	.00328	.19431	.83
B X A	4	.10175	.02544	1.50696	.24
Shoot growth:					
Error 1	12	7738.18344	644.84862		
Ortet age (A)	2	353.41520	176.70760	.27403	.77
Error 2	21	1396.56682	66.50318		
Branch order (B)	2	78.76706	39.38353	.59221	.56
B X A	4	242.97906	60.74477	.91341	.47

Table 2—Rooting success, plagiotropic growth, cull rate, and shoot growth of 1st-, 2d-, and 3d-order branch tips from 10-, 15-, and 20-year-old Sitka spruce trees1/

Ortet age and branch order	Rooting success of hormone treatment 2/: 0 p/m IBA	Rooting success of hormone treatment 2/: 5000 p/m IBA	Average rooting	Average plagiotropism 3/	Cull rate	Shoot growth
	Percent	Percent	Percent		Percent	mm
10 years:						
1	93 (2)	67 (3)	77 (5)	1.3 (4)	0 (4)	51 (4)
2	57 (5)	57 (5)	57 (10)	1.4 (7)	0 (7)	57 (7)
3	63 (5)	51 (5)	57 (10)	1.5 (8)	2 (8)	45 (8)
Mean	66 (12)	57 (13)	61 (25)	1.4 (19)	1 (19)	51 (19)
15 years:						
1	52 (3)	71 (2)	60 (5)	1.2 (4)	7 (5)	33 (4)
2	74 (5)	57 (5)	66 (10)	1.4 (9)	14 (9)	25 (9)
3	77 (5)	54 (5)	66 (10)	1.3 (9)	10 (9)	31 (9)
Mean	70 (13)	58 (12)	65 (25)	1.3 (22)	11 (23)	29 (22)
20 years:						
1	71 (2)	76 (3)	74 (5)	1.6 (4)	12 (5)	44 (5)
2	71 (5)	51 (5)	61 (10)	1.6 (9)	13 (10)	40 (9)
3	77 (5)	63 (5)	70 (10)	1.3 (10)	11 (10)	39 (10)
Mean	74 (12)	61 (13)	67 (25)	1.5 (23)	12 (25)	40 (24)
All ages:						
1	69 (7)	71 (8)	70 (15)	1.3 (12)	7 (14)	43 (13)
2	67 (15)	55 (15)	61 (30)	1.5 (25)	10 (26)	39 (25)
3	72 (15)	56 (15)	64 (30)	1.4 (27)	8 (27)	38 (27)
Mean	70 (37)	59 (38)	64 (75)	1.4 (64)	8 (67)	40 (65)

1/ Numbers in parentheses are the number of rows of 7 cuttings (replications) on which each weighted mean is based.

2/ IBA = indole-3-butyric acid.

3/ 0 = orthotropic, 1 = slightly plagiotropic, 2 = very plagiotropic.

Table 3—Average rooting success, plagiotropism, cull rate, and shoot growth of cuttings from individual trees in the 10-, 15-, and 20-year-old classes[1/]

Ortet age and tree number	Rooting success 2/		Plagiotropism 3/		Cull		Shoot growth	
	Percent				Percent		mm	
10 years:								
1	91	(5)	1.4	(5)	3	(5)	50	(5)
2	23	(5)	1.2	(2)	0	(2)	22	(2)
3	83	(5)	1.4	(5)	0	(5)	35	(5)
4	100	(5)	1.5	(5)	0	(5)	83	(5)
5	9	(5)	1.3	(2)	0	(2)	54	(2)
Mean	61	(25)	1.4	(19)	1	(19)	51	(19)
15 years:								
1	69	(5)	1.6	(5)	19	(5)	29	(5)
2	97	(5)	1.3	(5)	0	(5)	32	(5)
3	23	(5)	1.4	(3)	0	(4)	21	(3)
4	43	(5)	1.1	(4)	13	(4)	39	(4)
5	91	(5)	1.3	(5)	19	(5)	24	(5)
Mean	65	(25)	1.3	(22)	11	(23)	29	(22)
20 years:								
1	49	(5)	1.3	(5)	12	(5)	46	(5)
2	81	(5)	1.9	(5)	3	(5)	44	(5)
3	89	(5)	1.5	(5)	13	(5)	41	(5)
4	40	(5)	.9	(40)	21	(5)	24	(4)
5	79	(5)	1.8	(4)	0	(5)	44	(5)
Mean	67	(25)	1.5	(23)	12	(25)	40	(24)
Mean of all ages	64	(75)	1.4	(64)	8	(67)	40	(65)

1/ Numbers in parentheses are the numbers of rows of 7 cuttings (replications) on which each mean is based.

2/ Rooting success for each ortet was based on 5 replications of 7 cuttings, whereas growth trait data were based solely on measurements within replications where rooting had occurred.

3/ 0 = orthotropic, 1 = slightly plagiotropic, 2 = very plagiotropic.

Discussion

Ten- to twenty-year-old Sitka spruce can be cloned easily with rooted cuttings. Trees of precommercial thinning age can be rooted and, in later years, broad sense heritability values for selected phenotypic traits can be determined from the rooted cuttings. Only small differences in rooting success were found between trees of the three age classes. No ortet failed to root, but 3 of 15 ortets averaged less than 25-percent rooting. Thus, about 20 percent of ortets selected for cloning programs might not be suitable if many ramets per clone are needed. Selecting 25 percent more ortets than are actually needed will compensate for the trees that root poorly.

Rooting success was better than published reports suggest. Better rooting probably resulted from a more favorable rooting environment. Rooting success of the control treatment—70- and 74-percent for 15- and 20-year-old ortets, respectively—was higher than the reported 54-percent rooting obtained with optimum IBA treatment on cuttings of 17-year-old Sitka spruce ortets or the 38 percent for control cuttings (van den Driessche 1985). Rooting results similar to those from the 15-year-old ortets were reported for Sitka spruce cuttings gathered from hedges of 14- to 16-year-old ramets

(69-percent rooting) (van den Driessche 1983). Eighty-three percent rooting was obtained with cuttings from 8-year-old ramets (Roulund 1971); cuttings from younger ortets and serially propagated hedges usually root more successfully than do cuttings from older ortets. For the cuttings from the oldest ortets to root best is unusual. Such an occurrence may simply be the result of sampling only five ortets in each age class.

Study of hormone and branch-order effects on rooting success indicated that, under the environmental conditions of this study, considerably better rooting occurred without hormone treatment. The difference of 11 percent between 70- and 59-percent rooting for 0 and 5000 p/m IBA, respectively, was large but not statistically significant. Lack of significance resulted because of the insensitivity of the analysis. An extremely conservative analysis of variance test was used to compensate for irregularities caused by the small sample size and the unbalanced design of the study. The sensitivity problem was compounded even more in the analysis of the three growth traits because measurements could be taken only on cuttings that had rooted; thus they had fewer datum points than for rooting success, where all cuttings were evaluated. An experiment with greater replication and an equal number of cuttings of each branch order would have been more sensitive, and significance might have been detected for several variables—especially for the difference in rooting between second- and third-order shoots of 15- and 20-year-old ortets.

Insensitivity in detecting significant treatment differences was even more pronounced for the cull-rate analysis because the only cuttings evaluated were those that both had rooted and had new shoot growth in 1985. Far fewer culls were found with cuttings from 10-year-old ortets than from 15- and 20-year-old ortets, yet the analysis of variance indicated no significance. The difference in cull rate may relate to cuttings of younger ortets rooting more rapidly or to having the inherent ability to induce the formation of more abundant adventitious root primordia. Greater vigor of cuttings from younger ortets was also suggested by longer shoot growth of cuttings from 10-year-old ortets.

The 5000 p/m IBA treatment, the same treatment that is very good for Douglas-fir cuttings (Copes 1983), may be too concentrated for promoting rooting of Sitka spruce. It appeared to decrease rooting of second- and third-order branch tips of 15- and 20-year-old ortets. Similar reduction in rooting success was not seen with cuttings from 10-year-old ortets. One researcher found that a 3000 p/m IBA treatment applied as a quick dip stimulated rooting in Sitka spruce cuttings, but the treatment was less successful than a 25 p/m treatment applied as a dilute soak (van den Driessche 1985). Both the dilute soak and the quick dip IBA treatments gave better rooting results than the control. In Douglas-fir cuttings, noticeable differences in rooting were noted when IBA treatment was applied to twigs of different branch orders (Roberts and Fuchigami 1973). A direct comparison of the present study's 5000 p/m IBA treatment with published reports in which different concentrations of IBA were used is difficult because the control cuttings of the present study rooted better than the best hormone treatments reported in the literature.

The high incidence of plagiotropic growth the year of grafting is not unexpected with conifer cuttings from 10- to 20-year-old ortets (Wühlisch 1984). Observations must be taken in a few years on the transplanted cuttings to determine the extent and duration of the condition. If cuttings from younger ortets are less likely to be plagiotropic, they would be better for clonal tests. The same condition is true of branch-order effects on leader growth and tree form.

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