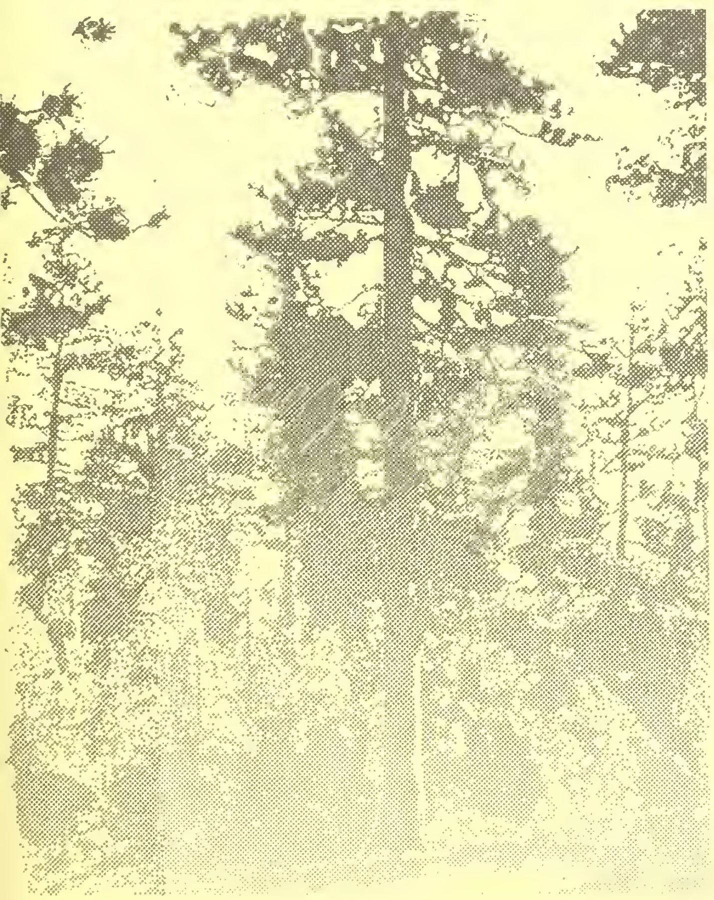
PONDEROSA PINE

SAPLINGS RESPOND TO CONTROL OF SPACING AND UNDERSTORY VEGETATION

JAMES W. BARRETT



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INTRODUCTION

Recent forest inventories indicate that about 5 million acres of commercial ponderosa pine forest land east of the Cascade Range in Washington and Oregon have a dense understory of suppressed trees.[1] On many additional acres, the overstory has been removed, leaving dense thickets of 40- to 80-year-old, sapling-sized trees. Some managers have chosen to thin these residual stands while others, still hesitant about the investment in thinning, have elected to let the understory develop naturally. Most agree, however, that if these stands are to make reasonable progress toward producing a merchantable product, they must be thinned.

The type of precommercial thinning selected for these stands may imply the product mix of a multiple use manager or the anticipated market of a private company. If a forester chooses a narrow spacing, he is forecasting a market for small trees by the time the next thinning is needed. On the other hand, choice of a wide spacing implies that the forester is aiming toward larger trees suitable for sawing or peeling or that he is interested in increasing forage and/or water yields. Both routes may be equally productive.

Since optimum tree spacing depends on product objective, the forester must know the growth possibilities at a number of spacings to satisfy varied management objectives. In addition, he needs to know the competitive effects of understory vegetation, soil moisture availability, and limb development, all of which can affect the production of useful wood.

[1] Personal communication with Donald R. Gedney, Forest Survey, Pacific Northwest Forest and Range Experiment Station, Portland, Oreg.

This paper presents 8-year-growth results from a spacing study designed to give the manager a wide range of alternatives from which to choose an initial spacing.

The first 4-year results from this experiment were presented in 1965 (*1*).

STUDY AREA

The study is located on the Pringle Falls Experimental Forest, 35 miles southwest of Bend, Oreg. Study plots are on an east-facing slope at about 4,400 feet elevation. Annual precipitation averages 24 inches, approximately 85 percent of which falls between October 1 and April 30. A snowpack of 24 inches is common from January to March. Daytime temperatures during the growing season range between 70° and 90°F. Nights are cool with occasional frosts. Site index of old-growth ponderosa pine in the area indicates a height of 78 feet at age 100, average site quality IV (*10*).

Soil is a regosol developed in dacite pumice originating from the eruption of Mount Mazama (Crater Lake) 7,300 years ago. The pumice averages 33 inches deep and is underlain by sandy loam paleosol developed in older volcanic ash containing cinders and basalt fragments. The Lapine soil series is the most common although a few areas of Longbell[2] soil occur in the study area.

Before study installation, the timber stand consisted of old-growth ponderosa pine averaging 17,000 board feet per acre with a 40- to 70-year-old understory of 1- to 5-inch saplings as dense as 20,000 stems per acre on

[2] Tentative series not yet correlated.

some milacre quadrats (fig. 1) but averaging about 7,000 stems per acre. Ground vegetation consisted of antelope bitterbrush (*Purshia tridentata* (Pursh.) D.C.), snowbrush ceanothus (*Ceanothus velutinus* Dougl.), and pine manzanita (*Arctostaphylos parryana* var. *pinetorum* (Rollins) Wiesl. & Schr.).[3] The sedge, *Carex rossii* Boott., although not abundant before thinning, flourished after thinning in stands where trees were widely spaced. Some grasses and other herbaceous vegetation were also present.

EXPERIMENTAL DESIGN AND METHODS

Thirty rectangular 0.192-acre plots were selected in sapling-sized reproduction containing a minimum of 1,000 trees per acre. The mature overstory was carefully removed (*2*), and plots were thinned to spacings of 6.6, 9.3, 13.2, 18.7, and 26.4 feet. Each density was replicated six times. Understory vegetation was removed on three of six replications for each stand density by a combination of herbicides and mechanical treatments.[4] On the remaining 15 plots, vegetation including brush, grasses, sedges, and herbs was measured as percent cover in 1959, 1963, and 1967 by a systematic sampling of 100 points per plot (*8*).

Logging of overstory and thinning of saplings was started in the fall of 1957 and completed in the fall of 1958. Thus, there was one growing season between thinning and

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[3] Authorities for common and scientific names in this publication are: for trees, "Check list of trees of the United States (including Alaska)," by Elbert L. Little, Jr.; for shrubs, "Standardized plant names," by Harlan P. Kelsey and William A. Dayton.

[4] Statistically the experiment is a 5 by 2 completely randomized factorial replicated three times. Analysis of variance and orthogonal comparisons were used to judge the significance of treatment effect.

Figure 1. Ponderosa pine stand before harvesting overstory and thinning understory to different spacings.

initial measurement on some plots and up to two seasons on others. (This was not inadvertently related to treatment.) All recent logging and thinning slash was removed from the plots and burned.

Three additional plots of old-growth ponderosa pine with an undisturbed sapling understory were reserved as check plots for soil moisture study.

Tree measurements were made in the fall of 1959, 1963, and 1967. Diameters were measured with a steel tape to the nearest one-tenth of an inch and heights with a sectioned aluminum pole to the nearest one-tenth of a foot.

One hundred and eighty-six measured trees formed the basis for calculating an equation that expressed volume of the entire stem as a function of diameter and height. Diameter and bark thickness were measured at 5-foot intervals on each sample tree. Eight trees per plot were measured on plots thinned to 6.6 feet, seven trees on plots thinned to 9.3 feet, six trees on plots thinned to 13.2 feet, and five on plots thinned to 18.7 and 26.4 feet. A new equation was calculated for each period.

Limb diameter was measured on 12 trees from each plot. The six largest limbs from each sample tree were measured to the nearest one-tenth of an inch just beyond bole-branch swell.

Soil moisture was sampled with a neutron probe. Access tubes 5 feet long were installed in the approximate center of a square formed by four trees. Three tubes were installed on each plot. Five readings were taken, each at 1-foot intervals through the profile. The five readings were averaged and converted to percent moisture by volume using a calibration coefficient developed by the Douglass (*6*) method. Soil moisture measurements were made in late April and again in September from 1961 through 1964 and in 1967. Soil moisture was measured at 3-week intervals throughout the growing season from 1961 through 1964. Soil moisture use in this paper is the difference between total water at the beginning and the amount at the end of the growing season. Precipitation occurring between soil moisture measurements was not measured. Therefore, some moisture could have been used but not accounted for in calculated soil moisture use determinations. This was usually negligible, but in 1963 intermittent summer rains were heavy enough to affect moisture use figures. Also, it should be noted that, since access tubes were centered among four trees, water use per acre in the thinned stand is underestimated. A random or mechanical location would have given a more reliable estimate per unit of land area. However, positioning the tubes in this manner had the advantage of measuring soil moisture at the most sensitive point in the stand for detecting complete site occupation by roots (*3*).

RESULTS

General

Forty- to 70-year-old ponderosa pine saplings responded well to overstory harvest, thinning, and removal of understory vegetation (fig. 2), i.e., where any competition was removed, trees grew better. Furthermore, there was no visible evidence of shock to the

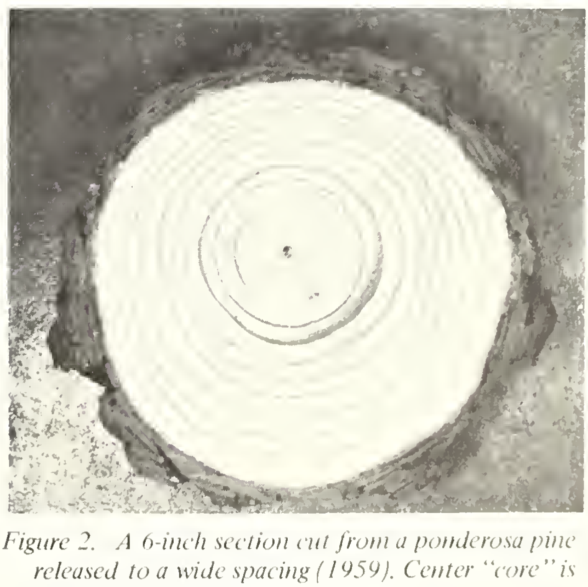


Figure 2. A 6-inch section cut from a ponderosa pine released to a wide spacing (1959). Center "core" is 1.5 inches in diameter.

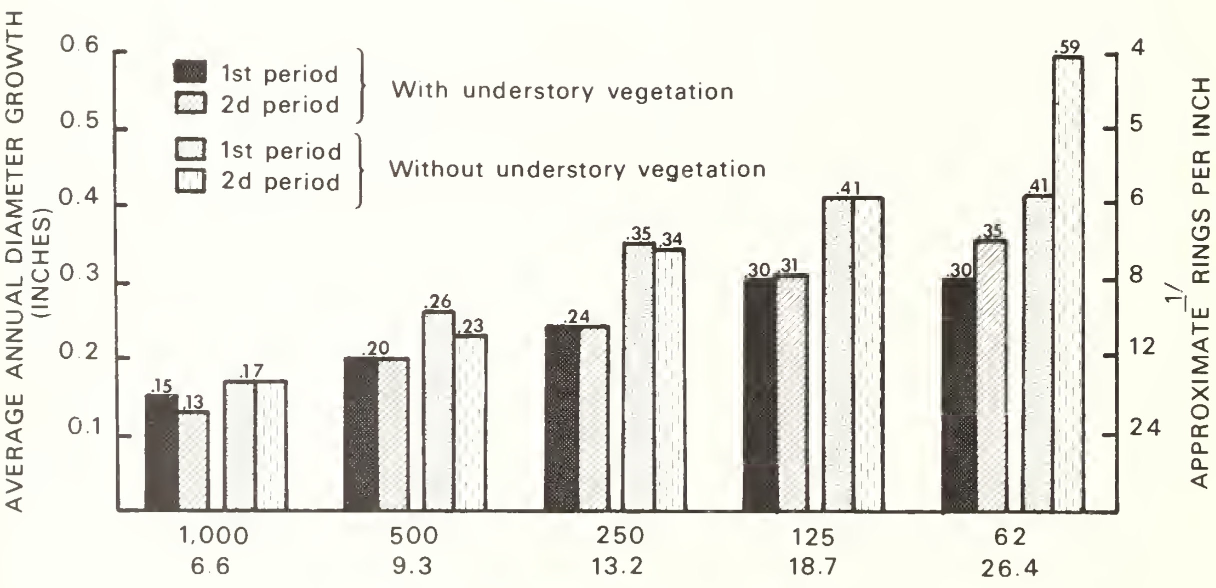
remaining trees after this competing vegetation was removed. Thinning to a wide spacing stimulated the growth of understory vegetation such as manzanita, snowbrush, bitterbrush, and sedge. In some instances, these understory plants seemed to offer as much competition to released trees as if four times as many trees were left. Removal of understory vegetation allowed additional amounts of soil moisture to be available for tree growth.

Diameter Growth

Tree spacing significantly affected diameter growth, during both the first and second 4-year growth period (fig. 3). Orthogonal comparisons showed a real trend, in both growth periods, of increasing diameter growth with increasing tree spacing. For example, during the last period and where understory vegetation was left, trees at the narrowest spacing grew at an average rate of 1.3 inches per decade compared with 3.5 inches at the widest spacing. Where vegetation was removed, trees at the widest spacing grew at a rate of 5.9 inches per decade compared with 1.7 inches at the narrowest spacing. Although diameter growth rates increased at the widest spacings in the second period, the slight falling off of growth from the first to the second period at the narrowest spacings was not statistically significant.

Ratios of wood to bark were statistically the same for all treatments. Thus, varying bark growth rates are not involved in the diameter growth shown in figure 3.

Understory vegetation has offered considerable competition to diameter growth, especially at the wider spacings. During the second period, for example, tree growth at the widest spacing was reduced about 40 percent by understory vegetation. As numbers of trees increased, the effect of understory vegetation on growth diminished. The highly significant spacing times understory vegetation treatment interaction indicates this effect is probably real rather than the product of chance variation.



1/ Adjusted for bark growth.

Figure 3.—Average annual diameter increment of ponderosa pine saplings during the first and second 4-year growth periods.

Orthogonal comparisons between treatments indicate that trees spaced 18.7 feet are competing with one another after only 8 years. Trees spaced 26.4 feet may be competing, but we can't really tell because we had no wider spacing for comparison. However, earlier growth studies[5] with free-growing ponderosa pine trees (trees growing without competition from other trees) in central Oregon indicate that trees spaced 26.4 feet in this study, and having no competing understory vegetation, are probably free growing after 8 years.

Where vegetation was removed, the largest trees of each spacing grew best. For example, in figure 4 for the 62 largest, well-distributed trees per acre selected from a stand containing 1,000 trees per acre, the average diameter growth rate (0.29 inch) is nearly twice that of the average of all trees (0.16 inch) in the stand. Even though the growth rate of larger trees was greatest in each treatment, they were held back by other trees. To illustrate, the average growth of the stand containing just 62 trees per acre was about 0.5 inch per year, but as we add two, four, eight, and 16 times as many trees, the growth of the 62 largest trees in each treatment became less and less until it finally reached 0.29 inch in the 1,000 trees per acre stand (fig. 4). Therefore, trees occupying the most favorable position in the stand were not independent of stand density.

[5] Unpublished progress report on file in the Pacific Northwest Forest and Range Experiment Station's Silviculture Laboratory, Bend, Oreg.

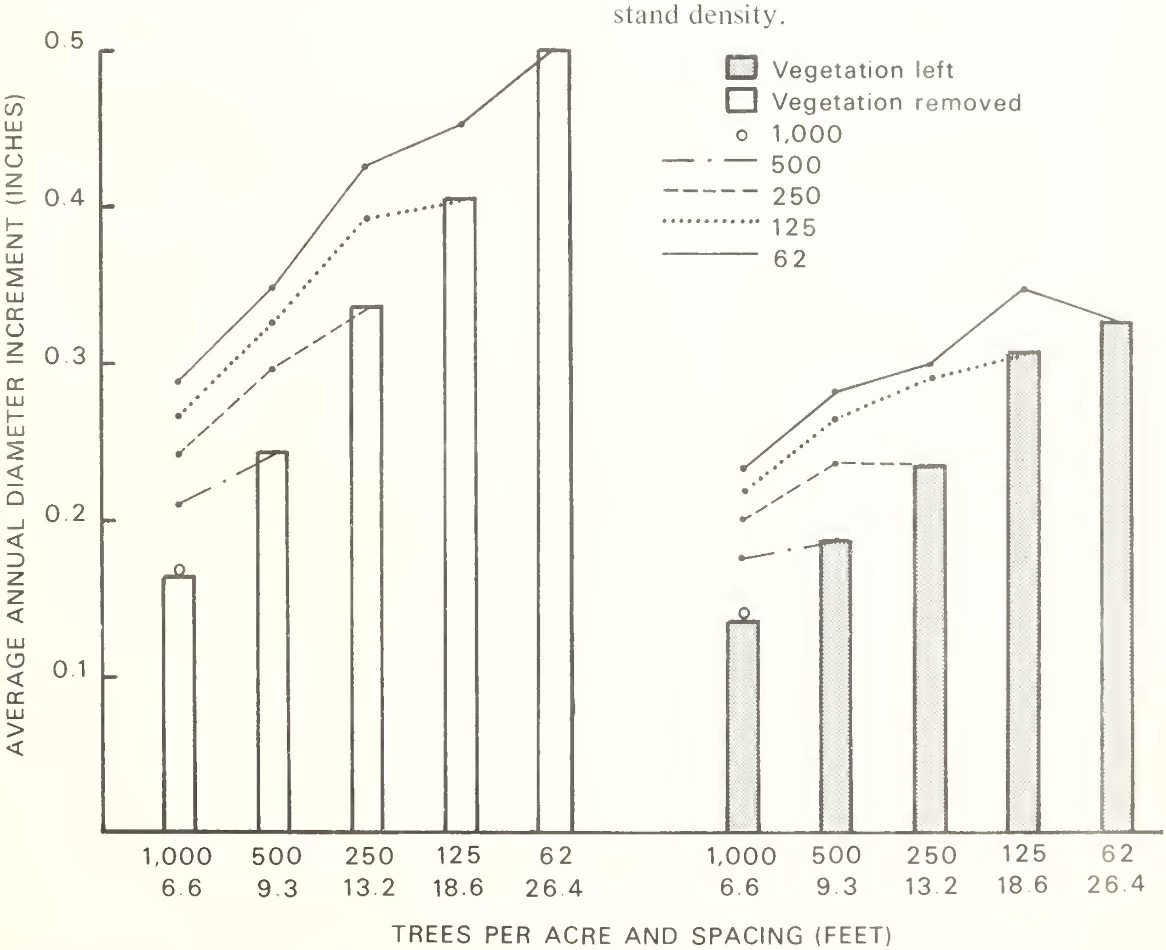


Figure 4.—Average annual diameter increment of ponderosa pine saplings thinned to various spacings (1959-67). Bars show diameter growth for total number of trees at each spacing. Points above bars show growth of the stated number of the largest well-distributed trees within the stand.

Similar trends existed where understory vegetation was left, but differences between spacings were not so pronounced, due to the competitive effect of understory vegetation. Exceptional diameter growth of individual trees in denser stands could almost always be accounted for by localized wide spacing or a lack of competing understory vegetation.

Basal Area

Basal area increased to about 56 square feet per acre at the closest spacing (table 1), or about 25 percent of that found in fully stocked normal stands past age 50 (*10*).

Basal area increment over the 8-year period was greatest at the closest spacing where the growing stock base was highest. Increment decreased progressively as spacing was increased. However, basal area was accumulating most rapidly per unit of initial basal area at the wide spacings where diameter growth was the greatest. For example, at the widest spacing (62 trees per acre) where understory vegetation was removed, basal area increased to about eight times its initial quantity directly after thinning. Where 500 trees were left, the basal area increase was only 4.7 times. Also, where understory vegetation was removed on the widest spacing (26.4 feet) basal area was almost as high as that of the closest spacing only 8 years ago. This indicates a rapidly expanding growing stock base at the wide spacings which could lead to reasonable wood production per acre on fewer trees in the near future.

Height Growth

Height growth did not respond dramatically to increased growing space until the second 4-year period, although spacing did significantly affect growth during both periods (fig. 5). Greater growth was observed

Table 1.—*Average basal area per acre of ponderosa pine saplings directly after thinning and 4 and 8 years later, and 8-year basal area increment*

Treatment	Trees per acre and spacing (feet)				
	1,000-6.6	500-9.3	250-13.2	125-18.7	62-26.4
	Square feet				
Vegetation left:					
1959	21.8	7.9	5.4	3.3	1.5
1963	36.9	17.1	12.3	7.9	3.7
1967	55.9	31.6	21.8	14.4	7.5
8-year increment	34.1	23.7	16.4	11.1	6.0
Vegetation removed:					
1959	15.8	7.9	4.9	4.3	1.6
1963	31.4	21.4	14.8	11.5	4.9
1967	52.4	37.4	30.1	22.2	13.0
8-year increment	36.6	29.5	25.2	17.9	11.4

at progressively wider spacings. For example, during the first period, where understory vegetation was removed and 1,000 trees per acre left, trees grew an average of 0.2 foot per year compared with 0.5 foot where only 62 trees were left. In the second period, however, trees at the widest spacing averaged 1.2 feet per year.

Understory vegetation reduced height growth on all spacings during both periods except during the first period where trees were spaced 6.6 feet. Growth reductions from understory vegetation were more severe as spacing increased. A maximum reduction in height growth of 42 percent occurred in the second period at the widest spacing.

Height growth of individual trees ranged from an unmeasurable amount for some trees at the 6.6-foot spacing to almost 2.0 feet per year for one tree at the widest spacing. During the first period growth at the widest spacing was erratic, with some trees growing a foot or more in a year and others much less. During the second period, however, variation was greatly reduced at the wide spacings because all trees tended to grow uniformly well. Evidently there is a time lag, closely related to tree density, before trees are able to respond fully to their new spacing environment.

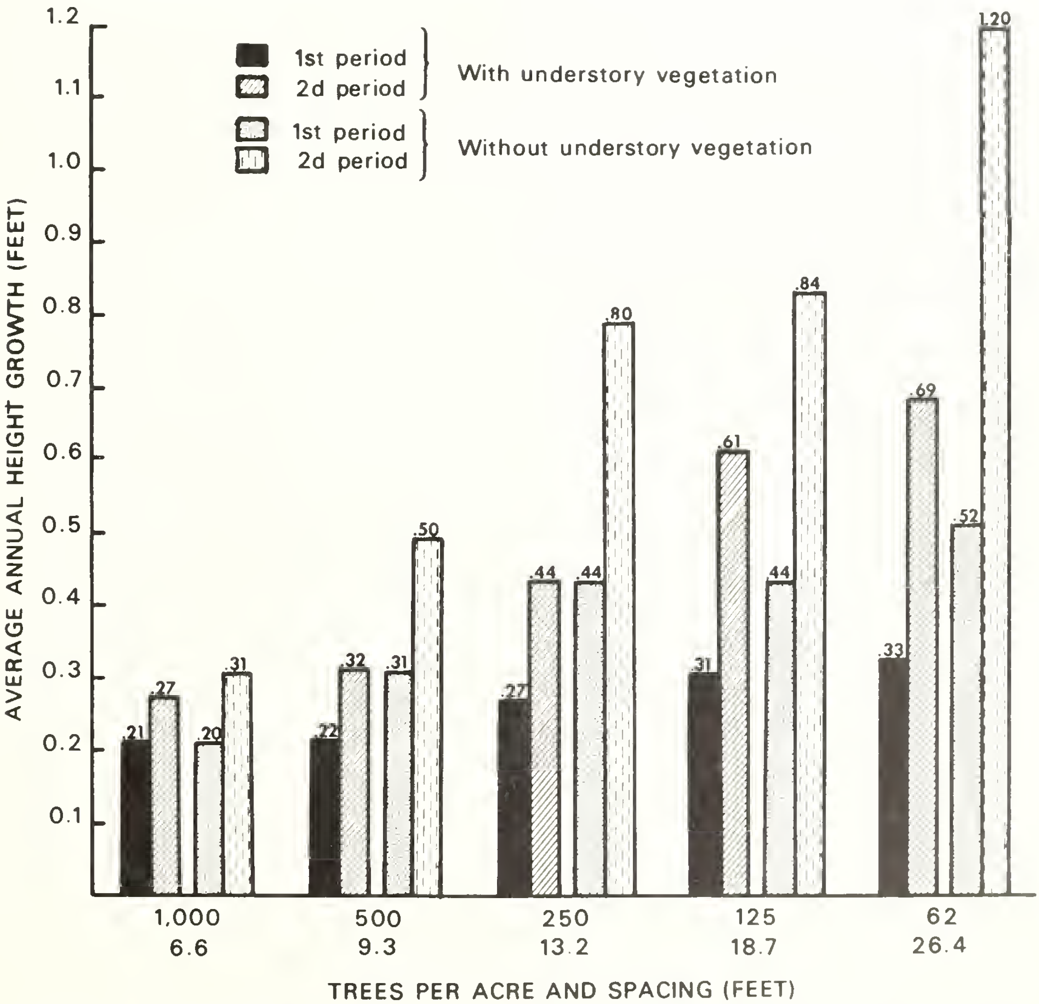


Figure 5.—Average annual height growth during the first and second 4-year growth periods.

Figure 6.–Ponderosa pine released to a wide spacing (1959), shows excellent height growth and possibly undesirable limb development in the lower whorls.

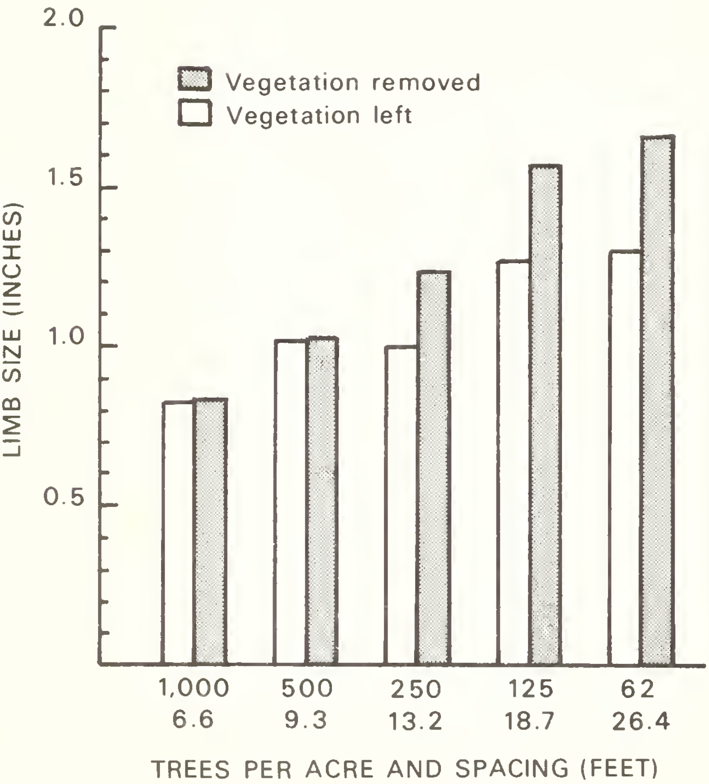


Figure 7. Average limb size of the six largest limbs on ponderosa pine saplings after 8 years.

Limb Growth

Tree branches also responded to thinning and to removal of understory vegetation (figs. 6 and 7). The six largest branches per tree averaged about 1.7 inches in diameter at the widest spacing compared with only 0.8 inch at the 6.6-foot spacing. The effect of spacing, understory vegetation, and the interaction of spacing and understory vegetation on limb growth are all statistically significant at the 1-percent level of probability.

Increment borings from branches at the widest spacings show that diameter growth rates of 1.4 inches per decade are not unusual on some of the larger branches. Branch whorls on many trees are extremely close together due to their restricted height growth during the suppression period before thinning and overstory removal. These whorls could easily grow together forming an undesirable defect on the bole.

Limb size was a function of tree size. Therefore at wide spacings where current bole diameter was large, average limb size was large. For trees of the same initial d.b.h., branch size increased slightly with spacing.

Cubic Volume Increment

Both reduced tree density and the presence of understory vegetation lowered annual cubic wood production, i.e., more wood per acre was produced at the higher densities where understory vegetation had been removed. But, at the higher densities, small spindly stems which may never reach merchantable size are included in the volume.

The highest tree density where vegetation was removed produced 41 cubic feet per acre per year during the second period. Production decreased with increased spacing. The widest spacing produced only 8 cubic feet per acre per year during the second period where vegetation was left (fig. 8). At the end of the second 4-year period, the highest density where understory vegetation was left contained an average of about 448 cubic feet per acre compared with only 57 cubic feet at the lowest density (table 2). However, the average diameter of the high density stand was 3.2 compared with 4.7 feet at the low density (table 3). Where understory vegetation was removed, average diameter of the widely spaced stand was twice that of the closely spaced stand.

A consistent increase in yearly wood production was observed from the first period to the second (fig. 8). This was most impressive at the three wider spacings where vegetation was removed. Production from the first 4-year period to the second was almost doubled at the 13.2- and 18.6-foot spacings and tripled at the widest spacing.

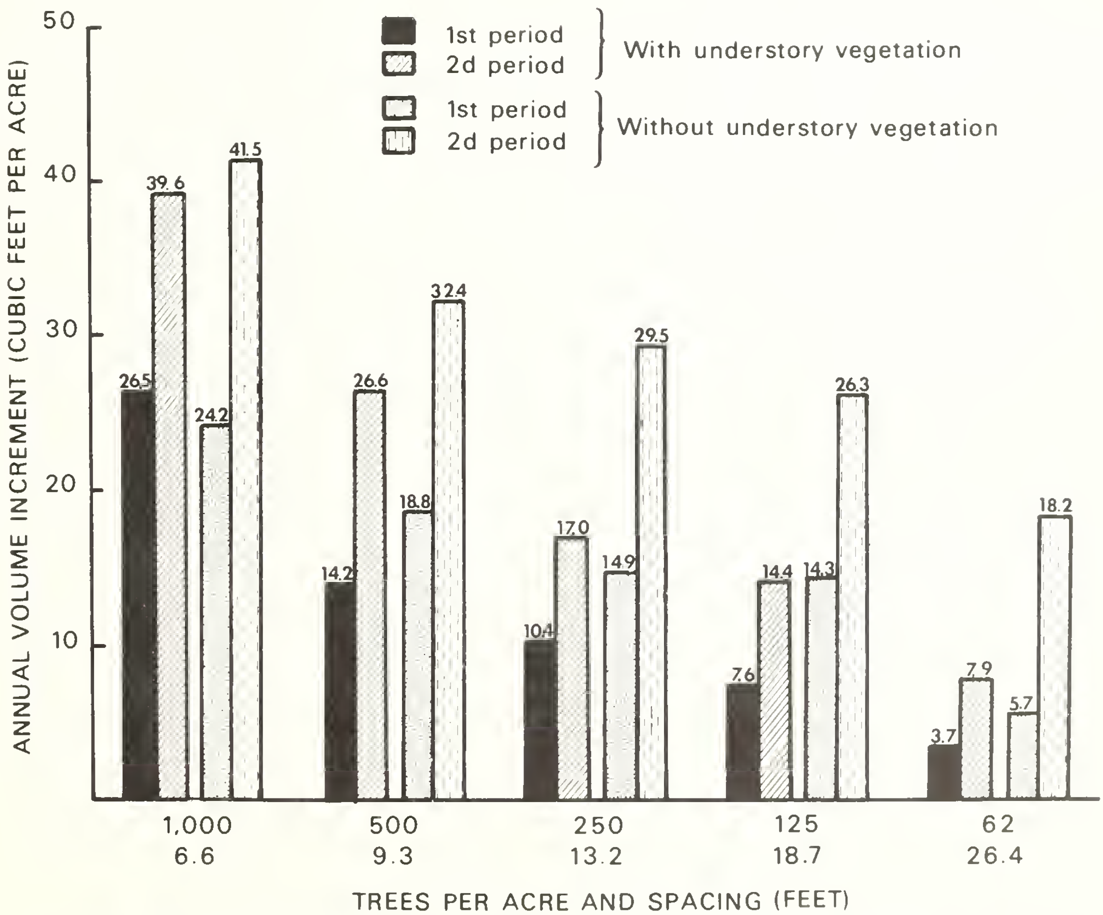


Figure 8. Average annual cubic volume increment of ponderosa pine saplings during the first and second 4-year periods.

Table 2.—*Net yield of ponderosa pine saplings at the end of the second 4-year period*

Treatment	Trees per acre				
	1,000	500	250	125	62
	Cubic feet				
Vegetation left	448	240	156	113	57
Vegetation removed	396	271	212	195	108

Table 3.—*Average diameter of ponderosa pine saplings in 1959 and 8 years later*

Treatment	Trees per acre				
	1,000	500	250	125	62
	Inches				
Vegetation left:					
1959	2.0	1.7	2.0	2.2	2.1
1967	3.2	3.4	4.0	4.6	4.7
Vegetation removed:					
1959	1.7	1.7	1.9	2.5	2.2
1967	3.1	3.7	4.7	5.7	6.2

Understory vegetation reduced volume increment during both periods, except for the 6.6-foot spacing during the first period. This effect was most pronounced at the two widest spacings during the second period where average reduction of cubic increment was about 50 percent. Furthermore, this increasing deterrent of understory vegetation on growth at wider and wider spacings (spacing and understory vegetation interaction) was significant at the 5-percent level of probability.

The full impact of understory vegetation and tree competition may be more readily comprehended by examining production of the largest diameter trees in each treatment. The cubic volume increments of the 500, 250, 125, and 62 largest diameter trees in each stand treatment are compared in figure 9. Where vegetation was removed, the larger trees in a spacing treatment always produced less annual volume than the same number of trees growing without any other tree competition. For example, the 250 largest trees in a 1,000-tree-per-acre treatment produce about 19 cubic feet per acre, but where only 250 trees are left, production is almost 30 cubic feet.

On the other hand, where vegetation is not removed, there is almost no difference between

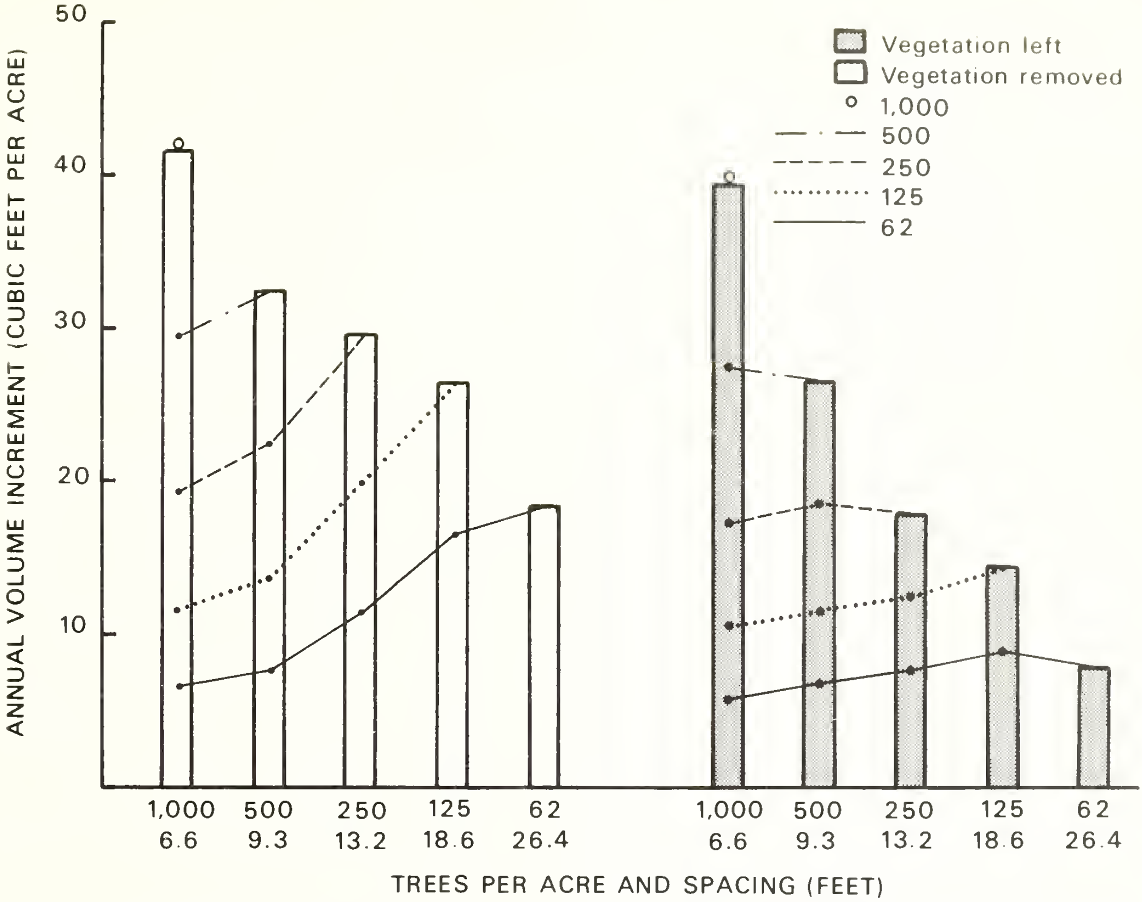


Figure 9.—Periodic annual volume increment of ponderosa pine saplings thinned to various spacings (1963-67). Bars show increment for total number of trees at each spacing. Points within bars show increment of the stated number of the largest well-distributed trees within the stand.

production rates for the same treatments and tree numbers. For example, there is little difference between the volume production of the "best" 250 trees in the 1,000-tree-per-acre treatment compared with that in a plot density of 250 trees. Similar conclusions can be drawn from other treatments and tree numbers. Evidently the growing space created by fewer and fewer trees was soon occupied by understory vegetation which offered as much competition or sometimes more than many more trees.

This suggests that maximum benefits from thinning will be gained only by maintaining some suppression of understory vegetation for at least part of the life of the stand.

Mortality

Only 12 trees died of a total of 2,232. Two-thirds of this mortality occurred where 1,000 trees per acre were left and was due mostly to *Armillaria* root rot, although the *Armillaria*-caused mortality was not related to spacing.

In terms of cubic volume, losses were extremely small. For example, the heaviest loss was at the 6.6-foot spacing where vegetation was left, and this amounted to only 0.5 cubic foot per acre per year during the last period. Losses on the other treatments were 0.1 cubic foot or less. No mortality took place during the first period.

Other Thinning Effects

The tree spacing to be selected in a precommercial thinning depends, in part, upon the total "product mix" desired from the forest, that is, wood, water, and forage. Narrow spacings tend to increase total wood production, if small trees can be used. On the other hand, wider spacings tend to favor forage and water production. Therefore, an understanding of the effect of thinning on forage and water is important in selecting an appropriate initial spacing.

Figure 10.–Ponderosa pine saplings thinned to a wide spacing (1959). Understory vegetation left (top). Understory vegetation removed (bottom).

Forage.–Thinning stimulated not only growth in diameter and height of trees but also growth of understory vegetation (figs. 10 and 11).

Four years after thinning, it was obvious that most thinned plots in this experiment where understory was left had considerably more understory vegetation than nearby unthinned stands. Furthermore, by this time there was a tendency for greater amounts of understory vegetation to occur at wider spacings except for the widest spacing. By 1967, we were tempted to speculate that vegetation was responding to the additional amounts of light, soil moisture, and nutrients provided by wider spacing, as differences in amounts of vegetation present at the various spacings were significant at the 5-percent level of probability. In addition, orthogonal comparisons showed a trend toward more understory vegetation at wider spacings, although the 125-tree-per-acre treatment averaged more understory vegetation than the 62-tree-per-acre treatment (as indicated in figure 11). Statistical tests showed no real difference between the two treatments.

Vegetation crown cover increased with time through all the spacings tested (fig. 11). For example, at the 6.6-foot spacing, density percentages ranged from 18 percent in 1959 to almost 29 percent in 1967 and at the 18.7-foot spacing, from about 29 to 47 percent.

Bitterbrush was the principal understory species, making up about 45 percent of the total vegetation in 1967. Snowbrush and grasses were also present but in lesser amounts. There was a surprising increase in sedge (15 percent of the area) at the 18.7-foot spacing, where in 1959 sedges had covered only 5 percent of the ground. Bitterbrush and Ross' sedge were the most responsive understory vegetation species to overstory removal and thinning.

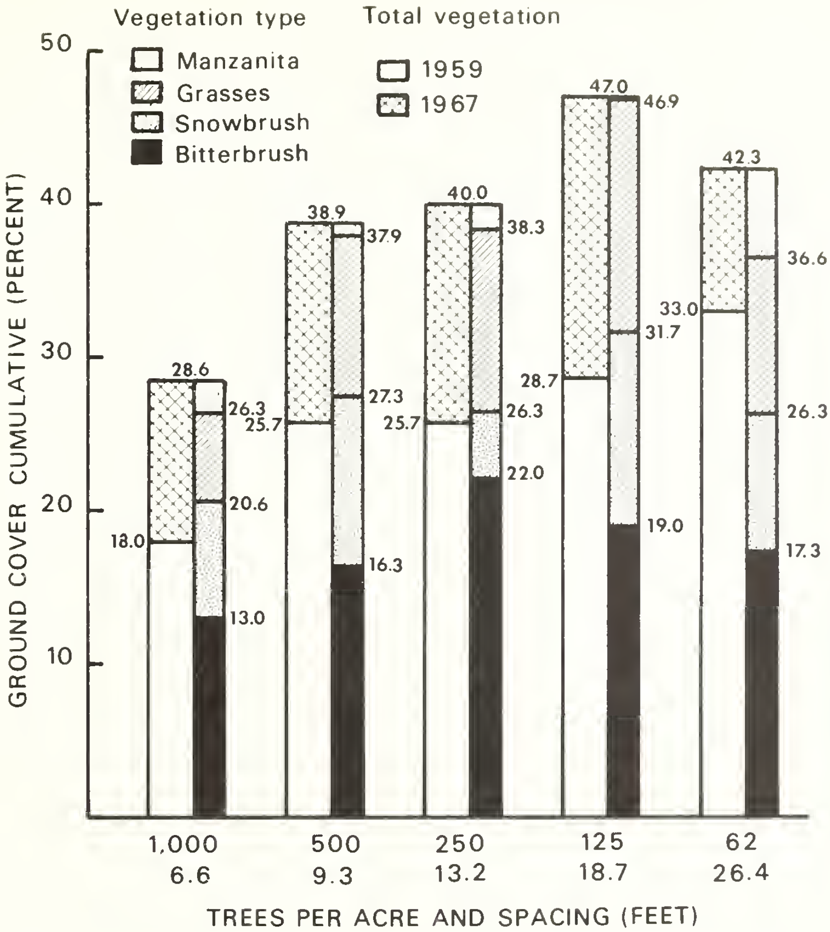


Figure 11.—Average percent of ground covered by understory vegetation in 1959 and 1967 and percent covered by type of vegetation in 1967.

These results indicate possibilities for increasing forage production for domestic livestock and wildlife. Thus, forage production and nutrition are being evaluated in this study (*5*) and in other spacing studies in ponderosa pine (*9*).

On plots where understory vegetation was removed and the ground kept clean, sedge was most difficult to eradicate. After sedge plants were removed with grub hoe, 1 year later they were established again and had developed extensive root systems. Bitterbrush seedlings were visible 2 to 3 years after hoeing.

Water use.—Overstory harvest, thinning, and understory vegetation removal have completely changed the water-use characteristics of this site. More water has become available for trees and possibly streamflow. When the soil moisture use in a stand containing mature overstory, dense understory trees, and natural understory vegetation is compared with soil moisture used in a stand thinned to 125 trees per acre and the understory vegetation suppressed, we find that moisture left in storage at the end of the growing season increased several years during and after 1961 by almost 50 percent. To illustrate, figure 12

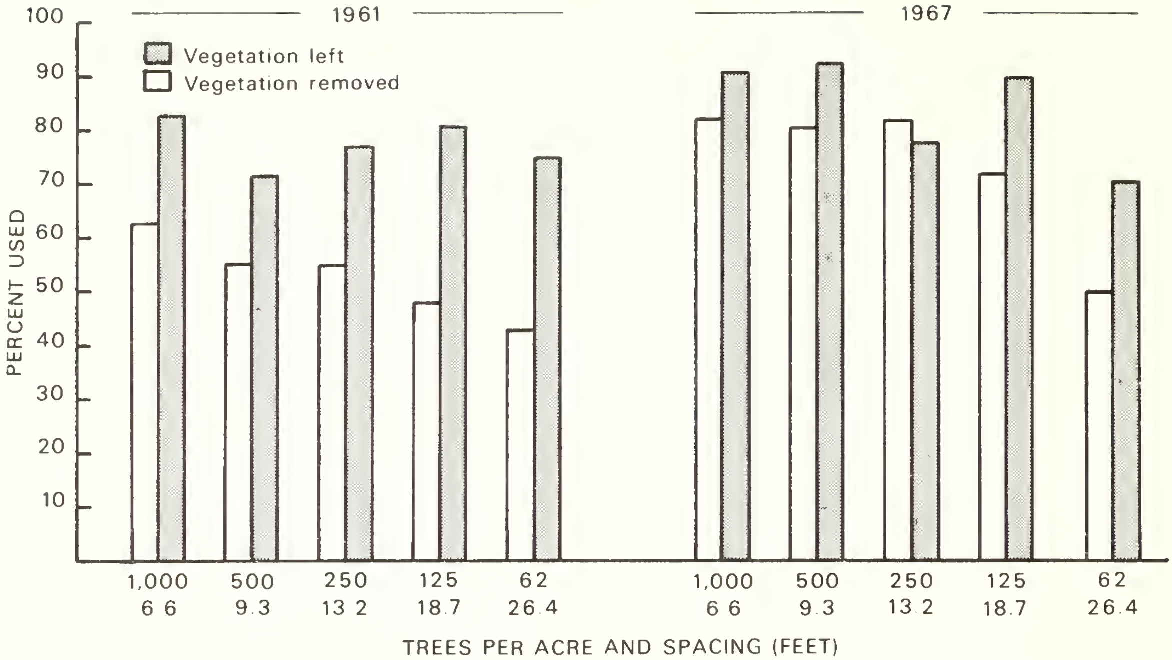


Figure 12.–Percent of available soil moisture used by ponderosa pine sapling stands thinned to different spacings.

shows that the 125-tree-per-acre treatment when vegetation was removed used only 48 percent of the soil water that is available for all vegetative growth. Other treatments show more or less water contributing to deep storage depending on tree density. If we thin to 125 trees per acre and let understory vegetation develop naturally, the gain over the untreated stand is about 20 percent. Even though this estimate is slightly high because of sampling point location, it does appear that the stand treatment would promote notable contributions to deep storage in some watersheds.

In 1961, several years after thinning, all plots where understory vegetation was left used an average of about 77 percent as much water as used by the untreated stand (fig. 12). In contrast, plots where vegetation was removed used only 53 percent of that used by the uncut stand. Six years later, in 1967, these percentages had risen to 83 and 73, respectively. Evidently, enlarged root systems and greater transpiring leaf area accounted for these changes. During the 8 years of observation, water-use figures indicate that the soil site complex was gradually being occupied by trees and understory vegetation, but total use had not been reached. For example (fig. 13), the untreated stand used almost 10 inches of water in the 5-foot profile, but the two narrowest spacings where understory vegetation was left used slightly less than 9 inches. Sensing only at the most critical position in the stand would indicate that it may not be long before complete utilization of the site will occur at the narrow spacings. On the other hand, where vegetation was removed and trees widely spaced, it may be some time before the site will be completely utilized.

A surprisingly small amount of soil moisture held in the 5-foot profile at the beginning

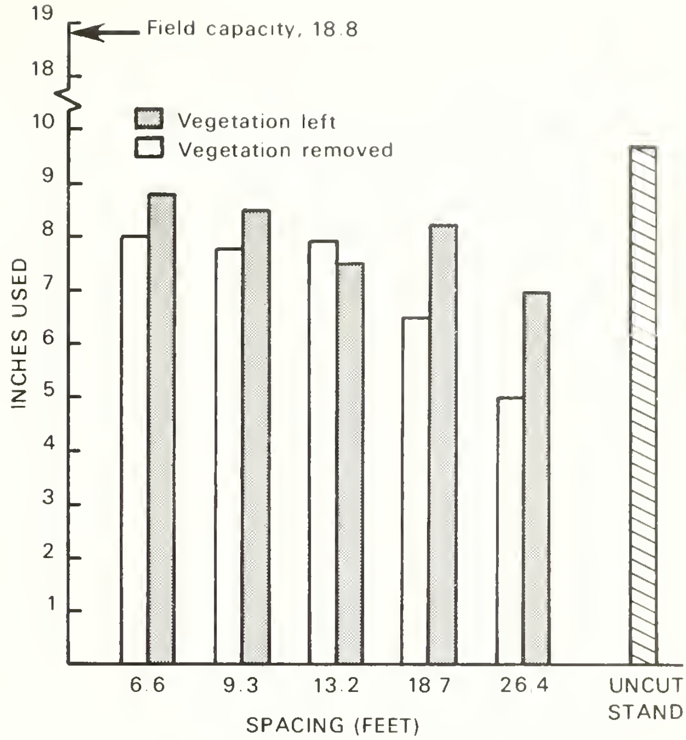


Figure 13.–Inches of water used by ponderosa pine sapling stands thinned to different spacings and by the uncut stand (1967).

of the growing season was actually used by the untreated stand. For example, in 1967 about 3.8 inches of water per foot was present in the profile, yet only 52 percent of this soil water was actually used by a stand that was obviously occupying the site. Some of this nonuse can probably be attributed to the lack of roots in the infertile C horizon. Thus, water is withdrawn heavily from the A, AC, and D horizons only. Dyrness and Youngberg (*7*) observed this on Lapine soils farther south in central Oregon and attributed it to a lack of fertility in the C horizon. Also, pumice subsoils are not easily penetrated by roots (*11*), i.e., the C horizon offers a physical barrier to root development. Where burrowing animals and windthrow have caused mixing of the C horizon with the buried soil, much greater root development has taken place and therefore greater water use. In addition, Cochran (*4*) reported that poor contact between plant roots and individual particles in pumice soils may impede the flow of moisture to the roots.

CONCLUSIONS

After 8 years of observation, the following may be concluded:

1. Diameter and height growth of sapling ponderosa pine may be accelerated by increasing growing space per tree and removing competing understory vegetation.

2. Limbs on released trees also respond to increased growing space and removal of competing vegetation.

3. Maximum benefits to tree growth from thinning will be gained by maintaining some suppression of understory vegetation development over at least part of the stand's life.

4. Thinning to a wide spacing and continued suppression of understory vegetation could appreciably increase water yield for domestic use.

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PREDICTING PRODUCT RECOVERY FROM LOGS AND TREES

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INTRODUCTION

Value of logs or trees is judged by buyers and sellers on the basis of some estimate of the amount of lumber, veneer, pulp, or other product that can be made from them. This paper discusses estimating equations, based on size of logs or trees, that can be used for such predictions. Some of these have been used for many years; other are of recent origin. Formula log rules are familiar to foresters who studied mensuration in college; other predictors will be strangers to most.

This paper briefs some historical development of timber product recovery prediction equations and demonstrates relationships among various equation forms. It states statistical considerations important in the development of such predictions. It discusses primary units of tree measure—volume, surface, and length. It shows that use of these units leads to equations with certain limitations on their predictive ability. It points out that these independent variables may be used for estimating other quantities of interest related to log and tree size such as sawing time, hauling costs, or log weight. Finally, it presents estimating equations that recently have been developed to predict volume of Douglas-fir lumber and veneer and value of lumber. It should serve as both a refresher on the subject of formula-type board-foot log rules and an introduction to newer product recovery predictors. Some of this is so new that it is a progress report on unfinished research.

Although discussion is divided into five sections, there is a development of the interrelations among the sections. This development contains a great many equations because such estimates are based on equations. Most new developments are presented as one further step from a previous equation. Hopefully, such a step-by-step approach will clarify some of the many ramifications and implications of these estimators and their transformations.

Regular Formula Log Rules and Some Variations

Log rules are one of the oldest kinds of estimators of lumber recovery from logs. One of the oldest formula log rules still in use was published by Clark in 1906 (*3*). He pointed out that allowance must be made for shrinkage and waste in estimating the volume of square-edged boards that could be manufactured from logs. He also indicated that shrinkage and kerf allowances were in proportion to the cross sectional area of the log (proportional to the square of diameter or D^2) and that allowances for circular form of log, minor crook, and average sweep were in proportion to the bark surface area (or for a given length in proportion to diameter or D). His basic equation for board feet of lumber in a 4-foot section of log, assuming 1/8-inch kerf, is $B = 0.22D^2 - 0.71D$ (where B is board feet of lumber and D is scaling diameter in inches). In this, the coefficients (0.22 and 0.71) include the allowances he found suitable in studies of hardwoods and conifers in the Northeast. When this basic 4-foot equation is used for longer logs with an allowance of 1-inch-in-8-feet increase in diameter, the equation becomes $B = aD^2 + bD + c$ with the coefficients (a, b, and c) changing for each log length.

The Scribner log rule is not a formula log rule, but an equation was published in 1925 (*1*) that does a good job of duplicating Scribner estimates. This is based on the same equation form as one given in the last paragraph for the International rule. This equation also serves as the basis for several other log rules. Some coefficients for 16-foot logs are

Log rules	*a*	*b*	*c*
Scribner	+0.79	-1.98	-4.30
British Columbia	+ .76	-2.28	+1.71
International 1/4-inch	+ .80	-1.37	-1.23
Doyle	+1.00	-8.00	+16.00

To convert most of these to rules for logs of any length, it is necessary to divide the coefficients by 16 and put the unknown length (L) into the equation

$$B = a'D^2L + b'DL + c'L.$$

In this form, the first term can be recognized as proportional to scaling cylinder volume, the second term to scaling cylinder lateral surface, and the third term to length.

Since the International rule allows for taper, the coefficients of its equation must be determined from the basic equations for 4-foot sections, first reducing the coefficients by dividing by four and then averaging the coefficients for the indicated number of 4-foot sections. A six-term equation written by Schumacher (*10*) does this for logs of any length. Some coefficients for logs of different lengths are

Log rules	*a′*	*b′*	*c′*
Scribner	+0.049	-0.124	-0.269
British Columbia	+ .048	- .143	+ .107
International 1/4-inch (16-foot logs)	+ .050	- .086	- .077
International 1/4-inch (32-foot logs)	+ .050	- .014	- .063

Log rules with such coefficients are useful for estimating board feet of potential lumber. If we want to compare volume of lumber with volume of log (the recovery ratio or percent recovery), we have to change these coefficients. The easiest change is to compare the volume of lumber with the volume of scaling cylinder (recognizing that this is an approximation since logs have slightly more volume than their scaling cylinders). The cubic-foot volume of the scaling cylinder (C_C) is

$$C_C = 0.00545\,D^2L.$$

Dividing this into the Scribner board-foot estimate, we get

$$B_S/C_C = (0.049D^2L - 0.124DL - 0.269L)\,/\,(0.00545D^2L)$$
$$= 9.06 - 22.7/D - 49.3/D^2.$$

This estimates board feet of lumber per cubic foot of scaling cylinder. It can be changed to a rough estimate of recovery ratio by changing board feet of lumber to cubic feet of lumber. Dividing both sides of the equation by 12 does this:

$$B_S/12C_C = C_S/C_C = 0.75 - 1.89/D - 4.11/D^2.$$

This equation shows that Scribner formula rule estimates, converted to cubic feet of rough green lumber, are three-fourths or less of the total cubic volume of the scaling cylinder. Since the scaling diameter and its square appear in the denominators of terms with negative coefficients, the predicted recovery is lower for smaller logs. Predicted percentage converted to lumber of any log is less than this because the log is larger than the scaling cylinder.

If it is assumed that logs of a given length are frustums of either cones or paraboloids and an equation is written showing Scribner estimates of lumber recovery per cubic foot of the entire log (C_L), instead of just the scaling cylinder, the result will be

$$C_S/C_L = a + b/D + c/D^2 + d/D^3 + e/D^4 + f/D^5 + \ldots$$

In this equation, the terms with the cube and higher powers of D enter because the log is tapered.[1] The effect of these terms is quite small.

A similar equation for International 1/4-inch estimates of lumber recovery for 16-foot logs, which assumes conical taper of 1 inch in 8 feet, divided by cubic volumes of the same shape logs is

$$C_I/C_L = 0.76 - 2.84/D + 4.53/D^2 - 4.49/D^3 + 3.02/D^4 - 4.03/D^6 + \ldots$$

If the International equation for logs of all lengths (*10*) is divided by the cubic volume of conical "logs" of the same lengths, the first two terms stay the same but succeeding terms have powers of L in their numerators.

These equations, expressing lumber recovery in cubic feet as a fraction of log cubic volume, can be changed back to estimates of recovery in board feet of lumber per cubic foot of log by multiplying all coefficients by 12.[2]

There are two things I want to emphasize about these formula log rules: (1) Board-foot log rules are estimates of lumber recovery. The numbers on scale sticks are units of estimate, not units of measure. (2) When we express lumber recovery as cubic feet of rough green lumber per cubic foot of log, we are well on our way to accounting for all the fiber in the log. When we also compute or measure the cubic feet of sawdust per cubic foot of log, we can estimate the cubic feet of chippable residue.

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[1] The equation for the volume of the frustum of a cone, where $(D_L - D_S)/L = a$ (i.e., a is increase in diameter per foot of length when D_S is small end diameter and D_L is large end diameter) is

$$V = \pi L\ (D_S^2 + aD_SL + a^2L^2/3)/4.$$

For logs of a given length, this reduces to

$$V = bD_S^2 + cD_S + d$$

which gives the series indicated when divided into the Scribner equation. Similarly, the equation for a frustum of a paraboloid of a given length reduces to

$$V = eD_S^2 + f$$

which gives a similar series.

[2] This assumes the dimensions of rough green lumber are the nominal dimensions. Other assumptions about dimensions require conversion factors ranging from about 11 to 13.

Empirical Log Rules and Batch Studies

In 1940, Schumacher and Jones reported a study of empirical log rules (*10*). This report includes three important principles.

The first principle is that a rational and useful algebraic form for estimates of lumber recovery (B) in mill studies is

$$B = aD^2L + bDL + cL.$$

This three-term equation is the same as the formula log rule. This means that such log rules are no more empirical than the log rules just discussed since they use the equation based on Clark's theoretical work. What distinguishes them is that they rely on least squares fitting of the equation to observed data.

The second principle is that to get least squares estimates, unaffected by unequal variances, this equation must be weighted. Schumacher stated ". . . As volume is a function of the product of linear dimensions, it is to be expected that the standard deviation of volume of single logs . . . is proportional to D^2L." He demonstrates this by showing that a sloping straight line fits the standard deviations of volume of 820 logs divided into 30 size-classes and plotted over size-class. Statistically, this requires the sum of squared residuals to be weighted by the reciprocals of variances. This is accomplished by dividing both sides of the equation by D^2L. When the dependent variable is divided by D^2L, we get for a new dependent variable a value proportional to board feet of lumber divided by volume of scaling cylinder. We could further scale the variables by dividing them all by 0.005454 in which event our "transformed" dependent variable would be ratio of board feet of lumber to cubic feet of scaling cylinder:

$$B/0.005454D^2L = B/C_C.$$

Since dividing all observed values by a constant has no effect on the coefficients derived by least squares, this step is unnecessary when processing data. It is only useful if we want to look at observed values of board feet of lumber per cubic foot of scaling cylinder.

Dividing by D^2L also gives us dimensionless ratios for dependent variables that do not have built-in high correlations with the independent variables. Such high correlations sometimes lead to acceptance of functions that do not estimate as well as those derived from analysis of dimensionless ratios. There appears to be a tendency to accept oversimplified functions that have high correlations.

The third principle that Schumacher discussed is the suitability of the basic algebraic relation for analysis of batch data. This idea was suggested by Sir Ronald Fisher in 1936 at a seminar in Asheville, N.C. The problem was allocation of transportation costs to logs of different sizes when there was a fixed rate (Y) for each full carload. The equation for each carload he suggested was

$$Y = a\Sigma D^2 + b\Sigma D + cN$$

where Σ is sum for each carload and N is number of logs for each carload. This was to be fitted for all observed carloads. This batch equation has been used by Day and by Hasel in logging cost problems (*5, 8*), by Chisman and Schumacher and by Lexen in stand density studies allocating areas to trees of different sizes based on plot summaries (*2, 9*), and by Schumacher and Jones in the study of empirical log rules I have already mentioned (*10*).

Other uses that are appropriate are studies of log weights based on truck weighing and studies of the effect of log size on sawing time based on shift totals.

The principle involved in such studies is that where only the total Y is observed it represents the sum of individual y's for each member of the batch, group, or plot. Where each individual y is highly correlated with the size of the same individual, and the relation can be expressed in an equation with linear coefficients, analysis of sets of data using only totals will yield equations that predict individual y's.

It should be apparent that Fisher's equation

$$Y = a\Sigma D^2 + b\Sigma D + cN$$

would be rewritten if there were much variation in log length as

$$Y = a'\Sigma D^2 L + b'\Sigma DL + c'\Sigma L.$$

This is the unweighted form of the equation that Schumacher and Jones fit to data on logs used and lumber produced on each of 18 days at a small sawmill. They compared the standard error of their batch equation with a standard deviation of volume from the 820 individual observations and estimated that 23-day totals would have been required for the same amount of information on single saw logs that was contained in direct measurement of 820 individual saw logs.

Cubic Volume, Surface Area, and Length Are Primary Units of Tree Measure

In 1954, Grosenbaugh showed that log total cubic volume, surface area, and length could be substituted for corresponding measures of the scaling cylinder in log rules (*6*). Several years later, he described the use of these primary units in product recovery studies and for other purposes (*4*).

The benefits of this change in variables are apparent in tree estimates. Each tree has but a single total merchantable cubic volume, surface area, and length. Repeated careful measurements should be extremely close to these totals. Each tree can have many different $\Sigma D^2 L$ and ΣDL since there are many different ways to buck the tree and each $D^2 L$ and DL is based on a particular scaling cylinder. Further, the total volume of the scaling cylinders is less than the merchantable volume of the tree. When a tree is a candidate for more than a single use, it is convenient not to have to generate separate sets of scaling cylinder dimensions for saw logs and for veneer blocks.

In some trees, all logs are in a single stratum of quality and defect.[3] In other trees several strata of quality and defect can be recognized. Fisher's batch equation appears suitable for use on trees or on strata within trees. Because log dimensions within each tree are progressively smaller the coefficients of estimating equations differ somewhat from those based on random batches of logs.

Grosenbaugh also has showed how weight can be substituted for cubic volume as a primary unit of log measure (*7*). Truck scales make this one of the quickest ways to measure logs. Total length of logs on the load should also be recorded so that these two

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[3] It is assumed that external indicators exist that suggest changes in value of product (quality) and changes in volume of product (defect).

measures can be substituted in product estimating equations for volume and length. Generally the weight/volume ratio for a given class of logs does not vary much, so estimators based on weight will be as accurate as those based on volume. Obviously the weight/volume ratio varies with species, is different for small cold decked logs than for those measured soon after cutting, and may also vary with log diameter. But these sources of variation also require different product estimating coefficients. If it is feasible to aggregate the square root of the product of weight and length, this aggregate figure can be substituted for surface area in estimating equations.

The idea that surface area is a unit of log or tree measure seems hard for some people to grasp. Most are quite ready to accept length and cubic volume as units of measure—length is a basic unit and volume is a derived unit, the product of three lineal dimensions. When a surface is flat, it is customary to measure it in acres, square feet, or square inches—the product of two lineal dimensions. The log surface we are interested in is the inside bark surface which excludes the end surfaces. It can be visualized as a flat sheet wrapped around a solid whose shape is almost cylindrical.

For cylinders measured in feet of length and inches of diameter, we have

Cubic volume:	C(cubic feet) = $D^2L/183.3 = 0.005454\,D^2L$.
Surface area:	S(square feet) = $DL/3.819 = 0.2618\,DL$.
Length:	L(feet) = L.

The equations for frustums of cones and paraboloids, which usually approximate log shapes more closely than cylinders, are only a little more complicated. They may be based on length and diameters of both ends, and each can be related to diameters of the same length cylinder having equal volume or surface. Diameters of these cylinders are about midway between the two end diameters of the frustums and can be called equivalent cylinder diameters (D_E).[4] My reason for mentioning this comes from consideration of the equation expressing cubic feet of lumber (Y)

$$Y = aC + bS + cL.$$

When this is weighted by dividing by C (the equivalent of D^2L in previous equations), it becomes

$$Y/C = a + bS/C + cL/C.$$

This can be rewritten in terms of equivalent cylinder diameters:

$$Y/C = a + 0.26\,bD_EL/0.0054D'^2_E\;L + cL/0.0054D'^2_E\;L$$

which can be simplified to

$$Y/C + a + b'/D''_E + c'/D'^2_E$$

where D'_E and D''_E are slightly changed values of D_E.

The next step is to extend this concept of equivalent diameters from logs, where they approximate mid-diameters, to trees. In trees the diameters (and squared diameters) corresponding to $(\Sigma C/\Sigma S)$ and $(\Sigma C/\Sigma L)$ are weighted averages, not simply half the basal

[4] The equivalent cylinder diameter based on S is not identical to that based on C.

diameters or their squares. The ratios of these sums include the information on average log size that is needed to make good estimates of product recovery for trees.

Another way of viewing this is that when we use C, S, and L in a weighted analysis we are really fitting a function that includes reciprocals of a diameter and a squared diameter. In most of the rest of this discussion, I shall use only this last form of the equation or a closely related one based on cubic volume and scaling diameter.

When the weighted product recovery equation

$$Y/C = a + bS/C + cL/C$$

is fit to data from trees with two strata of quality or defect, it may be written in the form of a batch equation

$$Y_T/C_T = aC_1/C_T + bS_1/C_T + cL_1/C_T + dC_2/C_T + eS_2/C_T + fL_2/C_T$$

where the subscripts

T is individual tree total,
1 is stratum 1 total in each tree, and
2 is stratum 2 total in each tree.

With this form of the equation, the individual sections that produce each board or each sheet of veneer are not identified and are not necessarily the same as the sections recognized in the tree. A tree that has more of its volume in high quality sections than another tree will produce a greater proportion of high quality products. Where Y_T is total product value, it will tend to be higher even when the high quality tree section is less than a full log in length. The efficiency of this form of the equation is being tested.

The coefficients of this equation depend not only on how the tree is bucked but also on the efficiency and product objectives of the mill. It should be apparent that each set of coefficients will serve only for the mill at which it was produced. Area averages will be based on several studies which include different bucking rules and different mill objectives and efficiencies.

Characteristics of Equation $Y = a + b/D + c/D^2$

Since both the theoretical log rule equation and the tree product equation based on volume, surface, and length are transformed by weighting to the same form, it seems appropriate to examine some of the characteristics of this equation. This will give insight into why the equation works and also into some of its limitations.

Figures 1 and 2 show different families of curves that are generated by holding two of the coefficients constant and requiring the third coefficient to be either positive or negative. Figures 1A and 1B have the coefficient of one of the reciprocal terms set at zero and the other negative. These families show lower Y values as D gets smaller. The rate at which Y decreases depends on whether the coefficient that varies belongs to the D or D^2 term. Figure 1C, with both coefficients of the reciprocal terms negative, is intermediate in shape between figures 1A and 1B. It is easy to visualize the effects of positive coefficients. The families of curves would be symmetrical around the line $Y = 0.7$ to those plotted. However, all curves as plotted show the decline in recovery ratio that is typical of small diameter logs in sawmills or veneer mills. Figure 1D is included to show

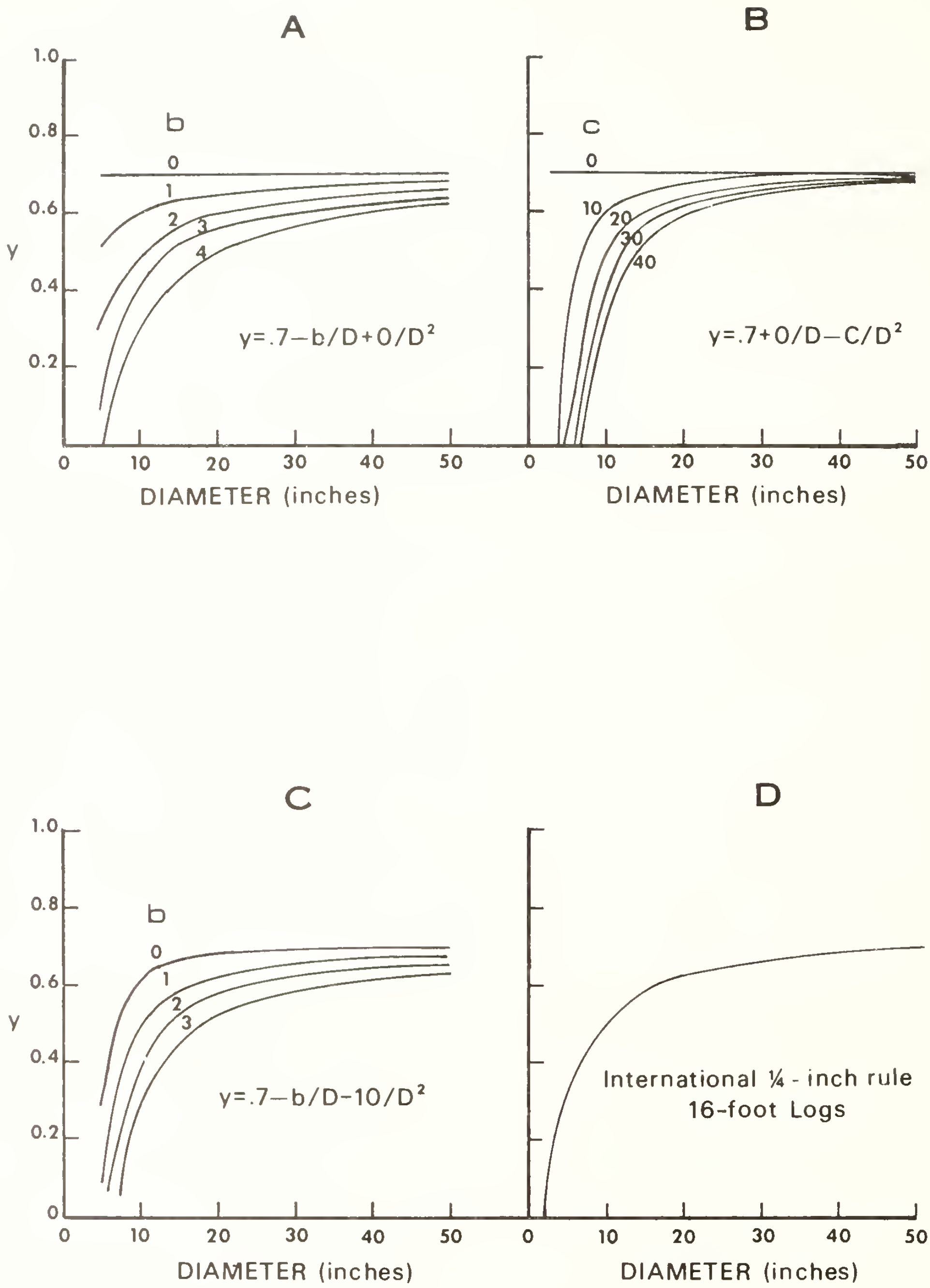

Figure 1.—Families of curves: $Y = a + b/D + c/D^2$.

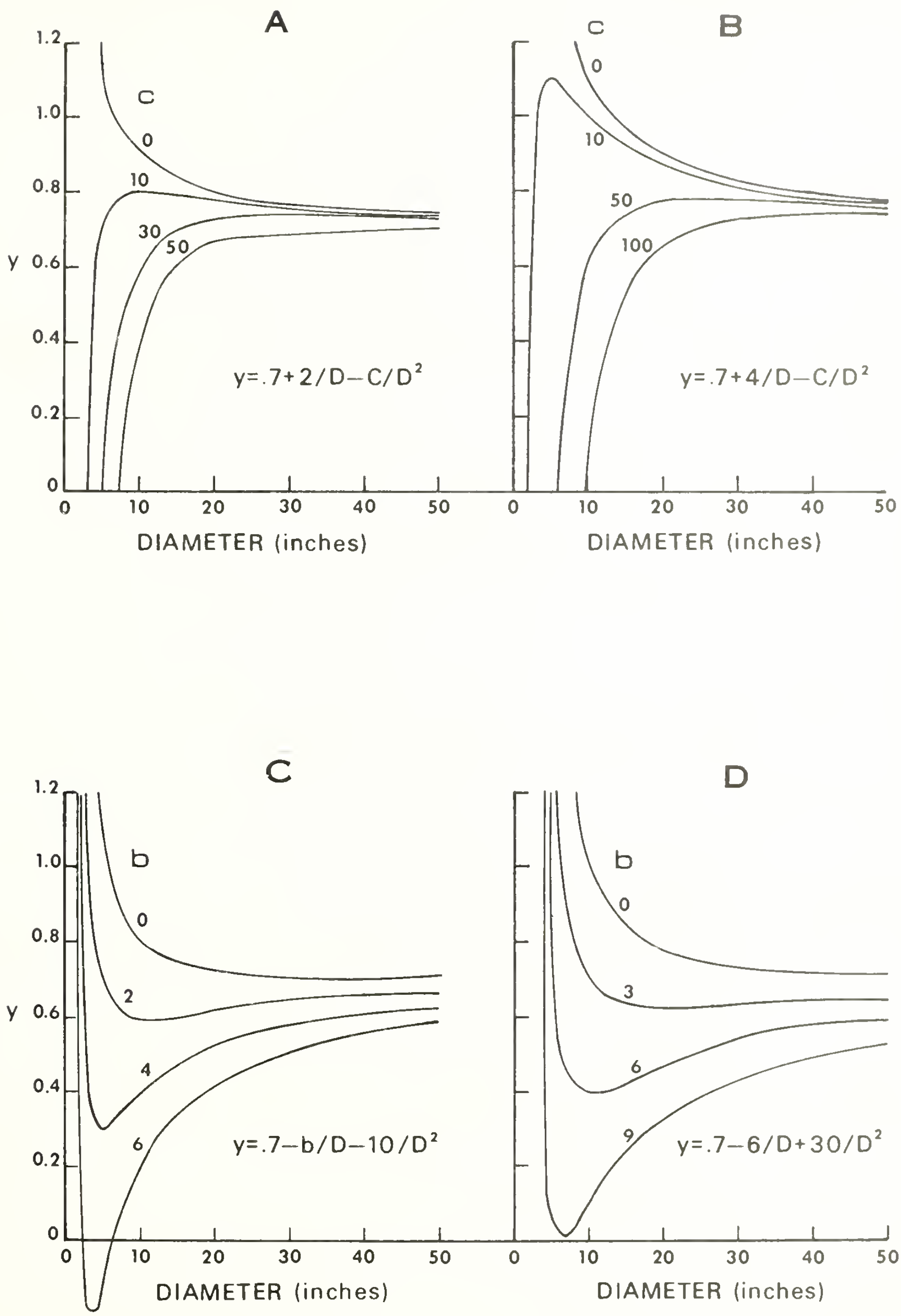

Figure 2.—Families of curves: $Y = a + b/D + c/D^2$.

that the family of curves in figure 1C describes the lumber recovery ratio estimated by the International rule.

Having looked at some well behaved curves belonging to the family, the reader should consider some that appear erratic. Figure 2 illustrates some of the families generated when the coefficient of one of the reciprocal terms is positive and the other negative. Mirror images of these (rotated around $Y = 0.7$) can be produced by multiplying the coefficients of the second and third terms by -1. When such equations fit product recovery data, it usually is essential that the equations not be used for small logs and may be necessary to restrict any use of the equation to all the logs or trees from which they were derived. These restrictions seem much less important for the families of curves plotted in figure 1.

Some of these curves, such as the upper two in figure 2B, may fit data from a batch of large logs (none under 18 inches) with defect increasing as diameter increases. Others, such as the third and fourth curves in figure 2D, may fit data where the recovery ratio or other dependent variable drops markedly between 40 and 20 inches. The shape of this last curve suggests that other functions might better fit the data.

If in fitting these weighted equations either of the coefficients of the last two terms is not negative or close to zero, the estimates should be plotted over diameter to see whether estimates for small diameters are reasonable. With negative coefficients, unreasonable estimates are less likely, but it is still possible to get estimates of zero recovery for 7- or 8-inch logs or positive recovery for 3- or 4-inch logs. This happens because mill recovery studies seldom include logs whose diameter reduces recovery to less than about 35 percent.

When solving equations in volume, surface, and length, it is convenient for plotting purposes to assume 1 inch of taper in 8 feet and reduce equivalent diameters (middle diameters) to small end diameters.

Product Recovery Equations for Lumber and Veneer

These equations have been fit to data gathered by this Station's Grade and Quality of Western Timber Project at three mills. The coefficients presented are for illustrative purposes only, and their use should be limited to this purpose or to the mill and assumptions for which they were derived.

Figure 3A, showing cubic volume of lumber recovery as a ratio to volume of log, demonstrates similarities among three mills. The equations on which these curves are based are

1. $Y/C = 0.660 - 1.31/D - 0.182Z$ (solid line) ($N = 445$ logs).
2. $Y/C = 0.627 - 0.95/D - 0.270Z$ (dashed line) ($N = 360$ logs).
3. $Y/C = 0.649 - 0.01/D - 10.7/D^2 - 0.077Z$ (dotted line) ($N = 561$ logs).

Similar equations that give nearly identical estimates based on log volume, surface, and length, instead of log volume and scaling diameter, are

1. $Y/C = 0.661 - 0.031S/C - 0.187Z$.
2. $Y/C = 0.623 - 0.020S/C - 0.205Z$.
3. $Y/C = 0.626 - 0.018S/C - 0.109L/C - 0.067Z$.

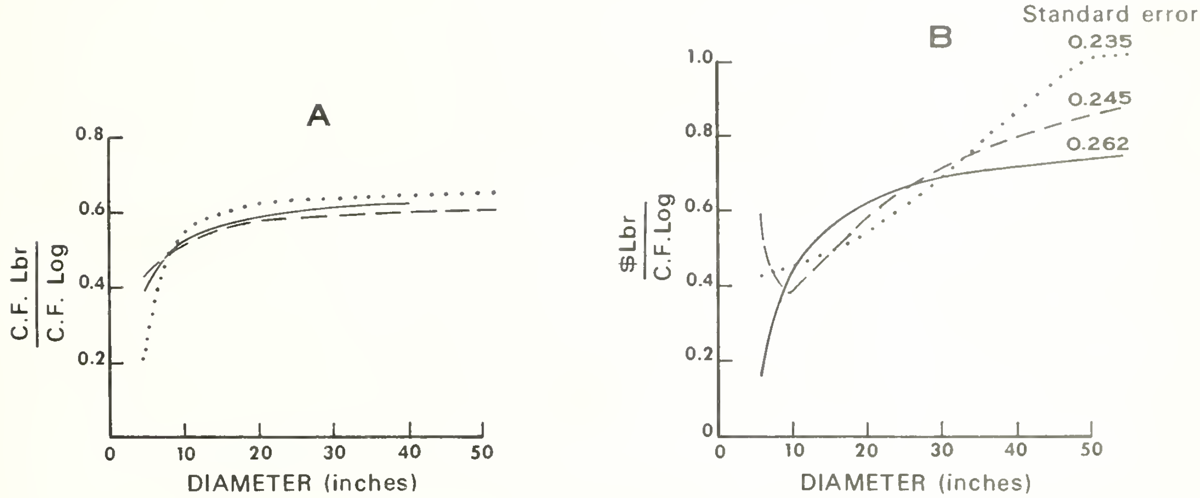

Figure 3.—Cubic feet of Douglas-fir lumber per cubic foot of log for three sawmills in Oregon and Washington.

To convert these equations to direct estimates of product volume, both sides should be multiplied by C. The last equation becomes

$$Y = 0.626C - 0.018S - 0.109L - 0.067ZC.$$

The Z in these equations is the defect ratio for those defects visible in the standing tree, i.e., the scaled defect deduction divided by the gross scale. The graphs show recovery for logs with average Z. Sound logs had only 0.01 greater recovery. Had all defects, including those visible on ends of logs, been used, this Z term would have had a larger effect.

The most effective weighting factor to use in these analyses appears to be cubic feet of log, not cubic feet of scaling cylinder or D^2L. In fitting of such weighted equations, the independent variables that usually have the smaller mean squared residuals are reciprocals of scaling diameters or their squares rather than the ratios L/C and S/C. These equations may provide the basis for judging the efficiency of other analyses of the same data either as individual logs or as entire trees.

When product value is substituted for product volume as dependent variable, the irrational curves previously mentioned sometimes result (fig. 3B). The dashed curve (based on $1/D$ and $1/D^2$) fits the data better than the solid curve (based on $1/D$). However, the lower end of this dashed curve is not acceptable as an estimate of value of small logs.

This strange curve can be explained. Dollar value of lumber per cubic foot of log is the product of lumber value for logs of different sizes and the ratio of lumber volume to log volume illustrated in figure 3A. If the range of lumber values from Select to Economy is 4 to 1, we can picture an average value per board foot falling steeply with log diameter from large clear peelers to limby upper logs.

The family of curves

$$Y = a + b/D + c/D^2$$

includes such rapid declines from 40 or 50 inches to 20 inches only in curves illustrated in figures 2C and 2D. These curves do not describe a steeply falling value in the middle and values that change gradually at the ends of the data.

The standard errors shown in figure 3B show the improvement in estimates from another function (dotted line). This is

$$Y = 0.383 + 2.72 \times 10^{-4} D^2 - 1.35 \times 10^{-9} D^5 - 0.490Z.$$

To estimate veneer recovery, I diagrammed a log to show how it might be converted to veneer (fig. 4).[5] This required several assumptions. The most important of these was

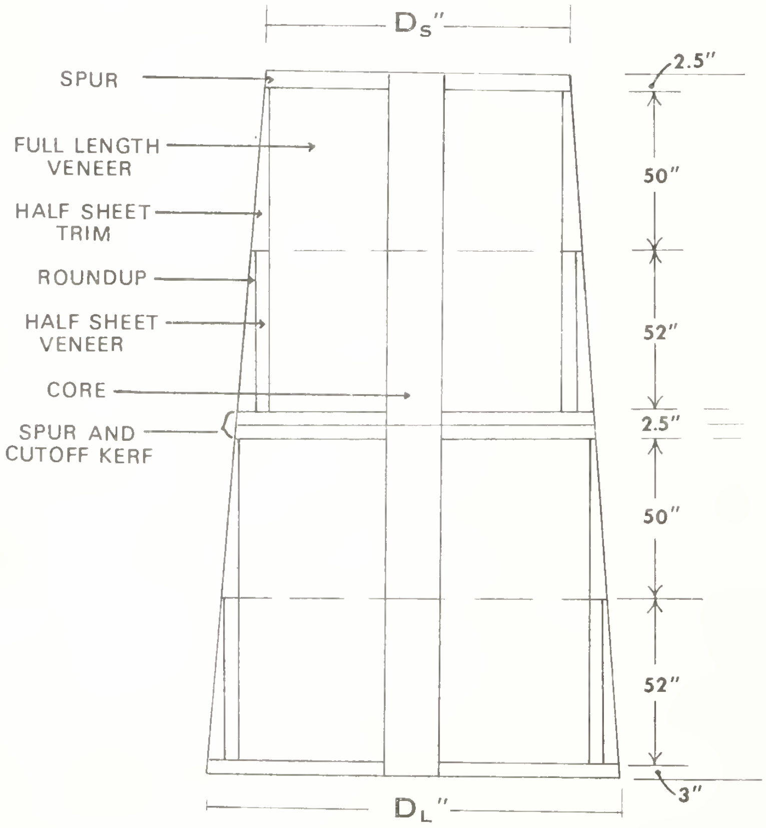

Figure 4.—Calculation of volumes in veneer logs (17 feet, 8 inches).

[5] Richard O. Woodfin, Jr., in the Station's Grade and Quality of Western Timber Project, provided information about veneer production and the approximate dimensions involved.

that all logs get a small diameter deduction for surface roughness and that out-of round logs get a deduction proportional to their diameter. These two deductions are for the material wasted before a full ribbon of veneer falls on the table. This diagram (fig. 4) was used to estimate green volume allocated to the veneer and several byproducts (assuming conical taper). These estimates are the basis for figure 5 which shows theoretical veneer recovery. Figure 5 shows that the diameter related losses due to taper and out-of-round may be nearly balanced by losses due to spur, kerf, and veneer shrinkage. Figure 5 can be compared with figure 6 which illustrates the recovery observed at one mill. The estimating equations for figure 6 are

Dry veneer	$y_1/C = 0.692 - 76.4/D^2 - 0.727\,Z.$
Core	$y_2/C = 0.031 + 72.4/D^2 + 0.022\,Z.$
Chippable waste and shrinkage	$y_3/C = 0.277 + 4.0/D^2 + 0.706\,Z.$

These equations are based on 193 8-foot blocks with an average recovery ratio of 48 percent and average scaled defect of 10 percent. This defect deduction is based on log scaling. Note the closeness of the dashed line on figure 5 to the estimates for sound logs on figure 6. Also note that the sum of the y intercepts is 1.000 and the sums of the coefficients are close to 0. This shows that all the volume of the log is accounted for by the three estimates.

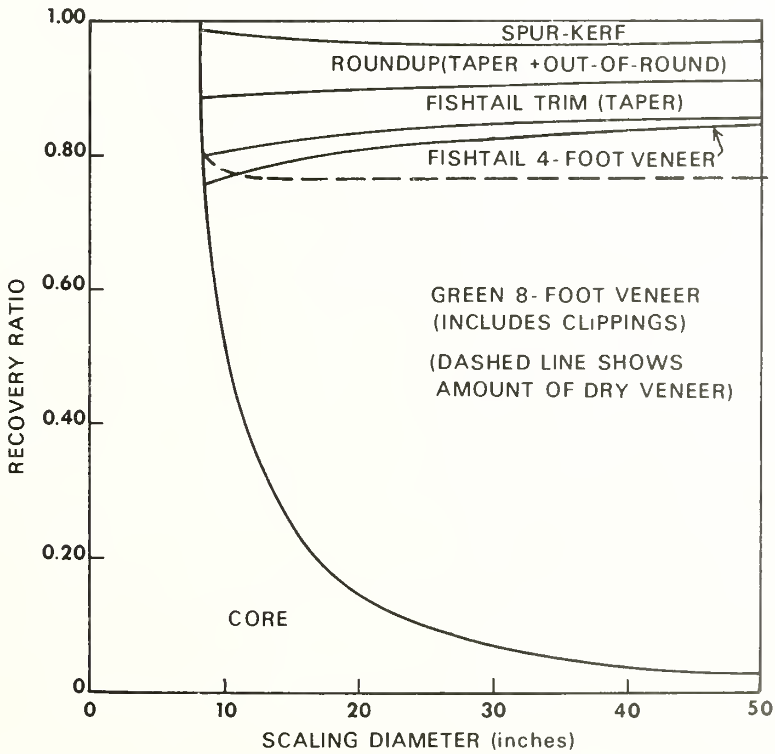

Figure 5.—Theoretical veneer recovery.

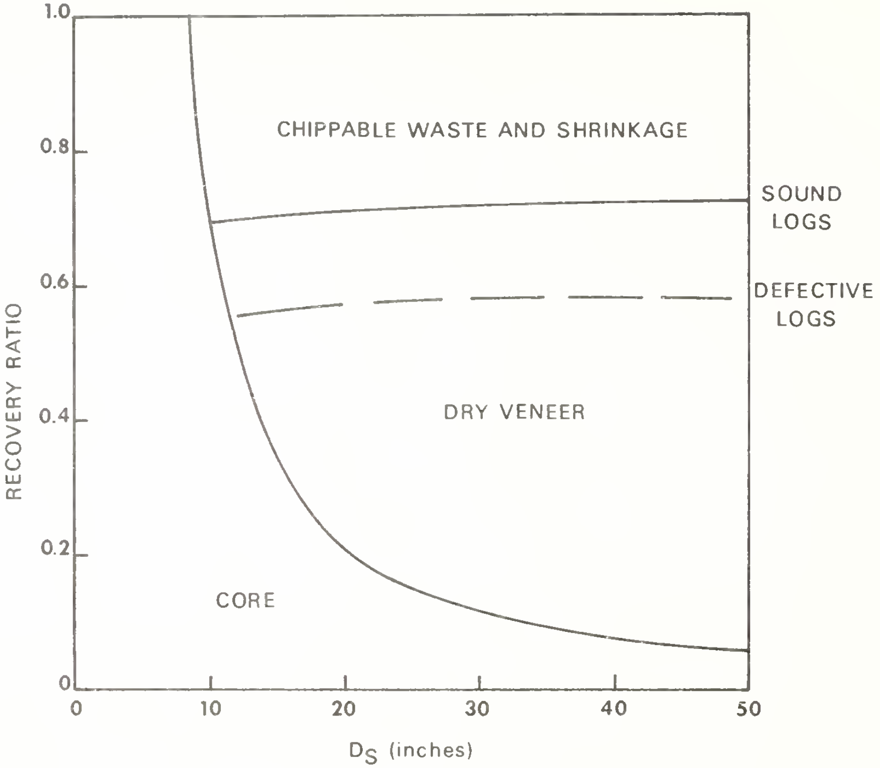

Figure 6.—Estimated veneer recovery based on observations at one mill.

SUMMARY

A theoretically based equation that has been used for formula log rules appears suitable for product recovery estimates

$$Y = aD^2L + bDL + cL$$

or, in another form,

$$Y = aC + bS + cL.$$

It has been shown that it usually should be fit by least squares as a weighted relation

$$Y/D^2L = a + b/D + c/D^2$$

or

$$Y/C = a + bS/C + cL/C.$$

Occasionally, these equations give wild estimates for small diameters, but such equations can be avoided.

There are benefits from using three units of tree measure (volume, surface, and length) rather than summations of measurements of scaling cylinders. A major one is the use of a single set of tree measurements to estimate different potential products. This same set of measurements can be obtained repeatedly by different observers.

There is no requirement that the quality or defect sections measured on the tree be identical with those into which the tree is bucked. The equation for two quality-defect strata within trees is

$$Y_T/C_T = aC_1/C_T + bS_1/C_T + cL_1/C_T + dC_2/C_T + eS_2/C_T + fL_2/C_T.$$

These equations have been tried for lumber and veneer recovery and work well for both.

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Estimates of potential amount of one or more products are a basic step in judging value of logs and trees. Amount of lumber has been estimated for many years by log rules, some of which are stated as equations. This paper shows how similar equations can be used to get estimates of products and byproducts other than lumber. It examines some statistical considerations important in use of these equations and their limitations as predictors. It should resolve some misconceptions about what log rules are and point the way to more refined predictors of product recovery.

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Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

1. Providing safe and efficient technology for inventory, protection, and use of resources.
2. Development and evaluation of alternative methods and levels of resource management.
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1970

OUR SAWDUST AND BARK
TS ORIGIN, PROPERTIES, AND FFECT ON PLANTS

by W. B. BOLLEN and K. C. LU

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE
PORTLAND, OREGON

CONTENTS

INTRODUCTION

Large amounts of sawdust from the Pacific Northwest lumber industry are used as horticultural mulch, providing a market for a product that not long ago posed a disposal problem. Ground bark is now also in demand by horticulturists and home gardeners. Bark also is subject to many of the changes applicable to sawdust, and the information presented in this paper is pertinent to processors and users of either material.

Partially rotted sawdust is generally preferred for horticultural use over fresh material because of its more pleasing dark color and its lower demand for nitrogen. Most horticultural sawdust is highly beneficial to plant growth (Allison and Anderson 1951, Shutak and Christopher 1952, Dunn, Macdonald, and Baker 1952, Lunt 1955, Anderson 1957, Bollen and Glennie 1961). However, some darkened sawdust is strongly acid and produces fumes toxic to vegetation (Bollen and Lu 1966).

Sawdust is usually stored in large piles (fig. 1). Under such conditions, moist sawdust may become compacted to the extent that air is excluded from the center of the pile. In the absence of free oxygen, anaerobic micro-organisms generate various organic acids and produce heat (Carlyle and Norman 1941, James and Lejeune 1952).

Figure 1.—Sawdust storage pile with sour center. Source of samples 1 and 4.

As heating of the interior of the sawdust pile increases, thermophilic microbes add to the total energy conversion until temperatures become high enough to inactivate all microbial life. Heating is further increased by interaction of the chemical products and autooxidative processes, often leading to charring, if not spontaneous combustion, in large piles. Temperatures as high as 900° F. have been recorded in fermenting wood chips (Chalk 1968), and serious economic losses of this material are suffered (Chalk 1968, Shields 1967). Piles of chunk or ground tree bark, moist hay or grain, compost piles, and manure heaps are all subject to such heating during fermentation.

In piles of finely divided wood fibers, including sawdust, wood in the highly heated portion of the pile undergoes charring and destructive distillation. This process produces pyroligneous acid which, in turn, contains acetic acid and lesser amounts of other fatty acids, methanol, formaldehyde, ketones, phenols, and other compounds which can be harmful to plant life (Hawley 1946). These decomposition products produce a persistent acrid odor to the charred material and to that of surrounding areas of the pile. The microbial generation of organic acids is often so intense that the emitted acrid vapors can be overwhelming.

Such odors arising from sawdust should be ample warning of its unsuitability for application near plants. Injury or killing of shrubs and young fruit trees has been observed after the plants were mulched with fermented sawdust. Our study sought the reasons for the ill effects of sour sawdust on plant growth and suggests simple tests that gardeners and horticulturists can use to determine for themselves if a particular lot of sawdust is safe to use.

ANALYSES OF SOUR SAWDUST

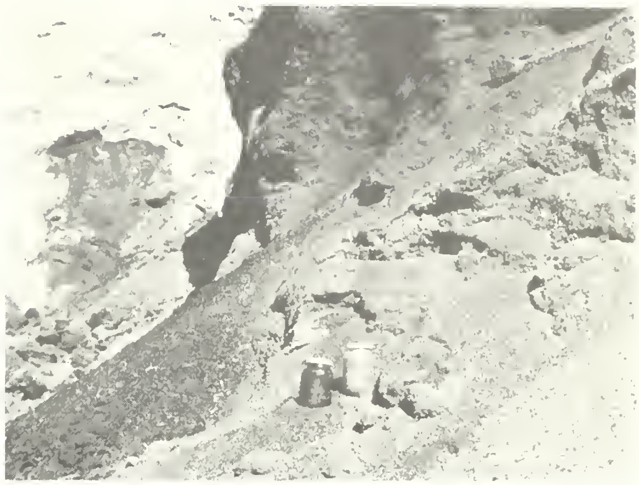
Methods

Preliminary tests were made on black Douglas-fir sawdust taken from several gardens and lawns where damage to plants followed almost immediately after application. Acrid odors and strong acidity (pH 1.9-2.2) were found.

Samples of Douglas-fir sawdust representing the following conditions were then collected in sterile, 1-gallon screwcapped jars:

1. Sour sawdust from the fermented center of a large pile (figs. 1 and 2).
2. Sour sawdust from a second pile.
3. Sour sawdust from a third pile.
4. Dark brown sawdust immediately above the fermented center of pile No. 1.
5. Light-colored weathered sawdust from the edge of a pile stored in an orchard for 2 years.
6. Fresh sawdust collected directly under a gang saw operating on cants from ponded logs.

Figure 2.—Closeup of sour sawdust in center of pile shown in figure 1. Note black appearance of sample 1 in jar; contrast with light color of "normal" sawdust from surface of pile shown in upper left. Dark area in "normal" pile shows exposed, wet sawdust below surface.



All samples were screened through a 10-mesh sieve and placed in screwcapped 1-gallon jars. Titratable acidity, pH, and lime requirement determinations were made on the samples as received. For ash, carbon, and nitrogen analyses, subsamples were air-dried and hammermilled to pass a 60-mesh sieve. All samples were weighed on an ovendry basis, and results are so expressed.

Data were obtained by the following procedures:

Water content--by drying at 105° C. for 24 hours.
Ash--burning in a muffle furnace at 700° C.
Nitrogen--Kjeldahl method.
Carbon--dry combustion at 1,400° C. (Allison, Bollen, and Moodie 1965).
pH--on 1:10 mechanically stirred water suspensions of 10-mesh[1/] material after 1 hour preliminary stirring, using the glass electrode with a Beckman[2/] automatic titrator.

The results are shown in table 1.

In addition to the foregoing properties, total acidity was determined by titration with 0.1 NaOH of 10-gram samples in 100 milliliter water while stirring 1 hour on the Beckman automatic titrator. The first titration was made after the 1:10 suspensions stood 24 hours with occasional stirring. The titration was extended to 48 hours and to 7 days. Results are given on a cumulative basis and expressed as pounds of limestone ($CaCO_3$) required to neutralize 1 ton (dry basis) of sawdust (table 2). The end point of pH 8.35 was chosen because this is the value at which carbonates are converted to bicarbonates, also, it is near the neutralization point of phenolphthalein which is commonly used as an indicator for titration of weak acids with strong bases. Acidity of water extracts (table 3) and effect of Added $CaCO_3$ on pH (table 4) were determined in similar manner.

1/ All of sample passing a 10-mesh sieve.
2/ Mention of products by name does not constitute endorsement by the U.S. Department of Agriculture.

Table 1.--*Analysis of sour and other Douglas-fir sawdust*

Sample number	pH	Lime requirement	Ash	Total carbon	Kjeldahl N	C/N ratio
		Pounds $CaCO_3$ per ton	*Percent*	*Percent*	*Percent*	
1 Sour[1/]	2.2	292	1.90	53.26	0.07	761
2 Sour[1/]	2.2	300	.93	53.60	.06	893
3 Sour[1/]	2.1	295	1.03	56.25	.08	703
4 Dark brown[2/]	2.5	69	1.10	49.33	.11	448
5 Weathered[3/]	4.0	8	.41	49.49	.04	1,237
6 Fresh[4/]	4.0	8	.39	50.30	.04	1,258

[1/] Samples of sour sawdust from spontaneously heated and partially charred centers of different piles.

[2/] Sample of dark brown, not charred, sawdust taken near heated and charred area.

[3/] Sample from edge of shallow pile weathered 2 years.

[4/] Sample taken directly under gang saw.

Table 2.--*Titratable acidity and pH of 1:10 water suspensions of sour, weathered, and fresh Douglas-fir sawdust*[1/]

Sample number	pH[2/]	0.1 N NaOH to titrate to pH 8.35, cumulative[3/]			Total acidity as acetic
		24 hour	48 hour	7 days	
		Milliliter	*Milliliter*	*Milliliter*	-- *Percent* --
1 Sour	2.2	261.0	278.7	291.9	17.5
4 Dark brown	2.5	58.2	61.9	68.8	4.1
5 Weathered	4.0	5.2	6.3	7.8	.5
6 Fresh	4.0	5.9	7.1	8.3	.5

[1/] 10.0 grams(ovendry basis), all of sample passing 10-mesh sieve, in 100 milliliters distilled water.

[2/] After stirring 1 hour.

[3/] During 1 hour stirring after standing for each interval. Values equivalent to pounds $CaCO_3$ required to neutralize 1 ton sawdust, ovendry basis.

Table 3.--*Titratable acidity of successive 1:5 water extracts of sour sawdust (sample 1)*[1/]

Extract number	pH	0.1 N NaOH to neutralize 100 milliliters to pH 8.35	$CaCO_3$ equivalent per ton sawdust
		Milliliters	*Pounds*
1	2.0	415	208
2	2.3	214	107
3	2.8	58	29
4	2.8	38	19
5	3.0	29	15
6	3.0	29	15
Total		783	393

[1/] 1,380-gram wet sample, equivalent to 730 gram, ovendry basis, shaken with 3 liters of cold water 10 minutes and suction filtered to apparent dryness. Repeated 5 times.

Table 4.--*Effect of $CaCO_3$ on pH of 1:10 water suspensions*

Sample number	$CaCO_3$			Duration of contact[2/]					
			0 hours[1/]	2 hours	18 hours	36 hours	60 hours	134 hours	7 days
	grams	*pounds/ton*	- - - - - -	- - - - - -	- - - -	*pH*	- - - -	- - - -	- - - -
1	2.5	100	2.2	3.4	3.4	3.4	3.4	3.6	3.5
1	5	200	2.2	4.4	4.4	4.3	4.4	4.5	4.3
1	7.5	300	2.2	5.7	6.1	6.4	6.8	6.8	7.0
4	1	40	2.5	4.7	4.6	4.2	4.4	4.4	4.4
4	2.5	100	2.5	6.0	6.4	6.4	6.4	6.4	6.4
5	1	40	4.0	6.6	7.0	7.0	7.0	6.9	6.9
6	1	40	4.0	6.5	6.8	6.8	6.8	6.7	6.8

[1/] Before adding $CaCO_3$.

[2/] With intermittent stirring.

Acid identification was done by gas chromatography[3/], using an F & M Scientific Corporation, Model 402 gas chromatograph with a 4-foot, 6- by 4-millimeter Pyrex U column packed with Chromsorb PAW 60-80 coated with 20 percent of Neo Pental Glycol Succinate. Chromatographs of 1:10 distilled water extracts, obtained after mechanically shaking the suspension 1 hour before filtering through a Pyrex M fitted glass filter, were made from sour and fresh sawdust. Standards were run on reagent-grade formic, acetic, propionic, butyric, and caproic acids.

Numbers of micro-organisms were determined by the dilution plate method, using peptone-glucose-acid agar (Waksman and Fred 1922) for molds, and nutrient agar and Brewer's anaerobic agar (Anonymous 1953) (with anaerobic incubation) for bacteria.

Carbon dioxide production by fresh sawdust was measured on 50-gram samples (ovendry basis) with a water content of 107 percent, as obtained from the gang saw, placed in each of three 1-pint bottles and connected to a moist, CO_2-free air supply in a 28° C. incubator. The exit air was bubbled through 1N NaOH in test tubes. At 1, 5, 8, 12, 19, and 28 days the tubes were removed and replaced with tubes of fresh alkali, and the absorbed CO_2 was determined by double titration on a Beckman automatic titrator (Bollen and Glennie 1961).

Results and Discussion

Samples 1, 2, and 3 of sour sawdust were strongly acid as shown not only by the very low pH but also especially by the total acidity expressed as lime requirement, which ranged from 292 to 300 pounds of $CaCO_3$ per ton of sawdust, dry basis, equivalent to 17.5- to 18.0-percent total acids as acetic (tables 1 and 2). A bulk sample of charred material stored in a 10-gallon tinned milk can illustrated the potency of this highly acid sawdust. Several months after collection, we tried to open the can. It was so corroded from the inside it fell apart.

Although the dark brown sample taken above the black sample No. 1 had a pH of 2.5, compared with 2.1 to 2.2 for the sour sawdust, the total acidity was much less, only 69 pounds $CaCO_3$ equivalent per ton. This dark sawdust apparently absorbed enough volatile acid from the underlying heated sawdust to lower the pH considerably, but the total acidity was little more than one-fourth as much. Higher total carbon values (table 1) of the sour sawdusts is evidence of strong spontaneous heating, leading to loss of CO_2 and some of the volatile acids and other organic compounds.

Although much of the acidity was rapidly soluble in water, an additional 10 percent of the total was found at 7 days. Probably some additional acid would be released over a more prolonged time. This is indicated also by the acidity determined on successive water extracts (table 3). Fifty-three percent of the total acid extracted was in the first extract, 27 percent in the second extract, followed by less and less until only 3.7 percent was in the sixth extract. It is thus evident that much of the acidity is persistent; in a mulch, even under leaching by rainfall or irrigation, the toxicity would be prolonged, and the total lime requirement could reach 400 pounds per ton.

[3/] Assistance of Dr. A. W. Anderson, Professor of Microbiology, Oregon State University, in performance of the gas chromatography is gratefully acknowledged.

Many of the organisms in weathered sawdust probably represent contaminants from the soil; although in fresh sawdust, the microbes could have developed from forms contaminating the logs, from contaminants carried by air, and from other sources. Water would contribute many organisms to ponded logs. Runoff from leaf surfaces can inoculate bark of standing trees with a variety of microbes. However, bacteria and fungi are known to occur in healthy as well as in diseased plant tissue. The presence of a fungus in living tissues of conifers has been reported by Lewis (1924). Bloomberg (1966) found fungi of soil-borne and seed-borne origin in Douglas-fir roots, shoots, and seed coats, and Hudak (1964) detected micro-organisms in sound wood of western hemlock. Bacteria as well as fungi have been found in normal heartwood of sugar maple (Basham and Taylor 1965). A rod-shaped, gram-negative bacterium occurred in normal sapwood of 135 out of 229 cottonwood (*Populus deltoides*) trees sampled by Toole (1968). *Bacillus polymyxa* and other sporeforming, facultatively anaerobic bacteria have been found in freshly felled ponderosa and sugar pine trees and in great abundance in log pond water (Ellwood and Ecklund 1959). These bacteria attack hemicellulose and pectin, causing destruction of sapwood and ray cells.

Although it is thus possible that cells of wood and bark contain bacteria and fungi that have entered through wounds, stomata, or other openings, the role of such organisms in the fermentation of sawdust, chip, and bark piles would seem to be minor. It is more likely that most, if not all, of the microbes involved arise from various outside contaminations.

Naturally occurring enzymes in freshly cut wood can continue respiration for several days. Studies by Springer and Hajny (1970) indicate that heat is released from fresh, green aspen and Douglas-fir chips free of micro-organisms by action of enzymes in the living ray parenchyma cells. However, it seems unlikely that such enzymes take part in the fermentation of piled sawdust or bark because logs are not usually milled within a few days after the trees are felled.

The organisms in fresh sawdust (sample 6) from ponded logs metabolize rapidly under favorable conditions, shown by the rapid evolution of CO_2 (fig. 3). Incubated samples produced this gas at only a slightly decreasing rate during 28 days, at which time 0.44 percent of the total carbon was evolved as CO_2. Because CO_2 production releases heat, such activity in a large insulated mass could soon lead to considerable rise in temperature and consequent high acidity.

GREENHOUSE STUDIES WITH SOUR SAWDUST

Methods

Radish, sunflower, corn, and onion seeds were planted in Cloquato silt loam soil in a series of flats in one of which the soil was left bare, and the others were covered with 1-inch-deep mulches of the different sawdusts. In a second set of flats, young tomato, pepper, and cabbage plants were transplanted and mulched as for the seeded flats. All were left in the greenhouse and watered as necessary.

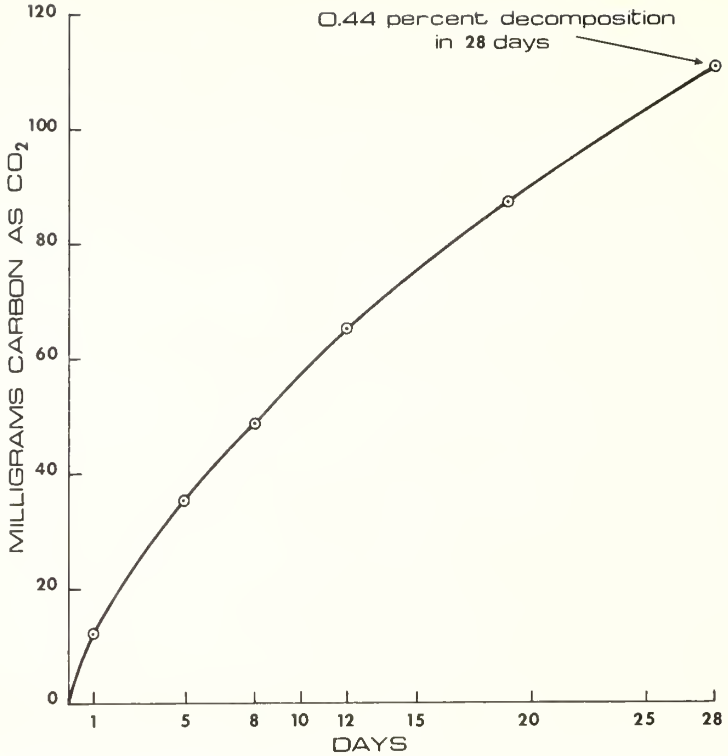


Figure 3.—Carbon dioxide evolution from fresh Douglas-fir sawdust (50 grams, ovendry basis, incubated at 28° C. with 107-percent moisture (38 percent of water-holding capacity)).

Results and Discussion

Seed germination under both weathered and fresh sawdust (samples 5 and 6, page 2) was comparable for radish, sunflower, and corn, but the plants became more or less yellow, indicating nitrogen deficiency. A light application of ammonium nitrate in solution after 28 days alleviated these symptoms. Onion seed germination under these sawdusts was much less than in the unmulched soil, but the seedling development was normal. The most striking results were with the sour sawdust (sample 1). No radish and few sunflower seeds germinated; the sunflower seedlings soon yellowed, died, and appeared bleached. Corn and onion seeds germinated well, but again, the seedlings soon died. The dark brown sawdust (sample 4), only slightly less acid than the sour sawdust, gave similar results, although sunflower germination was better (figs. 4 and 5).

The sour sawdust mulch killed and bleached the transplanted tomato, pepper, and cabbage plants within 7 days. Pepper plants grew normally under the other sawdusts. Cabbage was normal under fresh sawdust but under weathered and dark brown sawdust died within 28 days. Tomato plants under fresh, weathered, and dark brown sawdust (samples 6, 5, and 4) survived but showed nitrogen deficiency.

These results illustrate the deadly potency of sour sawdust and confirm similar results experienced in a number of home gardens. Attempts to render the sawdust safe

Figure 4.—Effect of different sawdust mulches on plant growth: (1) Leached Douglas-fir sour sawdust; (2) fresh sawdust collected directly under a gang saw operating on cants from ponded logs; (3) light-colored weathered sawdust from the edge of a pile stored in an orchard for 2 years; (4) sour sawdust from the fermented center of a large pile (figs. 1 and 2).

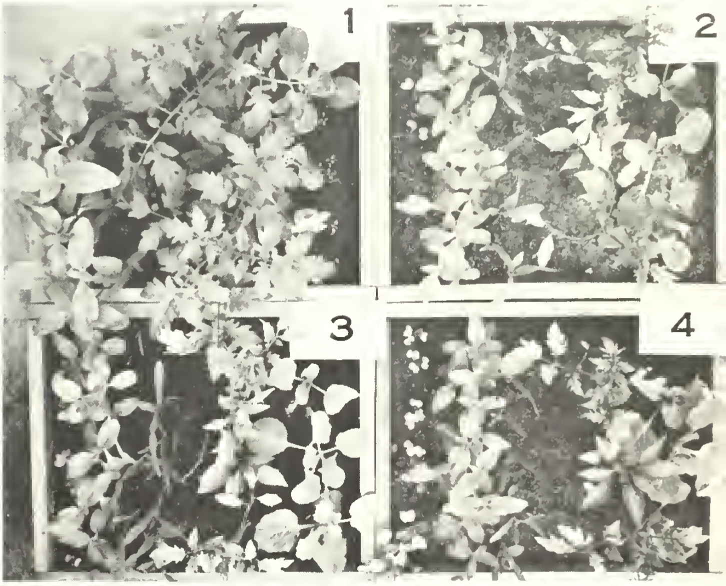


Figure 5.—Effect of different mulches on plant growth: (1) Soil only, no mulch; (2) wheat straw; (3) red alder sawdust; (4) fresh sawdust collected directly under a gang saw operating on cants from ponded logs.

by spreading it on open ground in a layer 3 to 4 inches deep for several weeks during the summer were not successful. Some of the volatiles undoubtedly were dissipated, but the sharp odor and most of the acidity remained. Copious leaching in the laboratory was effective but would be impractical for field use (table 3 and fig. 4).

Under field conditions sour sawdust around plants may injure or kill not only seedlings but also shrubs and small trees. The fumes will at least cause yellowing or bleaching of leaves and defoliation, even if below-ground parts are not harmed. In some cases recovery follows. This is generally true with lawn grass. Severity of injury is dependent upon rate of application and weather conditions. Leaching by rain or irrigation accelerates root damage, and warm air and heating by sunlight hastens evolution of fumes and rapid injury to leaves and tender plants.

Table 4 shows the amount of $CaCO_3$ required to bring water suspensions of the sawdust to neutrality. Three hundred pounds $CaCO_3$ per ton of sour sawdust, dry basis, and 7 days contact with intermittent stirring raised the pH to 7.0. For the less acid, dark brown sawdust, 1 ton would be nearly neutralized by 40 pounds of $CaCO_3$. Nevertheless, even this less acid material exhibited some toxicity in the greenhouse study.

Plate counts of micro-organisms showed that the sour and dark brown sawdusts were sterile (table 5). Dilutions as low as 1:10 showed no molds or bacteria, either aerobic or anaerobic. Also, samples of the sawdust placed directly on plates of various media gave no growth. The sterility can be attributed to the high temperature and acidity developed during the fermentation and subsequent reactions. Weathered sawdust was higher in molds but lower in bacteria than the fresh sawdust. *Trichoderma* predominated in the fresh sawdust, and *Penicillium* species comprised the other molds present. Weathered sawdust, on the other hand, contained few *Penicillium* species, no *Trichoderma* , and a majority of unidentifiable forms. Five percent of the total bacteria in weathered sawdust were *Streptomyces* , but none were found in the fresh sawdust.

Table 5.--*Bacteria and molds in fresh and sour Douglas-fir sawdust*[1/]

Sample number	Sawdust	Molds			Bacteria		
					Aerobic		Anaerobic[2/]
		Total	Penicillia	Trichoderma	Total	Streptomyces	Total
		Thousands	*Percent*	*Percent*	*Millions*	*Percent*	*Millions*
1	Sour	0	0	0	0	0	0
4	Dark brown	0	0	0	0	0	0
5	Weathered	11,400	5	0	1.8	5	.3
6	Fresh	900	23	77	3.4	0	1.9

1/ Numbers per gram, ovendry basis.

2/ Including facultatively anaerobic aerobes.

CONCLUSIONS

The damaging effect on plants of mulches of very dark to almost black sawdust is due largely to acetic acid and lesser amounts of other volatile organic acids. These acids result from fermentation and subsequent spontaneous heating and chemical changes that occur within large compact storage piles. Such sawdust should not be used for horticultural purposes. It cannot be economically neutralized or otherwise rendered nontoxic. Bark also can undergo fermentation and become strongly acid. It, too, should be regarded as potentially toxic if it presents a highly pungent acrid odor.

The simplest test a home gardener or horticulturist can use to determine if a very dark sawdust should not be used is to smell it. If a handful held near the nose is strongly pungent, with a penetrating, intolerable acrid odor, such sawdust will certainly injure plants.

If a simple pH test kit is available it may be used: Shake one part of sawdust with 10 parts of water, let stand a few minutes, and determine pH of the liquid. A pH below about 3.5 indicates probably unsafe material. In case of doubt, refer a sample to your Agricultural Extension Agent.

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Black sawdust resulting from fermentation and heating in compacted centers of large piles is strongly acid and injurious to shrubs and plants. Its very dark color and acrid odor should warn against use for mulching and other horticultural purposes. Bark in large, moist piles is subject to similar microbial and chemical transformations.

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1970
USDA FOREST SERVICE RESEARCH PAPER PNW-109

SELF-FERTILITY OF A CENTRAL OREGON SOURCE OF PONDEROSA PINE

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...IC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
...EPARTMENT OF AGRICULTURE FOREST SERVICE
PORTLAND, OREGON

INTRODUCTION

This report will describe the effect of self-, cross-, and open- or wind-pollination on seed and seedling production of 19 ponderosa pine (*Pinus ponderosa* Laws.) trees in the eastern foothills of the Cascade Mountains south of Bend, Oreg. The study is part of a continuing investigation of self-fertility in several conifers growing in the Pacific Northwest to evaluate the effect of inbreeding on fertility and vigor and to provide information which may be useful in regeneration and tree improvement programs in these species.

MATERIALS AND METHODS

Study trees were located in two stands south of Bend, Oreg. One stand (Lava Butte) was at about 4,000-foot elevation and was pure ponderosa; the other (Kiwa Springs) was at about 4,500-foot elevation and was a mixture of ponderosa and lodgepole (*Pinus contorta* Dougl.) pines. Ten scattered trees were self- and cross-pollinated at each location.

Controlled pollinations using fresh pollen were made in the spring of 1967. Thirty to 50 female strobili on each tree were covered with isolation bags about 3 weeks prior to pollen shed. Approximately half of these strobili were self-pollinated and half cross-pollinated. Cross pollen was a mixture from six trees growing about 2 miles north of the Lava Butte group. The isolation bags were removed for 1 to 3 minutes while either self or cross pollen was poured directly on the female strobili.

Three weeks after pollination, isolation bags were replaced by cloth bags to protect conelets from insects. When bagged cones were collected in 1968, 10 to 25 open-pollinated cones were also collected from each of the trees. Number of female strobili were tallied when each of the operations was performed: May 25, 1967 (strobili just emerging), June 20 (pollination), July 15 (bagging to protect from insects), April 25, 1968 (replacement of torn insect bags), September 5 (cone collection).

Numbers of full-sized, normal-appearing seeds (hereafter called "round" seeds) were tallied for each cone. Round seeds were X-rayed and seeds with plump megagametophytes and embryos (hereafter called "filled" seeds) tallied. Filled seeds were further separated and recorded as to whether the embryo was greater than three-quarters the length of the embryo cavity, between one-half and three-quarters length, or less than one-half length.

Germination tests were conducted using seeds with full-sized embryos (i.e., seeds with embryos greater than three-quarters the length of the embryo cavity). Except for five families which had too few seeds, 100-seed lots were germinated in a commercial "germinator" at 30° C. day temperature and 20° C. night temperature with 12-hour photoperiods and thermoperiods. Prior to germination, seeds were stratified for 3 weeks at 5° C. The germination test was discontinued when no germination had occurred for a period of 1 week.

Separate germination tests were run on seeds with undersized embryos. The tests were the same as for seeds with full-sized embryos, except that stratification period was 6 weeks and the criterion of germination was a little different. For seeds with full-sized embryos, germination was considered complete when the radicle appeared. However, germination of seeds with undersized embryos was not considered complete until some cotyledonary tissue could also be seen outside the seedcoat--these seeds frequently stop developing after only a small portion of the embryo protrudes.

Germinant seedlings from seeds with full-sized embryos were planted at 3- by 3-inch spacing in a nursery seedbed for growth and survival tests. The seedbed was under 45-percent shade and was watered and weeded regularly. Seedlings were arranged in "seed tree groups" with selfs in the center of each group and seedlings from cross- and wind-pollination of the same seed tree on either side of the selfs. Survival was recorded on 45 of the germinant seedlings (except for four families which did not have that many seedlings) at the end of the first growing season.

Differences between self- and cross-pollination or among self-, cross-, and wind-pollination were tested for significance using analysis of variance. All tests, except that for numbers of round seeds per cone, were based on percentage data, and these were angularly transformed before analysis.[1] Most analyses consisted only of effects due to seed tree and pollen treatment, which were tested against the interaction term. Two exceptions were the cone set analysis, where what appeared to be a large location difference was tested against variation among trees across pollen treatments within locations, and the analysis of relative self-fertility, where between locations mean square was tested against within locations mean square.

[1] Accompanying the conclusions of each statistical test are treatment means. These means are not the untransformed arc sine means, as one might suspect, but are the arithmetic means which are presented to allow readers to compare these averages with averages for other species.

RESULTS

Cone set.--Loss of conelets during first and second year was determined only for female strobili which had been self- and cross-pollinated; development of open-pollinated conelets was not recorded. Seventy-five percent of the strobili developed into collectible cones after cross-pollination; 70 percent, after self-pollination. This difference was not statistically significant. Table 1 gives cone development by area and type of pollination. Cone loss was significantly greater at Lava Butte than at Kiwa Springs, but no explanation is available. Percent cone loss or abortion was approximately the same during the first and second years of development.

Seed set.--Seed counts were classified into round seeds and filled seeds and were recorded for self-, cross-, and open-pollinated cones. Trees at the two areas were tested separately and together. In each test, differences between trees were significant, but there was no evidence for differences among pollen sources, which indicates that type of pollination (self, cross, or open) does not affect the production of round seeds. Averages are given in table 2.

Yield of filled seeds was expressed as filled seeds per round seeds x 100, because non-round or flat seed represented no potential for development into a filled seed with mature embryo. Since self- and cross-fertility were ultimately to be compared, it was desirable that they be compared using a base which would represent the maximum expression of fertility for each type of pollination and each tree.

Yield of filled seed was significantly reduced by selfing (table 3). Average yields after self-, cross-, and open-pollination were, respectively, 23.7, 66.5, and 75.2 filled seeds per 100 round seeds.

Table 1.--*Percent*[1] *healthy female strobili after self- and cross-pollination at beginning and end of second year of cone development*[2]

Location and number of trees	Beginning of year		End of year	
	Self	Cross	Self	Cross
Lava Butte (9)	71	84	57	61
Kiwa Springs (10)	93	93	82	89
All trees (19)	82	88	70	75

[1] Percent healthy female strobili at times given is based on number of strobili initially isolated for pollination.

[2] Effect of type of pollination on percent healthy strobili at time of collection (end of year) was tested with analysis of variance and was nonsignificant.

Table 2.--*Number of round seeds per cone after self-, cross-, and open-pollination*[1]

Location and number of trees	Type of pollination		
	Self	Cross	Open
Lava Butte (9)	92.5	92.2	85.0
Kiwa Springs (10)	110.6	113.7	106.7
All trees (19)	102.0	103.5	96.4

[1] Effect of type of pollen on number of round seeds per cone was tested by analysis of variance and found to be nonsignificant.

Table 3.--*Yield of filled seeds*[1/] *after self-, cross-, and open-pollination, and relative self-fertilities*

Tree number	Type of pollination and yield of filled seed			Relative self-fertility[2/]
	Self	Cross	Open	
	- - - - *Percent* - - - - -			
LB-2	2.0	52.1	65.7	0.038
LB-9	5.9	72.5	78.8	.081
LB-5	9.4	65.1	74.9	.144
LB-7	14.7	89.7	83.2	.164
KS-2	13.6	75.1	78.7	.181
LB-1	9.9	52.4	41.3	.189
KS-5	17.8	87.4	77.1	.204
KS-4	15.0	68.9	77.3	.218
LB-4	13.9	50.7	72.2	.274
KS-9	26.3	66.6	83.0	.395
KS-3	28.4	69.6	75.2	.408
KS-6	30.5	73.9	80.7	.413
LB-3	29.4	62.8	79.1	.468
KS-10	43.8	87.0	84.3	.503
KS-1	34.6	63.3	67.0	.547
KS-8	47.6	77.0	80.6	.618
LB-8	30.4	47.2	87.1	.644
KS-7	30.1	41.5	70.1	.725
LB-6	46.9	61.6	72.1	.761
Lava Butte average	18.1	61.6	72.7	[3/] .307
Kiwa Springs average	28.8	71.0	77.4	[3/] .421
Grand average	[4/][5/] 23.7	[4/][5/] 66.5	[4/][5/] 75.2	.367

[1/] Filled seed per round seed times 100.

[2/] Relative self-fertility is quotient of column 2 divided by column 3, that is, filled seed per round seed after selfing divided by filled seed per round seed after crossing.

[3/] Relative self-fertilities of trees from Lava Butte and Kiwa Springs were not significantly different.

[4/] Differences in yield of filled seeds among pollination types were significant at the 99-percent probability level when tested by analysis of variance.

[5/] Cones averaged just slightly more than 100 round seeds per cone, so average number of filled seeds per cone is about 23, 66, and 75 after self-, cross-, and open-pollination, respectively.

Differences among pollination types were significant; even the difference between cross- and open-pollination was significant at the 95-percent probability level. Why controlled cross-pollination should produce fewer filled seeds than wind-pollination is not known; however, higher seed yield after wind- than after cross-pollination has also been reported in other pine species.[2]

Relative self-fertility.--Relative self-fertility is defined as filled seeds per round seed after selfing divided by filled seeds per round seed following controlled crossing. Reasons for use of this ratio have been described elsewhere,[3] but basically it is to reduce variation which is not associated with the genotype of the embryo but which affects seed yield, such as applying pollen when conelets are not fully receptive. Relative self-fertilities of the 19 trees are arrayed in table 3.

Variation in relative self-fertility is large, e.g., one tree set about 4 percent as many seeds after selfing as after crossing, whereas another set 76 percent as many seeds after selfing as after crossing. Average self-fertility for the 19 trees is 35 to 40 percent (mean = 36.7; median tree = 39.5 percent). The average relative self-fertilities of Lava Butte trees and Kiwa Springs trees did not differ significantly.

Relationship between yield of filled seeds after self- and after cross- and wind-pollination.--This relationship was tested with the ponderosa pine data first by regressing yield of filled seeds per cone after cross- or open-pollination on yield of filled seeds per cone after self-pollination; and second, by making the same regressions on filled seed yields which were adjusted by treating filled seeds as a percent of round seeds per cone. This adjustment was made because cones from separate trees differed greatly in cone size and in round seed production (for example, a three-to-one difference in number of round seeds per cone for different trees). Regression coefficients are given in table 4. The regression without adjustment means that for a change of one filled seed per cone after selfing, an accompanying change of 0.40 filled seed per cone after crossing is predicted. The regression with adjustment means that for a change of 0.1 filled seed per round seed following selfing, an accompanying change of 0.004 filled seed per round seed after crossing is predicted.

Germination.-- Germination results are given in table 5 for the seeds with full-sized embryos. Germination percentages across all families were 95.1, 96.2, and 95.8, respectively, for seeds from self-, cross-, and open-pollination. These percentages were not statistically different, so there was no evidence that inbreeding adversely affected germination of seeds with full-sized embryos.

When germination of seeds with undersized embryos was included, however, selfed seeds gave slightly less germination than crossed seeds. This lesser germination was because seeds with full-sized embryos had higher germination than did seeds with undersized embryos, and seeds from cross- and open-pollination had a higher proportion of full-sized embryos than did seeds from self-pollination.

Germination percentages were 91.6, 85.4, and 91.6 (self-, cross-, and wind-pollinated seeds, respectively) for seeds with embryos one-half to three-quarters the length of the cavity, and were 39.7, 45.3, and 55.0, respectively, for seeds with embryos less than one-half the length of the embryo cavity.[4]

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[2] E. B. Snyder and A. E. Squillace. Cone and seed yields from controlled breeding of southern pines. Southern Forest Exp. Sta. USDA Forest Serv. Res. Pap. SO-22, 7 p. 1966.

[3] Frank C. Sorensen. Estimate of self-fertility in coastal Douglas-fir from inbreeding studies. (Submitted to Silvae Genetica, 1968.)

[4] Many of these seed lots were very small (five to 15 seeds), so differences were not analyzed statistically.

Table 4.--*Regression coefficients for yield of filled seeds after cross-pollination on yield after self-pollination, and for yield after wind-pollination on yield after self-pollination*

Type of pollination	Regression coefficients	
	Without adjustment[1/]	With adjustment[1/]
Self- and cross-pollination	0.40	0.014
Self- and wind-pollination	[2/] .84	.038

1/ Adjustment for number of filled seeds per round seed.
2/ Significant at the 95-percent probability level.

Seeds with embryos one-half to three-quarters the length of the embryo cavity made up 9.5, 2.8, and 4.0 percent of filled self-, cross-, and wind-pollinated seeds, respectively; seeds with embryos less than one-half the length of the embryo cavity made up 11.9, 2.9, and 4.5 percent of filled self-, cross-, and wind-pollinated seeds, respectively. Germination percentages, taking into account all types of filled seeds, were 88.2, 94.4, and 93.8, respectively, for self-, cross-, and wind-pollinated seeds.

First-year survival.--First-year survival was significantly less ($p<0.05$) for the selfs than for the other two classes of seedlings (table 6). Although selfed families did not look quite as vigorous as noninbred progenies, the greater loss of selfed seedlings was not primarily due to any general weakness but to recessive lethal genes carried by four of the seed trees. Omitting mortality caused by these genes, survival was 97.3, 98.0, and 98.3 percent for progenies from self-, cross-, and open-pollination, respectively.

DISCUSSION

Although selfing in tree improvement may not have wide application,[5/] there may be cases where it is a useful technique.[6/] If so, self-fertility of ponderosa pine is high enough to permit the easy production of selfed seedlings. Selfing yielded about 37 percent as many filled seeds as crossing, and about 32 percent as many 1-year-old seedlings.

Parents that produce high seed yields when self-pollinated may tend to produce high yields when wind-pollinated (see footnote 5). A slight relationship of this type held for ponderosa pine; however, it appeared that the relationship occurred

[5] E. B. Snyder. Seed yield and nursery performance of self-pollinated slash pines. Forest Sci. 14: 69-74. 1968.

[6] A. L. Orr-Ewing. Inbreeding to the S_2 generation in Douglas-fir. Second World Consultation on Forest Tree Breeding, Sect. III (8/6), 13 p. 1969.

Table 5.--*Percent germination for self-, cross-, and open-pollinated seeds*[1/]

Seed tree	Pollen source		
	Self	Cross	Open
LB-1	84	95	88
LB-3	100	97	96
LB-4	98	99	100
LB-5	79	95	100
LB-6	100	100	100
LB-7	100	100	93
LB-8	98	93	100
LB-9	97	99	98
KS-1	100	99	97
KS-2	92	95	97
KS-3	87	90	91
KS-4	99	99	98
KS-5	98	100	100
KS-6	95	95	93
KS-7	99	98	88
KS-8	92	86	89
KS-9	97	94	97
KS-10	97	98	100
Average	95.1	96.2	95.8

[1/] Only filled seeds with embryos greater than three-fourths the length of the embryo cavity were used in this test.

Based on 100 filled seeds per progeny except for LB-1 x self, LB-4 x self, LB-9 x self, KS-3 x self, and KS-3 x wind, which had 43, 54, 79, 15, and 90 seeds, respectively.

Differences in percent germination among self-, cross-, and open-pollinated seeds were not statistically significant.

primarily because of differences among trees in cone size and round seed production. Still, it should be pointed out that even after adjustment for cone size, there was a small tendency for trees with greater self-fertility to produce a few more filled seeds when open-pollinated than did trees with lower self-fertility. If this relationship is real, it probably reflects a tendency for relatively self-fertile trees to produce a slightly higher proportion of selfed seeds in their wind-pollinated progenies.

Various pine species show considerable diversity in the effect of self-pollination on seed traits, with some species being more and some less self-fertile than ponderosa pine.[7/] However, compared with Douglas-fir, the one other western conifer whose average relative self-fertility has

[7] E. C. Franklin. Artificial self-pollination and natural inbreeding in *Pinus taeda* L. 127 p. 1968. (Ph.D. thesis on file at North Carolina State Univ., Raleigh.) Appendix table 3.

Table 6.--*Survival at end of first growing season of ponderosa pine seedlings*[1] *from self-, cross-, and wind-pollination*[2]

(In percent)

Seed tree	Pollen type		
	Self	Cross	Wind
LB-1	100	96	96
LB-3	98	100	100
LB-4[3]	69(98)	100	98(100)
LB-5	98	100	100
LB-6	96	98	100
LB-7	96	96	91
LB-8[3]	62(82)	98	98(100)
LB-9	96	100	100
KS-1	93	91	98
KS-2	96	96	98
KS-3	100	100	93
KS-4	100	98	100
KS-5	100	100	100
KS-6[3]	60(100)	100	98
KS-7	100	96	98
KS-8[3]	62(100)	98	98(100)
KS-9	100	100	98
KS-10	98	98	100
Average	90.2	98.0	98.0

[1] Based on 45 established seedlings in each family except for families KS-3 x self, cross, and wind, and LB-1 x self, which started with 12, 15, 15, and 33 seedlings, respectively.

[2] Differences in first-year survival were significant at the 95-percent probability level.

[3] These seed trees all carried recessive seedling lethal factors, whose effect was expressed soon after the seedcoat was shed. Number in parentheses is survival when mortality caused by these specific lethal alleles was omitted.

been studied and which is estimated at 10 to 12 percent (see footnote 3), ponderosa pine is considerably more self-fertile. In Douglas-fir, except for a small percentage of relatively self-fertile trees, the usual and main effect of natural selfing should be to decrease seed set. But this is not necessarily so with ponderosa pine. Greater self-fertility could lead to a moderately high incidence of selfed seedlings in an open-pollinated population. If this is accompanied by inbreeding depression, then *natural* self-pollination could lead to a decrease in seedling vigor as well as a decrease in seed set.

In other pine species, it has been observed that the incidence of natural selfing is higher in the lower than in the upper part of the crown (see footnote 7).[8/] This also can be reasonably assumed to be true for ponderosa pine, and if so, it has implications for seed collection practices. If self-fertility were low, then the collector would only get a higher proportion of empty seeds in a collection from the lower crown. But if self-fertility is relatively high, as is indicated here for ponderosa pine in Oregon, then a collection from the lower crown will not only yield somewhat fewer seeds but will also include seeds with a higher level of inbreeding, which most likely will produce seedlings with reduced vigor. It will probably be some time before there are reliable figures to attach to the amount of natural self-pollination and to the amount by which inbreeding reduces vigor. But for the present, it appears that good management practices dictate upper crown seed collections whenever possible.

[8] D. P. Fowler. Natural self-fertilization in three jack pines and its implications in seed orchard management. Forest Sci. 11: 55-58. 1965.

SUMMARY

Yield of filled seeds after self-, cross-, and wind-pollination was determined on 19 ponderosa pine trees at two locations in central Oregon. Type of pollination had no statistically significant effect on cone set or production of round seeds. However, production of filled seeds (that is, relative self-fertility) was only about 35 to 40 percent as great after selfing as after crossing. Relative self-fertility among the trees varied from 4 percent to 76 percent. Germination percent of filled seeds and first-year seedling survival were slightly less for inbred progenies than for crossbred and open-pollinated progenies.

Sorensen, Frank C.
1970. Self-fertility of a central Oregon source of ponderosa pine. USDA Forest Serv. Res. Pap. PNW-109, 9 p. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

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1970
USDA Forest Service Research Paper PNW 10

A Technique for the Solution of Skyline Catenary Equations

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NOMENCLATURE

(A) Left support point (see fig. 3).

(B) Right support point (see fig. 3).

(C) Carriage location (see fig. 3).

d Horizontal distance between support point (A) and the carriage position (C).

ϵ_i Length of horizontal moment arm from point (C) to the concentrated line weight in line segment i.

E_1, E_2 Error functions in the catenary formulation.

h Vertical distance between support point (A) and support point (B).

H Horizontal component of tension.

H_i Horizontal component of tension in line segment i.

L Horizontal distance between support point (A) and support point (B).

m Parameter in the catenary formulation.

m_i Parameter for line segment i.

M_i Moment associated with line segment i.

R_i Weight of line segment i.

s_i Length of line segment i.

T Tension in a line segment.

T_i^j Tension at point j in line segment i.

T_{all} Allowable tension in the skyline at point (A).

V Vertical component of tension.

V_i^j Vertical component of tension at point j in line segment i.

w Weight per unit length for a line segment.

w_i Weight per unit length for line segment i.

W_c Weight of carriage.

W_L Weight of log, assumed to be hanging vertically.

x Horizontal coordinate in the catenary formulation.

x_i^j Horizontal coordinate at point j in line segment i.

y Vertical coordinate in the catenary formulation.

y_i^j Vertical coordinate at point j in line segment i.

Δy Vertical distance between support point (A) and the carriage position (C).

CONTENTS

1.0 INTRODUCTION

A logging skyline, used extensively for harvesting timber in rough terrain where a dense road system is undesirable, consists of cables or wire ropes suitably tensioned and anchored. A concentrated log load is supported in the span between the anchor points and transported to another point in the span (landing).

The designer of such a skyline must determine the load-carrying capability in order to establish mechanical and economic feasibility. Unfortunately, the direct computation of skyline load-carrying capability is not a simple procedure. The mathematical model of the skyline cable arrangement consists of a set of hyperbolic functions. As these hyperbolic functions are transcendental (that is, they cannot be manipulated algebraically for direct solution), it is difficult to obtain numerical solutions. An iterative (trial and error) procedure is required to determine numerical results. In terms of man-hours or computer time, these trial-and-error procedures can become very costly. This paper presents an iterative procedure, developed to provide numerical solutions to skyline problems, which has proven to be more efficient than other methods in the use of computer time.

1.1 Background

The mathematical formulation of the skyline problem is treated under the more general classification of catenary problems (Inglis 1963). Specific treatment of logging skylines supporting concentrated loads appeared in papers by Anderson (1921) and Mills (1932). These papers establish the mathematical formulation of the problem and serve primarily to point out the difficulties in obtaining numerical answers to skyline problems.

More recent works have transformed these formulations into tables and graphs for easier solution of skyline problems. The latest of these, by Lysons and Mann (1967), uses a graphical technique to establish the geometric characteristics of the skyline setting, together with tabulated information to determine the payload capability. This procedure can be used for single-span and multispan standing skylines with clamping or nonclamping carriages. The resulting payload capability is for the critical midspan position where capability is a minimum. Mann (1969) treats the problem of determining payload capability of running skylines in a similar manner. However, these methods are time-consuming and require many man-hours when a large number of roads is involved.

To avoid this time-consuming procedure, the designer can use a digital computer to directly compute the load-carrying capability. These direct computations will encounter the numerical complications discussed in the introduction. The more common iterative techniques, purely mathematical, are not concerned with the physical characteristics of the problem and, without artificial constraints, can diverge from the real answer or converge to answers which have no physical significance. The physical constraints must be introduced to control the iterative procedure of these standard numerical techniques. An example of this was provided by Suddarth's discussion (1970) of a direct computation of the load-carrying capability of the running skyline. His method was convergent, and numerical results for load-carrying capability were obtained. However, the complications associated with introducing the physical constraints confused the logical flow of the algorithm and caused it to be relatively slow to converge.

Our method provides a more efficient iterative procedure. The standard numerical schemes are not used; we have used a method which contains the physical constraints as part of the procedure. This method is always convergent to the correct numerical result and generally requires not more than two or three iterations to converge. This method has been satisfactorily applied to both the standing and the running skylines and is also adaptable to analysis of other skyline configurations.

2.0 PROBLEM DESCRIPTION

Consider a single-span skyline with the geometry as shown in figure 1. In this cable system, the skyline is assumed firmly anchored at the tailhold while the line lengths are manipulated on drums at the yarder. Carriage vertical position is adjusted with the skyline length, while the horizontal location is controlled with the snubbing line. The carriage, shown in its simplest form in figure 2, is designed to run free on the skyline while held in position by the snubbing line. The problem is to determine the load-carrying capability at the carriage with the geometry shown and with a maximum operating tension specified in the skyline at the headspar.

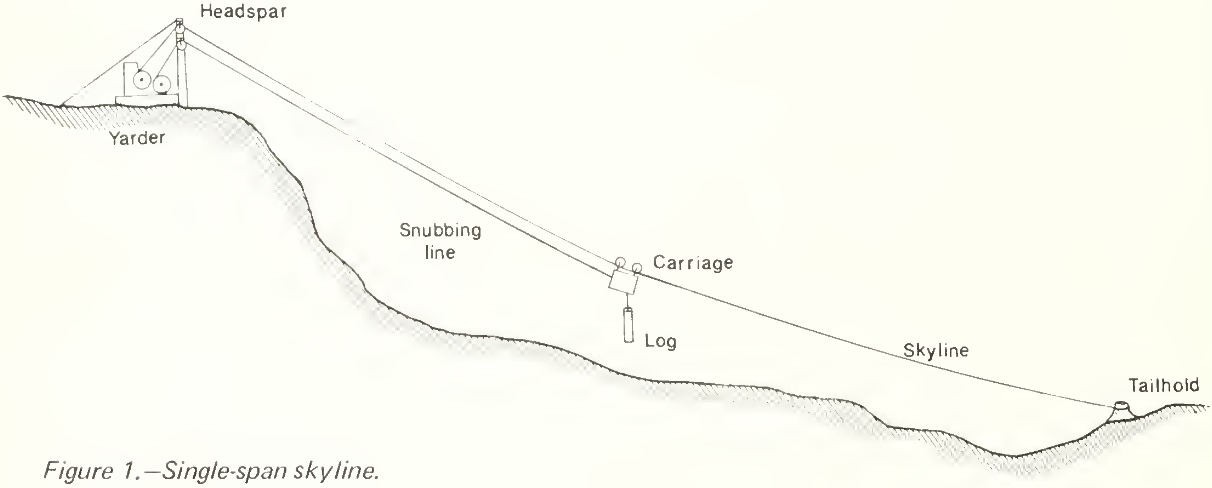


Figure 1.—Single-span skyline.

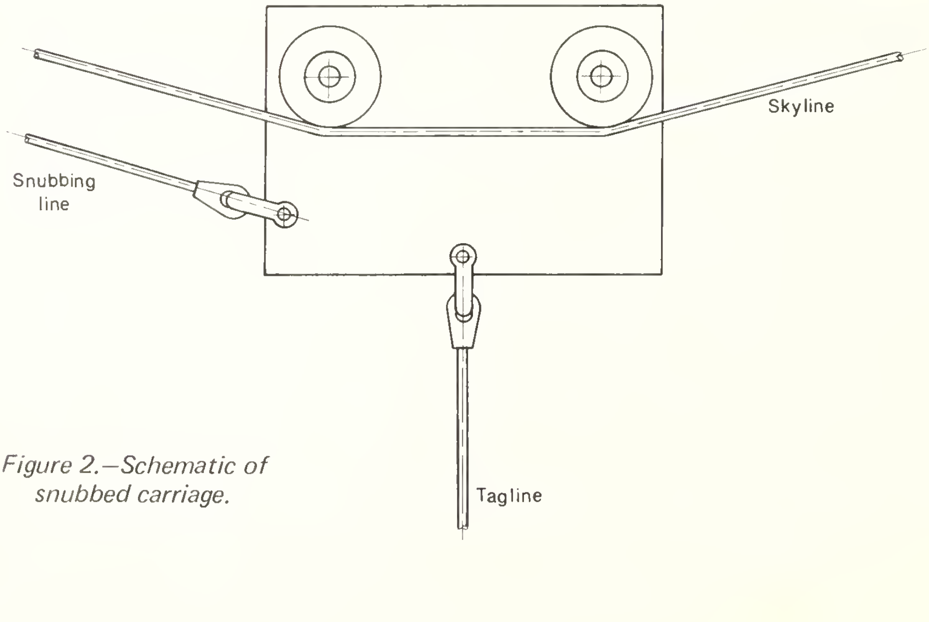


Figure 2.—Schematic of snubbed carriage.

3.0 CATENARY FORMULATION

The catenary formulation of the problem assumes completely flexible lines, with the cable weight distributed uniformly along the line segments (Inglis 1963). To develop the catenary expressions, it is convenient to adopt a reference coordinate frame, as shown in figure 3. In this coordinate frame, the governing expressions for each line segment become

$$y = m \cosh \frac{x}{m}, \tag{3.0.1}$$

$$T = wm \cosh \frac{x}{m}, \tag{3.0.2}$$

$$V = wm \sinh \frac{x}{m}, \text{ and} \tag{3.0.3}$$

$$H = wm. \tag{3.0.4}$$

The important parameter in these expressions is m. Once m has been determined, the problem has been solved and all other numerical values follow directly.

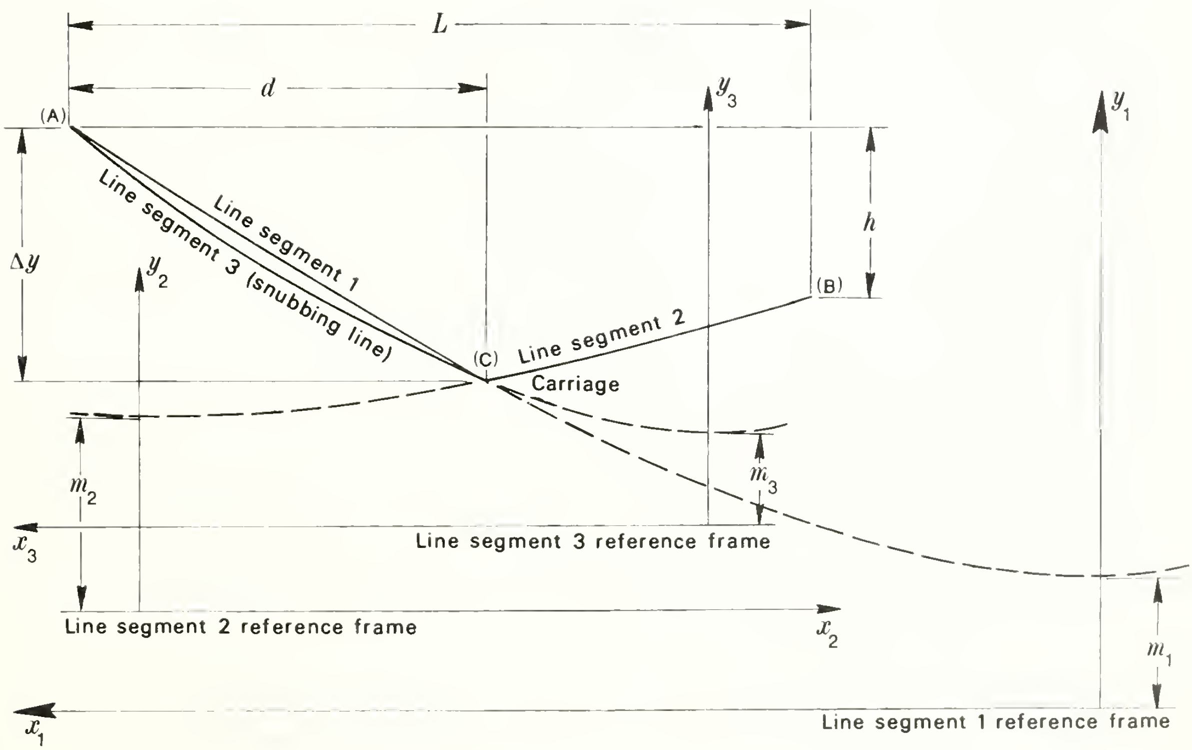


Figure 3.—Reference frames for the catenary formulation.

3.1 Boundary Conditions--Geometric

In the coordinate frames of figure 3, the known geometry of the problem can be introduced through six boundary conditions--two for each distinct line segment. These are:

Line segment 1 of skyline

$$y_1^a - y_1^c = \Delta y \tag{3.1.1}$$

$$x_1^a - x_1^c = d \tag{3.1.2}$$

Line segment 2 of skyline

$$y_2^b - y_2^c = \Delta y - h \tag{3.1.3}$$

$$x_2^b - x_2^c = L - d \tag{3.1.4}$$

Line segment 3 (snubbing line)

$$y_3^a - y_3^c = \Delta y \tag{3.1.5}$$

$$x_3^a - x_3^c = d \tag{3.1.6}$$

It is convenient to immediately incorporate these boundary conditions into the governing geometric equation (3.0.1). These can be combined to generate expressions for $\frac{x}{m}$, which are required arguments in the hyperbolic functions. These become:

Line segment 1 of skyline

$$x_1^a/m_1 = f_1(\Delta y, m_1, d) \tag{3.1.7}$$

$$x_1^c/m_1 = g_1(\Delta y, m_1, d) \tag{3.1.8}$$

Line segment 2 of skyline

$$x_2^b/m_2 = f_1(\Delta y - h, m_2, L-d) \tag{3.1.9}$$

$$x_2^c/m_2 = g_1(\Delta y - h, m_2, L-d) \tag{3.1.10}$$

Snubbing line

$$x_3^a/m_3 = f_1(\Delta y, m_3, d) \qquad (3.1.11)$$

$$x_3^c/m_3 = g_1(\Delta y, m_3, d) \qquad (3.1.12)$$

where these functions are defined as

$$f_1(p,q,r) = sinh^{-1}\left[\frac{p}{2q\ sinh\ \frac{r}{2q}}\right] + \frac{r}{2q}$$

$$g_1(p,q,r) = sinh^{-1}\left[\frac{p}{2q\ sinh\ \frac{r}{2q}}\right] - \frac{r}{2q}$$

3.2 Boundary Conditions--Force

In addition to horizontal and vertical forces balancing at the carriage, two other conditions must be met by the cable forces. The tension must be given at point (A) in the skyline, and the tension in segment 1 at (C) must be equal to the tension in segment 2 at (C). This latter condition is derived from the fact that the skyline goes under sheaves in the carriage which does not alter the tension. The boundary conditions can be expressed as follows:

Carriage force balances

$$w_1m_1 sinh\ x_1^c/m_1 + w_2m_2 sinh\ x_2^c/m_2 + w_3m_3 sinh\ x_3^c/m_3 = W_c + W_L \qquad (3.2.1)$$

$$w_1m_1 + w_3m_3 = w_2m_2 \qquad (3.2.2)$$

Line tension relationships

$$w_1m_1\ cosh\ x_1^c/m_1 = w_2m_2\ cosh\ x_2^c/m_2 \qquad (3.2.3)$$

$$T_1^c = T_2^c = T_{all} - w_1\Delta y \qquad (3.2.4)$$

These line tension relationships (3.2.3) and (3.2.4) can be rearranged to the forms

$$E_1 = T_{all} - w_1 \Delta y - w_1 m_1 \cosh x_1^c / m_1 \tag{3.2.5}$$

and

$$E_2 = T_{all} - w_1 \Delta y - w_2 m_2 \cosh x_2^c / m_2 \tag{3.2.6}$$

If the values of the errors E_1 and E_2 are zero, or at least within an acceptable range of zero, the parameters of m_1 and m_2 represent a solution to the problem.

All the relationships necessary to obtain a catenary solution are now available. There are 10 unknowns (x_1^a, x_1^c, x_2^b, x_2^c, x_3^a, x_3^c, m_1, m_2, m_3, and W_L) and 10 independent equations [(3.1.7) through (3.1.12), (3.2.5), (3.2.6), and boundary conditions (3.2.1) and (3.2.2)]. As these relationships are transcendental, an iterative scheme is required to generate a solution.

4.0 FORCE BALANCE FORMULATION

A set of algebraic equations can be developed from force and moment balances on the line segments and carriage (fig. 4). For example, line segment 1 can be described by the expressions

$$V_1^a = R_1 + V_1^c \tag{4.0.1}$$

$$H_1 = \text{constant in the line segment} \tag{4.0.2}$$

and

$$V_1^a = R_1 \frac{e_1}{d} + H_1 \frac{\Delta y}{d} \tag{4.0.3}$$

Line segments 2 and 3 can be described by similar equations. As in the catenary formulation, the carriage force balances and line tension relationships provide four expressions. These equations are written in the nomenclature of this formulation as:

Carriage force balances

$$V_1^c + V_2^c + V_3^c = W_c + W_L \tag{4.0.4}$$

and

$$H_1 + H_3 = H_2 \tag{4.0.5}$$

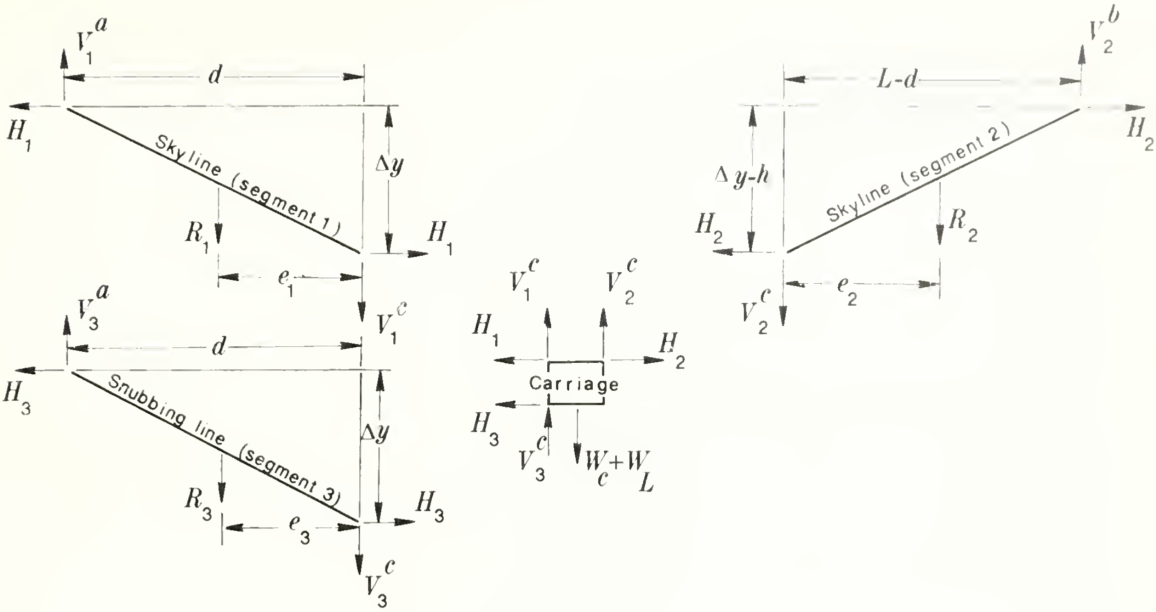


Figure 4.—Force balance formulation.

Line tension relationships

$$(V_1^c)^2 + (H_1)^2 = (V_2^c)^2 + (H_2)^2 \qquad (4.0.6)$$

and

$$T_1^c = T_2^c = T_{all} - w_1 \Delta y \qquad (4.0.7)$$

At this point, if the vertical forces, horizontal forces, and the pay-load weight W_L are considered unknowns, there are a total of 10 unknowns. Ten independent equations are available, and algebraic manipulation provides expressions which determine the horizontal forces directly. These expressions, listed in the order for solution with the necessary intermediate values, are

$$H_1 = \frac{-R_1 t_1 (t_2 - 1) + [(R_1 t_1 (t_2 - 1))^2 - (1+t_1^2)((R_1(t_2-1))^2 - (T_1^c)^2)]^{1/2}}{(1+t_1^2)}, \qquad (4.0.8)$$

$$H_2 = \frac{-R_2 t_3 (t_4 - 1) + [(R_2 t_3 (t_4 - 1))^2 - (1+t_3^2)((R_2(t_4-1))^2 - (T_2^c)^2)]^{1/2}}{(1+t_3^2)}, \qquad (4.0.9)$$

and

$$H_3 = H_2 - H_1 \qquad (4.0.10)$$

where

$$t_1 = \Delta y/d$$

$$t_2 = e_1/d$$

$$t_3 = \Delta y-h/L-d$$

and

$$t_4 = e_2/L-d \qquad (4.0.11)$$

Now we have an explicit solution for the horizontal tensions and, thus, the catenary parameters m_1, m_2, and m_3.

As values of horizontal tensions derived from these equations depend upon values for line weights and moment arms, the solutions for m_1, m_2, and m_3 will vary with the shape the lines adopt between these anchor points. If the lines were straight, rigid members, pinned at (A), (B), and (C), the weights and moment arms could be expressed as functions of the known quantities, namely,

$$R_1 = w_1((d)^2 + (\Delta y)^2)^{1/2} \qquad (4.0.12)$$

$$e_1 = d/2 \qquad (4.0.13)$$

$$R_2 = w_2((L-d)^2 + (\Delta y-h)^2)^{1/2} \qquad (4.0.14)$$

and

$$e_2 = (L-d)/2 \qquad (4.0.15)$$

and the horizontal tensions could then be computed. However, the lines are known to hang as catenaries, and their shapes are not known until the catenary solution is obtained.

In other words, we have arrived at a point similar to that reached in the catenary formulation. We have the equations available for computation of correct values of tension; however, they depend upon a knowledge of catenary line shapes which, in turn, depend upon the tension. Therefore, an iterative solution is also required in this formulation.

5.0 ITERATIVE TECHNIQUE

The catenary and force balance formulations, derived in the preceding sections, are both limited by difficulties which prevent solutions. The force balance formulation cannot provide accurate results without prior knowledge of the line weights and moment arms of the catenary line segments. The catenary formulation provides a complete set of equations; however, these equations are transcendental, and an iterative routine is required for solution. Convergence using the more common methods is slow, and the increase in complexity introduced by more cables in the system makes these direct mathematical methods unattractive. Our method is relatively insensitive to the complication of the cable system, and convergence is guaranteed by incorporating more of the physics of the system. In general, the method is an iterative procedure which uses the algebraic features of the force balance formulation and the tension and geometric expressions of the catenary formulation.

Direct solution by the force balance formulation is prevented by lack of knowledge concerning weights and moment arms of the lines hanging in catenary shapes. Weights and moment arms, however, could be computed if good approximations were available for the catenary parameters. These approximations can be provided by the force balance expressions. The line weights and moment arms are initially computed by assuming the line segments are straight, rigid, pinned members with the same unit weight as the actual cables. Once these approximations have been made, new weights and moment arms can be computed with the catenary expressions (see following section), and a second computation with the force balance equations will improve the approximations.

As the approximations of horizontal tension, and thus catenary parameters, improve, the approximations of line weights and moment arms improve, which improve the tension estimate, etc., until the procedure converges on the desired solution. This algorithm is discussed after the next section for the specific problem studied in this paper.

6.0 CATENARY LINE WEIGHTS AND MOMENT ARMS

To implement the iterative procedure described in the previous section, the hyperbolic function expressions for catenary line weights and moment arms must be available. These are derived below.

Consider the catenary line segment 1, as shown in figure 5. The line length of this segment can be expressed in terms of the appropriate catenary parameter m_1 and the values of x_1^a and x_1^c as

$$s_1 = m_1(\sinh x_1^a/m_1 - \sinh x_1^c/m_1) \qquad (6.0.1)$$

and the uniform line weight gives a concentrated load of

$$R_1 = w_1 s_1 \qquad (6.0.2)$$

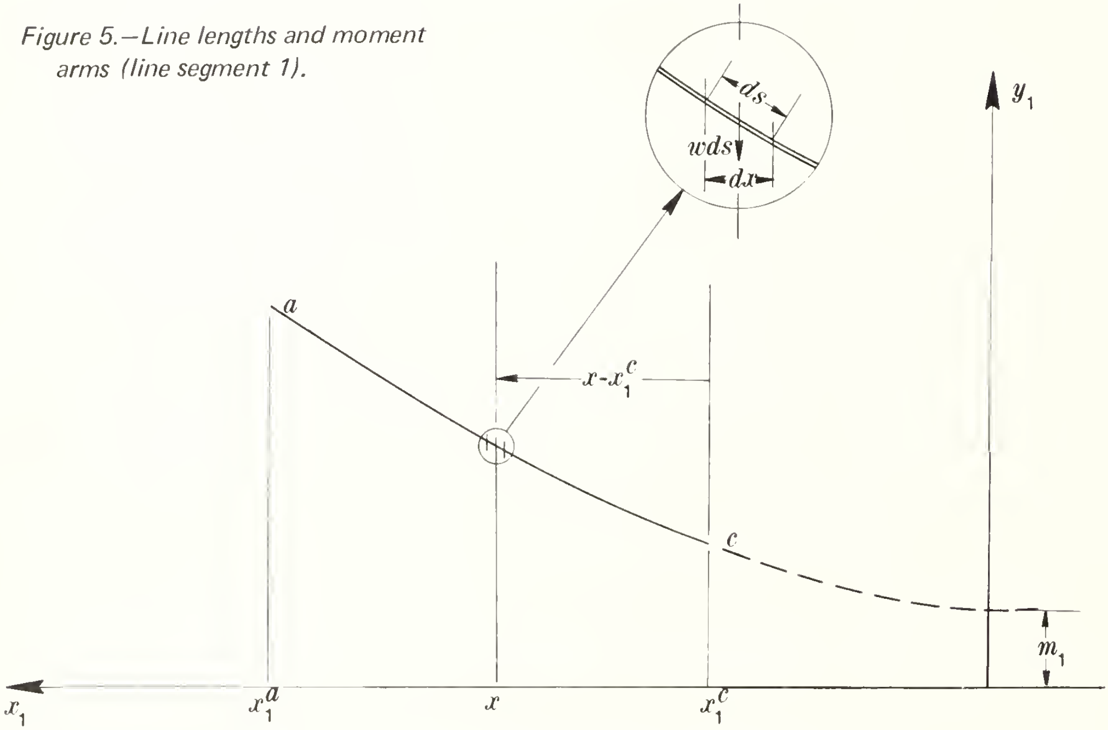
The moment arm expression is somewhat more involved. For a differential element, the moment about point (C) can be expressed as

$$dM_1 = (x - x_1^c)\ w_1\ \cosh x/m_1\ dx \tag{6.0.3}$$

or, expressed in terms of the catenary formulation,

$$dM_1 = m_1\ \left(\frac{x}{m_1} - \frac{x_1^c}{m_1}\right)\ w_1\ \cosh\ \frac{x}{m_1}\, d\left(\frac{x}{m_1}\right) \tag{6.0.4}$$

Figure 5.—Line lengths and moment arms (line segment 1).



The total moment about (C) for the entire line segment between (C) and (A) would be

$$M_1 = \int_c^a dM_1 = w_1 (m_1)^2 \int_{x_1^c/m_1}^{x_1^a/m_1} \left(\frac{x}{m_1} - \frac{x_1^c}{m_1}\right)\ \cosh \frac{x}{m_1}\ d\left(\frac{x}{m_1}\right) \tag{6.0.5}$$

This yields a moment arm expression for line segment 1 of

$$e_1 = \frac{M_1}{R_1} = w_1 m_1 \ f_2 (x_1^a, \ m_1, \ x_1^c)/R_1 \qquad (6.0.6)$$

where

$$R_1 = w_1 g_2 \ (x_1^a, \ m_1, \ x_1^c) \qquad (6.0.7)$$

and

$$f_2 \ (p,q,r) = q \ \left[(\frac{p-r}{q}) \ sinh \ \frac{p}{q} - cosh \ \frac{p}{q} + cosh \ \frac{r}{q} \right]$$

$$g_2 \ (p,q,r) = q(sinh \ \frac{p}{q} - sinh \ \frac{r}{q})$$

An analysis of line segments 2 and 3 will give the similar results as shown below:

$$e_2 = w_2 m_2 f_2 (x_2^b, \ m_2, x_2^c)/R_2 \qquad (6.0.8)$$

$$R_2 = w_2 g_2 (x_2^b, \ m_2, \ x_2^c) \qquad (6.0.9)$$

$$e_3 = w_3 m_3 f_2 (x_3^a, \ m_3, \ x_3^c)/R_3 \qquad (6.0.10)$$

and

$$R_3 = w_3 g_2 (x_3^a, \ m_3, \ x_3^c) \qquad (6.0.11)$$

7.0 ITERATIVE PROCEDURE FOR THE SINGLE-SPAN SKYLINE EXAMPLE

Consider the iterative procedure used for solution of the single-span skyline example. (For numerical example, see Appendix.) The subsections refer to blocks in the flow diagram (fig. 6), and the equations are those of this report.

7.1 Input

As formulated, this solution expects geometric quantities of L, d, Δy, and h, as well as skyline allowable tension, line weights per foot, and carriage weight as input.

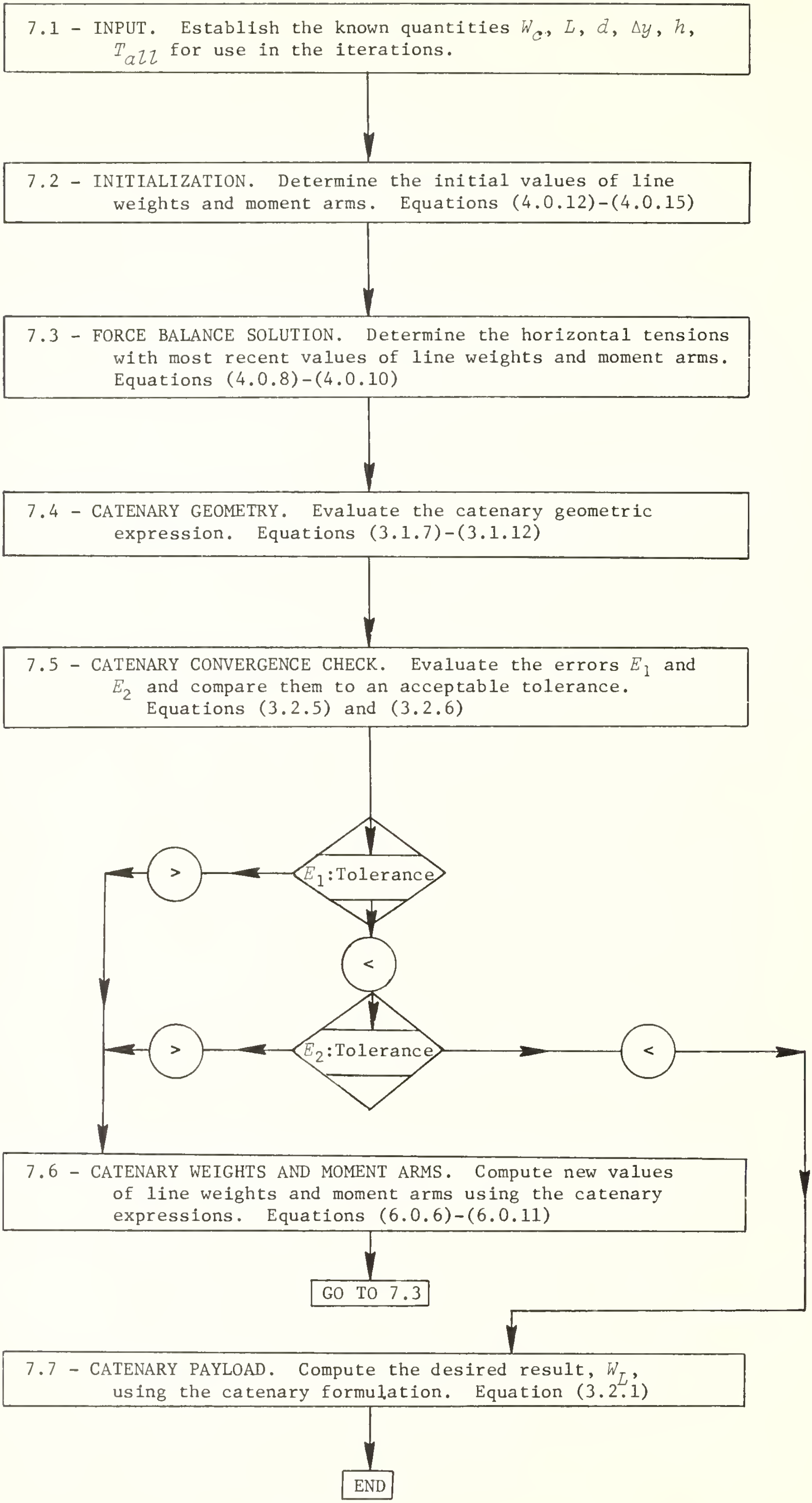


Figure 6.—Flow diagram of procedure.

7.2 Initialization

With the line segments approximated as straight, rigid members, pinned at points (A), (B), and (C), initial values for line weights and moment arms are computed.

7.3 Force Balance Solution

With the most recent values of line weights and moment arms, the force balance equations are solved for horizontal tensions which provide the catenary parameters.

7.4 Catenary Geometry

The catenary parameters generated in "Force Balance Solution" are used to compute the geometric functions expressed in equations (3.1.7) through (3.1.12).

7.5 Catenary Convergence Check

The catenary parameters and geometric functions are checked against the errors of equations (3.2.5) and (3.2.6) for convergence.

7.6 Catenary Weights and Moment Arms

The expressions of equations (6.0.6) through (6.0.11) are used to compute values for line weights and moment arms. The procedure returns to "Force Balance Solution" with these updated values.

7.7 Catenary Payload

The catenary expression for vertical force balance, equation (3.2.1), is used to compute payload W_L. Since the catenary parameters are available at this point, other tensions and components could be computed.

8.0 CONCLUSION

The algorithm presented in this paper has been extensively examined on a wide range of problems. In all cases, the convergence has been rapid, seldom exceeding two iterations. It should also be recognized that little additional complexity is introduced by adding lines or line segments to the cable system. Such cases will proportionately increase the number of force balance and catenary expressions involved; however, the logic of the procedure remains the same.

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APPENDIX

NUMERICAL EXAMPLE

To further clarify the algorithm discussed in this paper, a numerical example is presented. This example follows the procedure outlined in "Iterative Procedure for the Single-Span Skyline Example." Note that all calculations were done to 10 significant digits but have been rounded off for presentation.

7.1 Input

L = 2,500 feet	T_{all} = 64,000 pounds
h = 1,000 feet	$w_1 = w_2$ = 3.5 pounds per foot
d = 700 feet	w_3 = 1.85 pounds per foot
Δy = 600 feet	W_c = 5,000 pounds

7.2 Initialization

Equations used

$$R_1 = 3.5\,[(700)^2 + (600)^2]^{1/2} = 3{,}226.84 \quad (4.0.12)$$

$$e_1 = 700/2 = 350 \quad (4.0.13)$$

$$R_2 = 3.5\,[(1{,}800)^2 + (-400)^2]^{1/2} = 6{,}453.68 \quad (4.0.14)$$

$$e_2 = 1{,}800/2 = 900 \quad (4.0.15)$$

7.3 Force Balance Solution

$$H_1 = \frac{-(3226.84)(\frac{600}{700})(-0.5)+[(1382.9)^2-(1.7347)[(-1613.42)^2-(61900)^2]]^{1/2}}{1.7347} \quad (4.0.8)$$

$$H_1 = 47786.0$$

$$H_2 = \frac{-(6453.48)(\frac{-400}{1800})(-0.5)+[(717.08)^2-(1.049)[(-3226.8)^2-(61900)^2]]^{1/2}}{1.049} \quad (4.0.9)$$

$$H_2 = 59664.4$$

7.4 Catenary Geometry

$$m_1 = \frac{47786.0}{3.5} = 13653.1 \quad (3.0.4)$$

$$m_2 = \frac{59664.4}{3.5} = 17047.0 \quad (3.0.4)$$

$$\frac{x_1^a}{m_1} = sinh^{-1} \left[\frac{600}{2(13653.1)\ sinh \left[\frac{700}{2(13653.1)} \right]} \right] + \frac{700}{2(13653.1)} \qquad (3.1.7)$$

$$= 0.77660 + 0.02563 = 0.80223$$

$$\frac{x_1^c}{m_1} = 0.77660 - 0.02563 = 0.75096 \qquad (3.1.8)$$

$$\frac{x_2^b}{m_2} = sinh^{-1} \left[\frac{-400}{2(17047.0)\ sinh \left[\frac{1800}{2(17047.0)} \right]} \right] + \frac{1800}{2(17047.0)} \qquad (3.1.9)$$

$$= -0.22033 + 0.05280 = -0.16754$$

$$\frac{x_2^c}{m_2} = -0.22033 - 0.05280 = -0.27313 \qquad (3.1.10)$$

7.5 Catenary Convergence Check

$$E_1 = 61900 - (3.5)(13653.1)\ cosh\ (0.75096) = -5.640 \qquad (3.2.5)$$

$$E_2 = 61900 - (3.5)(17047.0)\ cosh\ (-0.27313) = -3.707 \qquad (3.2.6)$$

As these errors are greater than reasonable tolerance (say, 1.0 pound), the calculations will continue through an iteration.

7.6 Catenary Weights and Moment Arms

$$R_1 = 3.5(13653.1)[sinh\ (0.80223) - sinh\ (0.75096)] \qquad (6.0.7)$$

$$R_1 = 3227.0$$

$$e_1 = \frac{(3.5)(13653.1)^2}{3227.0} [(0.80223 - 0.75096)\ sinh\ (0.80223)$$

$$- cosh\ (0.80223) + cosh\ (0.75096)] \quad (6.0.6)$$

$$e_1 = 351.9$$

$$R_2 = 3.5(17047.0)\ [sinh\ (-0.16754) - sinh(-0.27313)] \quad (6.0.9)$$

$$R_2 = 6456.5$$

$$e_2 = \frac{(3.5)(17047.0)^2}{6456.5} [(-0.16754 + 0.27313) sinh(-0.16754)$$

$$-cosh(-0.16754) + cosh(-0.27313)] \quad (6.0.8)$$

$$e_2 = 896.6$$

Now return to force balance with these new R's and e's.

7.3 Force Balance

$$H_1 = 47781.7 \quad (4.0.8)$$

$$H_2 = 59660.8 \quad (4.0.9)$$

7.4 Catenary Geometry

$$m_1 = 13651.9 \quad (3.0.4)$$

$$m_2 = 17045.9$$

$$\frac{x_1^a}{m_1} = 0.77660 + 0.02563 = 0.80224 \quad (3.1.7)$$

$$\frac{x_1^c}{m_1} = 0.77660 - 0.02563 = 0.75096 \qquad (3.1.8)$$

$$\frac{x_2^b}{m_2} = -0.220332 + 0.052799 = -0.167533 \qquad (3.1.9)$$

$$\frac{x_2^c}{m_2} = -0.220332 - 0.052799 = -0.27313 \qquad (3.1.10)$$

7.5 Catenary Convergence Check

$$E_1 = -0.000505 \qquad (3.2.5)$$

$$E_2 = -0.000245 \qquad (3.2.6)$$

These are acceptable errors. Proceed to next section.

7.7 Catenary Payload

$$m_3 = \frac{(3.5)(17045.9) - (3.5)(13651.9)}{1.85} \qquad (3.2.2)$$

$$m_3 = 6421.1$$

$$\frac{x_3^c}{m_3} = 0.776348 - 0.054508 = 0.72184 \qquad (3.1.12)$$

$$W_L = (3.5)(13651.9)\,sinh(0.75096)+(3.5)(17045.9)\,sinh(-0.27313)$$

$$+ (1.85)(6421.1)\,sinh(0.72184)-5000 \qquad (3.2.1)$$

$$W_L = 27191.8$$

This is the load-carrying capability of the equipment operating with the geometry input.

Carson, Ward W., and Mann, Charles N.
1970. A technique for the solution of skyline catenary equations. USDA Forest Serv. Res. Pap. PNW-110, 18 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Presents an iterative technique for solution of skyline problems based on a catenary and force balance formulation. Trials of various skyline configurations show this technique is convergent in no more than three iterations. This information will be useful in developing a computer program for the analysis of suspended cable systems.

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The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

1. Providing safe and efficient technology for inventory, protection, and use of resources.
2. Development and evaluation of alternative methods and levels of resource management.
3. Achievement of optimum sustained resource productivity consistent with maintaining a high quality forest environment.

The area of research encompasses Oregon, Washington, Alaska, and, in some cases, California, Hawaii, the Western States, and the Nation. Results of the research will be made available promptly. Project headquarters are at:

College, Alaska	Portland, Oregon
Juneau, Alaska	Roseburg, Oregon
Bend, Oregon	Olympia, Washington
Corvallis, Oregon	Seattle, Washington
La Grande, Oregon	Wenatchee, Washington

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

USDA FOREST SERVICE RESEARCH PAPER PNW-11

COOPERATIVE LEVELS-OF-GROWING STOCK STUDY IN DOUGLAS-FIR

REPORT NO. 1

DESCRIPTION OF STUDY AND EXISTING STUDY AREAS

ACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
S DEPARTMENT OF AGRICULTURE
FOREST SERVICE
PORTLAND, OREGON

Levels-of-growing-stock study treatment schedule, showing percent of gross basal area increment of control plot to be retained in growing stock

Thinning	Treatment							
	1	2	3	4	5	6	7	8
	Percent							
First	10	10	30	30	50	50	70	70
Second	10	20	30	40	50	40	70	60
Third	10	30	30	50	50	30	70	50
Fourth	10	40	30	60	50	20	70	40
Fifth	10	50	30	70	50	10	70	30

Public and private agencies are cooperating in a study of eight thinning regimes in young Douglas-fir stands. Regimes differ in the amount of basal area allowed to accrue in growing stock at each successive thinning. All regimes start with a common level-of-growing-stock which is established by a conditioning thinning.

Thinning interval is controlled by height growth of crop trees, and a single type of thinning is prescribed.

Eight study areas, each involving three completely random replications of each thinning regime and an unthinned control, have been established in western Oregon and Washington, U.S.A., and Vancouver Island, Canada. Site quality of these areas varies from I through IV.

Climatic and soil characteristics for each area and data for the stand after the conditioning thinning are described briefly.

Keywords: Thinnings, stand growth, Douglas-fir.

Williamson, Richard L., and George R. Staebler. 1971. Levels-of-growing-stock cooperative study on Douglas-fir. Report No. 1--Description of study and existing study areas. USDA Forest Serv. Res. Pap. PNW-111, 12 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Thinning regimes in young Douglas-fir stands are described. Some characteristics of individual study areas established by cooperating public and private agencies are discussed.

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LEVELS-OF-GROWING-STOCK

COOPERATIVE STUDY

ON DOUGLAS-FIR

Report No. 1--Description of Study and Existing Study Areas

by

Richard L. Williamson, Mensurationist
Pacific Northwest Forest and Range Experiment Station

and

George R. Staebler, Director of Forestry Research
Weyerhaeuser Company

USDA Forest Service Research Paper PNW-111

Pacific Northwest Forest and Range Experiment Station
Forest Service
U.S. Department of Agriculture
Portland, Oregon
1971

Study area	*Cooperator*
Skykomish	Forestry Research Center Weyerhaeuser Company Centralia, Washington
Hoskins	School of Forestry Oregon State University Corvallis, Oregon
Rocky Brook	U.S. Forest Service Region 6 and Pacific Northwest Forest and Range Experiment Station Portland, Oregon
Clemons	Forestry Research Center Weyerhaeuser Company Centralia, Washington
Francis	Washington State Department of Natural Resources Olympia, Washington
Iron Creek	U.S. Forest Service Region 6 and Pacific Northwest Forest and Range Experiment Station Portland, Oregon
Stampede Creek	U.S. Forest Service Region 6 and Pacific Northwest Forest and Range Experiment Station Portland, Oregon
Campbell River	Canadian Forestry Service Department of Fisheries and Forestry Victoria, British Columbia

Consultative services have been provided by the University of Washington and the U.S. Bureau of Land Management.

INTRODUCTION

In 1962, representatives of State, Federal, and industrial forestry organizations met to organize a cooperative effort aimed at providing the biological information necessary to develop reliable yield tables for managed stands. The participants adopted a study plan[1] designed to examine (1) cumulative wood production, (2) tree size development, and (3) growth-growing stock ratios as affected by eight different thinning regimes. This study plan had been developed earlier at Weyerhaeuser Company, and procedural details to insure comparable data from all cooperators were developed by the Pacific Northwest Forest and Range Experiment Station, U. S. Forest Service.

Each organization present at the 1962 meeting designated a representative to the Levels-of-Growing-Stock Studies Committee operating under Station auspices. This committee has met annually to develop additional procedures to further assure validity of study results and to disseminate new information pertinent to the study. A current list of committee members is appended.

A brief description of the study design, together with a description of study areas established through 1964, was published in 1965.[2]

[1] George R. Staebler and Richard L. Williamson. Plan for a level-of-growing-stock study in Douglas-fir. Available through the Director, Pacific Northwest Forest and Range Experiment Station, P.O. Box 3141, Portland, Oregon 97208.

[2] Richard L. Williamson and George R. Staebler. A cooperative level-of-growing-stock study in Douglas-fir. USDA Forest Serv. Pac. Northwest Forest & Range Exp. Sta. 12 p., illus., 1965.

The committee decided in 1969 to publish results from all study areas in the Station's Research Paper series. All papers pertaining to this study will have a similar format and be consecutively numbered. The Canadian Forestry Service will publish its reports, using the common format and report-number series. Since treatments at different study areas are staggered in time, the committee members will present information as soon as possible through reports on individual study areas. Whenever possible, results from two or more study areas will be presented together to facilitate area comparisons. This report is intended to bring readers up-to-date on all study areas and to clarify study procedures.

DESCRIPTION OF EXPERIMENT

The experiment is designed to test a number of thinning regimes beginning in young stands made alike at the start through a "calibration" thinning. Thereafter, through the time required for 60 feet of height growth, growing stock is controlled by allowing a specified addition to the growing stock between successive thinnings. Any extra growth is cut and is one of the measured effects of the thinning regime.

Study Area Selection

Criteria for study area selection are:

(1) Dominant portion of the stand 20 to 40 feet tall.

(2) Tree growth not seriously diminished by competition.

(3) Species other than Douglas-fir constitute no more than 20 percent of residual stand basal area.

(4) Trees distributed uniformly over the area.

(5) Site quality uniform through area.

Presumably, stands in the specified height range are sufficiently adaptable to recover rapidly from any minor competition effects existing before conditioning thinning.

These criteria could not be met in all cases. The stand which best met these criteria in southwestern Oregon was 55 feet tall, but all other criteria were satisfied. Alternative stands had either severe competition and/or patchy stocking.

Experimental Design

A single experiment consists of eight thinning regimes plus unthinned plots whose growth is the basis for treatment in these regimes. There are three plots per treatment arranged in a completely randomized design for a total of twenty-seven 1/5-acre plots. Experience indicates that a gross area of approximately 9 acres is required for a study area.

Interaction of site quality and treatment can be evaluated by replicating installations on each site quality class. Cooperative effort has made this replication possible.

Crop Tree Selection

Well formed, uniformly spaced, dominant trees at the rate of 80 per acre, or 16 per plot, are designated as crop trees prior to initial thinning. Each quarter of a plot must have no fewer than three suitable crop trees nor more than five--another criterion for stand uniformity.

Initial or "Calibration" Thinning

All 24 treated plots are thinned initially to the same density to minimize the effect of variations in original density on stand growth. Density of residual trees is controlled by quadratic mean diameter of the *residual* stand according to the formula:

Average spacing in feet = 0.6167 (quadratic mean d.b.h.) + 8.

Some basic stand characteristics resulting from sample solutions of this equation are:

Quadratic mean diameter	Spacing	Trees per acre	Basal area per acre
(Inches)	*(Feet)*	*(Number)*	*(Square feet)*
3	9.8	449	22.0
4	10.5	398	34.8
5	11.1	355	48.2
6	11.7	318	62.4

If one concentrates on leaving a certain amount of basal area corresponding to an estimated overall quadratic mean d.b.h. ($\bar{\bar{D}}q$), then the residual number of trees may vary freely and the actual $\bar{D}q$'s may vary between plots up to ± 10 percent. Alternatively, if emphasis is on leaving a certain number of trees corresponding to an estimated overall $\bar{\bar{D}}q$, then the basal area may vary and the actual $\bar{D}q$'s may vary up to ± 15 percent between plots.

The choice of emphasis is optional, but the basal area guide is recommended for better control of growing stock.

In addition to achieving a common density, the objective of the calibration thinning is to leave a stand as uniform and as evenly spaced as possible. The effect of different thinning regimes in stands as nearly alike as possible at the start is being measured. The interval following conditioning thinning permits the trees to adjust to the common density of the plots before treatment thinnings are started.

Treatments

The eight thinning regimes tested differ in the amount of basal area allowed to accumulate in the growing stock. The amount of growth retained at any thinning is a predetermined percentage of the gross increase found in the unthinned plots since the last thinning (table 1). The average residual basal area for all thinned plots after the calibration thinning is the foundation upon which all future growing stock accumulation is based. As used in the study, control plots may be thought of as providing a "local gross yield table" for the study area.

Thinning *regimes* are being tested, rather than single thinnings. Several treatments (1, 3, 5, 7) are of approximately constant cutting intensities, differing among themselves in level only; two treatments (2, 4) vary intensities from heavier to lighter; and two treatments (6, 8) vary intensities from lighter to heavier.

Clearly, this range of treatments will explore the ability of Douglas-fir to respond to varying degrees of release as the stands pass through critical developmental stages. After several treatment thinnings, densities should range from very high basal area levels to very low levels in which all trees grow as open-grown trees do. The range in yield, tree size, and growth-growing stock ratios should permit foresters to choose regimes that will satisfy any particular objective of management.

Four factors may be expected to strongly influence the results of a thinning regime: (1) volume of growing stock retained; (2) interval, or years between thinnings; (3) kind of thinning practiced--low, high, selection, etc.; and (4) site quality. A complete experiment would probably test three levels of each of the four factors in combination resulting in an experiment with 81 different treatments. In this study, only growing stock will be purposely varied, however, and the other factors will be held as constant as possible as explained in the paragraphs that follow.

Control of Thinning Interval

Thinnings will be made whenever average height growth of crop trees following the year of the calibration thinning comes closest to each multiple of 10 feet.

Table 1.--*Levels-of-growing-stock study treatment schedule, showing percent of gross basal area increment of control plot to be retained in growing stock*

Thinning	Treatment							
	1	2	3	4	5	6	7	8
	Percent							
First	10	10	30	30	50	50	70	70
Second	10	20	30	40	50	40	70	60
Third	10	30	30	50	50	30	70	50
Fourth	10	40	30	60	50	20	70	40
Fifth	10	50	30	70	50	10	70	30

Control of Type of Thinning

As far as possible, type of thinning is eliminated as a variable in the treatment thinnings through several specifications:

1. No crop tree may be cut until all noncrop trees have been cut (another tree may be substituted for a crop tree damaged by logging or killed by natural agents).
2. The quadratic mean diameter of cut trees should approximate that of trees that are available for cutting.
3. The diameters of cut trees should be distributed across the full diameter range of trees available for cutting.

DATA COMPILATION

Stand data for all studies in this cooperative effort are calculated and compiled by the same set of computer programs. Basic data for each tree are d.b.h., basal area, total cubic volume, and condition class (damage or mortality). Diameter at breast height, basal area, and cubic volume are summed by condition class within each plot. These sums are averaged for the three plots within each treatment. Plot and treatment values of basal area and cubic volume are expressed on a per-acre basis.

Tree volumes are currently based on a standard volume table for Douglas-fir,[3] as expressed mathematically.[4] Volumes from this table are usually poor estimates of volume from trees less than about 12 inches d.b.h., and the Station's mensuration project is investigating alternate volume bases.

STUDY AREAS

Lands of site quality I through IV are represented by eight study areas to date. Basic data for each study area are summarized in tables 2 and 3. Data in table 2 apply to the stands at times of calibration thinnings. Data in table 3 are mostly long-term averages[5] for weather stations nearest their respective study areas.

Skykomish Tree Farm

The Skykomish study on the Skykomish Tree Farm of Weyerhaeuser Company was the first installed in this cooperative effort. Many of the details of the standardized work plan were developed at this study area.

This natural stand (fig. 1) was approximately 20 years old when the study was established in 1961. At this time, there was no specification limiting the percentage of other species in residual stands. Even though proportionately more hemlock than Douglas-fir was cut in the calibration thinning, the stand still contained about 50 percent hemlock after this thinning.

This study area occupies a north-facing slope along Youngs River near Sultan, Wash., at about 500-foot elevation. The slope averages about 35 percent. Soils[6] are in the Oso series and are derived from basaltic parent material weathered in place. The area has been mildly glaciated, but surface disturbance was minor and there was little deposition of glacial till.

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[3] Richard D. McArdle, Walter H. Meyer, and Donald Bruce. The yield of Douglas fir in the Pacific Northwest. U.S. Dep. Agr. Tech. Bull. No. 201, 74 p., illus., rev. 1961.

[4] Robert O. Curtis. A formula for the Douglas-fir total cubic-foot volume table from bulletin 201. Pac. Northwest Forest & Range Exp. Sta. USDA Forest Serv. Res. Note PNW-41, 8 p., 1966.

[5] Meteorology Committee, Pacific Northwest River Basins Commission. Climatological handbook Columbia Basin States. Six vols., Vancouver, Wash., 1969.

[6] Personal communication from Eugene Steinbrenner, Weyerhaeuser Company, Centralia, Wash.

Table 2.--*Statistics of the study areas at time of conditioning thinning*

Study area and year established	Estimated site index[1] (index age: 50 years)	Age	Average height of crop trees	Quadratic mean d.b.h.		Trees per acre, all species		Basal area per acre	
				Control	Thinned	Control	Thinned	Control	Thinned
	Feet	*Years*	*Feet*	----*Inches*----		----*Number*----		--*Square feet*--	
Skykomish, 1961	119	[2]16	44	4.7	5.1	1,197	358	144.2	50.8
Hoskins, 1963	133	[2]13	36	3.7	5.2	1,727	345	133.8	49.8
Rocky Brook, 1963	90	21	28	3.3	4.0	1,300	400	85.0	35.7
Clemons, 1964	148	19	31	4.0	4.1	687	395	59.9	35.8
Francis, 1963	148	18	25	3.3	3.8	887	405	51.5	31.0
Iron Creek, 1966	127	17	36	3.7	5.0	1,125	355	82.0	47.4
Stampede Creek, 1968	95	[2]29	55	4.7	6.6	995	290	118.5	68.1
Campbell River, 1969	119	21	38	3.8	5.0	1,083	355	87.6	47.9

[1] James E. King. Site index curves for Douglas-fir in the Pacific Northwest. Weyerhaeuser Forest. Pap. No. 8. Weyerhaeuser Co. Forest. Res. Center, Centralia, Wash., 49 p., 1966.

[2] At breast height.

Table 3.--*Climatic data*[1] *for study areas*

Study area	Weather station	Average precipitation		Length of growing season	Average growing season temperature
		Annual	May-August		
		------*Inches*------		*Days*	*Degrees F.*
Skykomish	Snoqualmie Falls	60.3	11.4	151	59.2
Rocky Brook	--	[2]80.0	--	--	--
Clemons	Oakville	54.5	9.2	156	59.9
Francis	Willapa Harbor	87.5	13.8	197	59.4
Iron Creek	Rainier-Longmire	82.4	14.8	133	59.9
Hoskins	--	[2]80.0	--	--	--
Stampede Creek	Prospect	41.7	6.4	92	60.9
Campbell River	Campbell River	58.5	10.0	149	58.4

[1] Meteorology Committee, Pacific Northwest River Basins Commission. Climatological handbook Columbia Basin States. Six vols., Vancouver, Wash., 1969.

[2] Estimated from isohyetal map; see footnote 1.

B

Figure 1.—The Skykomish area in 1969, just before the second treatment thinning. *A*, thinned area (treatment 6). Ribboned trees were removed in this thinning. *B*, unthinned area, with more than 4,000 stems per acre.

B

Figure 2.—Study area near Hoskins, Oreg. *A*, treated plot, with control plot in the background. *B*, treatment plots.

In spite of severe opening-up by the conditioning thinning, the stand survived the 1962 Columbus Day windstorm with little loss and, in general, is very thrifty.

This study area received the second treatment thinning in the winter of 1969.

Hoskins

The Hoskins study was established by the School of Forestry, Oregon State University, and was made possible through the provision of land and timber by T. J. Starker and Bruce Starker, professional foresters and private landowners.

The stand was approximately 20 years old when the study was begun in 1963. This natural stand is outstandingly uniform in age and stocking (fig. 2); consequently, very little effort was required to mark all plots to the specified residual basal area and average diameter at the conditioning thinning.

The area is just west of the Coast Ranges' summit near Hoskins, Oreg., about 25 miles northwest of Corvallis. The aspect is southerly, with slopes from 15 to 55 percent. Elevation is about 1,000 feet. Soil information is currently not available.

Annual measurements at this study area have provided reliable determination of rate of response to thinning.

Rocky Brook

In 1963 the U.S. Forest Service (Region 6 and the Pacific Northwest Forest and Range Experiment Station) installed a study area on the Hoodsport Ranger District, Olympic National Forest, near Brinnon, Wash.

The Rocky Brook stand (fig. 3) was planted in 1942 and had plentiful natural fill-in. Installation was difficult because of several small foci of *Poria weirii* root rot throughout the stand. Ten spare plots were established in anticipation of undiscovered *Poria weirii* and future snow damage problems.

The stand occupies a glacier-formed, gently sloping (average 10 percent, short pitches up to 55 percent) terrace near the bottom of a deep, glaciated canyon. The gravelly, sandy loam soils are phases of the Hoodsport series.[7] Aspect is southerly. Cool temperatures, short growing season, and the stony, infertile soil probably contribute to the low site quality.

This study area, at 2,500-foot elevation in the Olympic Mountains, was hit by a record snowfall immediately after conditioning thinning in the fall of 1963. Spare plots were used at the first treatment thinning in the fall of 1969 to replace heavily damaged plots.

Clemons Tree Farm

This study area is in a stand planted in 1947. It occupies a very high quality site near Blue Mountain, about 10 miles west of Oakville, Wash., on the Clemons Tree Farm of Weyerhaeuser Company. Plots are grouped on top of a low ridge with gentle (0-15 percent) slopes at about 800-foot elevation. Aspect is northerly. Soils[8] are in the Astoria series derived from very deep marine sediments and are characteristically highly productive.

Because the plantation was badly browsed and suppressed by bracken in its early years, site index estimation is even more difficult than in most young stands

[7] Intensive soil survey report of the Rocky Brook Study Area, by Loren R. Herman, Soil Scientist, Region 6, U.S. Forest Service. On file in Portland, Oreg., and in Olympia, Wash.

[8] See footnote 6, page 4.

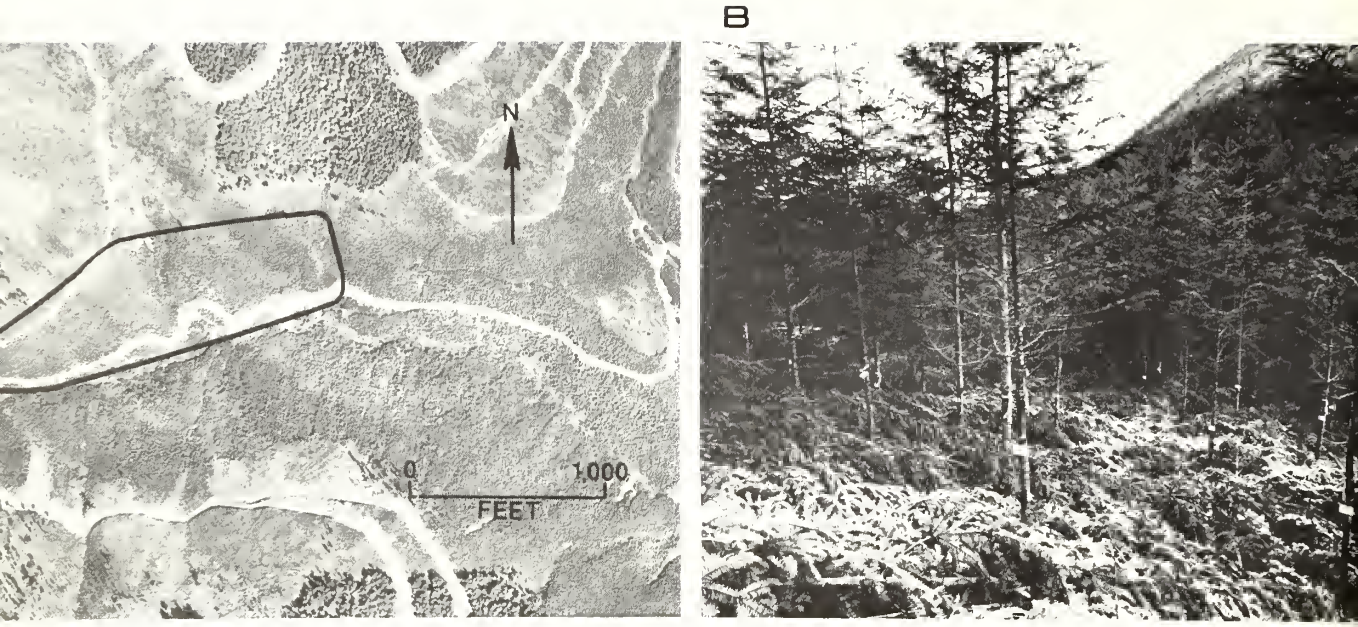

Figure 3.—The Rocky Brook study area, located on the Hoodsport Ranger District, Olympic National Forest, near Brinnon, Wash. *A*, aerial view. *B*, treatment plot.

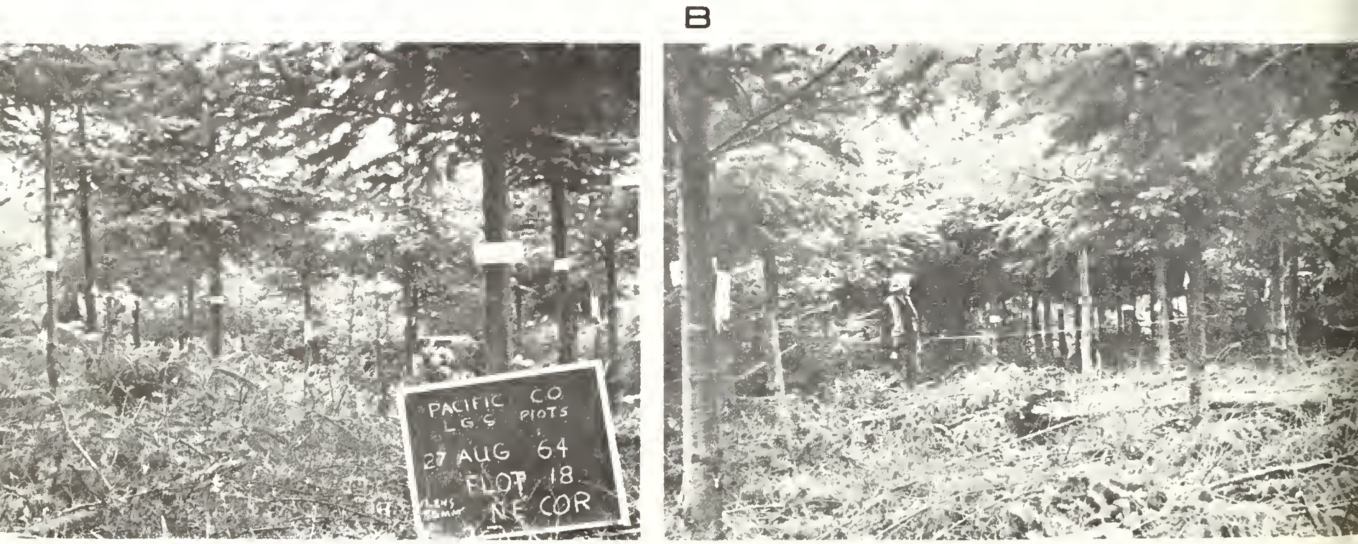

Figure 4.—Washington State Department of Natural Resources study area in the Willapa Hills near Raymond, Wash. *A*, treatment plot after thinning. *B*, treatment plot after thinning, with control plot in background.

and has been based primarily on current terminal growth.

In the conditioning thinning, the majority of trees removed were deformed or of poor quality because of browsing or damage from a severe freeze in 1955.

Many trees felled in thinning had 4-foot leaders. The study includes two control plots installed 1 year previously for another experiment. Growth on these two plots in 1964 was 11 square feet of basal area per acre on 500 trees larger than 2.3-inch d.b.h. Average diameter increased a little more than 0.4 inch in the year between measurements. Obviously, the growth capacity of Douglas-fir on the site is exceptional.

The second thinning treatment was in the fall of 1970.

Francis

The Washington State Department of Natural Resources established a study in 1963 in a stand planted in 1945. The stand (fig. 4) is located on a gentle ridgetop at about 1,500-foot elevation in the central Willapa Hills near Raymond, Wash. Slope of ground varies mostly from 0 to 10 (maximum, 25) percent with aspects either level or confined to the NW and NE quadrants.

Stand growth on this area, like that on the Clemons area, will probably be very high since some trees have current terminal growth of about 4 feet. Soils in the area have not been classified but are described as a deep, well-drained silt loam developed in a mild, wet, coastal climate.[9]

The stand received the second treatment thinning in the fall of 1969.

Iron Creek

The second Forest Service study area is located on the Randle District of the Gifford Pinchot National Forest near Randle, Wash.

The stand (fig. 5) was planted in 1949, and little natural fill-in occurred. Before study establishment, black bears had girdled many trees in the general area. Approximately 20 percent of the trees left by the conditioning thinning had been partially girdled. A strong fence was built around the study area to prevent further damage.

The stand occupies a midslope position at about 2,500-foot elevation. Aspect is easterly, and slopes are gentle, averaging about 25 percent. The deep, well-drained soil is derived from volcanic ejecta overlying a residual soil developed on fractured volcanic rock. Surface soils range from sandy loam to loam with interbedded pumice.[10]

First thinning treatment was in the fall of 1970.

Stampede Creek

The third Forest Service study is located on the Tiller District of the Umpqua National Forest near Tiller, Oreg. This stand (fig. 6) originated from natural seed fall about 10 years after a wildfire in 1929. This 10-year period allowed brush species to develop so that seedling density was not as heavy as in normal stands.

At age 29 years (1968), when this study area was established, the height of trees (about 55 feet) exceeded study plan specifications, but the initial relatively wide

[9] Personal communication from H. W. Anderson, Soils Scientist, Washington State Department of Natural Resources.

[10] Preliminary estimate by Loren R. Herman, Soil Scientist, Region 6, U.S. Forest Service.

B

Figure 5.—Iron Creek area after conditioning thinning in 1966. *A*, thinned area. *B*, unthinned control plot.

B

Figure 6.—Stampede Creek area after conditioning thinning in 1968. *A*, thinned area. *B*, unthinned control plot.

spacing prevented severe competition. Tree distribution is fairly uniform. To gain regionwide sampling, it was considered better to accept a too tall stand of fairly uniform stocking and moderate competition than to accept a stand of specified height with uneven stocking or severe competition. No better alternative stands could be found in the southwestern Oregon area.

The study area occupies a broad, minor ridge near the headwaters of Stampede Creek. Slopes are gentle, averaging about 25 percent, and aspect is generally northeast. Soil in the study area is unnamed and derived primarily from volcanic tuffs and breccias. Soil texture is of heavy loam overlying heavy clay loam.

Campbell River

The Canadian Forestry Service, Department of Fisheries and Forestry, completed plot establishment in 1969 in an area 15 miles west of Campbell River, Vancouver Island, B. C. , Canada.

This stand is from 2-year-old seedlings planted in 1950. Natural fill-in has been light, and species other than Douglas-fir (mostly western hemlock and western redcedar) occur in small amounts (fig. 7).

The stand occupies a westerly aspect at 900-foot elevation in gently rolling topography. The soil is a well-drained young Podzolic developed from gravelly, sandy glacial till.[11]

[11] Personal communication from Paul Diggle, Canadian Forestry Service, Department of Fisheries and Forestry.

Figure 7.—Typical stand conditions at Campbell River. *A*, before conditioning thinning. *B*, after conditioning thinning.

Other LOGS (levels-of-growing-stock) reports:

WILLIAMSON, RICHARD L., and GEORGE R. STAEBLER.
1965. A cooperative level-of-growing-stock study in Douglas-fir. USDA Forest Serv. Pac. Northwest Forest and Range Exp. Sta., 12 p., illus. Portland, Oregon.
Describes purpose and scope of a cooperative study which is investigating the relative merits of eight different thinning regimes. Main features of six study areas installed since 1961 in young stands are also summarized.

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SEASONAL FORAGE USE BY DEER AND ELK ON THE STARKEY EXPERIMENTAL FOREST AND RANGE, OREGON

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ABSTRACT

Seasonal forage use by mule deer (Odocoileus hemionus hemionus) *and Rocky Mountain elk* (Cervus canadensis nelsoni) *was determined in the three major habitats--open forest, dense forest, and grassland--that characterize the ponderosa pine-Douglas-fir* (Pinus ponderosa-Pseudotsuga menziesii) *vegetation type of the Blue Mountains of eastern Oregon. Food grades derived from data on diet and forage abundance were used to compare the habitats as sources of forage. Open forest land rated highest in spring, summer, and fall. This habitat had a season-long abundance of forage, particularly elk sedge* (Carex geyeri), *a highly preferred grasslike plant. Grassland rated second in the spring when succulent forbs were abundant but dropped to third during the summer and fall periods when grassland plants were largely dry and unpalatable. Deer and elk then sought food as well as cover in the forest habitats. Although low-growing shrubs contributed most to the dense forest food grade, that habitat was probably more important as cover than as a source of food.*

Keywords: Forage plants, habitats, food habits, mule deer *(Odocoileus hemionus hemionus)*, Rocky Mountain elk *(Cervus canadensis nelsoni)*, elk sedge *(Carex geyerii)*, Starkey Experimental Forest and Range, Oreg.

A knowledge of local wildlife preferences for food and cover is prerequisite to the effective management of the animals and their habitat. It is particularly important to administrators of public lands for which the management objective is to enhance or maintain suitable habitat while minimizing conflicts with other resources.

Mule deer (*Odocoileus hemionus hemionus*) and Rocky Mountain elk (*Cervus canadensis nelsoni*) spend 8 or more months of the year on midelevation ranges in the ponderosa pine-Douglas-fir (*Pinus ponderosa-Pseudotsuga menziesii*)[1/] type of the Blue Mountains of eastern Oregon.

Interactions of deer and elk use with livestock grazing, logging, and other resource uses are frequent and far-reaching. Yet, despite a need for better coordinated management, the local habitat needs of big game have not been extensively studied. The only published information available is that of Skovlin et al. (1968). However, because they studied big game-cattle relationships, their findings were limited to forage species and habitats important to cattle.

This paper presents the results of a 3-year study of seasonal forage use by deer and elk on a portion of the Starkey Experimental Forest and Range, an area representative of the central Blue Mountains.

DESCRIPTION OF THE STARKEY EXPERIMENTAL FOREST AND RANGE

In the Starkey Range in the central Blue Mountains near La Grande, Oregon, undulating uplands are dissected by moderate to steeply walled drainages; elevations range from 3,500 to 5,000 feet. Annual precipitation averages 20 inches, of which nearly half is snow. The soils and vegetation have been described by Strickler (1966); soils originated from basalt and pumicite. The vegetation is closely associated with soil type and depth, and habitats have developed in a mosaic pattern. Three distinct types of habitats--open forest, dense forest, and grassland--have been classified.

The open forest is the most extensive habitat, covering almost half the area (fig. 1). It consists of ponderosa pine and Douglas-fir intermixed in open stands on ridgetops and moderately sloped south exposures. Principal understory plants include bunchgrasses, elk sedge (*Carex geyeri*), and low-growing shrubs. Heartleaf arnica (*Arnica cordifolia*), lupines (*Lupinus* spp.), and several other forbs are abundant in spring and summer.

The dense forest is found on north and east exposures on deep pumice soils (fig. 1). It includes mature stands of mixed conifers, mainly Douglas-fir, grand fir (*Abies grandis*), and western larch (*Larix occidentalis*); and seral stands dominated by lodgepole pine (*Pinus contorta*). Huckleberries (*Vaccinium* spp.), twinflower (*Linnaea borealis*), and pyrolas (*Pyrola* spp.) are among the most abundant understory plants.

[1/] Scientific names for grasses and sedges are according to Hitchcock (1950); for forbs and shrubs, Hitchcock et al. (1955-69); for trees, Little (1953). Common names are according to Garrison et al. (1967).

Figure 1.--*Major habitats of the Starkey Experimental Forest and Range: open forest (top), dense forest (middle), grassland (bottom).*

Grassland openings are intermingled with the forest habitats (fig. 1). Bunchgrasses such as bearded bluebunch wheatgrass (*Agropyron spicatum*), Sandberg bluegrass (*Poa secunda*) and onespike danthonia (*Danthonia unispicata*) form the principal plant cover. However, composition varies greatly with season. During the spring and early summer while the shallow soils are wet, many species of succulent forbs are abundant. Among the more important ones are common camas (*Camassia quamash*), serrated balsamroot (*Balsamorhiza serrata*), and bicolor biscuitroot (*Lomatium leptocarpum*).

Deer, elk, and cattle share the range. Cattle are grazed approximately 4 months each summer. Skovlin et al. (1968) reported that deer use averaged 2.8 days per acre and elk use averaged 1.5 days per acre annually. The seasonal length of big game use varies and is determined by weather conditions, particularly snow accumulation. In most years deer and elk inhabit the area from early April through late December. Numbers of deer seem to remain relatively constant during the period of use. The elk population, however, is highest during May and June and again in November when a part of the elk herd is migrating across the area to or from adjacent summer ranges.

METHODS

The Study Area

The study was conducted during 1964 through 1966 in an area of experimental range from which cattle were excluded. Open forest comprised 47 percent of the area; grassland, 41 percent; and dense forest, 12 percent. Water was available on or adjacent to the study area at all seasons.

Measurements

Deer-elk diet was calculated from estimates of forage production and utilization. Data were taken three times a year in each type to follow changes in use brought about by seasonal changes in forage availability and palatability. The first measurements were made in June while spring forbs were abundant. The elk population was usually at its peak at that time. Summer measurements were taken in mid-August after grass and shrub growth was complete. Fall measurements were made in late November or early December just before snow forced deer and elk to move to their winter ranges.

Herbage production was estimated by species on clusters of permanent plots randomly located within each habitat. Each cluster consisted of 10 plots regularly spaced along a 100-foot line. A total of 450 plots were examined each season. Individual plots covered a rectangular area of 1.92 square feet. Production was determined by the weight-estimate method of Pechanec and Pickford (1937b). Only herbage considered potentially palatable was included in the estimate. For example, the dry, cured portions of grasses and the older, woody stems of shrubs were excluded. The summer production estimate minus summer forage use was taken as the fall estimate since little growth occurred between the two sampling dates. The small amount of grass regrowth that occurred in the grassland during the fall was estimated and added to the fall production estimate.

Utilization was estimated on circular plots of 6 square feet positioned concentrically over the production plots. The ocular-estimate-by-plot method (Pechanec and Pickford 1937a) was used. Although it is probable that the actual diet included a few additional species not sampled, it is unlikely that any of these missed made up an appreciable part of the diet. Occasional light use by small herbivores such as rabbits, mice, and squirrels when noted was not included in the utilization estimates.

Forage ratios and food grades (Hess and Swartz 1940) were calculated for forage species and habitats. These indexes allow comparison of individual food items and habitats as sources of forage. The forage ratio of a given species is the ratio of its percentage of the diet to its percentage of the total forage available. For example, in a given habitat at a given season, suppose that species X made up 10 percent of the total amount of all species eaten and that it made up 5 percent of the total amount of all species available, then its forage ratio would be 10/5 = 2.0. A ratio greater than 1 indicates a preference; a ratio of less than 1 suggests the species was eaten but not sought out. The food grade is the result of weighting herbage production according to the forage ratio. Those species with a forage ratio of 1 or more are given their full production value; those with a forage ratio of less than 1 are given a value equal to the forage ratio times herbage production. For example, if species X had a forage ratio of 2.0, as above, and produced 20 pounds of available forage per acre, its food grade value would be 20. If, however, its forage ratio had been 0.8 instead of 2.0, its food grade value would be 0.8 (20) = 16. The sum of these values for species making up 1 percent or more of the diet constitutes the seasonal food grade for the habitat. Thus, the food grades represent the effective production of food species. Food grades and production estimates are all expressed in pounds (dry weight) per acre.

RESULTS

Forage availability and animal use varied during the 3-year study period. The fluctuations were related to yearly differences in seasonal precipitation and temperature. The results presented here are 3-year averages.

Use was recorded on 73 species, including 15 grasses and grasslike plants, 46 forbs, and 12 shrubs. Most forage use was concentrated on a few species but none were heavily used. Five species made up more than one-half of the total diet for combined seasons and habitats.

Spring

The spring period showed the greatest variety and abundance of forage species. Many forbs and grasses were available, or palatable, only during the spring and early summer. Forage production averaged 336 pounds per acre in grassland, 324 in open forest, and 155 in dense forest. Forage use was highest in the grassland, lowest in the dense forest.

Forbs were the most important plant group in the spring diet, accounting for more than half of the forage eaten and almost half of that available (table 1). Twenty-two of 29 species used in the grassland and 22 of 38 species used in the open forest were forbs. The most important forbs were common camas and bicolor biscuitroot in the grassland, and heartleaf arnica in the open forest. Forbs were not important in the dense forest diet.

Table 1.--*Spring diet of deer and elk and forage availability in three habitats on the Starkey Experimental Forest and Range, Oregon*

(In percent)

Species[1/]	Grassland		Open forest		Dense forest		Combined habitats[2/]	
	Diet	Available forage	Diet	Available forage	Diet	Available forage	Diet	Total available forage
Grasses:								
Carex geyeri	--	0	30	29	--	1	14	14
All grasses	9	41	32	50	[3/] 2	4	18	43
Forbs:								
Arnica cordifolia	--	0	17	10	--	3	8	5
Balsamorhiza serrata	9	10	--	<1	--	0	--	4
Camassia quamash	38	6	--	<1	--	0	17	3
Geum triflorum	--	0	5	1	--	0	--	<1
Lomatium leptocarpum	14	11	--	<1	--	0	6	5
Lomatium nudicaule	7	1	--	<1	--	0	--	<1
Lupinus spp.	--	0	6	8	--	0	--	4
Microseris nutans	5	5	--	<1	--	0	--	2
Sidalcea oregana	6	<1	--	0	--	0	--	<1
All forbs	91	59	46	38	[3/] 3	41	63	47
Shrubs:								
Spiraea betulifolia	--	0	6	3	--	1	--	1
Symphoricarpos albus	--	0	12	3	--	<1	6	2
Vaccinium membranaceum	--	0	--	0	14	7	--	<1
Vaccinium scoparium	--	0	--	0	72	18	6	1
All shrubs	--	0	22	12	95	55	19	10

[1/] Species listed constituted at least 5 percent of the diet in a habitat; a dash indicates less than 5 percent.

[2/] Data for each habitat were weighted by the acreage of the habitat, then combined.

[3/] Neither the forage class nor any species constituted 5 percent of the diet; the class percentage is shown for comparison with the other classes.

The remainder of the diet was equally divided between grasses and shrubs. Grasses were almost as abundant as forbs but made up less than 20 percent of the diet. Most use was observed on elk sedge, a grasslike species, in the open forest. Shrubs were available only in the forest habitats. Huckleberries (*Vaccinium scoparium* and *V. membranaceum*) dominated the dense forest diet. Common snowberry (*Symphoricarpos albus*) was used most heavily in the open forest.

Even though forage use was lowest in the dense forest, more elk pellet groups were observed there than elsewhere, indicating that elk probably used it primarily for cover.

Summer

As spring forbs dried and shattered, forage availability changed quickly. Animal diets indicated a response to these changes since the proportion of forbs in the diet dropped sharply and grasses and shrubs increased (table 2).

The greatest change took place in the grassland openings, where grasses as well as forbs became dry and unpalatable. The few succulent plants present during the summer period were mostly stemmy, aromatic species such as low gumweed (*Grindelia nana*). By mid-August usable grassland forage dropped to less than 100 pounds per acre. Accordingly, summer forage use was less than 25 percent of the spring average. Light use was recorded on 15 species including seven grasses and eight forbs. The most heavily used species was Oregon checkermallow (*Sidalcea oregana*); although not abundant, it made up 40 percent of the grassland diet.

In the open forest, the loss of spring forbs was largely offset by the rapid growth of other species, particularly elk sedge. Production dropped slightly to 287 pounds per acre. Although the number of species eaten decreased to 27, forage consumption increased as deer and elk shifted from the grassland to the forest habitats. Elk sedge was the principal food item. Its increased use, coupled with the decrease in forbs, accounted for the dominance of grasses in the summer diet.

Summer forage production in the dense forest reached a high of 180 pounds per acre. Use also increased. Forbs were abundant, but shrubs continued to dominate the diet. Adenocaulon (*Adenocaulon bicolor*) was the only forb accounting for more than 5 percent of the diet.

Fall

Diet and forage availability for the fall period are summarized in table 3. The major portion of the diet was grasses and elk sedge. Elk sedge continued to be the most important item in the open forest and the entire study area. Several grasses were also used in the grassland. Although these species were mostly dry and unpalatable during the summer, fall precipitation, coupled with mild temperatures, stimulated a small quantity of regrowth. This regrowth was very attractive to big game, particularly deer, and accounted for 98 percent of the grassland diet. Sandberg bluegrass was fed upon more than any other of the eight species on which use was recorded. As expected, forbs were a minor item, and the proportion of shrubs increased.

Table 2.--*Summer diet of deer and elk and forage availability in three habitats on the Starkey Experimental Forest and Range, Oregon*

(In percent)

Species[1]	Grassland		Open forest		Dense forest		Combined habitats[2]	
	Diet	Available forage	Diet	Available forage	Diet	Available forage	Diet	Total available forage
Grasses:								
Carex geyeri	--	0	62	46	--	1	45	30
Danthonia unispicata	16	28	--	0	--	0	--	5
Koeleria cristata	6	3	--	1	--	0	--	1
Sitanion hystrix	20	<1	--	0	--	0	--	<1
All grasses	44	37	64	72	5	6	52	58
Forbs:								
Adenocaulon bicolor	--	0	--	0	9	1	--	<1
Polygonum douglasii	5	18	--	0	--	0	--	3
Sidalcea oregana	40	1	--	0	--	0	5	<1
All forbs	56	63	13	14	13	41	19	27
Shrubs:								
Ribes lacustre	--	0	--	0	6	1	--	<1
Rosa spp.	--	0	7	<1	--	2	5	<1
Spiraea betulifolia	--	0	8	3	--	1	6	2
Symphoricarpos albus	--	0	8	4	--	<1	6	3
Vaccinium membranaceum	--	0	--	0	20	5	--	<1
Vaccinium scoparium	--	0	--	0	42	16	6	2
All shrubs	--	0	23	14	82	53	29	15

[1] Species listed constituted at least 5 percent of the diet in a habitat; a dash indicates less than 5 percent.

[2] Data for each habitat were weighted by the acreage of the habitat, then combined.

Table 3.--*Fall diet of deer and elk and forage availability in three habitats on the Starkey Experimental Forest and Range, Oregon*

(In percent)

Species[1]	Grassland		Open forest		Dense forest		Combined habitats[2]	
	Diet	Available forage	Diet	Available forage	Diet	Available forage	Diet	Total available forage
Grasses:								
Agropyron spicatum	10	3	--	<1	--	0	--	<1
Calamagrostis rubescens	--	0	6	19	--	3	--	13
Carex geyeri	--	0	50	46	--	1	34	30
Danthonia unispicata	24	27	--	0	--	0	6	6
Koeleria cristata	26	3	--	<1	--	0	6	<1
Poa secunda	34	4	--	0	--	0	8	<1
All grasses	98	39	59	72	[3] 2	6	64	58
Forbs	2	61	--	14	5	41	1	27
Shrubs:								
Chimaphila umbellata	--	0	--	0	8	18	--	2
Pachistima myrsinites	--	0	--	<1	33	5	--	<1
Spiraea betulifolia	--	0	15	3	--	1	6	2
Symphoricarpos albus	--	0	22	4	--	<1	8	2
Vaccinium membranaceum	--	0	--	0	20	5	--	<1
Vaccinium scoparium	--	0	--	0	26	16	--	2
All shrubs	--	0	41	14	93	53	35	15

[1] Species listed constituted at least 5 percent of the diet in a habitat; a dash indicates less than 5 percent.

[2] Data for each habitat were weighted by the acreage of the habitat, then combined.

[3] Neither the forage class nor any species constituted 5 percent of the diet; the class percentage is shown for comparison with other classes.

Forage Ratios and Food Grades

The seasonal values listed in table 4 give added meaning to the information presented on forage availability and diet. For example, in the grassland during the spring, the forage ratio of common camas was 6.2; thus, it was preferred over serrated balsamroot rated at 0.9. However, because it was less abundant than the latter species, its food grade value was lower (20.3 vs. 28.8). The importance of elk sedge is further emphasized by these indexes. Because it was both sought out and abundant at all seasons, it made up a large share of the total food grade for the season. In fact, during the summer and fall periods, the food grade for elk sedge alone was greater than that for all grassland and dense forest species combined.

Largely owing to elk sedge, the open forest received the highest food grade in each season. The grassland rated second in the spring while succulent forbs were available but dropped to third during the summer and fall when grassland plants were mostly dry and unpalatable. The slight rise in the fall value for the grassland reflected the availability and use of grass regrowth. Shrubs accounted for most of the total food grade for the dense forest in each season.

DISCUSSION

Seasonal trends were apparent in deer and elk use of habitats and forage classes. They resulted from the interaction of many factors, the most important of which was the availability of preferred forage. Thus, during the spring, deer and elk fed mostly in the grassland and open forest where succulent forbs were available. The abundance of forage in those habitats was reflected in their high food-grade values. However, later, as the preferred forbs matured, deer and elk shifted almost entirely to the forest habitats for food as well as cover. Accordingly, summer and fall food grades for the grassland were low. Those for the open forest also dropped, but not greatly, because elk sedge and several kinds of shrubs were available to take the place of the spring forbs. On the other hand, the dense-forest food grade was highest in the fall when shrubs reached their greatest importance in the diet. Similar seasonal shifts in habitat use have been reported by Smith (1952), Stevens (1966), and others.

Use was recorded on many species, but regardless of season, only a few made up the bulk of the diet. The staple forage species was elk sedge. This plant is also an important forage on other ranges (Murie 1951; Young and Robinette 1939). It is important because it remains palatable as well as abundant throughout the grazing season. Perhaps its palatability is also enhanced by the relatively high nutrient content that it maintains throughout the growing season (Skovlin 1967).

Several species were very abundant but rarely eaten. Some were apparently unpalatable, and others were little used because of the availability of more preferred species. For example, Douglas stonecrop (*Sedum douglasii*) was abundant in the grassland and in parts of the open forest but was not eaten. Twinflower made up nearly half of the forage available in the dense forest, but few plants were utilized, although DeNio (1938) found it commonly used on winter range in Idaho. The effect of vegetal composition on diet was also well illustrated by the use of bunchgrasses. Deer and elk have been observed

Table 4.--*Seasonal forage ratios and food grades for three habitats on the Starkey Experimental Forest and Range, Oregon*

Species[1/]	Forage ratio			Food grade (pounds per acre)		
	Spring	Summer	Fall	Spring	Summer	Fall
Grassland:						
Agropyron spicatum	0.2	0.8	3.5	--	2.3	3.0
Danthonia unispicata	.2	.6	.9	8.5	14.6	24.5
Koeleria cristata	.9	2.2	10.0	--	2.5	2.6
Poa secunda	.1	0	9.4	--	--	3.6
Achillea millefolium	.6	.2	.1	8.6	2.3	--
Balsamorhiza serrata	.9	.5	0	28.8	2.3	--
Camassia quamash	6.2	0	0	20.3	--	--
Grindelia nana	.3	.3	.3	--	2.2	--
Lomatium leptocarpum	1.3	0	0	36.8	--	--
Microseris nutans	1.0	0	0	16.0	--	--
Polygonum douglasii	0	.3	0	--	4.5	--
Total for the type[2/]	--	--	--	153.1	33.6	36.9
Open forest:						
Calamagrostis rubescens	<.1	<.1	.3	--	--	16.6
Carex geyeri	1.0	1.4	1.1	94.2	131.7	129.2
Arnica cordifolia	1.7	3.6	0	32.1	--	--
Lupinus spp.	.8	1.7	0	18.7	--	--
Spiraea betulifolia	2.4	2.4	4.9	--	9.2	8.9
Symphoricarpos albus	3.7	2.1	5.9	11.0	10.9	10.6
Total for the type[2/]	--	--	--	197.1	172.8	173.9
Dense forest:						
Pyrola spp.	0	0	1.0	--	--	5.0
Chimaphila umbellata	.2	.2	.5	4.5	7.2	14.7
Pachistima myrsinites	.5	.5	7.1	3.1	3.9	8.3
Rosa spp.	.8	1.6	.4	--	4.5	--
Vaccinium membranaceum	2.1	3.8	3.8	10.3	9.7	9.6
Vaccinium scoparium	3.9	2.6	1.7	28.7	29.0	27.6
Total for the type[2/]	--	--	--	53.7	64.0	73.4

[1/] Species listed constituted at least 5 percent of the seasonal food grade; a dash indicates the food grade was less than 5 percent.

[2/] Includes all species that constituted 1 percent or more of the seasonal diet for the habitat.

to graze bunchgrasses heavily during the winter and early spring on winter ranges adjacent to the study area. Yet, they grazed grasses little when they reached this area in late spring, apparently because more preferred forbs were also available. For the same reason, they relished the regrowth of grasses in the fall when forbs were not available.

Although many of the forage species used by big game on the study area are shared with cattle on adjacent ranges, the lack of excessive use on any species found by this study corroborates the conclusion of Skovlin et al. (1968) that no direct competition for forage exists on the Starkey Range. Nevertheless, competition may occur on similar ranges that are overstocked with either cattle or big game. It is most likely to develop in the open forest in the summer and fall when both cattle and game are using that habitat. Elk sedge and shrubs would be the key plants in demand. Because of its comparative size, as well as the potential for competitive forage use, the open forest should receive the greatest consideration in management plans for dual-use ranges in the central Blue Mountains.

The dense forest has the greatest potential for habitat improvement. At present, the understory of mature stands produces relatively little palatable forage for either big game or livestock. But this amount can be greatly increased by a coordinated harvest of merchantable trees. Selective or patch cuttings can create seral plant communities with a great number of forage species, many of which remain palatable throughout the grazing season. As this study previously pointed out, these stands are important cover, particularly for elk. Hence, portions of stands suitable as cover should be left available, but their optimum size and distribution have not yet been determined.

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USDA Forest Service Research Paper PNW-113

NURSERY FERTILIZATION OF DOUGLAS-FIR SEEDLINGS with different forms of nitrogen

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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
Forest Service U.S. Department of Agriculture
Portland, Oregon
1971

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ABSTRACT

Three commercial fertilizers--ammonium sulfate, calcium nitrate, and urea--were tested to determine the relative values of ammonium, nitrate, and urea as nitrogen sources for Douglas-fir seedlings. The seedlings were grown at a forest tree nursery in western Washington and the fertilizers were broadcast at 50 pounds nitrogen per acre in May and again in September. Seedling growth in the nursery and outplanting performance of the trees fertilized with nitrate and urea were essentially the same and superior to the ammonium treatment.

Keywords: Forest nursery fertilization, Douglas-fir seedlings, ammonium sulfate, calcium nitrate, urea, survival, height growth, ovendry weight.

INTRODUCTION

Millions of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) seedlings are annually produced in forest tree nurseries and outplanted throughout the Pacific Northwest. To maximize production, nurseries in the region apply intensive cultural practices, fertilization being one of the most common.

Presently, the nurseries follow different fertilization regimes which vary basically in the amount and form of nitrogen. Although amounts of nitrogen fertilizer applied are logically based upon the fertility of the nursery soil, choice of the nitrogen source has been largely empirical.

Experiments with herbaceous plants (*3, 5, 6*) and nutritional studies with seedlings of some coniferous species (*4, 9, 14*) have shown that the source of nitrogen supply greatly affects both the growth and the chemical composition of plants. Such information, however, is not available for Douglas-fir, although many nitrogen fertilization studies have been made on the species. Similarly, information is still lacking on the effects of nitrogen source applied in the nursery on outplanting performance of Douglas-fir. Changes in growth and chemical composition of the trees due to nursery fertilization treatments could substantially affect the success of regeneration. Recent field and laboratory studies point to the importance of nursery nutrition to survival and growth of outplanted Douglas-fir trees (*2, 7*). In addition, results of other studies (*11, 13*) indicate that different fertilization regimes may alter acceptability of Douglas-fir trees to deer. The impact of these potential differences could be most important in areas where deer browsing is a problem.

This paper reports effects of nursery fertilization with ammonium, nitrate, and urea nitrogen fertilizers on growth and survival of Douglas-fir seedlings. It is part of a larger study on effects of nitrogen nutrition in the nursery on the morphology and chemical composition of the seedlings and deer preference for the fertilized trees.

MATERIALS AND METHODS

One-year-old Douglas-fir seedlings grown from a low-elevation seed source at the Webster State Forest Nursery near Olympia, Wash., were selected in March 1967. The seedlings, in nine 4- by 165-foot nursery beds, were fertilized at sowing in April 1966 with the nursery's standard ammonium phosphate-sulfate fertilizer (16-20-0) at the rate of 300 pounds per acre. Average seedling height was about 8 centimeters, and stocking within all beds was relatively uniform with an average of 45 seedlings per square foot.

Three commercial fertilizers in granular form were tested. These fertilizers, ammonium sulfate, calcium nitrate, and urea, supplied nitrogen in the form of a cation, an anion, and an undissociated molecule, respectively. Each fertilizer treatment was replicated three times, and treatments were assigned to the nine beds at random. In May and again in September, the fertilizers were broadcast with a tractor-drawn spreader at the nursery's standard rate of 50 pounds nitrogen per acre. In both the ammonium sulfate and urea treatments, seedlings received the assigned nitrogen treatment plus calcium sulfate containing calcium equivalent to that in the calcium nitrate treatment. Thus, the sulfate ion was the only variable among the three treatments. This imbalance was not considered serious, since the sulfate level was apparently adequate in the nursery soil and because no special need of it by Douglas-fir is indicated in the literature. Furthermore, it was impossible to completely balance the treatments.

Response to fertilization was evaluated while seedlings were still in the beds. Color of the trees was compared visually; and, at bimonthly intervals, seedling heights were determined by measuring 30 trees chosen at random from each replication.

In November, sample trees from each of the nine beds were lifted by hand and tied in bundles of five seedlings each. Fifteen and eight representative bundles of seedlings from each treatment were used for subsequent determinations of dry weights and outplanting performance, respectively.

Dry weights were determined in the laboratory. Seedlings were washed free of soil and severed at the root collar. Roots and tops from each bundle were then dried to constant weight in a forced-air oven at 65° C.

Effects of treatments on survival and growth of outplanted stock were evaluated in an exclosure near the nursery. The test area had droughty soils and was occupied by a dense cover of forbs and grasses; it was selected to provide a severe comparison among treatments. Seedlings were randomized at 3- by 3-foot spacing in four blocks containing 10 trees of each treatment. The trees were examined frequently, and height growth and survival were determined after the first and second growing seasons.

RESULTS

Seedling Response to Treatment

Visual color comparisons in the nursery indicated treatment differences between seedlings. Trees fed nitrate or urea were darker green than those of the ammonium treatment. Color differences were evident approximately 3 weeks after the first fertilization in May and continued essentially unchanged until lifting in November.

Over the growing season, three main stages of seedling height growth were evident: (a) very rapid growth from May to July, (b) rapid growth from July to September, and (c) a leveling-off stage from September to November (fig. 1). Seedlings, therefore, put on virtually all of the season's height growth

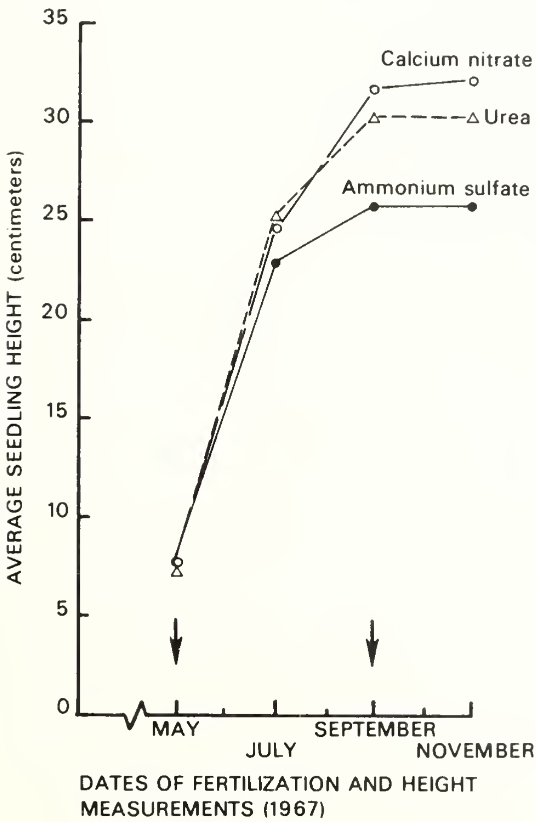

Figure 1.--*Effect of nursery fertilization with different forms of nitrogen on height of Douglas-fir seedlings. (Arrows signify fertilization dates.)*

during the 4 months following the first fertilization. During this period, average rates of growth, and in turn final heights, varied by treatment. Thus, at lifting, nitrate and urea, which promoted the fastest growth, produced the tallest seedlings, while ammonium, which was associated with the slowest growth, produced the shortest trees (table 1).

Ovendry weights of shoots but not of roots were affected by treatment, and effects paralleled those observed with seedling heights (table 1). Thus, ovendry weights of nitrate and urea shoots were essentially the same and exceeded those from the ammonium treatment. This indicates that differences in height growth were due to treatment effects on production of dry matter in the shoots.

Table 1.--*Effect of nursery fertilization with different forms of nitrogen on growth of Douglas-fir seedlings*[1/]

Nitrogen-fertilizer treatment	Ovendry weight		Height
	Shoot	Root	
	- - - *Grams* - - -		*Centimeters*
Ammonium sulfate	2.5 a	1.1 a	25.9 a
Calcium nitrate	3.5 b	1.2 a	32.2 b
Urea	3.3 b	1.2 a	30.4 b

[1/] Fertilizers were applied to the seedlings in the nursery at 50 pounds of nitrogen per acre in May and again in September, and seedlings were lifted in November 1967.

Ovendry weight and height values are, respectively, averages of 75 and 90 seedlings each.

Means in each column followed by the same letter(s) do not differ significantly at the 5-percent level, using Tukey's test (*15*).

Outplanting Survival and Growth

Survival and growth were generally poor despite careful lifting, handling, and planting of the stock (table 2). This poor performance was probably a reflection of the severe environment of the test area.

Nearly 25 percent of the seedlings died the first year, and many more failed to survive the second. Urea treatments survived best during both years; and after the second season, survival was intermediate with nitrate- and lowest among ammonium-treated trees.

Seedlings grew little either year regardless of treatment. After two growing seasons, the trees averaged only about 10 centimeters taller than at planting.

Table 2.--*Effect of nursery fertilization with different forms of nitrogen on survival and height growth of outplanted Douglas-fir seedlings*[1/]

Nitrogen-fertilizer treatment	Survival		Height growth	
	First season	Second season	First season	Second season
	- - - - *Percent* - - - -		- - - *Centimeters* - - -	
Ammonium sulfate	78 ab	33 b	5.0 a	5.5 a
Calcium nitrate	65 b	48 ab	5.4 a	4.0 a
Urea	83 a	60 a	4.8 a	5.0 a

1/ Fertilizers were applied to the seedlings in the nursery at 50 pounds of nitrogen per acre in May and again in September, and seedlings were lifted in November 1967.

Fertilized seedlings were outplanted in an exclosure, and survival and height growth were determined in September 1968 and 1969.

Survival percents are based upon 40 seedlings of each treatment, and height growth values are averages for surviving seedlings of each treatment.

Means in each column followed by the same letter(s) do not differ significantly at the 5-percent level, using Tukey's test (*15*).

DISCUSSION AND CONCLUSION

Data from the nursery, laboratory, and exclosure indicate definite differences in the value of the three different forms of fertilizer nitrogen for Douglas-fir seedlings. Under conditions of the experiments, responses to urea and nitrate were essentially the same, and both fertilizers were superior to ammonium. Known differences between the three nitrogen fertilizers are in effects on soil pH, losses through leaching and volatilization, susceptibility to transformations through microbial and enzymatic action, fixation by soil particles, and availability characteristics. These differences and our limited studies do not indicate a definite basis for the observed differential effects caused by the nitrogen sources. Clearly, satisfactory explanation of results can only be obtained through sophisticated nutritional studies dealing with all aspects above plus detailed analysis of the chemical makeup of seedling tissues and photosynthetic efficiency of foliage during the experiments.

It is not possible to make meaningful comparisons with results of other studies in the literature. With both herbaceous and conifer species, earlier experiments dealt mostly with evaluation of ammonium and nitrate nitrogens, with few reporting on comparative effects of the three nitrogen sources. In addition, these experiments often gave conflicting results, with ammonium (*9, 16*), nitrate (*4, 6*), or urea (*14*) as the favored nitrogen source. Still other studies showed little differences between the nitrogen sources (*8*), or differences depending upon nitrogen level (*12*), pH of the rooting medium (*1*), and age of the test plant (*10*). Obviously, therefore, the most suitable nitrogen source for a plant species would depend upon many factors which should first be identified and then studied carefully under actual conditions of its growth.

We believe that differences among treatments in our results are of sufficient magnitude to justify consideration in nursery management practice. In addition, because of the complexity of the factors involved, we emphasize the need for on-the-site investigations at different nurseries to determine the best fertilization regime for Douglas-fir.

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USDA FOREST SERVICE RESEARCH PAPER PNW-114

INFLUENCE OF ENDRIN ON SOIL MICROBIAL POPULATIONS AND THEIR ACTIVITY

PROTECT
Use Pesticides Safely
FOLLOW THE LABEL
U.S. DEPARTMENT OF AGRICULTURE

W. B. BOLLEN
C. M. TU

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE
PORTLAND, OREGON

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Keywords: Endrin, soil microbiology, pesticides, aerial tree seeding.

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife --if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

SUMMARY

Endrin applied to soil at rates of more than three times the maximum that might be expected from application of endrin-treated tree seed exerted no appreciable effect on numbers of soil microbes or on ammonification, nitrification, or sulfur oxidation. The decomposition of soil organic matter, as indicated by the production of CO_2, was increased significantly in the presence of endrin.

Results of our study agree substantially with other studies, indicating that a very high rate of endrin in soil would be necessary to alter microbial properties. We conclude that the relatively insignificant amount of endrin formulation applied to forest soil from coated tree seed is unlikely to damage soil microbes and their activities.

INTRODUCTION

Endrin[1/] is used in the Douglas-fir region of the Pacific Northwest to protect aerially or hand sown forest tree seeds against rodents. Common practice is to apply 0.5 to 1 pound (about 20,000 seeds) of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) per acre or approximately one seed per 2 to 4 square feet. The seed is coated with endrin at rates of 0.5 to 1 percent of seed weight (Radwan, Crouch, and Ellis 1970). At this rate, 1 to 4 grams of endrin are applied per acre.

Small amounts of endrin may move from the seedcoat onto the soil, but the amount of chemical thus introduced into the forest environment is very small. If all of the endrin from one seedcoat entered 1 cubic inch of soil immediately beneath the seed, an endrin concentration of 3 to 6 parts per million (p.p.m.) would result. Such spots of contamination would be scattered, however, because an average of only one seed falls per 1 or 2 square feet of soil surface. Impregnating seed with endrin (Radwan, Crouch, and Ellis 1970), rather than coating it as is now done, should further reduce the amount of endrin that could reach the soil.

We have the obligation to determine the effect of any introduced chemical on the forest environment (Tarrant 1967). One important potential of introduced chemicals is the effect of such materials on soil micro-organisms and on their role in maintaining soil fertility.

MATERIALS AND METHODS

The objective of this study was to determine the effect of endrin on soil microbial populations, decomposition of native organic matter, transformation of native soil nitrogen, ammonification of peptone, nitrification of ammonium sulfate, and oxidation of flour sulfur. Endrin, 19.7 percent active ingredient, was applied to samples of three Willamette Valley soils at rates of 0, 1, and 10 p.p.m. active ingredient. Chemical, physical, and microbial characteristics of the three soils and details of methods used in the present study have been previously described (Tu and Bollen 1968).

[1/] 1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-1,4-endo, endo-5,8-dimethanonapthalene. In the study reported herein, a Shell Chemical Company emulsion containing 19.7 percent active ingredient was used. (Mention of companies or products by name does not constitute an endorsement by U.S. Department of Agriculture.)

RESULTS AND DISCUSSION

Soil Microbial Populations and Their Activity

We found no significant differences in populations of bacteria, *Streptomyces*, molds, or *Penicillia* 30 days after endrin was added to soil (table 1). These findings are similar to those of Martin et al. (1959) that endrin in concentrations up to about 1,000 p.p.m. did not affect soil micro-organisms.

This lack of effect of endrin on soil microbial plate counts is in contrast to the highly significant increase in decomposition of soil organic matter as indicated by CO_2 production (table 1). Such an increase could be the result of a stimulation of microbes unable to develop on plating media and could also be an expression of Heuppe's principle that toxic substances below an inhibitory level may act as a stimulant (Clifton 1950, p. 274-276). Although the CO_2 increase was statistically significant, the small amounts involved make it of little practical importance except to reinforce findings that microbial populations were little affected by endrin.

The amounts of endrin applied, even at the highest rate of 10 p.p.m., were so low that neither the endrin itself nor the inactive ingredients of the formulation could have directly contributed significantly to the increased CO_2 production which could have come from the traces of carbon introduced in the chemical formulation. Korte (1966) showed that some soil microbes can attack and degrade endrin, probably in several stages. However, microbial metabolism of many pesticides and other exotic substances in nature may not provide a source of energy nor elements necessary for growth; this phenomenon is termed cometabolism (Alexander 1967, p. 331-342).

Table 1.--*Effect of endrin on populations of soil microbes and decomposition of soil organic matter*[1/]

Variable	Endrin (p.p.m.)		
	0	1	10
Total bacteria (millions/gm. of soil)	126	142	168
Streptomyces (percent of total bacteria)	58	71	65
Total molds (thousands/gm. of soil)	148	109	130
Penicillia (percent of total molds)	51	50	52
Decomposition of soil organic matter--carbon evolved as CO_2 (mg./80 g. soil/30 days)	<u>13</u>	<u>15</u>	<u>17</u>

Note: p.p.m. = parts per million.

1/ Data are averages of duplicate determinations for each of the 3 soils incubated at 28° C., with water content near field capacity, for 30 days. Values underlined are significantly different from one another at the 1-percent level of probability.

Transformation of Soil Nitrogen in the Presence of Endrin

None of the differences between untreated soils and those to which endrin was added were significant in terms of ammonification or nitrification of soil nitrogen (table 2). Similar findings were reported by Martin et al. (1959) and Jones (1956).

The interaction between soils and treatments was highly significant, both for soil ammonium and nitrate. This means only that the three soils reacted to treatments somewhat differently in magnitude of response.

Findings from this portion of the study support results of the microbial investigations and indicate further that the presence of endrin at rates up to 10 p.p.m. had no deleterious effect on the function and activity of soil micro-organisms.

Table 2.--*Effect of endrin on the transformation of native soil nitrogen*[1/]

Endrin treatment (parts per million)	NH_4^+-N	NO_2^--N	NO_3^--N
	Parts per million		
0	66.67	0.40	23.00
1	95.83	.60	18.50
10	75.83	.62	20.17

[1/] Data are averages of duplicate determinations for each of the 3 soils incubated at 28° C., with water content near field capacity, for 30 days. No differences between levels of endrin were significant at the 5-percent level of probability.

Transformation of Peptone, Ammonium Sulfate, and Sulfur in the Presence of Endrin

None of the differences between endrin treatments were significant in the case of soils to which peptone, ammonium sulfate, or flour sulfur were added (table 3). These data further confirm the lack of effect of endrin on soil microbial populations and their activity seen in other portions of this study. They also give added support to the findings of Jones (1956) that endrin, along with several other chlorinated hydrocarbon insecticides, is not toxic to ammonification below a rate of 1,000 p.p.m. nor to nitrification below a rate of 100 p.p.m.

Table 3.--*Effect of endrin on the transformation of peptone, ammonium sulfate, and flour sulfur*[1/]

Soil treatment	Data expressed as	Endrin (p.p.m.)		
		0	1	10
		- - *Parts per million* - -		
Soil + peptone at 1,000 p.p.m. N	NH_4^+-N	692	755	767
Soil + ammonium sulfate at 200 p.p.m. N	NO_3^--N	60	56	44
Soil + flour sulfur at 1,000 p.p.m. S	SO_4^{-2}-S	278	288	328

Note: p.p.m. = parts per million.

[1/] Data are averages of duplicate determinations for each of the 3 soils incubated at 28° C., with water content near field capacity. Incubation periods were 5 days for soil plus peptone and 30 days for soil plus ammonium sulfate and soil plus flour sulfur. No differences between levels of endrin were significant at the 5-percent level of probability.

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Endrin applied to soil at rates of more than three times the maximum that might be expected from application of endrin-treated tree seed had no appreciable effect on numbers of soil organisms or on ammonification, nitrification, or sulfur oxidation. Decomposition of soil organic matter was increased significantly in the presence of endrin.

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ACKNOWLEDGMENTS

We wish to acknowledge the cooperation of the Forest Survey Project, Pacific Northwest Forest and Range Experiment Station, in making available data from a pilot study of clearcuts in western Washington. This project is continuing its study to provide estimates of usable logging residues in Washington, Oregon, and California. We appreciate the help of Gus Peterson, Check Scaler, Mount Hood National Forest, for his assistance in logging residue measurement; and the advice and instruction provided by George Harrington, Crown Zellerbach Corporation (Portland, Oregon) in determining log quality for chip utilization.

ABSTRACT

This paper presents the results of ground measurements of logging residue weights and volumes on 30 clearcut units in Douglas-fir forests of western Oregon and Washington. Additional information is given on quantities of material left as slash which might be utilized. These measurements were made on public lands, using a method developed in Canada.

Keywords: Slash disposal, cutting (harvest), forest fuels, fuelwood use, clearing operations.

INTRODUCTION

Even with today's improved standards of utilization, timber harvesting in the Douglas-fir region continues to produce large accumulations of smashed logs, limbs, tops, rotten wood, and broken-down underbrush littering the ground. These residues must be removed from logged units to allow ground space for regeneration, to eliminate obstacles to future harvesting, and to reduce the fire hazard. Also, residue accumulations may obstruct recreational opportunities and efficient forest management and, to many, represent both a depreciation of natural beauty and a waste of potentially usable wood products.

Foresters responsible for execution of postsale slash disposal and reforestation actions need to know more about the quantities, distribution, and characteristics of residues left on the ground after logging (fig. 1). This information can be used to more effectively prescribe stand treatment, determine sale utilization standards for the sale contract, and plan postsale fuel treatments and reforestation measures. Such information is an important component in determination of sale operational costs for use in stumpage appraisal and is of value to potential purchasers of salvage sales.

With this knowledge, the postsale forester has a better basis on which to make important decisions on whether to prescribe burn, plan relogging for utilization of substandard material,[1] or to manage the fuels complex under an extra fire protection program until the hazard has abated. The line transect sampling method presented here will also be of interest to foresters. It is a relatively efficient way, considering both time and cost, to gather and assemble logging residue information. It could be readily used to gather additional local data to strengthen the data presented in this report for specific sale planning purposes.

To date, slash volume data available have been derived from fuels research in the California Region and therefore are not directly applicable to Douglas-fir cutover areas in Oregon and Washington forests. Sundahl (1966) made weight

[1] *Substandard material consists of logs and pieces large enough to be usable but which are rotten and/or broken so that less than one-third of their contents is usable for sawed products. This material cannot be sold as saw logs but may be marketable, at reduced prices, for the production of chips.*

Figure 1.—The forester needs to know the amount and kind of residues left from logging if he is to make effective decisions on fuels management and utilization. This unit on the Hickman Lake sale, Mount Hood National Forest, contains 10,447 cubic feet of slash per acre, of which 3,778 cubic feet per acre could be utilized for chip material. Slash weights totaled 138 tons per acre.

measurements in slash and litter from two 90-year-old forest cover types at the Challenge Experimental Forest following clearcuttings. Ponderosa pine and ponderosa pine-Douglas-fir types in that area yielded 53-110 tons of slash per acre. These estimates were based on slash weight tables developed by Chandler (1960) from earlier work by Storey, Fons, and Sauer (1955). Chandler's tables refer to the five predominant species of the west-side mixed-conifer timber type in California. Fahnestock (1960), in appraising the potential fire hazard of slash in the northern Rocky Mountains, modified the California method to show crown weight (ovendry) as a function of diameter at breast height and crown length.

A fuel volume study in the Douglas-fir region by McArdle (1930) determined the volume of coarse debris (pieces more than 3 inches in diameter and 3 feet long) in cords per acre. He estimated slash amounts on individual plots from 17-137 cords per acre (approximately 25-185 tons per acre by our calculation). Hodgson

(1930) reported on an extensive study of logging wastes in the entire Douglas-fir region, including private, Federal, and State lands. He determined that over 3 billion board feet of cordwood or larger size was being left in the woods after logging.

In more recent years, study plans for slash volume measurements in the Douglas-fir region were undertaken by Scott[2] and by Hendee and Kreiss,[3] but studies were not completed.

A very recent method developed in Canada is the inventory of slash fuels using 70-mm. low-level photography. According to Muraro (1970), fuel loadings calculated from measurements on 70-mm. photography are equally as reliable as those obtained from ground sampling methods.

Surveys of utilizable logging residuals were conducted by the Washington Institute of Forest Products in 1950 (State of Washington 1950) and by the U.S. Department of Commerce in 1963 (U.S. Department of Commerce 1964). Their data indicate a wide range of usable wood per acre left after logging and an average of over 20 percent of the original stand remains on site as potentially utilizable material.

[2] *Norman C. Scott. Slash volume sampling study. Study plan on file at USDA Forest Serv., Pac. Southwest Forest & Range Exp. Sta., Forest Fire Lab., Riverside, Calif., 1964.*

[3] *John C. Hendee and P. R. Kreiss. Look at some logging slash fuel weights in second-growth Douglas-fir on the Siuslaw National Forest. Unpublished manuscript on file at USDA Forest Serv., Pac. Southwest Forest & Range Exp. Sta., Forest Fire Lab., Riverside, Calif., 1965.*

Our paper presents the results of ground measurements of coarse logging residue weights and volumes on 30 clearcut units on public lands in western Oregon and Washington.

SAMPLING PROCEDURE

A line intersect method derived by Warren and Olsen (1964) in New Zealand, and modified by C. E. Van Wagner (1968), was used in selecting the sample of volumes and weights of logging residues on all units in this study. Only *coarse* residues (pieces 4 inches and larger) were measured in the study. Weights for *fine fuels* (needles, twigs, small limbs, splinters, and other small fragments) were not determined. This material can be sampled only by collecting and weighing fuels on narrow strips or small plots within the slash complex. Munger and Matthews (1941) determined that fine fuels in Douglas-fir slash plots averaged 64 cords per acre, or 38.5 tons. We estimated the fine fuels on our study areas ranged from 20-40 tons per acre in addition to the measured tonnages shown in table 1.

Thirty clearcut units were sampled. On 16 of the clearcuts, two transect lines crossing at about right angles were located in the units to give the best estimates of the residue volumes. The lengths of the lines varied from 2,000 feet to 3,400 feet per unit, depending on the diagonal distances across the units as shown in figure 2.

Volume data for the remaining 14 units were provided by a

Table 1.--*Residue weights and volumes on units measured in this study*

Unit	Forest	State	Township	Range	Acres	Type of logging	Volume		Weight	
							Gross	Net1/	Gross	Net1/
							Cubic feet per acre		*Tons per acre*	
Huckleberry #1	Mount Baker	Wash.	33N	11E	18	High-lead	2,900	2,091	40	27
Ditney #2	Mount Baker	Wash.	31N	7E	74	High-lead	9,087	2,895	122	39
Double Eagle #2	Mount Baker	Wash.	30N	10E	54	Skyline	5,348	1,771	72	24
West Copy #2	Snoqualmie	Wash.	28N	12E	25	High-lead	6,494	2,648	87	35
Money Creek #4	Snoqualmie	Wash.	26N	10E	64	High-lead	8,006	4,045	108	54
Cold #4	Gifford Pinchot	Wash.	11N	9E	54	High-lead	6,000	2,103	80	28
Spring #1	Gifford Pinchot	Wash.	10N	10E	53	High-lead	3,513	1,558	47	21
Guard #1	Gifford Pinchot	Wash.	10N	7E	26	High-lead and tractor	5,362	2,984	72	41
Clear Creek #5	Gifford Pinchot	Wash.	9N	7E	45	High-lead	7,455	3,143	100	42
Twin Falls #13	Gifford Pinchot	Wash.	8N	9E	47	Tractor	5,080	*	70	*
Poison Creek #1	Gifford Pinchot	Wash.	8N	8E	45	Tractor	5,077	*	70	*
Poison Creek #2	Gifford Pinchot	Wash.	8N	8E	55	Tractor	6,896	*	95	*
Poison Creek #3	Gifford Pinchot	Wash.	8N	8E	55	Tractor	8,804	*	121	*
Valley #1	Gifford Pinchot	Wash.	8N	7E	36	High-lead	7,773	4,462	104	60
Peak #3	Gifford Pinchot	Wash.	7N	7E	55	High-lead	8,593	3,474	115	47
Silver Dungeness #2	Olympic	Wash.	28N	4W	35	High-lead	3,417	2,288	46	31
South Fork Skokomish L-35	Olympic	Wash.	23N	5W	46	High-lead	2,405	1,733	32	23
Cook Creek #1	Olympic	Wash.	22N	10W	129	High-lead	8,779	2,974	118	40
Section 8	Quinalt Indian Reservation	Wash.	23N	11E	150	High-lead	18,634	*	227	*
Upper Wash Creek #3	Mount Hood	Oreg.	6S	5E	100	High-lead	14,390	7,472	191	100
South Fork Mountain #4	Mount Hood	Oreg.	6S	5E	100	High-lead	6,112	2,208	80	29
Hickman Lake #5	Mount Hood	Oreg.	1S	7E	38	High-lead	10,447	3,778	138	50
Hospital Creek #1	Willamette	Oreg.	20S	2E	31	High-lead	6,026	*	79	*
Hospital Creek #2	Willamette	Oreg.	20S	2E	43	High-lead	9,241	*	121	*
Hospital Creek #3	Willamette	Oreg.	20S	2E	40	High-lead	8,830	*	116	*
Hospital Creek #4	Willamette	Oreg.	20S	2E	20	High-lead	8,763	*	115	*
Bruno Mountain #15	Willamette	Oreg.	10S	7E	14	High-lead	13,663	*	180	*
Bruno Mountain #16	Willamette	Oreg.	10S	6E	14	High-lead	11,219	*	147	*
Bruno Mountain #18	Willamette	Oreg.	10S	6E	17	High-lead	7,000	*	92	*
Twin Lakes Ridge #9-1	Umpqua	Oreg.	27S	2W	26	High-lead	6,236	*	82	*

1/ Chippable material.

* Not measured.

Figure 2.—On 16 of the 30 clearcuts sampled, two transect lines crossing at right angles (as shown above) were located in the units. This is the 100-acre Upper Wash Creek Unit, Mount Hood National Forest. It contained 14,390 cubic feet of residues per acre, with 7,472 cubic feet per acre of material which could be chipped if it could be removed. The unit had 191 tons of residues per acre.

research team from the Forest Survey Project, of the Pacific Northwest Forest and Range Experiment Station, as part of a pilot study on utilization of residues.[4] These units were sampled by a 30-chain continuous transect, taken in 5-chain segments, along randomly chosen azimuths located within each clearcut unit. Figure 3 is an aerial view of one clearcut, with the directions of the lines indicated.

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[4] Forest Survey Project. Operating plan for a pilot study of the amount and kind of residues left after clearcut logging on the National Forests of western Washington. Unpublished study plan on file at USDA Forest Serv., Pac. Northwest Forest & Range Exp. Sta., Portland, Oreg., 1969.

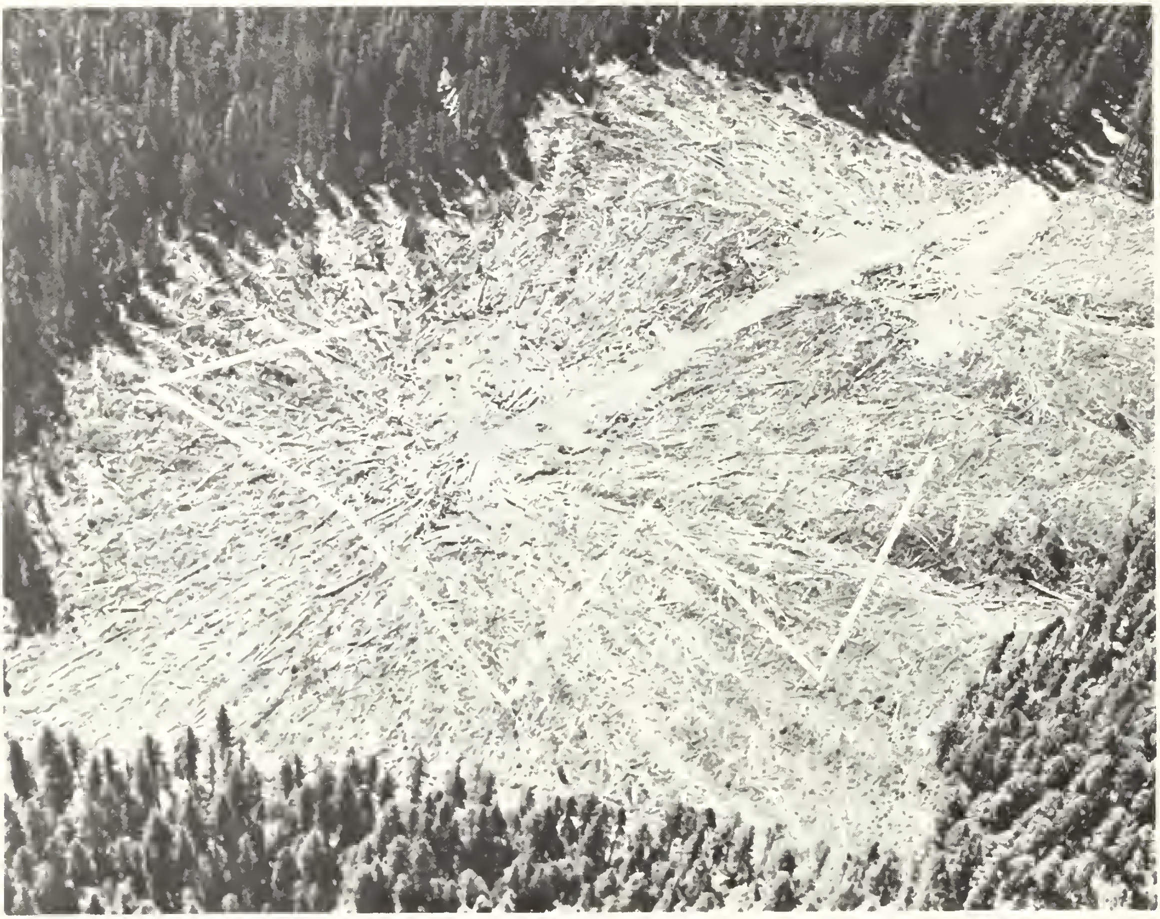

Figure 3.—The 14 units measured by the Forest Survey team were sampled by a 30-chain continuous line transect, taken in 5-chain segments, along randomly chosen azimuths located within the clearcut (as shown in this aerial view).

Diameters were recorded of all pieces intersected by the transect lines. On 17 of the units (14 sampled by the Forest Survey Project and 3 by us), logs suitable for pulp chips were recorded separately from those pieces considered waste material only. Utilization standards for chippable logs vary considerably between companies in the Northwest pulp markets. Foresters planning to sample residues for chip utilization should obtain local criteria in applying this method. The criteria we used for the units on which we measured chippable material (Upper Wash Creek #3, South Fork Mountain #4, and Hickman Lake #5) was that a chip log be at least 50 percent sound, 6-inch diameter (small end), and 12-foot length. The criteria used by the Forest Survey team on the 14 units they measured was that a chip log be at least 10 percent sound, 5-inch diameter (small end), and 4-foot length.

On the remaining 13 units no differentiation was made between waste and chippable material in the residues complex.

Logging residue volumes were determined by using the equation

$$V = \frac{0.00857\,\Sigma d^2}{L}\ (43,560)$$

where

V = volume in cubic feet per acre
d = diameter of logs in inches
L = length of transect line in feet

The equation used for finding residue weights in tons per acre was

$$W = \frac{11.65\,S\,\Sigma d^2}{L}$$

where

S = specific gravity[5/]

RESULTS

A total of 1,509 acres were sampled in this study. Table 1 provides a summary of logging residue weights and volumes on the 30 units sampled. Species composition of residues was almost entirely Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), except for the Quinault Indian Reservation (Olympic Peninsula) where the slash was entirely western redcedar (*Thuja plicata* Donn). The mean gross volume of residues on 27 of the 30 units sampled was 7,430 cubic feet per acre with a standard error of the mean of 8.7 percent (651 cubic feet).[6/] The volume of logging residues suitable for manufacture of pulp chips (based on the criteria described), on the 17 units on which such residues were sampled, averaged 45 percent of the gross volume.

Slash fuel weights (usable and nonusable residues combined) ranged from 32 tons per acre (South Fork Skokomish Unit, Olympic National Forest) to the 227 tons per acre encountered on the Quinault Indian Reservation (fig. 4).

DISCUSSION AND CONCLUSIONS

The data presented give an indication of the large volumes and tonnages of logging residues being left in the Douglas-fir forests of the Northwest. It is such volumes as these that have prompted increased attention to residue management programs and to providing opportunities for better utilization.

5/ *Specific gravity (at 12 percent moisture content) was taken from Wood Handbook, Agr. Handb. No. 72, Forest Prod. Lab., USDA Forest Serv. (table 12, p. 70-77), 1955.*

6/ *Three of the units (Upper Wash Creek #3, South Fork Mountain #4, and Hickman Lake #5) were measured to a 6-inch diameter limit instead of 4 inches. Because of this, they are not included in our calculation of the standard error of the mean.*

Figure 4.—Some of the heaviest concentrations of logging residues encountered in western Oregon and Washington were found on lands of the Quinault Indian Reservation, on the Olympic Peninsula in western Washington. One slash fuel complex, like that in the photo above, contained 18,634 cubic feet of residues per acre, or 227 tons of fuel per acre. The wood species on this area is almost completely western redcedar (Thuja plicata *Donn).*

A number of National Forests in Oregon, Washington, and northern California are experimenting with contract reyarding or clean-logging of cutting units instead of broadcast slash burning. In the process, chippable logs are selected, cable or tractor yarded, loaded, and hauled to the nearest chipping plant for processing. Remaining unutilizable debris is yarded into large piles (fig. 5) for burning when smoke dispersal conditions are most favorable. This modifies the slash hazard and reduces potential smoke problems from large-scale broadcast burning. Such residue reduction programs are contingent, of course, on usefulness of species for chips, current market conditions, and proximity of the logging unit to the processing plant.

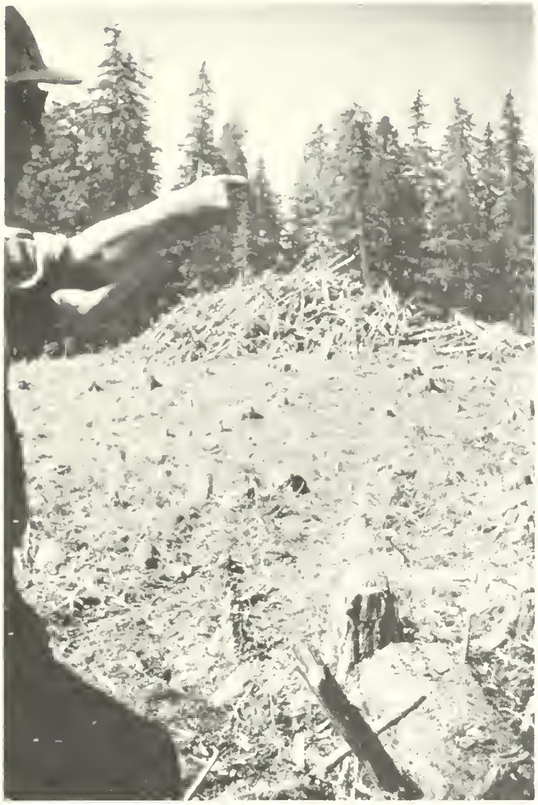

Figure 5.--This clearcut slash area has been cleaned of larger fuel by high-lead yarding. Unutilizable material is yarded to concentrated piles, such as this one, for burning when smoke dispersal conditions are most favorable.

The presale forester should be alert for possible residue utilization on timber sales where cruise data indicate a relatively high percent of defect in a species useful for chips. Further study is needed to determine just what relationship actually exists between percent of defect estimates and actual volume of logging residuals--and if these can be correlated to provide a reasonably accurate presale estimate of potential residual utilization.

Study is also needed to determine the total magnitude of logging residues developed in the Douglas-fir region and their distribution by species, size, and suitability for pulping. Since we commenced work on this paper, such studies have been undertaken.

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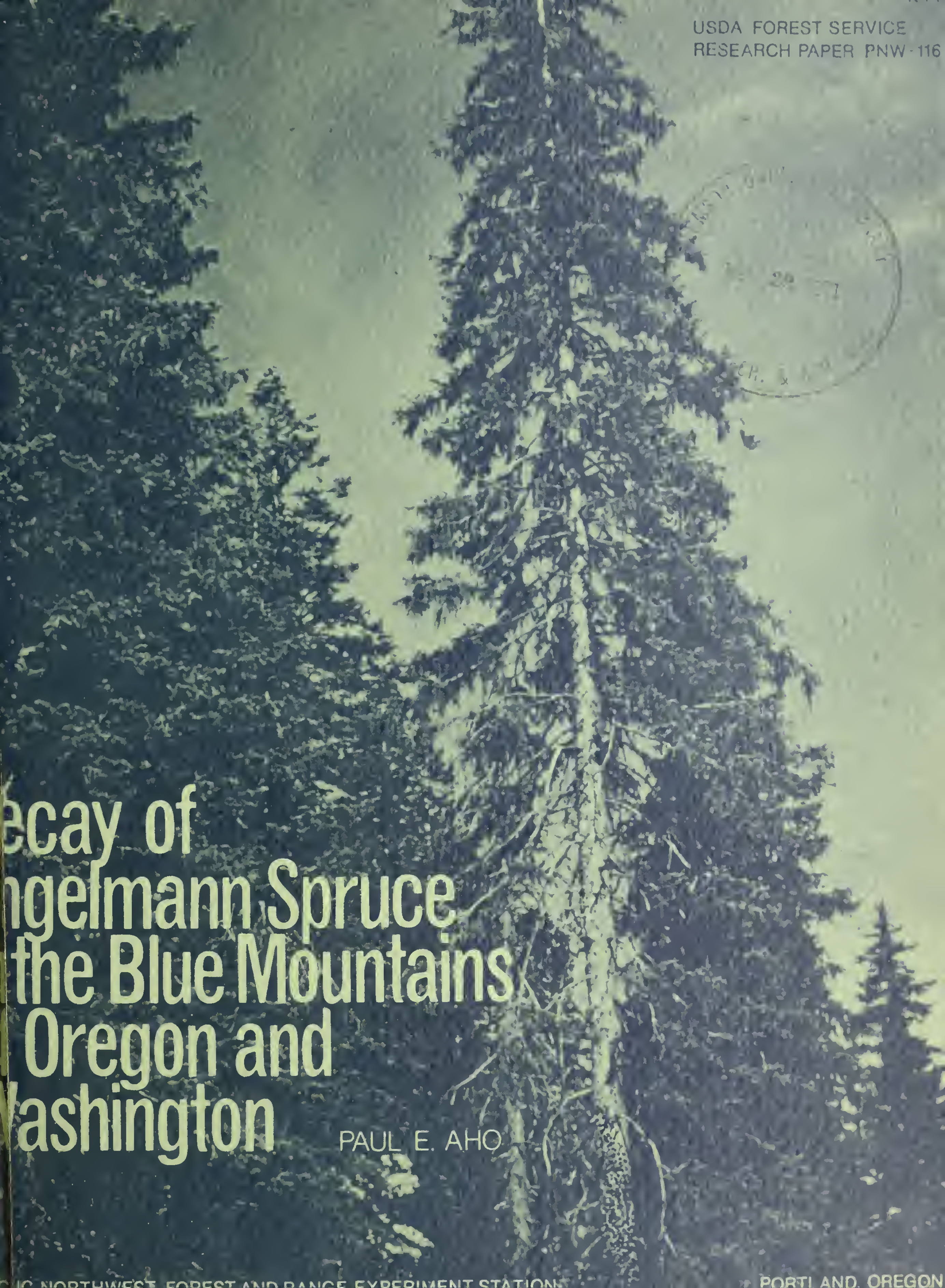

ecay of ngelmann Spruce the Blue Mountains Oregon and ashington

PAUL E. AHO

IC NORTHWEST FOREST AND RANGE EXPERIMENT STATION

PORTLAND, OREGON

CONTENTS

Keywords: Decay fungi (wood), defect indicators (wood quality), fungi (forest damage).

SUMMARY

A total of 292 Engelmann spruce were dissected and examined for decay and other defects in seven areas in the Blue Mountains of southeastern Washington and northeastern Oregon. Decay on a cubic-foot basis was 3.3 percent for pole trees and 5.4 percent for sawtimber. Defect loss in sawtimber spruce amounted to nearly 12 percent of the gross merchantable board-foot volume. Decay varied among study areas and could not be explained on the basis of age differences.

A possible cyclic relationship was indicated between decay and age and diameter, rather than a progressive increase in decay with increasing age and diameter.

Eleven fungi were associated with 75 percent of all infections and those resulted in 80 percent of the total decay cubic volume. *Polyporus tomentosus* var. *circinatus* alone caused 44 percent of the individual infections; however, only 10 percent of the decay cubic volume was associated with this fungus. Trunk rotting fungi were responsible for only 11 percent of all infections, but these caused nearly 30 percent of the decay cubic volume. *Stereum sanguinolentum* and *Fomes pini* were the two most important trunk decaying fungi. Roots were entrance courts for 74 of 109 individual fungal infections. All *P. tomentosus* var. *circinatus* infections took place through the roots.

Defect indicator factors are given as: (1) percentages of tree gross merchantable cubic- and board-foot volumes, and (2) average length deductions below and above indicators with flat percentage factors for hidden defect.

INTRODUCTION

Engelmann spruce (*Picea engelmannii* Parry) is an important component of upper-slope forest types[1] in many areas in the Blue Mountains of northeastern Oregon and southeastern Washington. More than 5 percent of the total Scribner board-foot volume and total growing stock (cubic volume) of all species in the Blue Mountains is Engelmann spruce.[2] Logging and management activities have been increasing rapidly in many of these mature or overmature stands. Defect information, particularly extent of decay losses in standing trees, is essential for obtaining reliable estimates of sound volumes used in forest management.

In 1959, the Pacific Northwest Forest and Range Experiment Station began a heart rot-defect study in the upper-slope forest types in the Blue Mountains. Guides for estimating defect in grand fir (*Abies grandis* (Dougl.) Lindl.), Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco), western larch (*Larix occidentalis* Nutt.), and Engelmann spruce have been published (Aho 1966). This paper provides a more detailed account of defect in Engelmann spruce and the fungi associated with decay.

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[1] Upper-slope forest types are defined here as commercial stands of mixed conifers at elevations above the ponderosa pine type.

[2] Forest Survey data, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

LITERATURE REVIEW

Engelmann spruce decay studies have been carried out in the Rocky Mountains of Colorado and Alberta, Canada. Hornibrook (1950) presented means for estimating defect in standing mature and overmature Engelmann spruce, lodgepole pine (*Pinus contorta* Dougl.), and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) in Colorado. Most cull was associated with the following defect indicators in order of their importance: conks, swollen knots, hollow sound produced when tree is hit with an axe, decay on increment core, crook and sweep, fire scars, forks, cankers, frayed branch stubs, lightning scars, frost and wind cracks, and top injuries. Decay caused 87 percent of the total defect in the three species. Eleven species of fungi were listed, but *Fomes pini* Brot. ex Fr.) Karst., *Polyporus circinatus* Fr., and *Coniophora cerebella* Pers. were responsible for about 90 percent of the decay volume. The trunk rots accounted for 73 percent (*F. pini* alone caused 64 percent) and root and butt rots 14 percent of the total defect. Various indicators and decays were described. Recommended scaling practices were given but not for individual tree species.

Etheridge (1956) studied decay of subalpine spruce species, including Engelmann, white (*Picea glauca* var. *albertiana* (S. Brown) Sarg.), and black (*P. mariana* (Mill) B.S.P.) spruces on the Rocky Mountain Forest Reserve in Alberta. Although approximately half of the total infections were butt rots and half were trunk rots, 70 percent of the decay losses were attributable to trunk rotting fungi. Nearly 94 percent of the total decay was associated with fungi which produce white rots. Most trunk rot was caused by *F. pini*, *Stereum sanguinolentum* (Alb. and Schw. ex Fr.) Fr., and *Peniophora septentrionalis* Laurila, while *Polyporus circinatus* var. *dualis* Peck and *Flammula connissans* Fr. were associated with the majority of root and butt rots.

Decay in subalpine spruce averaged 20 percent of the gross merchantable volume and ranged from approximately 1 to 42 percent among sample areas (Etheridge 1958). Decay increased with increasing tree age and diameter at breast height (d. b. h.).

Hinds and Hawksworth (1966) studied indicators and associated decay in Engelmann spruce in Colorado. *F. pini* punk knots or conks, broken tops, dead top with adjacent dead rust brooms, basal wounds, dead rust brooms, dead leaders, frost cracks, all forks, two trees joined at base, spike tops, and trunk wounds were indicators consistently associated with decay. These indicators were divided into three classes and cull factors developed for each grouping. Trunk rot fungi were associated with 88 percent of the total decay. *F. pini* was responsible for the greatest number of infections and greatest amount of cull. It also was the only fungus associated with all of the reliable indicators previously mentioned. *Stereum sanguinolentum* and *S. sulcatum* Burt. were other significant causes of white trunk rot. *Fomes nigrolimitatus* (Rom.) Egel., *Pholiota alnicola* (Fr.) Singer, *Polyporus tomentosus* Fr. var. *circinatus* (Fr.) Satory & Maire, and *Corticium radiosum* (Fr.) Fr. caused the major white butt rots and *Coniophora puteana* (Schum. ex Fr.) Karst., the major brown butt rot.

METHODS

This study was made in mature and overmature upper-slope stands in the Blue Mountains of eastern Oregon and Washington. Engelmann spruce was found in seven of the 11 study areas. All 5-inch d. b. h. and larger trees were dissected and examined for decay on systematically selected 1/5-acre plots, Field methods and procedures for measuring defect have been reported

(Aho 1966) and are not repeated here except as needed for clarity.

Defect-estimating equations relating percent decay[3] (based on cubic feet) and percent defect[4] (based on board feet) to certain tree characteristics and external defect indicators were developed from multiple regression analyses for pole and sawtimber Engelmann spruce (Aho 1966). Independent variables, when the dependent variable was decay percent based on cubic feet, were tree d. b. h., age, the presence or absence of basal injuries, trunk injuries more than 1 foot long, and broken tops below merchantable top diameter. In addition, presence or absence of frost cracks was included as an independent variable when percent defect based on board feet was the dependent variable.

Samples were obtained from all decay columns in trees to determine the fungi present and the amount of decay associated with each fungus. Cultures were made by aseptically planting decayed wood chips on 2-percent malt agar in test tube slants. Fungi isolated were studied for identification by the author and Mrs. Frances Lombard, mycologist, Forest Disease Laboratory, Laurel, Maryland.

RESULTS AND DISCUSSION

A total of 292 Engelmann spruce were examined. This included 141 pole and 151 sawtimber trees 5.0- to 10.9-inch d. b. h. and 11.0 inches and over, respectively. The basic data are summarized in table 1 by study areas. The average age of all poles was 119 years; decay in these was 3.3 percent of the gross merchantable cubic volume. Sawtimber averaged 154 years; decay caused a loss of 5.4 percent of the gross merchantable cubic volume and 11.1 percent of the gross board-foot volume. Application of cull rules in effect in 1966 (log is cull if less than one-third sound) and inclusion of other defects increased board-foot defect to 11.8 percent in sawtimber.

Decay varied considerably among areas and could not be explained solely by age. For example, on the Round Mountain sale, sawtimber averaged 110 years and defect was 13.5 percent of the gross board-foot volume. On the Swamp Creek No. 2 sale, average age was 171 years, but defect was only 4.7 percent of the gross board-foot volume (table 1). Board-foot defect among study areas ranged from approximately 5 to 36 percent, whereas in Alberta the range was from 1 to 42 percent (Etheridge 1958) and in Colorado, 7 to 26 percent (Hinds and Hawksworth 1966).

Age-decay relationship.--The incidence and severity of decay usually increase with tree or stand age (Wagener and Davidson 1954). In this study, trees were grouped by 50-year age classes and percent decay determined for each class in cubic feet and board feet (fig. 1). Although there were too few trees in age classes over 200 years to draw definite conclusions, the data suggest decay may be cyclic rather than progressive.

In trees under 100 years, decay in cubic feet was negligible. It increased to 5.6 percent in the 100- to 149-year age class and decreased to 5.0 and 4.2 percent in the 150- to 199- and 200- to 249-year age classes, respectively. In the 250- to 299-year age class, decay increased to 8.1 percent, dropping to less than 1 percent at ages 300-349, and then rising to 33.6 percent in trees over 350 years old.

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[3] In cubic-foot measure, decay is the only defect.

[4] In board-foot measure, defect includes volume loss associated with decay, shake, frost cracks, and sound volume lost in cull logs. A cull log is one less than one-third sound. Crook, sweep, or breakage in felling are not included in defect.

Table 1.--*Summary of basic data for Engelmann spruce study*

Study area and Ranger District	Trees 5.0- to 10.9-inch d.b.h.							Trees 11.0-inch and greater d.b.h.									
	Basis		Average			Cubic-foot volume		Basis		Average			Cubic-foot volume		Board-foot volume		
	Plots	Trees	Age	D.b.h.	Height	Gross merchantable	Decay	Plots	Trees	Age	D.b.h.	Height	Gross merchantable	Decay	Gross merchantable	Decay	All defect 1/
	--Number--		*Years*	*Inches*	*Feet*	*Cubic feet*	*Percent*	*--Number--*		*Years*	*Inches*	*Feet*	*Cubic feet*	*Percent*	*Board feet*	*---Percent---*	
Round Mountain, Pendleton	2	6	75	8.1	61	66.7	3.6	10	46	110	18.1	85	3,209.2	5.4	15,824	11.8	13.5
Mount Nebo, Joseph	6	42	131	7.9	47	283.8	4.5	10	57	187	16.6	94	3,699.0	7.4	18,570	14.5	14.8
Abel's Ridge, Pomeroy	4	40	94	8.0	60	402.2	2.9	4	22	125	14.5	90	1,063.1	2.2	4,515	6.1	6.1
Swamp Creek No. 2, Walla Walla	4	5	152	9.3	21	52.3	8.8	4	12	171	21.9	127	1,583.4	2.0	8,967	4.4	4.7
Texas Bar, Ukiah	5	27	159	6.2	54	245.2	2.8	4	12	189	11.6	88	496.3	4.0	1,968	10.7	10.9
Wolf Creek, Baker	5	17	93	6.9	41	91.2	.4	2	2	204	16.3	91	115.5	18.9	501	35.5	35.5
Trout Farm, Prairie City	2	4	114	5.9	32	11.8	0	0	--	--	--	--	--	--	--	--	--
Total or average	28	141	119	7.5	52	1,153.2	3.3	34	151	154	16.9	93	10,166.5	5.4	50,345	11.1	11.8

1/ In board-foot measure, defect includes volume loss associated with decay, shake, frost cracks, and sound volume lost in cull logs. A cull log was one less than one-third sound.

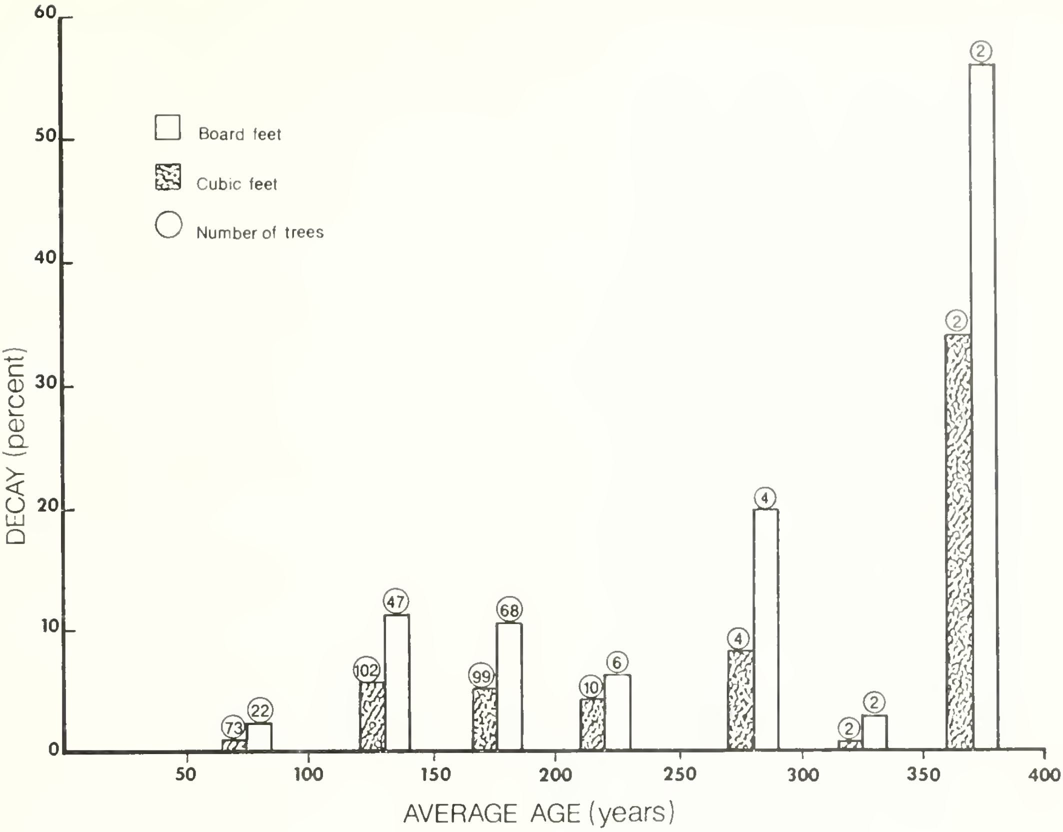

Figure 1.—Percent of cubic- and board-foot volumes decayed in Engelmann spruce by 50-year age classes.

Cyclic trends have been reported for Douglas-fir (Boyce and Wagg 1953) and subalpine fir (Hinds et al. 1960). As was the case in subalpine fir, it is likely that decay increases with age in Engelmann spruce stands until the most defective trees are eliminated by wind, beetles, root rot, or some other destructive agent. Decay percent in surviving trees is, therefore, lower. Decay then builds up in the stand until mortality of the most defective trees again lowers the decay percent for the stand. However, a larger sample in older age classes is necessary to confirm a cyclic decay-age relation in Engelmann spruce.

Root and butt rots.--Root and butt rots may be important contributors to the cyclic decay-age relationship in subalpine fir in Colorado (Hinds et al. 1960). They may kill trees directly or weaken them to the extent that insects finish them off. Mechanical weakening of roots and butts often results in windthrow or breakage (fig. 2). Root and butt rots occurred in 32 percent of all Engelmann spruce studied, whereas trunk rots were found in only 7 percent (table 2). Both types of rots appeared to become more prevalent with increasing tree age. However, root and butt rots do occur in a high percentage of young trees.

Diameter-decay relationship.--The incidence and severity of decay also usually increases with diameter, presumably because diameter is a function of age. Since diameter is easy to measure it may be more practical to relate decay to diameter

Figure 2.–Windbroken Engelmann spruce. Trees weakened by root and butt rot are commonly destroyed by wind and may contribute to cyclic relation between decay and age.

than to age. However, where all Engelmann spruce were sorted by diameter class (fig. 3), no consistent relationship between decay and diameter was found. This may be because Engelmann spruce is a tolerant species and often is suppressed for many years. Thus each diameter class has a wide range of ages. Percent decay based on cubic feet increased progressively from 0.9 percent in 5.0- to 6.9-inch diameter class to 5.3 percent in the 9.0- to 10.9-inch class. Then decay decreased in the 11.0- to 14.9-inch class to 5.0 percent, rising again to 7.5 percent in trees in the 15.0- to 18.9-inch diameter class. Decay then dropped to 3.4 percent in the 19.0- to 22.9-inch class, rising again in the 23.0- to 26.9-inch class to 7.3 percent. The cyclic nature of decay in Engelmann spruce is again suggested by these data; however, the sample of trees larger than 24-inch d.b.h. is too small to be conclusive.

Decay fungi.--Eleven fungi responsible for 75 percent of all infections and 80 percent of the decay cubic volume were identified by cultural methods or occasionally by appearance of the decay (table 3). Some fungi not identified are still being studied. White rot fungi were associated with more

Table 2.--*Root and butt and trunk rots in Engelmann spruce by age class*

Age class (years)	Tree basis	Trees in class with:	
		Root and butt rots	Trunk rots
	Number	*Percent*	*Percent*
50-99	73	25	3
100-149	102	26	5
150-199	99	39	11
200-249	10	50	10
250-299	4	75	0
300-349	2	50	0
350-399	2	100	50
Total	292	32	7

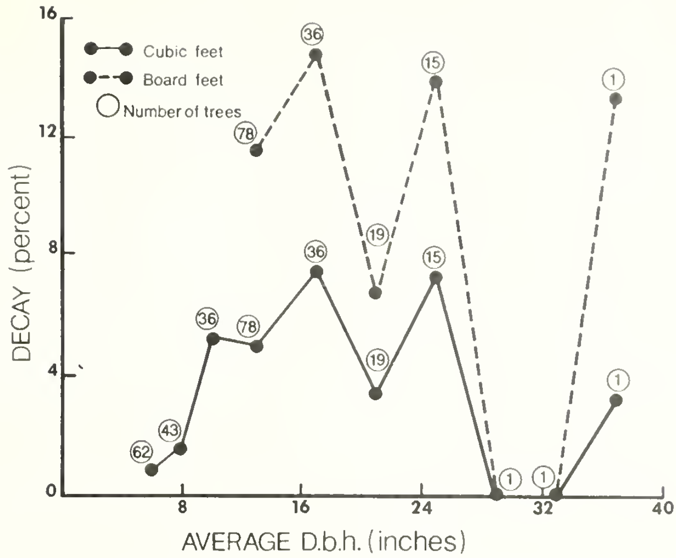

Figure 3.—Decay related to diameter of Engelmann spruce.

than 95 percent of all infections from which fungi were identified. Individual infections by four white root and butt rot fungi (*Polyporus tomentosus* var. *circinatus*, *Fomes annosus*, *Poria subacida*, and *Corticium galactinum*) accounted for nearly 60 percent of all infections and resulted in 42 percent of the decay cubic volume.

The most commonly occurring fungus was *Polyporus tomentosus* var. *circinatus* (fig. 4). Although this fungus alone was responsible for nearly 44 percent of all infections, it caused less than 10 percent of the decay cubic volume. This fungus caused only 4 percent of the identified infections in Engelmann spruce in Colorado (Hinds and Hawksworth 1966). Average decay volume per infection by *P. tomentosus* was only 1.1 cubic feet (table 3), compared with 3.1 cubic feet in the Colorado study.

Polyporus tomentosus var. *circinatus* appeared to occur in pockets or foci in the stand. Where this fungus was encountered, anywhere from a few to nearly all Engelmann spruce on a plot were infected. Infection apparently spreads from diseased trees to uninfected neighboring trees through roots. Dead and dying trees, indicating parasitic attack by this fungus, were not observed.

Fomes annosus (Fr.) Karst. was the second most commonly isolated fungus. Nearly 10 percent of all infections and approximately 14 percent of the decay cubic volume were attributable to this fungus. Usually two or three neighboring trees were infected, indicating tree-to-tree spread through roots.

Neither *F. annosus*, *Poria subacida* (Peck) Sacc., nor *Corticium galactinum* (Fr.) Burt was listed as causing decay in Engelmann spruce in either the Colorado or Alberta defect studies (Hinds and Hawksworth 1966, Etheridge 1956). In the present study, *C. galactinum* caused only three infections; however, extensive loss usually resulted.

Table 3.--*Fungi associated with decay of Engelmann spruce*

Fungus	Infections		Average decay volume[1/]		Percent of total decay volume[1/]	
	Number	*Percent*	*Cubic feet*	*Board feet*	*Cubic feet*	*Board feet*
White root and butt rots:						
Polyporus tomentosus Fr. var. *circinatus* (Fr.) Satory & Maire	50	43.8	1.1	30	9.6	12.3
Fomes annosus (Fr.) Karst.	11	9.6	7.4	115	13.7	12.3
Poria subacida (Peck) Sacc.	4	3.5	9.0	100	6.1	5.3
Corticium galactinum (Fr.) Burt	3	2.6	25.6	459	13.0	16.3
White trunk rots:						
Stereum sanguinolentum (Alb. & Schw. ex Fr.) Fr.	5	4.4	7.9	199	6.7	7.0
F. pini (Brot. ex Fr.) Karst.	3	2.6	30.2	218	15.3	11.6
S. chailletii (Pers. ex Fr.) Fr.	2	1.8	13.7	125	4.6	4.4
Polyporus versicolor L. ex Fr.	1	.9	.4	1	.1	(2/)
Brown trunk rots:						
Peniophora spp.	1	.9	7.2	66	1.2	1.1
Trechispora raduloides (Karst.) Rogers	1	.9	5.4	--	1.0	--
Mixed[3/]	5	4.4	10.3	103	8.7	9.2
Unidentified	28	24.6	4.2	52	20.0	20.5
Total	114	100.0	--	--	100.0	100.0

1/ Infections in pole and sawtimber size trees are included under cubic-foot measurement, but only infections in trees larger than 11.0-inch d.b.h. are included under board-foot measurement.

2/ Less than 0.5 percent of the total board-foot decay volume.

3/ Fungi associated in mixed infections as determined by cultural techniques:

P. tomentosus var. *circinatus* - *S. sanguinolentum* (2 occurrences)
P. tomentosus var. *circinatus* - *Poria subacida*
P. tomentosus var. *circinatus* - *T. raduloides*
Trametes serialis (Fr.) - *S. sanguinolentum*.

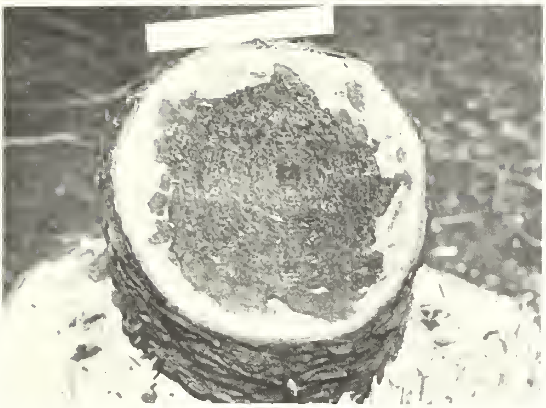

Figure 4.--*Polyporus tomentosus* var. *circinatus* root and butt rot of Engelmann spruce. Although diameter of decay column was very large at stump height, it usually extended only a few feet into the butt log.

Identified trunk rotting fungi caused only 12 percent of all infections, but these resulted in nearly 30 percent of all cubic volume decay loss. The ring scale fungus, *F. pini*, was responsible for only three infections; however, a loss of 15 percent of the total cubic volume resulted. This fungus was the most important fungus encountered in the Colorado and Alberta studies (Hinds and Hawksworth 1966, Etheridge 1956). Although *F. pini* infections resulted in extensive decay columns, no conks were produced on infected trees. This fungus commonly develops punk knots on Engelmann spruce in Colorado (Hinds and Hawksworth 1966).

Stereum sanguinolentum was isolated from eight trees--five individual infections and three in mixture with other fungi. This important slash-rotting fungus caused many infections in Engelmann and subalpine spruce in Colorado and Alberta, respectively. *Flammula connissans*, *Coniophora puteana*, *Peniophora septentrionalis*, *Fomes nigrolimitatus*, *Pholiota alnicola*, and *Corticium radiosum* were commonly associated with decay columns in the Colorado and Alberta studies (Hinds and Hawksworth 1966, Etheridge 1956) but were not isolated or identified in Engelmann spruce in this study.

Infection courts for fungi.--The important infection courts for fungi attacking Engelmann spruce are listed in table 4.

Table 4.--*Apparent infection courts for fungi attacking Engelmann spruce*

Fungus	Infection court								
	Roots	Basal injuries	Trunk wounds	Frost cracks	Forks	Crooks	Dead vertical branches	Crook and dead vertical branch	Broken tops
	Number								
Polyporus circinatus	50	0	0	0	0	0	0	0	0
P. versicolor	0	0	0	0	0	0	0	0	1
Fomes annosus	7	2	1	1	0	0	0	0	0
F. pini	0	1	0	0	1	1	0	0	0
Poria subacida	2	2	0	0	0	0	0	0	0
Corticium galactinum	2	0	1	0	0	0	0	0	0
Stereum sanguinolentum	0	1	0	0	1	1	0	0	2
S. chailletii	0	1	0	0	0	1	0	0	0
Peniophora spp.	0	0	0	0	0	0	0	1	0
Trechispora raduloides	1	0	0	0	0	0	0	0	0
Unidentified	12	7	3	2	0	0	1	1	2
Total infections[1/]	74	14	5	3	2	3	1	2	5

1/ Does not include entrance courts for five mixed fungal infections.

Roots and basal injuries including frost cracks were apparent entry points for 91 of 109 infections (mixed fungal infections are not included). Roots were the most common entrance courts for identified as well as unidentified fungi. All individual *Polyporus tomentosus* var. *circinatus* infections took place through roots. *Fomes annosus*, however, infected trees through roots and also through injuries, usually on the tree butt. Trunk decaying fungi such as *F. pini*, *Stereum sanguinolentum*, and *S. chailletii* attacked trees through injuries as was common in the Colorado study (Hinds and Hawksworth 1966). Branch infections by *F. pini* with subsequent production of swollen knots or conks were not found here. However, conks and punk knots were frequently found on Engelmann spruce in Colorado (Hinds and Hawksworth 1966). Dead tops associated with rust infections, important infection courts in Colorado, were not found in the Blue Mountains although an occasional large witches'-broom caused by a rust fungus was observed in some study trees.

A trunk rotting fungus, *Trechispora raduloides* (Karst.) Rogers, was isolated from what appeared to be a root and butt rot. It was not possible to determine whether the infection had taken place through a branch or through an old injury.

DEFECT INDICATORS AND ESTIMATING PROCEDURES

Factors for defect indicators are given as: (1) percentages of gross merchantable cubic- and board-foot tree volumes as reported by Aho (1966), and (2) average length deductions below and above indicators with flat percentage factors for hidden defect. Many Engelmann spruce did not have visible indicators of decay, partly because nearly 70 percent of the individual fungal infections entered trees through roots (table 4). No fungi produced punky or swollen knots or conks. Therefore, indicator factors are for less reliable types, mainly injuries, including basal and trunk wounds, frost cracks, and broken tops.

The most reliable defect indicators were basal injuries (fig. 5). They are open or healed wounds in contact with the ground and may be caused by fire, falling trees, logging machinery, or rubbing or chewing by animals.

Frost cracks or seams are open or closed wounds (fig. 6) probably caused by freezing. They are not included as indicators of decay for cubic volume defect percentages but are included for board feet, because the frost crack itself is a deductible defect.

Trunk injuries (fig. 7) are open or closed wounds below the merchantable top but not in contact with the ground. Wounds less than 1 foot long or less than 5 years old should be ignored since there is seldom extensive decay associated with them.

Broken tops (fig. 8) below merchantable top diameter are also indicators of defect. No dead tops were encountered on study trees.

Percentage factors for defect indicators.--The following equations estimate defect in individual trees on a cubic- and board-foot basis and are repeated here for convenience (Aho 1966).

Cubic feet:

$$P_c = -5.108 + 0.046A + 13.126B + 0.139D + 1.798E + 6.150T \quad (1)$$

$$P_c = -1.124 + 13.696B + 0.324D + 2.032E + 6.587T \quad (2)$$

Board feet:

$$P_b = -4.909 + 0.097A + 35.814B - 0.100D + 6.013E + 3.542F + 30.201T \quad (3)$$

$$P_b = 3.837 + 37.464B + 0.271D + 2.640E + 2.522F + 35.529T \quad (4)$$

Where

P_c = percent of gross merchantable cubic-foot volume that is cull.

P_b = percent of gross merchantable board-foot volume that is cull.

A = tree age.

B = 1 if one or more basal injuries present; 0 if no basal injury present.

D = tree diameter outside bark at breast height.

E = 1 if broken top present; 0 if no broken top present.

F = 1 if one or more frost cracks present; 0 if no frost cracks present.

T = 1 if one or more trunk injuries longer than 1 foot present; 0 if no trunk injuries present.

To provide a quick reference for use in the field, tables 5 and 6 were developed from equations 1 and 3. Familiarity with the indicators (figs. 5A, 6A, 7A, and 8A) aids in effective application of the given defect percentages. Defect percentages are presented for individual and combinations of indicators. Procedure would be as follows. Injuries less than 5 years old are ignored because decay development is seldom extensive behind recent wounds. D.b.h. is measured, age roughly estimated, and the presence of appropriate indicators noted. From these, defect percentages from the proper table can be read. For example, a 20-inch, 225-year-old Engelmann spruce with no indicators would have deductions of 8 percent of its total cubic-foot volume (table 5) and 15 percent of its board-foot volume (table 6). A 12-inch, 125-year-old Engelmann spruce with a top injury and basal injury would have deductions of 17 percent in cubic feet (table 5) and 48 percent in board feet (table 6).

Table 5.--*Percentages of gross merchantable cubic-foot volume cull in Engelmann spruce, by d.b.h., age, and indicator class*[1]

Indicator class	D.b.h. class and age (years)											
	8 inches		12 inches			20 inches			28 inches			
	75	125	75	125	175	125	175	225	125	175	225	275
	Percent											
No indicators	0	2	0	2	5	3	6	8	5	7	9	11
Top injuries	1	4	2	4	6	5	8	10	6	9	11	13
Trunk injuries[2]	6	8	6	8	11	10	12	14	11	13	15	18
Basal injuries[2]	13	15	13	15	18	17	19	21	18	20	22	25
Top and trunk injuries[2]	7	10	8	10	13	11	14	16	12	15	17	19
Top and basal injuries[2]	14	17	15	17	20	18	21	23	19	22	24	26
Trunk and basal injuries[2]	19	21	19	22	24	23	25	27	24	26	28	31
Top, trunk, and basal injuries[2]	21	23	21	23	26	24	27	29	26	28	30	33

[1] Derived from equation 1,

$$P_c = -5.108 + 0.046A + 13.126B + 0.139D + 1.798E + 6.150T,$$

where A = tree age; B = 1 if one or more basal injuries present, 0 if no basal injury present; D = tree diameter outside bark at breast height; E = 1 if broken top present, 0 if no broken top present; and T = 1 if one or more trunk injuries longer than 1 foot present, 0 if no trunk injuries present.

[2] No deduction for frost cracks.

Table 6.--*Percentages of gross merchantable board-foot volume cull in Engelmann spruce, by d.b.h., age, and indicator class*[1/]

Indicator class	D.b.h. class and age (years)									
	12 inches			20 inches			28 inches			
	75	125	175	125	175	225	125	175	225	275
	Percent									
No indicators	1	6	11	5	10	15	4	9	14	19
Frost cracks	5	10	14	9	14	18	8	13	18	23
Top injuries	7	12	17	11	16	21	10	15	20	25
Trunk injuries	31	36	41	35	40	45	35	39	44	49
Basal injuries	37	42	47	41	46	51	40	45	50	55
Frost cracks and top injuries	11	16	20	15	20	24	14	19	24	29
Frost cracks and trunk injuries	35	40	45	39	44	49	38	43	48	53
Top and trunk injuries	37	42	47	41	46	51	41	45	50	55
Frost cracks and basal injuries	41	45	50	45	49	54	44	49	53	58
Top and basal injuries	43	48	53	47	52	57	46	51	56	61
Trunk and basal injuries	67	72	77	71	76	81	70	75	80	85
Frost cracks, top, and trunk injuries	41	46	51	45	50	55	44	49	54	59
Frost cracks, top, and basal injuries	47	51	56	51	55	60	50	55	59	64
Frost cracks, trunk, and basal injuries	71	76	80	75	80	84	74	79	84	89
Top, trunk, and basal injuries	73	78	83	77	82	87	76	81	86	91
Frost cracks, top, trunk, and basal injuries	77	82	86	81	86	90	80	85	90	95

[1/] Derived from equation 3,

$$P_b = -4.909 + 0.097A + 35.814B - 0.100D + 6.013E + 3.542F + 30.201T,$$

where A = tree age; B = 1 if one or more basal injuries present, 0 if no basal injury present; D = tree diameter outside bark at breast height; E = 1 if broken top present, 0 if no broken top present; F = 1 if one or more frost cracks present, 0 if no frost crack present; and T = 1 if one or more trunk injuries longer than 1 foot present, 0 if no trunk injuries present.

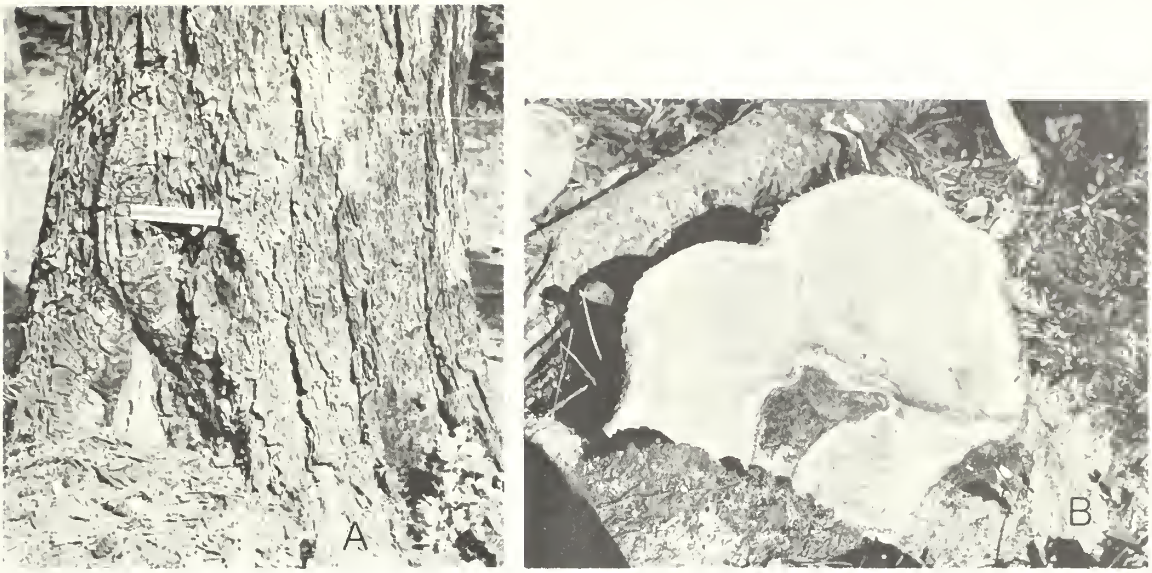

Figure 5.—*A*, Basal injury in Engelmann spruce (these indicators are sometimes inconspicuous and may be overlooked); *B*, decay associated with basal wound.

Figure 6.—*A*, Frost crack or seam on Engelmann spruce; *B*, decay associated with frost crack.

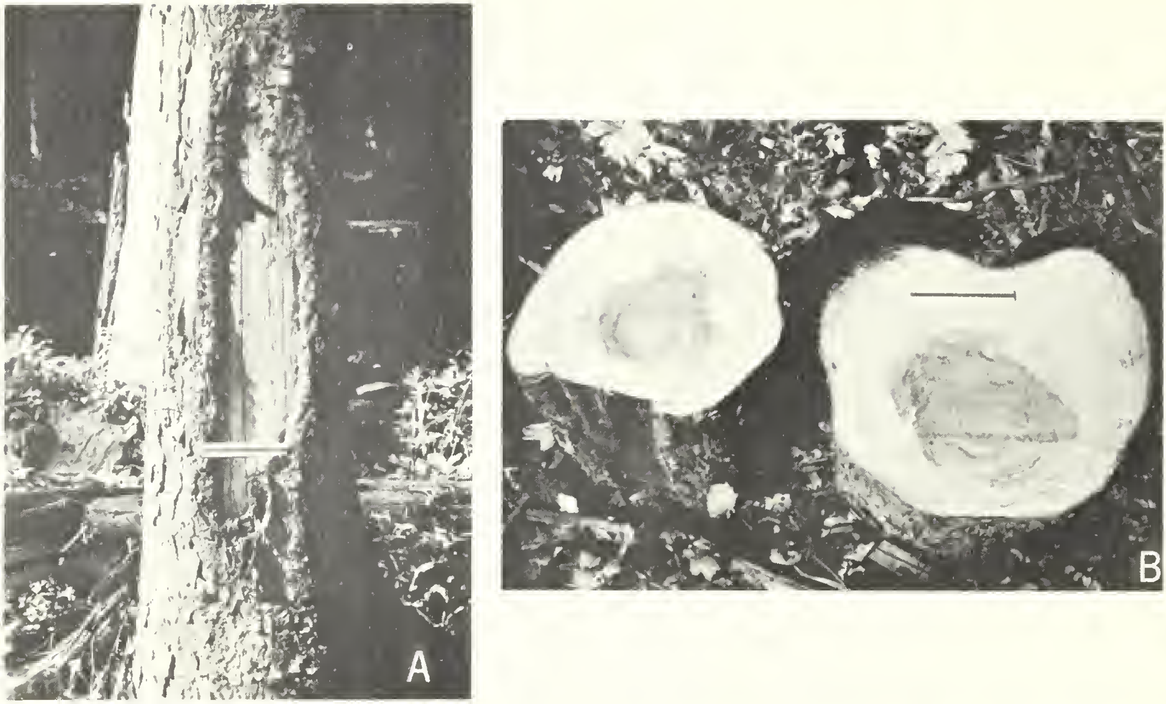

Figure 7.—*A*, Trunk injury in bole of Engelmann spruce; *B*, decay associated with old trunk injury.

Figure 8.—*A*, Broken top below merchantable top diameter indicates decay in Engelmann spruce; *B*, decay associated with broken top.

Equations 2 and 4 are included for use when age is not determined. These equations may be used to generate tables similar to those presented above.

Length deductions for indicators and flat factors for hidden defect.--Some timber cruisers prefer to use average length deductions below and above indicators to determine net tree volumes. Length deductions for commonly occurring defect indicators on Engelmann spruce are in table 7. All defect within the dimensions of the wound and that extending below and above, when appropriate, are included in the length deduction. Decay columns associated with indicators on the bole that extend into roots, broken tops, or another rot column are not included in the average deductions. Since, in most instances, there is no way of determining which injuries have associated decay, the average deductions for a given indicator class should be applied to all indicators of that class encountered, except recent injuries, i.e., those less than 5 years old, and trunk scars less than 1 foot long.

Hidden defect includes decay associated with indicators of minor importance and that caused by fungi which enter trees through roots or branches and produce no indicators such as conks. Minor indicators include crooks, forks, dead vertical branches, and trunk wounds less than 1 foot long. At times decay may be associated with these indicators, but this is so infrequent or so limited that it is probably best to include it as a flat percentage factor for hidden defect.

Total net cubic- and Scribner board-foot volumes, determined by application of average length deductions for indicators to individual trees, must be further reduced for hidden defect by 3 and 7 percent, respectively.

Application of length deductions for indicators and hidden defect percentage factors should be in the following manner. Net volumes of all sample trees are calculated, using the indicator length deductions where appropriate. After net tree volumes are totaled, the appropriate flat percentage factor (i.e., 3 percent to net cubic-foot volumes and 7 percent to net board-foot volumes) is applied to the total net sample volume. Sound net sample volume is thus obtained, excepting deductions for sweep, breakage in logging, and missing parts of trees such as broken tops or portions of butt logs burned away by fire.

Table 7.--*Length deductions for defect indicators on Engelmann spruce sawtimber*

Indicator	Frequency of infection	Average length deduction	
		Below	Above
	Percent	*Feet*	
Basal injuries	92	--	10
Trunk wounds	44	1	3
Frost cracks	36	--	2
Broken tops	40	3	--

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Dissections of 292 Engelmann spruce from seven areas in the Blue Mountains provided defect data. Variations in defect among areas, relation of defect with tree age and size, fungi associated with decay, and their infection courts are discussed. Two methods for estimating defect in standing trees are given.

Keywords: Decay fungi (wood), defect indicators (wood quality), fungi (forest damage).

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USDA Forest Service Research Paper PNW-117

INITIAL THINNING EFFECTS

in 70- to 150-year-old douglas-fir—western oregon and washington

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CONTENTS

ABSTRACT

Vigorous, mature (post-rotation age) Douglas-fir stands will probably exist for another 50 years or more on some properties in western Oregon and Washington. Intermediate harvests in the form of thinnings were analyzed on nine study areas ranging from 70 to 150 years old when thinned.

Recoverable cubic-volume growth, averaging 81 percent of normal gross growth, was recorded for up to 38 years with single thinnings and for 18 years with two thinnings. This percentage increases with stand age, but rate of response to thinning decreases with increasing stand age.

A dramatic 61-percent reduction in loss caused by bark beetles and substantial reductions in losses from windthrow (30 percent), breakage (33 percent), and suppression (46 percent) were measured.

Reserve basal area may be maintained between 60 and 85 percent of normal. Thinning should follow marking guidelines previously recommended but with more emphasis on crown release since spacing is important in vigorous, mature stands as well as in younger stands.

Keywords: Thinning (trees), forest cutting systems, Douglas-fir, *Pseudotsuga menziesii,* forest improvement cutting.

INTRODUCTION

The purpose of this paper is to present management guides toward maximum recoverable growth in vigorous, mature, essentially even-aged Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) stands. These guides primarily concern stands 70 to 150 years old, though inferences are expected to apply to older stands which are still vigorous. These guides supplement the theory and practice of commercial thinning in younger stands as well documented in USDA Technical Bulletin No. 1230 (Worthington and Staebler 1961).

The present inventory of post-rotation-aged Douglas-fir is so large that immediate harvest cutting is not a practical alternative for all such stands for all owners. Table 1 lists the volume and acreage of Douglas-fir stands in western Oregon and Washington in 1968 by 20- and 30-year age classes. At the average annual rate of cutting (11,530 million board feet) in the years 1960 to 1968, final harvest of all stands now over 100 years of age would take well over 20 years. Since current cutting includes timber types other than Douglas-fir and stands less than 70 years old, probably not more than two-thirds of current cutting comes from post-rotation-aged Douglas-fir. These factors extend the liquidation period for stands currently older than 70 years to well over 30 years. As some owners will be liquidating more slowly than the average, we expect that some vigorous, mature Douglas-fir stands will exist for another 40 to 50 years or more and will urgently need silvicultural treatment during the intervening years. During the next 30- to 50-year period, nearly 28 percent of the Douglas-fir timber types potentially pass through this 70- to 150-year-old range, providing regeneration cuts are not made prior to age 70.

Table 1.–*Inventory of Douglas-fir type, western Oregon and Washington, 1968*[1]

Age class	Area	Volume	
	Thousand acres	*Million cu. ft.*	*Million bd. ft. (Scribner)*
0-20	2,087	945	2,912
20-40	1,734	4,935	11,914
40-70	1,593	7,436	25,952
70-100	852	5,425	27,082
100-120	364	2,925	17,863
120-150	271	2,240	11,142
Total, 70-150	1,487	10,590	53,147
150-180	174	1,721	8,621
180+	2,567	28,222	124,999
Uneven-aged	4,800	24,335	110,644
Total	14,442	78,184	341,129

[1]Data from Pac. Northwest Forest & Range Exp. Sta. USDA Forest Serv. Resour. Bulls.

Most earlier reports concerning thinning of such stands (Steele 1948, 1954; Yerkes 1960) recommend removing only high-risk trees[1] and conclude that thinning cannot be expected to improve growth of residual trees sufficiently for full site utilization. Subsequent analysis (Williamson 1966) of data from some of the same plots reported above, together with more accurate site index estimates and a longer period of observation, convinced us that these earlier recommendations should be reexamined.

[1]Trees likely to die of any cause before the next scheduled cut.

METHODS

Study Areas

Permanent sample plot records for nine study areas were obtained from the Pacific Northwest Forest and Range Experiment Station and the Weyerhaeuser Company. These areas are characterized in table 2, with locations illustrated in figure 1. Some stand, treatment, and growth observations are recorded in table 3.

Table 2.—*Characteristics of existing thinning study areas in young-growth Douglas-fir over 70 years old*

Location (study number)	Legal location reference, Willamette Meridian	Age at establishment	Date of establishment	Remeasurement dates	Site index	Kind of thinning
Salmon Creek (34H)	T21S,R3E	79	1928	1933, 1938, 1944, 1967	148	low, moderate
Fall Creek (W10)	T18+19S,R2E	90	1948	1955, 1967	150	low, light
Indian Creek (W29)	T16S,R10W	77	1943	1947, 1967	170	crown, moderate
Henderson Creek (W14)	T19S,R11W	150	1947	1952	170	crown, moderate
Panther Creek (P22)	T4N,R7-1/2E	97	1939	1946, 1950, 1952, 1957, 1967	150	low, moderate
Boundary Creek (P26)	T4N,R8E	110	1952	1955, 1958, 1963	114 to 150[1]	low, light to heavy
Vail	T15N,R4E	90	1954	1959, 1964, 1967	140	low, heavy
St. Helens (3)	T10N,R3E	100	1946	1951	155	crown, heavy
St. Helens (4)	T10N,R2E	68	1950	1956, 1958, 1963	170	low, heavy

[1]Minor site index variation (± 5 feet) exists around the average presented for other areas. The range presented for Boundary Creek illustrates the extreme variability of one factor influencing growth within this area.

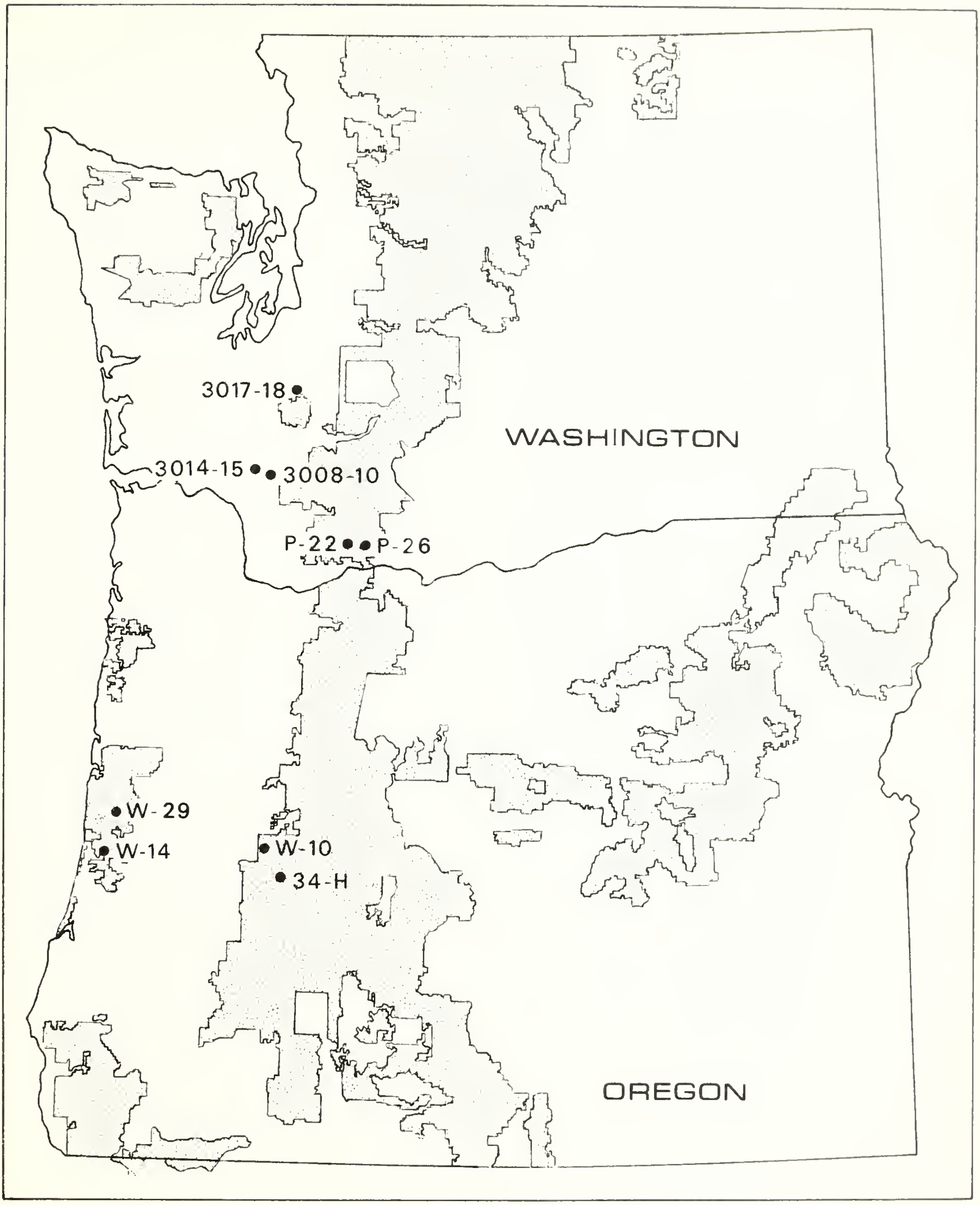

Figure 1.—Study area locations.

Table 3.—*Certain stand, treatment, and growth characteristics*

(Measurements are per acre)

Area (study number)	Plot	Initial basal area	Initial basal area percent normal	Percent cut	Kind of cut, d/D[1]	Residual basal area	Overall periodic annual growth: Net Basal area	Net Volume	Gross Basal area	Gross Volume
		Sq. ft.				*Sq. ft.*	*Sq. ft.*	*Cu. ft.*	*Sq. ft.*	*Cu. ft.*
Fall Creek (W10)	1	259	92	22	0.83	201	1.8	114	2.7	155
	2	251	88	0	–	251	1.6	119	2.8	169
Henderson Creek (W14)	1	411	119	27	.92	301	2.0	139	2.3	148
	2	398	115	12	1.05	350	2.4	159	2.8	173
	3	337	97	16	.90	282	.1	41	2.1	137
	4	365	106	0	–	361	.8	90	2.9	193
Indian Creek (W29)	26	331	123	28	1.08	238	-.2	10	2.8	152
	27	317	118	22	1.10	247	.1	29	2.6	153
	28	334	124	25	1.01	252	.8	50	2.8	143
	29	356	132	0	–	356	-.9	45	3.0	236
	30	297	110	0	–	297	-3.7	-155	2.0	127
Salmon Creek (34H)	4	200	76	39	.83	122	1.6	98	1.9	112
	5	202	77	0	–	202	.4	64	1.8	122
St. Helens (3)	3008	322	109	55	1.04	172	-3.3	-128	1.3	78
	3009	296	101	38	1.00	196	-1.7	-62	1.6	93
	3010	284	94	0	–	284	2.7	306	3.0	318
St. Helens (4)	3011	295	115	24[2]	.69	236	0	41	3.5	216
	3013	287	112	30[2]	.84	229	3.0	170	3.9	211
	3014	314	123	51[2]	.80	249	3.7	200	3.7	200
	3015	299	117	28[2]	.62	255	3.0	215	3.1	220
	1007	322	126	0	–	322	.6	112	3.6	243
Vail	1098	259	95	0	–	259	2.9	153	3.2	163
	1099	262	96	0	–	262	2.4	134	3.0	155
	3017	270	99	24	.74	204	1.6	47	2.3	76
	3018	254	93	30	.76	178	2.0	99	2.1	103
Boundary Creek (P26)	1	306	101	6	–	287	2.9	138	3.0	146
	2	224	83	36	.89	144	1.3	66	1.3	66
	3	293	97	24	.89	222	1.8	111	2.0	116
	4	264	87	18	.88	216	2.7	126	3.0	134
	5	210	71	22	.80	163	1.5	83	1.6	87
	6	258	87	7	–	239	1.9	113	2.3	133
	7	180	61	2	–	177	.8	57	2.1	111
	8	289	101	22	.90	224	1.0	57	1.6	90
	9	240	92	36	.95	155	.6	34	1.7	70
Panther Creek (P22)	91	306	109	32[2]	.95	237	1.0	57	([3])	([3])
	92	247	86	36[2]	.85	223	.9	54	([3])	([3])
	93	278	96	27[2]	.96	241	1.7	98	([3])	([3])
	94	248	87	27[2]	.93	223	1.2	77	([3])	([3])
	95	254	88	31[2]	.92	237	.6	48	([3])	([3])
	96	250	86	28[2]	.83	232	1.0	73	([3])	([3])
	97	262	91	36[2]	.88	234	1.5	84	([3])	([3])

[1] Ratio of quadratic mean diameter of cut trees to that of all trees before cutting.

[2] Sum of cuts 1 and 2 as percent of basal area before cut 1.

[3] Loss of individual tree identification resulted in estimate of net growth only for overall period.

Most of these studies were early attempts to evaluate commercial thinning. Salable volume was obtained primarily from the larger diameter classes, though plot records and the appearance of the stands today indicate a conscious effort was generally made to leave the best dominants and codominants as crop trees and to remove as many poor intermediate and suppressed trees as possible.

Most of the studies had been abandoned for from 9 to 20 years, perhaps because of a lack of dynamic response to thinning in these older stands and the potential for more rewarding research efforts in more responsive younger stands. Nevertheless, the foresight exhibited by the people responsible for establishing these studies and imposing treatments is remarkable, since the prevailing opinion was that "thinning" in these older stands should be confined to removal of high-risk trees.

Plot Examinations

Diameter (b.h.) on all trees and total height of at least 20 trees per plot were remeasured for all nine areas. Most plots also were examined subjectively for (1) plant (species and vigor) and soil (depth and stoniness) indicators of possible gross errors in site index estimates, (2) external causes of mortality, and (3) other factors that might obscure treatment effects.

Stand Compilation and Summary

Data for each plot were compiled and summarized by the same methods as follows:

1. Scribner and International 1/8-inch board-foot volumes for trees 11.0-inch d.b.h. and larger, to 8-inch and 5-inch tops, respectively.
2. Cubic-foot volumes for trees 5.0-inch d.b.h. and larger, to 4-inch top.
3. Basal area for all trees over 1.5-inch d.b.h.
4. Gross and net growth and mortality, by cause.

Analysis

Most of the studies examined here were established with unreplicated treatments and presented a maze of stand conditions, treatments, apparent site qualities, and growth responses that made reliable empirical evaluation of growth-treatment relationships extremely difficult.

Stepwise multiple regression analysis was chosen as the most acceptable means of developing approximate functions illustrating these growth-treatment relationships. Bias was recognized as probable in some or all tests of significance and in values of regression coefficients, because the data deviated widely from the theoretical assumptions underlying multiple regression analysis. However, the regression trends discussed below fit the observed data very well (overall period correlation coefficient = .97). Because these study areas typify well-stocked stands throughout the Douglas-fir type, we think the trends are generally applicable.

No exact interpretations regarding volume growth will be attempted here since gross periodic annual *basal area* growth is much more precisely estimated than is volume growth. Basal area was the treatment response analyzed by stepwise regression. There is evidence[2] from the Voight Creek Experimental Forest[3] that, in moderately to heavily thinned 38- to 45-year-old stands, absolute form factor for individual trees increased only 0.004 in 9 years, and degree of release did not significantly affect this increase. In addition, height growth in these older stands is small. The trends regarding basal area growth, discussed below, probably apply equally as well to volume growth.

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[2] Data on file at the Forestry Sciences Laboratory, Pacific Northwest Forest and Range Experiment Station, Olympia, Wash.

[3] The Forest is maintained in cooperation with St. Regis Paper Company.

RESULTS AND DISCUSSION

In addition to the usual beneficial results of thinning (less capital investment, transfer of growth to fewer and better trees, a more vigorous stand with less risk of mortality), two results were readily apparent and deserve initial emphasis. One is that average mortality from bark beetle (in most cases, probably due to Douglas-fir bark beetle) (*Dendroctonus pseudotsugae*, Hopkins) in these thinned plots during the total observation periods was only about 40 percent of that on the unthinned plots.

The second is that stand age and estimated site index are the primary factors influencing long-term growth in these thinned stands, and that other possible factors such as intensity of cut apparently exerted very little additional influence.

First period growth (5 to 7 years after thinning) for these plots can be expressed by the following equation:

$$(1)\quad y = -0.856 + 0.02389(rba\%) + 5346\left(\frac{1}{age}\right)^2 + 0.0003669(site)^{3/2}. \quad (r = .92)$$

Overall period growth (5 to 38 years after thinning) can be expressed as follows:

$$(2)\quad y = -17.372 + 1.948(d/D) + 0.1776(p) - 0.0406(June) + 7907\left(\frac{1}{age}\right)^2 + 0.0015259(site)^{3/2}. \quad (r = .97)$$

In the above equations:

y = Gross periodic annual basal area growth.

$rba\%$ = Residual basal area as a percent of normal basal area.

d/D = Ratio of quadratic mean diameter of cut trees to that of all trees before cutting.

p = Total growing season (May-August) precipitation expressed as percent of normal for the measurement period.

$June$ = Periodic average precipitation for month of June, expressed as percent of normal June precipitation.

Readers should regard these relationships as tentative and use the above correlation coefficients to visualize only how well these equations describe these data.

Factors Influencing Gross Basal Area Growth

RESIDUAL BASAL AREA–PERCENT OF NORMAL–AND INTENSITY OF CUT

Because these stands were well stocked initially and represented approximately normal basal area conditions, "residual basal area" expressed as a percent of normal and "intensity of cut" (percent cut) provided similar, but complementary, expressions of treatment. Figure 2 illustrates observed growth trends relative to intensity of cut, but values on the ordinate scale also can be regarded as approximate percentages of normal basal area stocking because of the above similarity. Recoverable basal area growth (fig. 2) is equal to "net growth plus 80 percent of observed mortality." Different starting elevations for sloping lines indicate different intensities of initial thinning. Degree of slope represents relative growth rate.

Except for plots 3008 and 3009 which had heavy mortality, thinning intensity or residual basal area had little, if any, influence on growth relative to initial basal area (fig. 2). There is some variation in relative growth rate after thinning, but this is largely between study areas and probably reflects differences in stand age at time of treatment. In the 70- to 150-year-age range of these study areas, older stands evidently grow relatively more slowly. To further substantiate this age effect,

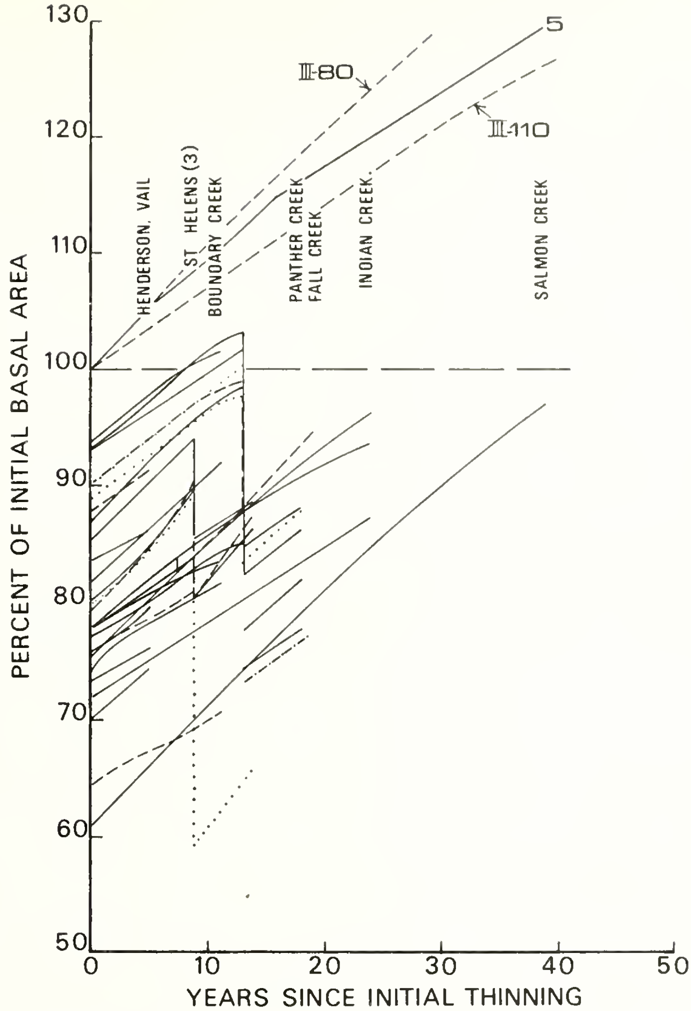

Figure 2.–Time and cutting intensity effects on recoverable basal area growth relative to basal area before cutting. All thinned plots and Salmon Creek plot 5 (unthinned).

two curves for site quality III gross yields (Staebler 1955) are shown by dashed lines—one for stands starting at age 80 and one for stands starting at age 110. The gross yield table values also indicate that site variations should have little influence on the slope of these curves. Values for Salmon Creek plot 5 (unthinned) are included because its long-term record provides a reliable basis for comparing thinned and unthinned stands. Results for this plot are representative of the other unthinned plots which remained well stocked. The curve for this plot represents total gross growth (net plus 100 percent of observed mortality). Growth of unthinned plot 5 declined relative to normal gross growth, whereas *estimated recoverable growth* of adjacent thinned plot 4 almost exactly paralleled it.

An apparent lack of a pronounced growth depression in the first 5 to 7 years after thinning is particularly noticeable. No doubt, some depression occurs in this period, but lack of annual measurements precludes knowledge of its timing and extent. This lack of pronounced depression is so generally contradicted by results from other experimental areas, though generally in younger stands, that it requires further study. The contradiction may be, in part, due to methodology. In the development of figure 2, thinned plot growth was *not* compared with growth of associated control plots, as is usually done, because before treatment several thinned plots differed appreciably in stand and site characteristics from their respective control plots. Nor was growth compared with normal values. Rather, the stand on each of these initially well-stocked plots was considered as having integrated the influence of all factors affecting productivity on the plot up to the time of cutting. Thus, each initial stand provided its own index to future productivity.

STAND AGE, MIDPERIOD

Gross basal growth during both initial and overall periods was closely dependent on stand age (fig. 3). For a given site index, growth steadily declined with age, though at a decreasing rate. Normal growth trends—indicated by dashed lines—are similar to those measured in this study.

SITE INDEX

Site index obviously is an important predictor of productivity (fig. 3). The site index trends in figure 3, derived from equation 2, however, appear too low for site indices below 140. Only three plots have estimated site index below this value and this paucity of data probably allowed curved distortion. Growth for these three plots corresponded more closely to normal gross yield trends (Staebler 1955) represented by dashed lines in figure 3.

KIND OF THINNING (*d*/*D*)

Kind of cut (fig. 4, equation 2) appeared to be more important in the overall periods (5 to 38 years) than for the first periods (5 to 7 years), when it usually would be expected to exert its strongest influence. This suggests that the release and growth stimulus provided by spacing upper crown classes are more lasting than those resulting from removing only suppressed and intermediate trees.

(GROWTH $(y) = -3.668 + 1.94791\,(d/D) + 7907\,(1/age)^2 + 0.0015259\,(site)^{3/2}, r^2 = .94$)

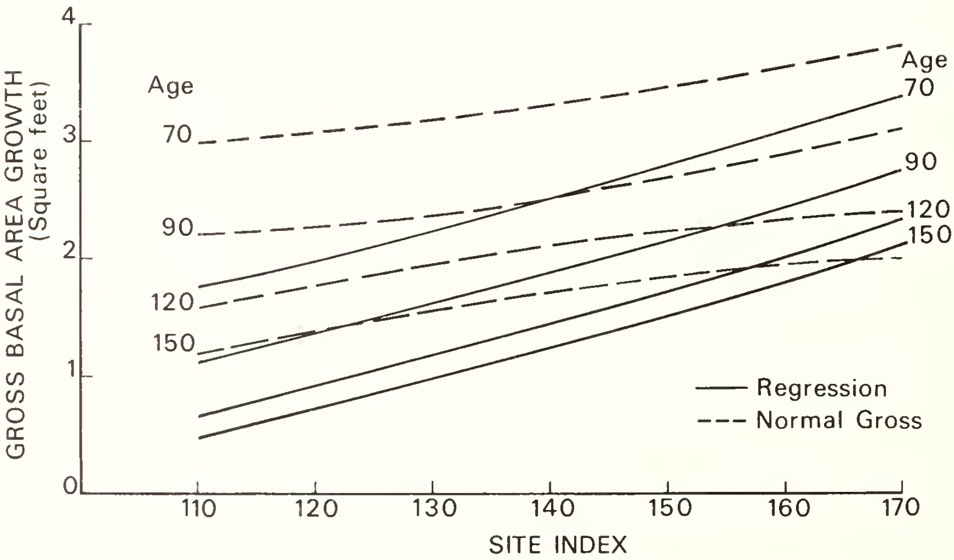

Figure 3.—Gross periodic annual basal area growth expressed as a function of age, site index, and *d*/*D* where *d*/*D* = 1.05.

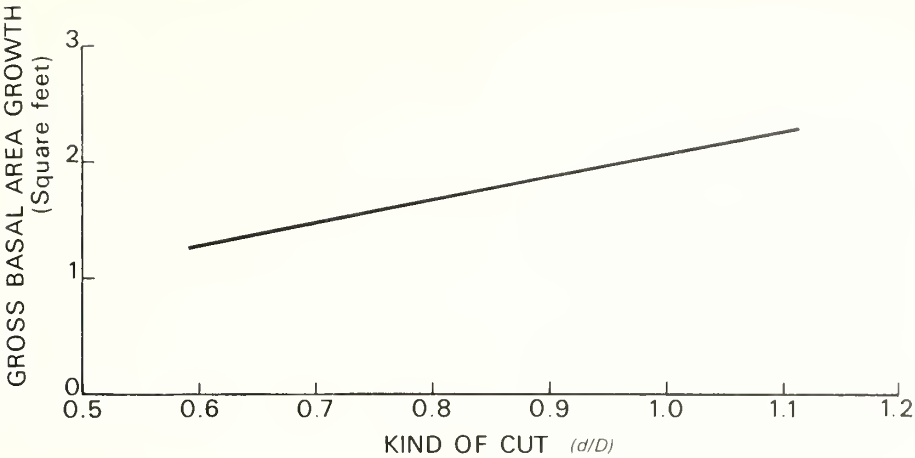

Figure 4.—Effect of kind of cut (d/D) on gross total periodic annual basal area growth, for age 90 and site index 150.

Low thinning appeared primarily to benefit other lower crown-class trees for a given amount of basal area removed. Crown thinning appeared to benefit primarily larger trees. This viewpoint is supported by analysis of basal-area growth of trees sampling the entire range of initial diameters in two stands similar regarding age, site, and initial density, one thinned from below (St. Helens 3011, 3014) and one from above (Indian Creek) (fig. 5). In each case, difference in growth is shown by comparison of thinned and unthinned stands. Study areas are not compared directly because of different period lengths. At Indian Creek, where the stand was thinned from above, basal-area growth of larger trees benefited substantially more from release than did that of smaller ones. At St. Helens plots 3011 and 3014, where trees were thinned from below, smaller trees benefited from release more than did larger trees. With respect to basal-area-growth *percent*, all size

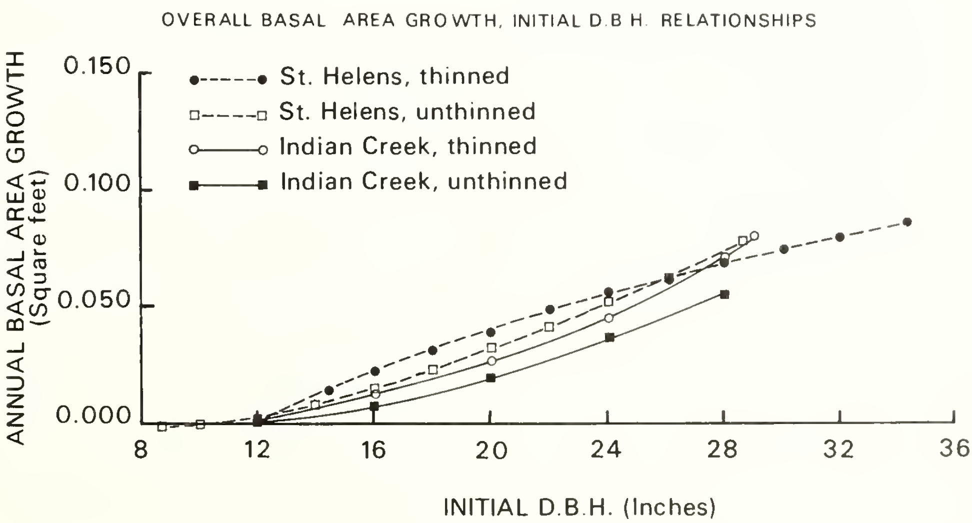

Figure 5.—Periodic basal area growth-initial d.b.h. relationships, Indian Creek and St. Helens 3011, 3014.

classes performed about the same at St. Helens (1.58 percent vs. 1.68 percent for small and large trees); the larger size classes performed considerably better at Indian Creek (1.63 percent vs. 0.95 percent).

TREE SPACING BEFORE THINNING

Response to thinning apparently had no relationship to prethinning density. This is remarkable, considering the wide range in the sample data. Density was expressed as growing space per tree relative to tree height before thinning and is one of numerous possible indices of competition. The ratio—43,560 ÷ number of trees x height—varied between 1.12 and 3.06, and number of trees relative to normal values varied between 55 and 159 percent.

REPEATED THINNING

As only two areas were thinned twice, the data are insufficient to make definite inferences. It seems fairly evident, from the trends of basal area for Panther Creek and St. Helens (fig. 2), that growth following the second thinning approximated that following initial thinning when levels of growing stock were maintained above about 60 percent of normal.

WESTERN HEMLOCK GROWING STOCK

This species generally contributed little or nothing to the growing stock of the studied stands. Appreciable amounts occurred at two study areas (up to 27 percent by basal area), but the occurrence did not appear to have influenced stand response relative to the other areas having little or no hemlock growing stock.

Mortality

GENERAL

Thinning these vigorous, mature stands reduced mortality due to all natural causes (fig. 6). It is likely that repeated thinning would have further reduced thinned plot mortality.

We attempted to relate amounts of different kinds of mortality to stand, environmental, and time variables. Except for windthrow, correlations with these independent variables were too weak to be significant. This is not surprising, considering the sporadic nature of nonsuppression mortality.

WINDTHROW

Concern about windthrow should not delay or forestall thinning, even in high-hazard areas. In these study areas, losses were generally lower in thinned than in unthinned stands. In high-hazard areas, windthrow was most serious immediately after cutting and decreased with time. Observed mortality is expressed by the following equation derived from data for all study areas:

$$y = 0.6282 + 8.01\left(\frac{1}{x}\right)^2. \quad (r = .85)$$

where:

y = windthrow, basal area per acre per year

x = (time since thinning) ÷ 2.

Except for two of the study areas (Henderson Creek, St. Helens 3008-9), plot data indicate that average windthrow mortality was practically constant with time—about 0.3 square foot of basal area per acre per year. These two areas illustrate the adverse results to be expected if sound principles of cutting in relation to windthrow (Gratkowski 1956; Ruth and Yoder 1953) are ignored. Topographic and/or soil characteristics, plus the existence of adjacent clearcuts and intermingled road clearings, evidently made these two partial cut residual stands extremely subject to windthrow. The St. Helens plots 3008-9, being situated on a moist flat in the bottom of a major east-west drainage, were responsible for the indication of much heavier windthrow mortality immediately after cutting. At Henderson Creek, the localized funneling effect of adjacent clearcut boundaries and road clearings on strong winds proved disastrous. Windthrow would have been serious even without partial cutting because of topography and exposure. Equally extensive windthrow in the adjacent uncut area supports this belief.

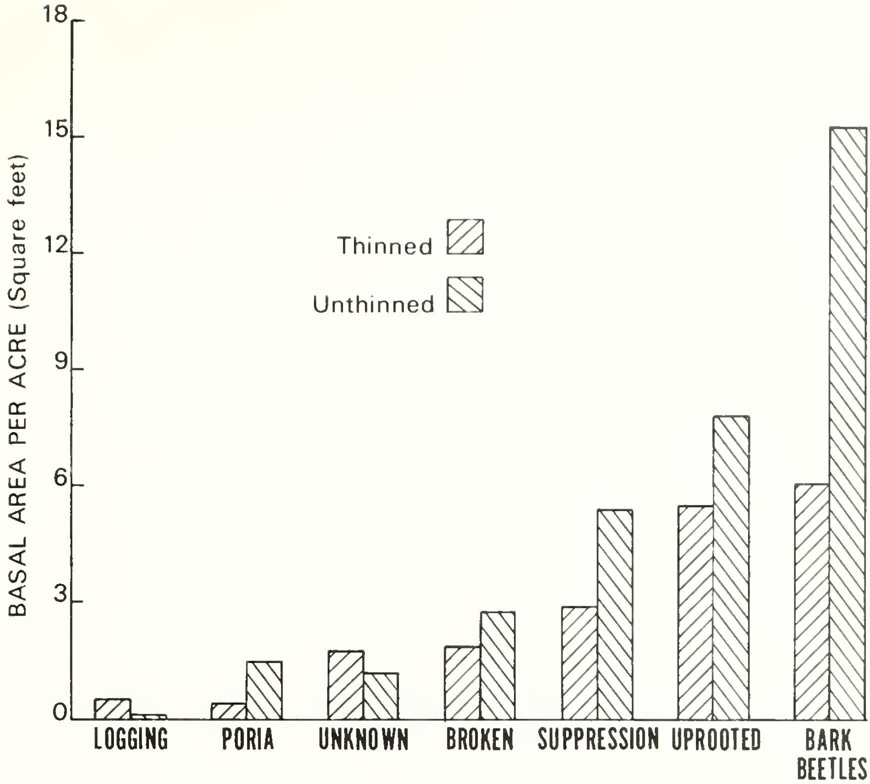

Figure 6.–Comparison of average cumulative mortality for thinned and unthinned areas.

BARK BEETLES

Thinning dramatically inhibited mortality by bark beetles, whether beetle attack occurred concurrently with thinning or followed thinning by varying periods up to 24 years.

Two of the studies were established in stands concurrently experiencing heavy bark beetle attacks. At Panther Creek, all plots were thinned; and at Boundary Creek, insect-infested trees were removed from "unthinned" stands as well as from thinned stands. At both places, bark beetle attacks rapidly subsided.

At a third study area (Indian Creek), bark beetles infested both thinned and unthinned plots soon after thinning and plot establishment. This early commercial thinning left considerable unmerchantable material on the ground. Very high initial basal area (122 percent of normal) probably decreased individual tree vigor. These circumstances apparently favored the bark beetle attack in the thinned stand; and over a 24-year period, the live stand basal area increased only 6 percent. However, mortality from bark beetles was only 42 percent of that in the unthinned plots which actually experienced a 17-percent *decrease* in live stand volume over the same 24-year period. It is likely that repeated thinning with closer utilization would have substantially lowered losses on the thinned plots.

There was no indication that bark beetles were attacking a fourth study area with mortality from bark beetles (Salmon Creek) when the study was established in 1928. Sporadic mortality occurred through the years, but these insects appear to have heavily attacked the unthinned plot during the 1952 epidemic. Most of the snags in this plot (fig. 7) appear to have been dominant and codominant trees.

'igure 7.—Mortality from bark beetles on unthinned Salmon Creek plot 5.

and there is little evidence of past wind damage in the stand. The adjacent thinned stand, heavily thinned from below, suffered little mortality of any kind.

One of the St. Helens plots (3011) illustrates, as did the Indian Creek plots, that thinned plots are not invulnerable to bark beetle attacks. A moderate amount of mortality from bark beetles occurred in this plot in conjunction with a larger amount of windfall mortality. These results confirm reports that abundant windfall (Rudinsky 1966) can provide conditions under which even healthy vigorous trees can succumb to bark beetle attack.

The heavy snow damage to stands in the winter of 1966 and the record drought in the summer of 1967 preceded observations of extensive mortality from bark beetles on the southern end of the Gifford Pinchot National Forest in the spring of 1968. The Boundary Creek study lies in this vicinity, and a 1968 fall examination revealed little mortality or attack on these plots, though considerable mortality occurred on adjacent unthinned areas. Plot mortality was concentrated on one lightly thinned plot where several trees apparently were overwhelmed by mass attack from a large beetle focus just outside the plot.

It is interesting to speculate on the possible benefits that could result from reducing mortality due to bark beetles in vigorous, mature stands throughout the Douglas-fir type to the extent that thinning has reduced it on these study plots (fig. 6). This subject surely merits further coordinated evaluation by silviculturists and entomologists. Some logical reasons for this reduction are presented by Rudinsky (1966) and Vité (1961).

Recoverable Basal-Area Growth

Few of these study areas were rethinned; thus mortality exceeded what one would expect under planned thinning regimes. We assumed that recoverable yield would equal the observed net growth plus 80 percent of the observed mortality. Though arbitrary, this 20-percent reduction in mortality recovery is our best estimate of probable losses to decay and breakage under scheduled thinning regimes.

Recoverable growth averaged 83 percent of normal gross periodic basal-area growth (Staebler 1955) between ages 70 to 110 and increased to about 110 percent at age 150. This relationship does not appear to be affected by estimated site index.

In the absence of planned thinning regimes, salvage operations alone are likely to be sporadic, marginally economic, and, to a large degree, governed by chance. Therefore, no attempt was made to estimate the relative advantages of salvage operations alone.

Cubic Volume Growth Relationships

The foregoing discussion of response to thinnings was related to basal-area growth, but forest managers are more directly concerned with volume growth response. Cubic-foot volume computations indicate that estimated recoverable cubic-foot growth averaged about 77 percent of normal gross growth (Staebler 1955) between ages 70 to 110 and increased to about 118 percent at age 150. More data are needed before a reliable trend of gross growth percent with age can be determined.

Management Guides

The reader is urged to review the cutting recommendations on pages 49-61 of USDA Technical Bulletin 1230 (Worthington and Staebler 1961), with respect to frequency, intensity, and type and size of trees. Our study indicates that these recommendations generally apply equally well to vigorous, mature stands in the 70- to 150-year-age range. Modifications of certain of these recommendations are discussed below.

PRIORITY OF CUT TREES

Apparently, thinning must improve spacing in the upper crown classes in order to appreciably increase growth of larger trees. Emphasis should not be placed only on removing primarily suppressed and intermediate trees.

Initial thinning in older stands should remove codominant and dominant trees whose removal will relieve clumpy conditions and provide release to better codominants and dominants. Removal of high-risk, lower crown-class trees is equally important. These findings suggest a slight revision (fig. 8) of figure 30 in USDA Technical Bulletin 1230 (Worthington and Staebler 1961). We suggest that spacing is important in vigorous, mature stands as well as in younger ones.

INTENSITY AND FREQUENCY OF THINNING

Foresters have considerable flexibility in varying the kind and intensity of thinning in older stands to suit market conditions and owners' general objectives of cutting.

One apparently can vary levels of growing stock as was done on these study areas (where 60 to 93 percent of normal were retained) and be assured that residual stands will retain near-maximum utilization of their sites. Stand and treatment conditions varied widely on these plots; yet in the analysis of overall period growth, no variable reflecting intensity of thinning appeared to influence growth.

The above treatments should probably be considered in conjunction with maximum

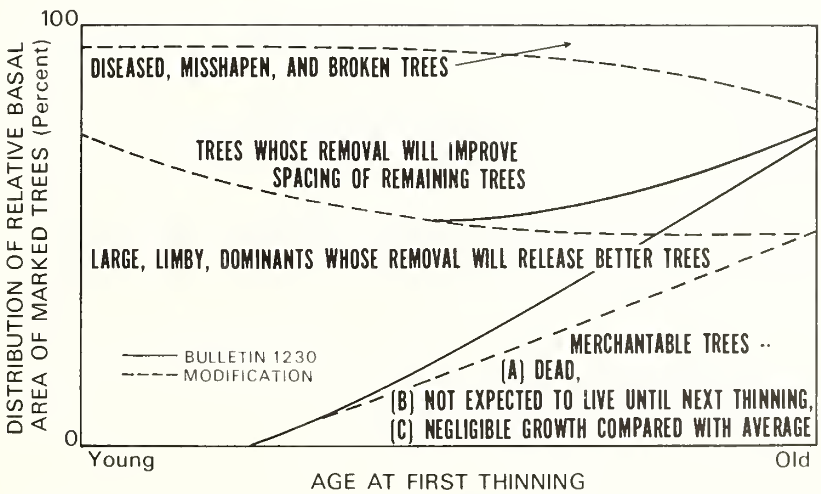

Figure 8.—Distribution of marked trees by relative basal area for initial thinnings of stands ranging from young to old. Modification of Figure 30, USDA Technical Bulletin 1230 (Worthington and Staebler 1961).

thinning intervals corresponding to about 10 feet of height growth. Although this is an untested standard in the Pacific Northwest, it is used in the British forest management tables (Bradley, Christie, and Johnston 1966) for young Douglas-fir and indicates, for instance, a reasonable interval of 15 years for a 100-year-old site index 140 stand. Shorter intervals with lighter cuts can be expected to improve the proportion of mortality that is converted to utilized growth and to provide leeway for such variables as local economic conditions and landowners' objectives.

These recommendations for vigorous, mature stands essentially agree with those of Harmon (1969). His recommendations apply to stands managed from an early age (even when precommercially thinned) so that potential crop trees would never be subjected to severe competition. His recommendation that intermediate cuts remove lower crown-class trees does not conflict with our recommendation to favor crown thinning to space upper crown-class trees, because of the difference in stand histories. Under the regimes he projects, it is likely there will exist no lower crown-class trees such as those found in previously unthinned, vigorous, mature stands. His regimes will remove less desirable codominants to give better trees room to grow; this is, essentially, what we are recommending.

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Intermediate harvests in the form of thinnings were analyzed on nine study areas in vigorous, mature stands ranging from 70 to 150 years old when thinned. Suggests that spacing is important in vigorous, mature stands as well as in younger ones.

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1. Providing safe and efficient technology for inventory, protection, and use of resources.
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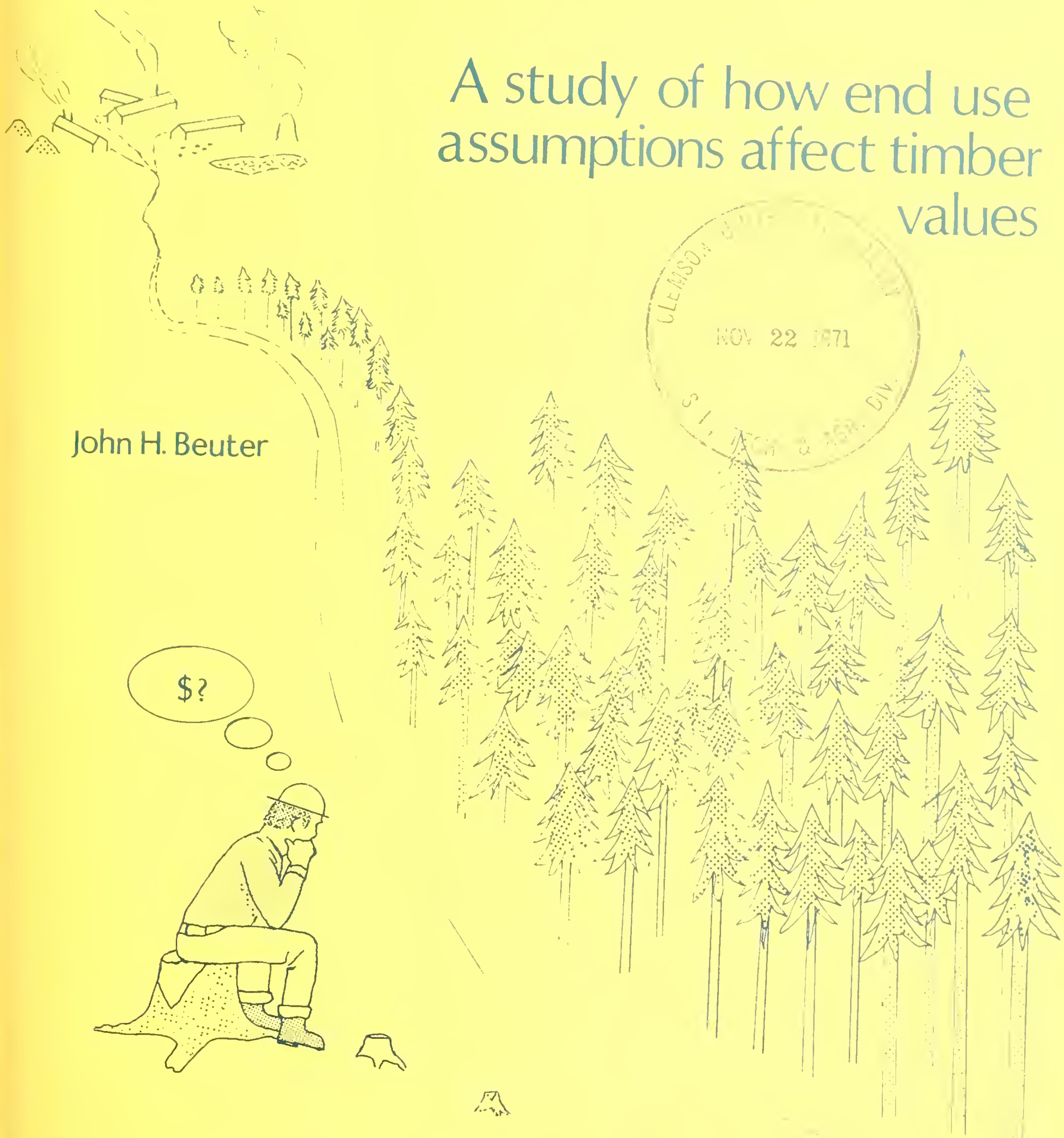
USDA FOREST SERVICE RESEARCH PAPER PNW-118 1971

TIMBER VALUE - a matter of choice

A study of how end use assumptions affect timber values

John H. Beuter



PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE
PORTLAND, OREGON

ABSTRACT

The relationship between estimated timber values and actual timber prices is discussed. Timber values are related to how, where, and when the timber is used. An analysis demonstrates the relative values of a typical Douglas-fir stand under assumptions about timber use.

John Beuter is now at Oregon State University, Corvallis.

Keywords: Forest appraisal, forestry business economics, timber value, stumpage price.

INTRODUCTION

There are many reasons why someone might want to know a value for a stand of timber. A seller wants to determine the minimum price below which he won't sell; a buyer wants to determine a maximum price above which he won't buy. The tax assessor wants to determine the stand's taxable value, and the banker wants to know its collateral value. The accountant uses the book value, and the economic analyst talks of the relative values for a set of alternative stand treatments. Different people, different objectives. Can it be expected that each will arrive at the same estimate of value for a given stand of timber? If they don't arrive at the same estimate of value, how do we know whose estimate is best? What is the relationship of price to their value estimates?

The purpose of this paper is to relate the concept of timber value to people and their objectives. The discussion is not about appraisal technique or methodology but rather about concepts underlying the determination of timber value. It is not directed solely at timber appraisers but at anyone who has had to think about timber value either as a buyer, as a seller, or as an analyst of alternatives which include the consideration of timber values.

The paper is divided into three parts. The first part deals with the concept of value and the relationship of value to price. The second part is a discussion of the underlying influences of timber values which are relevant to buyers and sellers of timber. The third part is a demonstration of the effects on timber value of differing assumptions of how, where, and when the timber will be used.

VALUE AND PRICE

Values Don't Exist Without People

The whole concept of value is meaningless without the existence of a decisionmaker. People estimate value to make decisions about exchange rates between commodities and the allocation of scarce resources. A value estimate reflects the specific objectives and knowledge of the estimator, i.e., the decisionmaker or his representative. A common misconception concerning value is that there is *a* correct and indisputable value for anything. In fact, there can be as many "correct" values as there are people to have them.

It is well known that value estimates can differ because different people use different data and data processing methods to develop them. Taking only this into account, it can be argued that one estimate of value is better than another because of better data or technique.

What is often overlooked, however, is that different people using the same basic data and technique can come up with different value estimates. These differences are due to differing objectives, assumptions, limitations, and judgment among the people estimating value. For example, assume my competitor and I both estimate the value of a timber stand by using identical data from identical sources and that our basic valuation technique is the same. I judge that 30 percent of the volume will be used for veneer and the rest for lumber, and my competitor judges that all of the timber will be used for lumber and none for veneer. Even though we used the same price and cost data, our value estimates differed because of the differing weights we assigned to the alternative products which could be produced from the timber, i.e., we arrived at different value estimates because our assumptions were different.

Some people have difficulty conceding that alternative values for a commodity exist. This difficulty is usually associated with the belief that the ultimate value for something is defined by its price.

How Is Value Related to Price?

The following distinction is made between value and price:

1. Value is an *estimate* of the amount (usually dollars) that will be paid by a buyer or accepted by the seller in exchange for a thing. The estimate is subject to the objectives, assumptions, limitations, and judgment of the person making it.

2. Price is the actual amount paid by the buyer and accepted by the seller in exchange for a thing at the instant in time that a transaction takes place.

For a particular transaction, there can be many values, but only one price. A transaction takes place when a buyer and the seller reach a compromise within a range of values. The range of values results from the buyer's inherent desire to minimize the price he pays for an item and the seller's inherent desire to maximize the price he receives for the item. Prior to the transaction, the seller usually determines a value that represents a minimum price below which he won't sell. Potential buyers determine values, which represent the maximum prices above which they won't buy. A transaction is possible at a price greater than or equal to the seller's value and less than or equal to some buyer's value (fig. 1). If the seller's value exceeds all buyers' values, there can be no transaction (fig. 2).

The actual process of how a price is reached differs with market situations and products. For some items such as chewing gum, an apparent market value, i.e., a "going price," is easily determined. For other items such as real estate or a timber sale, each sale involves a unique set of circumstances which makes it very difficult to predict the price which will finally result.

Much of the confusion about the concepts of value and price originates from confusion about the objectives of making value estimates. Consider the following definition[1] of market value:

> ...the highest price in terms of money which a property will bring if exposed for sale in the open market allowing a reasonable time to find a purchaser who buys with knowledge of all the uses to which it is adapted and for which it is capable of being used--said purchaser being under no compulsion to deal.

[1] American Institute of Real Estate Appraisers. Appraisal terminology and handbook Chicago, 268 p., 1967.

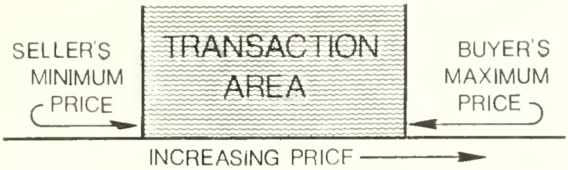


Figure 1.—Relationship of seller's and buyer's valuation when a transaction is possible.

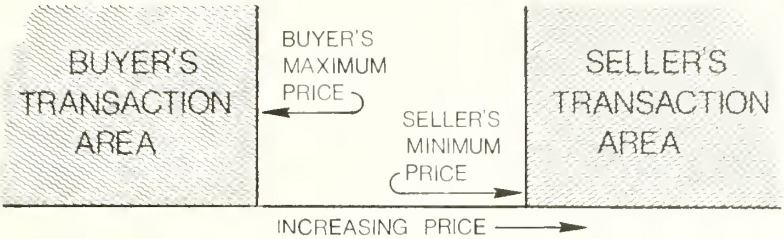


Figure 2.—Relationship of seller's and buyer's valuation when a transaction is impossible.

The definition implies that the objective of estimating market value is to predict price. However, the predicted price is subject to certain assumptions and limitations which are not likely to pertain to many actual transactions. It should not be surprising if the actual price turns out to be different from the estimated market value. The definition of market value covers only what the price *ought to be* under the restrictive set of market conditions which are specified. The actual price is the amount paid, regardless of whether the transaction took place while the seller or buyer held a gun at the head of the other!

Market value is just one example of a value estimate. The American Institute of Real Estate Appraisers lists 38 different kinds of value associated with real property.[2] Many of these are not related to a specific price. For example, taxable value may be linked to some average price over a number of similar transactions rather than a specific transaction price.

In summary, the relationship of price to value is not clearcut. Price represents a point within a range of values for a particular transaction. Other values for an item may or may not be related to a particular price depending on the objectives, assumptions, limitations, and judgment associated with them.

What Constitutes an Acceptable Value Estimate?

The ultimate criterion for the acceptability of a value estimate is how useful it is to the decisionmaker. The estimate gives the decisionmaker a market perspective--it affects his strategy. Successful value estimation requires knowing for whom and why the appraisal is being made. The successful appraiser knows what influences human behavior in the marketplace and recognizes significant changes in the influencing factors. He knows that what was true yesterday may not be true today, and he is constantly reacting to changing conditions. Above all he knows that he is not just coming up with a number, but that he is helping to evolve a strategy.[3]

[2] Arthur A. May. The valuation of residential real estate. New York, Prentice-Hall, Inc., 2d ed., 286 p., 1953.

[3] For a more detailed discussion of the role of appraisers, see Richard U. Ratcliff. A restatement of appraisal theory. Wis. Commer. Rep., Vol. III, No. 1. Madison, Univ. Wis., 50 p., 1963.

Regardless of how accurate value estimates are when measured against some standard, if they are not contributing to a successful strategy by the decisionmaker using them, then they are not acceptable value estimates.

FRAMEWORK FOR DETERMINING ALTERNATIVE TIMBER VALUES

At a point in time, a timber buyer can have a range of values for a stand of timber depending on the number of alternative uses that he recognizes for the timber. A timber seller also can have a range of values, but his alternative uses are likely to be restricted to retaining the timber as an investment in growing stock or exchanging the timber for something else of value to him--money, for example. The seller's value could be based on his costs of production; however, once the decision is made to sell the timber, these costs are irrelevant since his decision assumes at least one potential buyer exists whose value is greater than the cost of production. The seller's value at a point in time is derived from the value-generating uses of the potential timber purchasers.

Determining alternative values for a stand of timber at a point in time requires that all relevant uses for the timber be considered. Basic uses are usually obvious. For a versatile species like Douglas-fir, basic uses might include lumber, veneer and plywood, and pulp and paper manufacture, poles and piling, or log export.

Since a stand of timber is a bundle of logs and pieces of variable sizes and quality, it is likely that the disposition of the timber will involve several basic uses. It may therefore be relevant to consider combinations of basic uses in determining alternative timber values. This will usually involve the assumption of a decision rule for log use such as: each log will be channeled to the basic use that yields the highest net return.

As the number of basic uses increases, the number of possible timber values increases exponentially. Consider the case where three basic uses have been identified for a stand of timber that is to be sold. The buyers representing the three basic uses are identified as B_1, B_2, and B_3. Either B_1, B_2, or B_3 might buy and use all the timber in his own mill, accounting for three possible uses. If B_1 is the purchaser, he can resell all or a portion of the timber to B_2 or B_3 or to both of them. Thus B_1 has four options:[4]

1. Use all the timber himself.
2. Resell all or a portion of the timber to B_2.
3. Resell all or a portion of the timber to B_3.
4. Resell all or a portion of the timber to B_2 and B_3.

Since B_2 and B_3 also have four options each, there is a total of 12 possible combinations for timber use.

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[4]These options assume a fixed strategy for apportioning the timber among basic uses, e.g., each log will be used where it has highest net value. The main point for this discussion is that the option to resell timber is recognized, whether the amount resold is 5 percent or 95 percent of the volume in the timber sale.

The number of possible values associated with use combinations can be generalized for any number of basic uses.[5] The relationship between basic uses and possible values for up to five basic uses is as follows:

Number of basic uses	Possible number of stand values
0	0
1	1
2	4
3	12
4	32
5	80

The possible number of stand values would increase if additional complications were added to the model. For example, higher order reselling could be considered as when B_1 sells to B_2 who in turn sells to B_3. One incident has been reported where a log that was resold from a millyard deck eventually turned up in the same millyard after a series of resales!

So far the discussion has been limited to a cross section of values at a point in time. That is, at some given time the basic uses for a stand of timber are identified and located, and corresponding values are calculated based on the costs and returns of the possible use combinations. What happens if the restriction "at a given time" is relaxed?

Time or timing enters into timber valuation in several ways. The primary consideration is when the timber will be used. Since the value generated in use varies over time due to changes in economic conditions, it follows that timber values will also change over time.

The time at which a value estimate is made does not usually coincide with the time the timber is used; therefore, value estimation might also involve the projection of value-influencing factors to the anticipated time of use. These factors include wood product prices, technology, standards, or perhaps even human behavior.

It is beyond the scope of this paper to discuss changes in specific variables over time and their effects on timber values. It should be stressed, however, that each decisionmaker can use time-related factors differently to make value estimates, thereby adding to the possible number of values for a timber stand.

In general, there are three basic considerations in determining timber value: *How*, *where*, and *when* will the timber be used? If standards (quantity and quality measures) and decisionmaker judgment are held constant, differences in timber value estimates are due to differing assumptions with regard to one or more of these basic considerations.

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[5] The number of possible values for n basic uses is

$$n2^{n-1}$$

APPLICATION TO A REAL SITUATION

A simplified Douglas-fir marketing situation can be used to illustrate how a decision-maker's objectives and his assumptions affect timber value estimates.[6] In this study, a typical stand of Douglas-fir timber is to be sold as stumpage and there are two possible uses for the timber: lumber and veneer. The assumptions for timber use are as follows:

1. All the timber is used for lumber.
2. All the timber is used for veneer.
3. Some of the timber is used for lumber and some is used for veneer with each log being used where it has the highest value at a point in time.
4. Some of the timber is used for lumber and some is used for veneer with "peeler" grade logs being peeled for veneer and "sawmill" grade logs being sawed for lumber.

The framework underlying the study is that described in the preceding section. Timber values are influenced by assumptions of how, where, and when the timber will be used. Standards and judgment are held constant.

It was initially assumed for the study that location was not a factor in defining a basic use, i.e., transportation costs were assumed to be zero.

How Will the Timber Be Used?

The stumpage values for the stand were calculated monthly for the period 1960 through 1964 for each of the four use assumptions. Using the assumption of "peelers peeled-saw logs sawed" as a base, the values associated with the other three assumptions were found to vary markedly from the base (fig. 3).[7]

For example, if the assumption of "peeler peeled-saw logs sawed" yielded an estimated stand value of $50 per thousand board feet, some estimated values for the other assumptions would be as follows:

	January 1961	March 1962	November 1964
Peelers peeled-saw logs sawed	$50.00	$50.00	$50.00
Lumber only	57.80	54.35	66.70
Veneer only	41.65	44.40	35.45
Logs allocated to highest value	58.35	55.45	66.75

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[6] John H. Beuter. Stumpage appraisal under alternative assumptions of log use: a case study in the Douglas-fir subregion. Unpublished Ph.D. thesis on file at Iowa State Univ., Ames, 150 p., 1966.

[7] The actual values for each assumption will vary depending on logging and manufacturing costs and lumber and veneer recoveries. This study used regional average cost experience appropriate at the time shown as provided by the U.S. Bureau of Land Management and U.S. Forest Service. Lumber and veneer recoveries were averages of three Douglas-fir recovery studies done by the timber quality research unit of the Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. The recovery data were preliminary, and the results of its use as shown here should not be considered representative of any particular mill or group of mills.

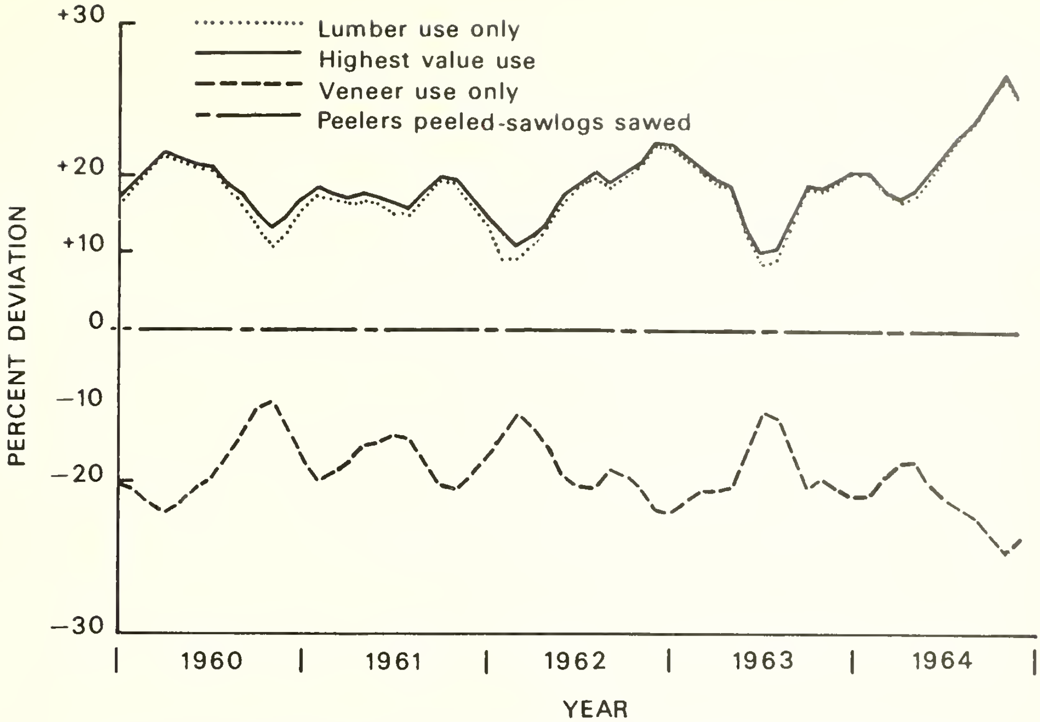

Figure 3.—Percent deviation of sale values made under the assumption of "highest value use," "all lumber use," and "all veneer use" from sale value made under the assumption of "peelers peeled-saw logs sawed," 1960-64.

The indicated differences in stand values associated with the use assumption could serve as a partial explanation for two timber-value oriented problems:

Case 1. The buyer who can't understand how his competitor can consistently bid more than he.

Case 2. The seller who can't understand why bids often exceed appraisals by a substantial amount.[8]

Within the context of figure 3, if the buyer in case 1 has a veneer mill and doesn't consider any alternative use for logs in the timber sale, he can be consistently outbid by other buyers who have a lumber mill or an integrated (lumber and veneer) operation.

If the seller in case 2 always assumes that "peeler" logs will be peeled and "saw logs" will be sawed, then a buyer who uses each log where it has highest value would have been able to consistently exceed the seller's estimated value for the stand.

This simplified situation masks the complexity of choosing among possible values, but it serves to illustrate the variability associated with the decisionmaker's assumption of timber use.

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[8] For a discussion of bid-appraisal relationships on public timber sales, see Walter J. Mead and Thomas E. Hamilton. Competition for Federal timber in the Pacific Northwest—an analysis of Forest Service and Bureau of Land Management timber sales. USDA Forest Serv. Res. Pap. PNW-64. Portland, Oreg., Pac. Northwest Forest & Range Exp. Sta., 63 p., 1968.

Where Will the Timber Be Used?

The effects of location can be illustrated using the data generated in this study. Under the assumption that each log will be used where it has highest value at a point in time, there is an allocation of the stand volume between possible uses (fig. 4). Since the values were calculated without considering transportation costs, the difference between the value of a log used for lumber compared with veneer has to more than cover the extra cost of handling and transporting the log for resale or allocation within an integrated operation.

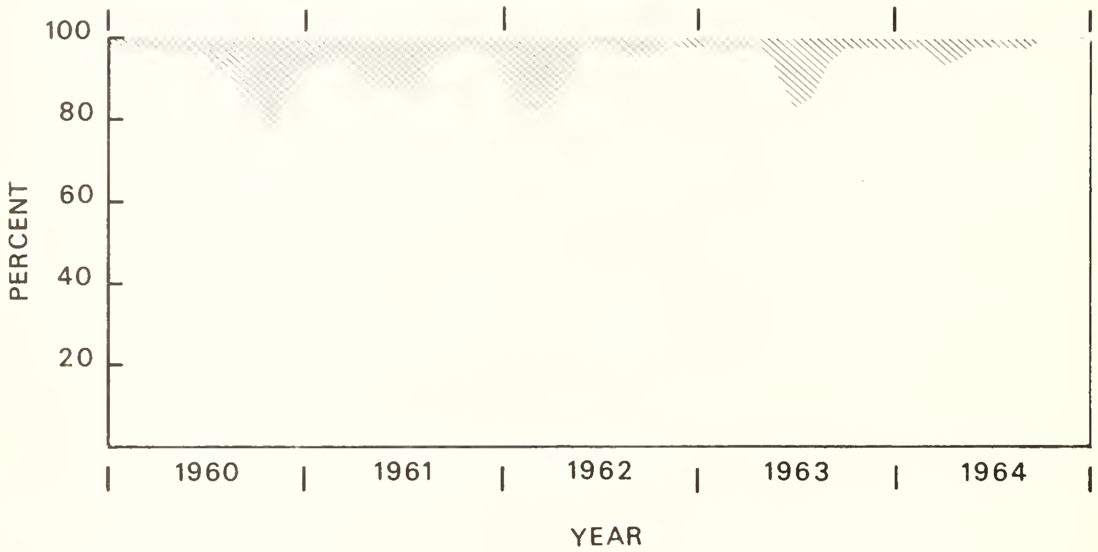

Figure 4.—Allocation of stand volume assuming each log is used where it has highest value, 1960-64. (Shaded area is allocation to veneer; unshaded area is allocation to lumber.)

For example, figure 4 shows that the bulk of the sale volume would have higher value if used for lumber. If a veneer mill operator bought the timber and wished to resell all logs that had higher net value when used for lumber, he would have to consider the margin available for the handling and transportation costs associated with resale. This margin averaged $18.42 per thousand board feet during the period 1960-64, ranging from a low of $13.12 to a high of $26.49 (fig. 5). Thus, the decision of where the timber should be used will vary depending on the relationship of the value differences between uses and the cost of reselling logs.

The average value differences depicted in figure 5 resulted from combining a variety of log sizes and grades. The fact that some logs can have value differences far in excess of the average is obscured. Operators who are prepared to analyze value differences for specific log grades and sizes could influence the value of a timber sale to

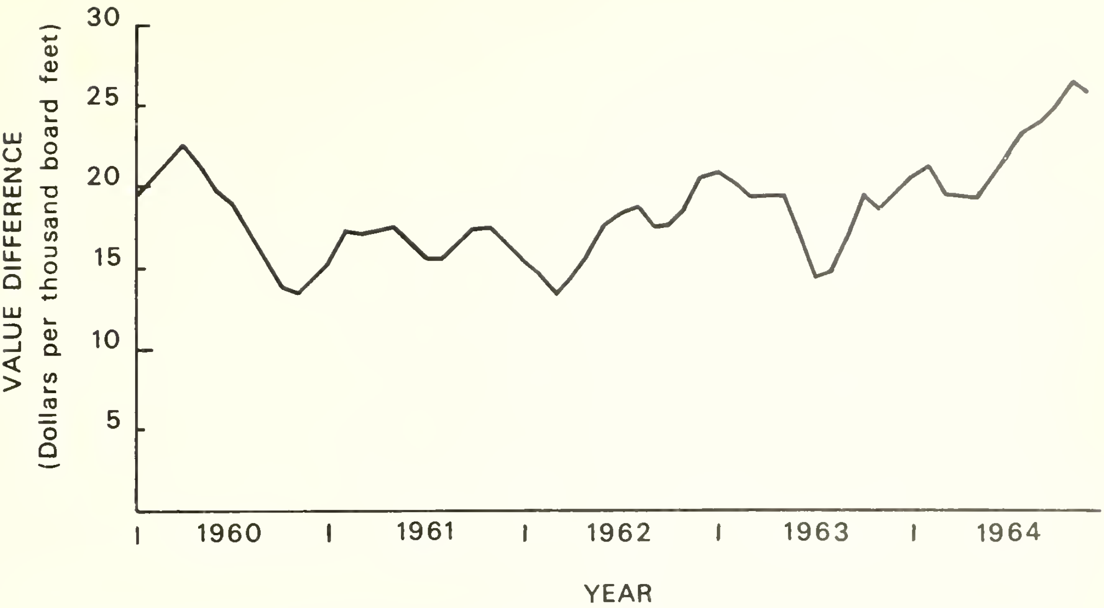

Figure 5.—Average value differences per thousand board feet for log volume having highest value used for lumber compared with use for veneer, 1960-64.

themselves by reallocating or reselling logs up to the point that the value difference of the next log or load of logs is less than the costs of extra handling and transportation.

<u>When Will the Timber Be Used</u>?

The changes in the relative values associated with the timber use assumptions over time are obvious (figs. 3-5). Relative changes in lumber and plywood prices result in some logs shifting from having highest value when used for lumber to highest value when used for veneer, or vice versa. For example, plywood prices were generally lower during 1960-64 than they were during 1957-59, and lumber prices remained fairly steady. This decrease in plywood prices relative to lumber prices resulted in timber stand values associated with veneer and plywood use moving relatively lower than the stand values associated with lumber use. The average percent of the stand volume allocated to veneer use under the assumption of each log being used where it has highest value would have been 18 percent during 1957-59 compared with 6 percent during 1960-64. The decisionmaker who is considering alternative uses in determining timber values should review his strategy periodically as significant changes in relative prices among alternative uses are noted.

The method by which the decisionmaker accounts for changes over time is important to his choice of timber values. The value estimates made by a decisionmaker during a year could vary significantly depending on how he accounted for changes over time. For example, there were significant changes in values during 1963 for each timber use (fig. 6).

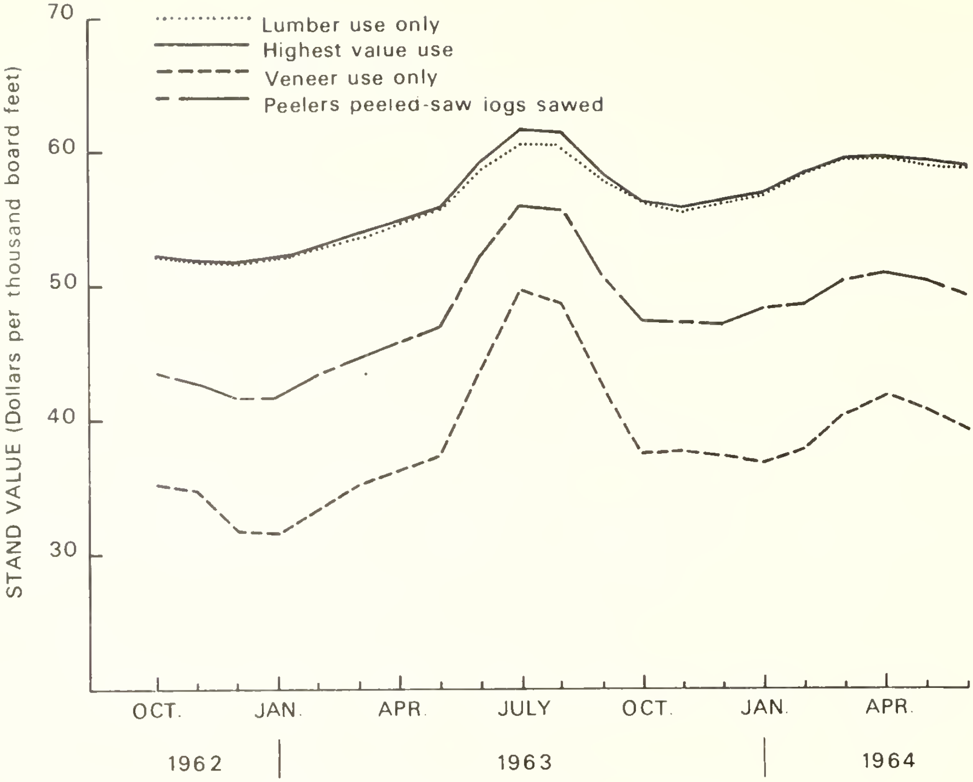

Figure 6.—Stand values by use assumption, 1963.

Assume that it is the end of 1962 and all decisionmakers are given a vision of 1963 which they all firmly believe (fig. 6). Each decisionmaker has certain constraints under which he operates regardless of his knowledge. Assume that the seller is constrained by the following requirements:

1. He must sell the timber during 1963.
2. He must appraise the timber as if "peeler" logs will be peeled and "saw logs" will be sawed.
3. He must base his appraised value on the previous 3-month's average value for the assumed timber use of the buyer.
4. The price he will accept must be greater than or equal to the value he has determined.
5. The timber will be sold on the first day of the month selected.

A buyer exists who has the following constraints:

1. He will use all the timber for lumber.
2. He has limited capacity to log and process the timber such that his expected returns are distributed as follows:
   a. In the first month of operating the timber sale, he can get returns from lumber sales equivalent to processing up to one-eighth of the timber sale volume.

b. In each succeeding month, he can get returns associated with up to one-half of the timber sale volume until the timber volume is exhausted.
3. He has no storage capacity for logs and lumber and no other source of timber such that once he begins logging, the cut volume must be processed and sold at the same rate as the logging is done--with exception that up to one-eighth of the cut timber can be "stored in transit" for up to 1 month.
4. All the timber must be cut within 6 months of the date of purchase so that lumber values up to 6 months from the date of purchase are the only ones pertinent to the timber value determination.
5. He will time his use of the timber to yield the highest value subject to the date the timber is sold.

The stumpage values calculated by the seller and the buyer show that a transaction was possible every month during 1963 (fig. 7).[9] If the seller, with his knowledge of the year's timber values subject to his constraints, wished to sell the timber in the month having the highest appraised value, he would choose September. It so happens that September is the month for which the buyer has calculated his lowest value; however, his value is still above the seller's so he could buy the timber. The buyer would have preferred that the timber be sold sometime between March 1 and June 1.

The point that has been illustrated is that the stumpage values calculated by sellers and buyers can be inherently different due to differing assumptions of timber use and differing methods of accounting for value changes over time. These differences have

[9] The seller and buyer both include allowances for profit and risk, and all cost data are compatible. As a result of this, seller and buyer values for a given month are comparable in every regard except use assumption and the accounting for time.

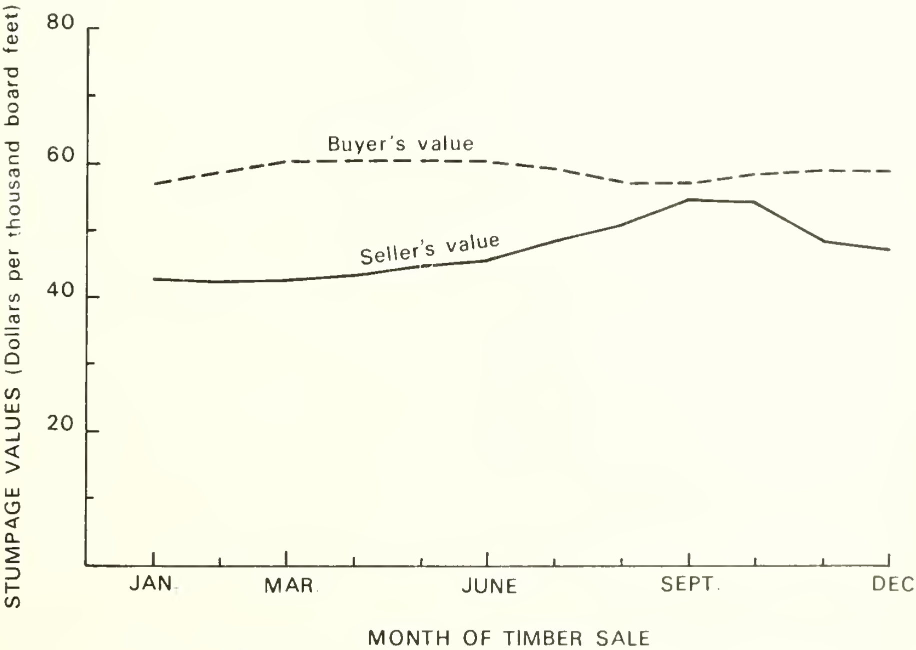

Figure 7.–Monthly stumpage values calculated by the seller and the buyer for the study timber sale, 1963.

important implications for explaining a portion of the disparity in appraisals and bids on public timber sales. To illustrate this, the example can be continued.

If the buyer were forced by competition to bid his full calculated value, the bid-appraisal ratio during 1963 could have ranged from 1.06 in September to 1.43 in March (fig. 8). Remember that this discrepancy between the appraisal and bid is due to different assumptions of how the timber was used and time accounted for. If the effect of differences in accounting for time is removed by assuming that the buyer also calculates his stumpage value by averaging the timber use values for the previous 3 months, the bid-appraisal ratio could then have ranged from 1.10 in September and October to 1.23 in February and March (fig. 8). This discrepancy between the seller's appraisal and the buyer's bid is due only to their differing assumptions of timber use.

This illustration may appear unreal because of the assumption that the seller and buyer know in advance what timber values will be during the year. It is true that the assumption of perfect knowledge is unreal, but the value calculations of the seller and buyer are not far from reality. Many appraisers representing sellers are constrained in the assumptions and knowledge they can use in making appraisals, e.g., the public agencies. On the other hand, buyers account for the future in setting timber values. Even though they don't have perfect knowledge of future values, they anticipate changes in value from the time they bid on the sale to the time they will realize a return from their investment in the timber.

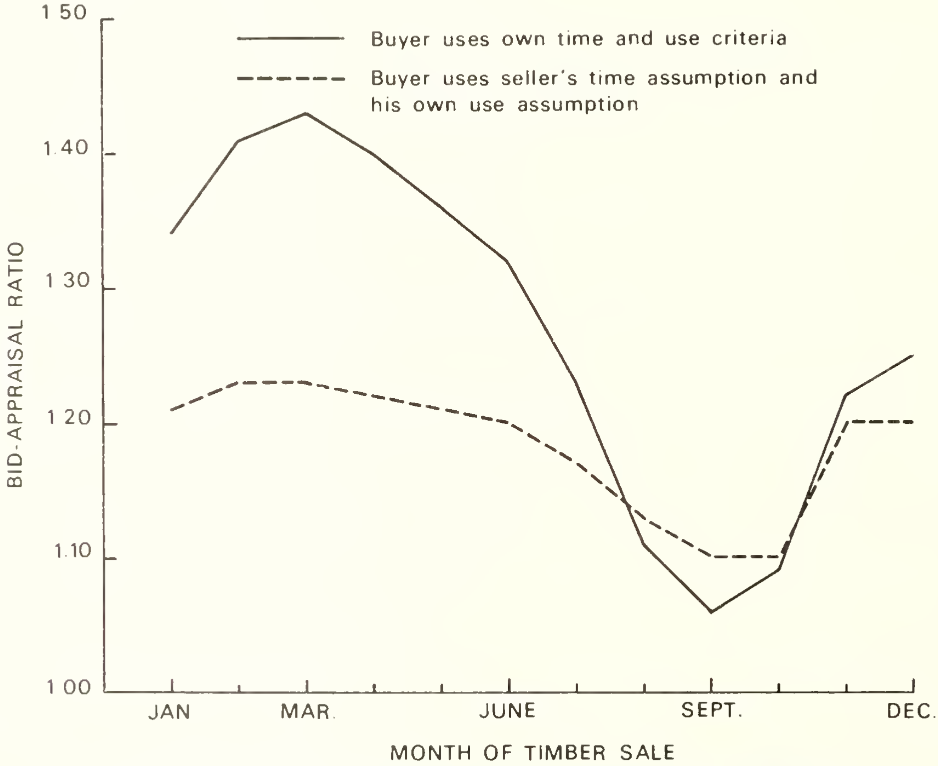

Figure 8.—Maximum bid-appraisal ratios under two criteria for calculating the buyer's stumpage value, 1963.

Beuter, John H.
1971. Timber value--a matter of choice. USDA Forest Serv. Res. Pap. PNW-118, 13 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

The relationship between estimated timber values and actual timber prices is discussed. Timber values are related to how, where, and when the timber is used. An analysis demonstrates the relative values of a typical Douglas-fir stand under assumptions about timber use.

Keywords: Forest appraisal, forestry business economics.

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CONCLUSION

Estimation of timber values is an important part of forest management. Timber value estimates are important to the decisionmaking process, from selection of timber growing as the land management alternative through the marketing of the final harvest cut. They are needed for such diverse reasons as determining trade-offs with competing land uses and the establishment of a value base for tax assessments.

Procedures for determining timber values vary widely, although most appraisals are linked to the concept of "market value" which broadly translates to "value-in-use." Problems arise when people with diverse objectives, assumptions, limitations, and judgment come up with diverse estimates of market value. Which value is correct?

The tendency is to relate the accuracy of value estimates to the price actually observed in a transaction. This is the situation when people get concerned about the bid-appraisal ratios on public timber sales. Do high bid-appraisal ratios indicate inaccurate appraisals? To answer that question one must consider the objectives and assumptions of the appraisal system. There are many possible values for a stand of timber. One of them will equal or be closest to the price provided a transaction takes place. However, all of them may have been accurate and rational estimates of the timber's value, differing only in the assumptions of how, where, and when the timber would be used. The only real basis for dissatisfaction with a particular value estimate is if it is a misinterpretation of the objectives of the decisionmaker for whom it was prepared and as a result leads him to a bad strategy.

This paper was not intended to suggest particular variables or assumptions that should be included in a timber valuation procedure. It was intended to point out the diversity of value estimates that are possible under alternative objectives, assumptions, and other factors related to particular decisionmakers. Hopefully, it will contribute to a better understanding of why rational decisionmakers can have diverse opinions of value and why rational value estimates can differ from price. This understanding should, in turn, underscore the need for clear objectives in designing timber valuation systems.

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

1971
USDA Forest Service Research Paper PNW - 119

Water Temperature in the Steamboat Drainage

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
PORTLAND, OREGON

ACKNOWLEDGMENTS

This report results from the cooperative efforts of personnel from land management agencies and others interested in the aquatic environment of Steamboat Creek. Frank Moore, ardent steelhead fisherman and owner of Steamboat Inn, was instrumental in stimulating interest in the potential water temperature problem; Thomas Glazebrook, then Assistant Regional Forester (R-6) in charge of Watershed Management, suggested an intensive study; the following individuals participated in planning and execution of a team effort to gather and analyze the necessary data:

Oregon State Game Commission--
Jerry Bauer
Richard Lantz
Dan Carlson

Oregon State University--George Brown

U. S. Department of the Interior, Bureau of Land Management--
Frank Oliver
Jesse McCabe
Robert Smith

U. S. Department of Agriculture, Forest Service, Umpqua National Forest--
Dallas Hughes
Richard Marlega
Cleon Puetz
Larry Thorpe
Ray Zalunardo

Pacific Northwest Regional Office--Gerald Swank

Pacific Northwest Forest and Range Experiment Station--
Jack Rothacher

Douglas County Water Resources Survey--Berl Oar

Basic field data are on file with the Douglas County Water Resources Survey, at the courthouse in Roseburg, Oregon.

Keywords: Temperature, watershed management, logging.

USDA FOREST SERVICE
Research Paper PNW-119

WATER TEMPERATURE IN THE STEAMBOAT DRAINAGE

Compiled by

george w. brown

gerald w. swank

and

jack rothacher

August 1971

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
Robert E. Buckman, Director Portland, Oregon

Forest Service U.S. Department of Agriculture

FORESTS AND WATER TEMPERATURE

High quality water from our forest lands is subject to a rapidly increasing demand. Water from forested watersheds is suitable for many uses. One of the characteristics that determines water's usability, particularly for fish, is temperature.

The forests in the watershed of the Umpqua River are an important resource of the area. Steamboat Creek, one tributary of the North Fork of the Umpqua, is also an especially important spawning area for anadromous fish, particularly summer steelhead. In recent years, attention has been drawn to the potential impact of timber harvest on water temperature. Concern that increased water temperature in Steamboat Creek and its tributaries might influence the steelhead habitat prompted this cooperative[1/] study.

Fish may be directly affected by water temperature. Like all organisms, fish have a range of temperatures in which their growth and development is optimum. Fish also have limits to their tolerance of temperature and may die if these limits are exceeded. The absolute value for the optimum temperature and the lethal limit depends on the species. The important point is that temperature is a key determinant of how a given fish species will survive in a stream.

1/ Cooperators in this study are listed on the inside of the cover.

Temperature may affect a fish indirectly by affecting other things in its environment. The amount of oxygen dissolved in water is inversely proportional to water temperature. Populations of most of the fish pathogens strongly increase as temperature becomes warmer. Finally, temperature can affect the distribution of fish species. As temperatures increase, "warm water" species proliferate at the expense of "cold water" species.

Water temperature may also affect taste, odor, and color of streamwater. Under some conditions increased temperatures stimulate excessive production of algae, damaging the quality of water for human consumption, depleting the oxygen supply for aquatic organisms, and lowering the esthetic quality of streams.

The temperature of small forested streams can be greatly affected by man's logging activity in the surrounding forests. Man affects stream temperature by changing the amount of shade that protects the stream from the sun. Brown (1969) showed that removing the shade above a small forest stream increased the solar heat load by about six times. Shade removal, and not increased air temperature or soil temperature, was responsible for large temperature changes observed during that study.

The magnitude of the temperature change observed after logging along small streams has varied with the degree of stream exposure and the size of the stream. In North Carolina, Green (1950) compared stream temperatures of farmed and forested watersheds and found differences as high as 13° F. In the Pacific Northwest, Chapman (1962) checked comparable logged and unlogged drainages in Oregon's Alsea River Basin and found temperatures to be as much as 10° F. greater in logged areas where riparian vegetation was completely removed.

For a 250-acre patch-cut watershed on the H. J. Andrews Experimental Forest in the Oregon Cascades, Levno and Rothacher (1967) found no statistical evidence of a change in maximum water temperature at the mouth of the main drainage, following logging and burning of 25 percent of the area. However, two of the three clearcut units were high up on the slope with only limited stretches of perennial streamflow. The third included a 1,300-foot stretch of the main channel which was still partially shaded by shrubs and alders. No measurement of changes in stream temperature within the clearcut unit was made at this time. Two years later, the 1964 floods scoured the main stream channel to bedrock and removed all streamside vegetation. The following summer Brown and Krygier (1967) found increases of as much as 16° F. from the time the water entered the clearcut at the upper edge of the unit until it left the area at the lower end, a distance of 1,300 feet exposed to direct solar radiation.

On another 237-acre watershed in the same area, no measurable increase was found at the gaging station at the lower end of the drainage as logging progressed along the upper slopes. After 100 percent of the drainage had been clearcut, but with slash and understory vegetation providing partial stream shade, maximum water temperatures showed an increase of approximately 4° F. After the entire drainage was burned in the fall of 1966 and approximately 2,000 feet of the stream channel was cleared of debris, maximum recorded temperature exceeded that of the adjacent unlogged watershed by 12° F.

Brown and Krygier (1970) reported an increase of 14° F. in monthly mean maximum temperatures after complete exposure of a small stream in Oregon's Coast Ranges. Annual maxima rose 28° F. on this small stream where discharge drops to 0.01 c.f.s. (cubic feet per second) in late summer. Temperatures declined as vegetation returned.

OBJECTIVES OF THIS STUDY

The principal objective of this study was to provide forest managers in the Steamboat Creek watershed with data that would help them make decisions about logging and its impact on water temperature. Because logging operations in Steamboat Creek are typical of much of the area on the west slopes of the Cascade Range, the results should be representative of temperature changes elsewhere although ranges may differ due to latitude and elevation differences. A second objective was measurement of the effectiveness of varying densities and types of streamside vegetation for temperature control. Another was to provide a field check of temperature prediction models.

The study has been deliberately limited to measurement of temperatures as they exist today in the Steamboat drainage. The Bureau of Land Management and the Oregon State Game Commission are cooperating in other long-term studies in the area including (1) the effects of restoration measures on stream temperatures in Pass Creek, (2) postlogging stream temperatures in Francis Creek, and (3) the effects on the Francis Creek fishery.

THE STUDY AREA

Steamboat Creek, located on the west slopes of the Oregon Cascades drains 227 square miles and flows into the North Umpqua River 39 miles northeast of Roseburg (fig. 1). Steamboat

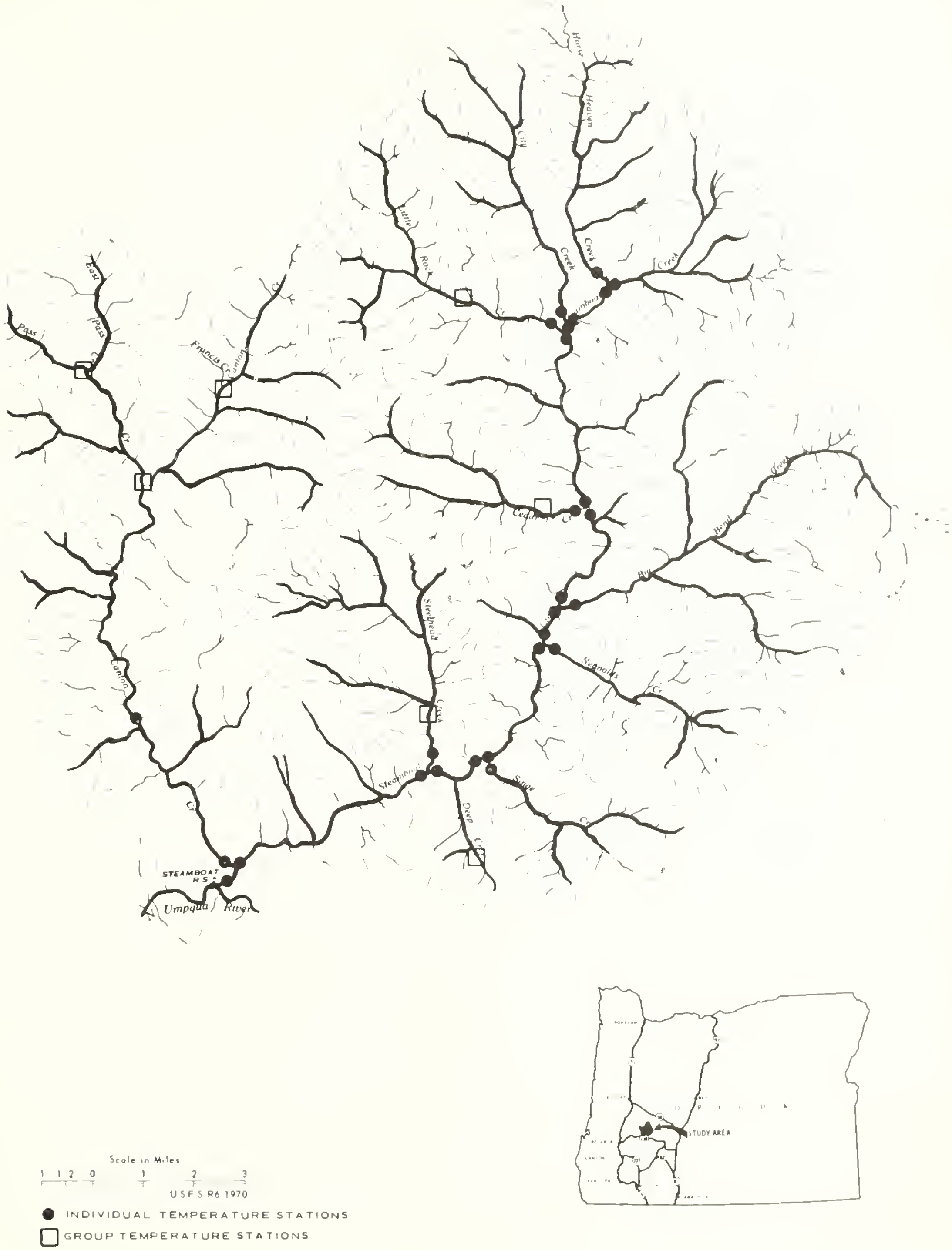

Figure 1.--Water temperature study area, Steamboat Creek drainage.

Creek and its tributaries are important spawning areas for anadromous fish, particularly summer steelhead; consequently, the entire drainage has been closed to fishing since 1932.

The Forest Service and Bureau of Land Management manage 81 percent and 12 percent, respectively, of the land in the Steamboat Creek drainage for a total of 93 percent under Federal jurisdiction. The remaining 7 percent is in private ownership, primarily in the Canton Creek drainage.

Most of the drainage has a cover of old-growth Douglas-fir. Road and logging development began in the drainage in 1955 and has expanded rapidly. Approximately 20,200 acres have been logged with a road system which extends up Canton and Steamboat Creeks and into the watersheds of most of the major tributaries. An estimated 35-50 miles of the 325 miles of live stream have been partially exposed during this period. Some sections of exposed stream are already shaded by regrowth of vegetation.

Summers are generally hot and dry. The bulk of the precipitation occurs from November through April. Precipitation at the Steamboat Ranger Station averages about 55 inches per year.

Topography is generally rough and mountainous with elevations ranging from 1,100 feet to 5,933 feet.

Flashy runoff and low base flow are characteristic of Steamboat Creek. Maximum recorded discharge is 51,000 c.f.s.; minimum recorded flow, 31 c.f.s. Peak flows generally occur between November and March; low flows generally occur in September and October.

The summer of 1969 was about average. Although there were many hot days, no air temperatures over 100° F. were recorded. Unusually heavy rains occurred in the last week of June. The rest of the summer was dry and warm until mid-September.

An unusually large snowpack in the previous winter contributed to high streamflow early in the summer. Streamflows were above normal in July but near normal later in the summer. A comparison with the four previous summers showed the following:

	Monthly minimum flow (c.f.s.)		
Year	*July*	*August*	*September*
1965	52	46	37
1966	46	34	34
1967	56	39	36
1968	47	42	50
1969 (study period)	78	50	43

STUDY RESULTS

Influence of Tributaries on Temperature of Steamboat Creek

The main stem of Steamboat Creek is important as a rearing area for small steelhead and a holding area for adults during the summer months. The objectives of this portion of the study were to determine what effect each tributary has on the temperature of Steamboat Creek and what temperature variations occur throughout its length.

Seventeen thermographs were installed in the main stem of Steamboat Creek above and below all major tributaries. These were continuous recording-type thermographs of various makes. Nine maximum-minimum thermographs were installed in each of the major tributaries just above their confluence with Steamboat Creek. All thermographs measured temperature to the nearest degree, and periodic checks were made for uniformity of accuracy. Streamflow measurements were made in these tributaries and in the main stem.

Maximum water temperatures occurred on July 27, 1969, and varied on the main stem of Steamboat Creek from 70° F. to 78° F. while major tributaries varied from 64° F. to 77° F. (fig. 2). Had July streamflow not been above normal, higher temperatures would be expected since maximums of 81° F. to 85° F. were measured in 1968. Even in the late 1950's prior to extensive development of roads and logging, stream temperatures of 75° F. were recorded in the main stem of Steamboat Creek and some tributaries.

Monthly averages of maximum temperatures for the 17 stations on Steamboat Creek ranged from 64° F. to 72° F. Monthly averages of the minimums ranged from 55° F. to 64° F. Monthly averages of diurnal fluctuations ranged from 6° to 12° F. Minimum temperatures occurred between 7 a.m. and 9 a.m. and maximum temperatures, between 2:30 p.m. and 4:30 p.m. Pacific standard time.

Most of the large temperature increases in Steamboat Creek occur within the main stream and not because of warm tributaries. The largest increase, between Little Rock and Cedar Creeks, is 5° F. Steamboat Creek flows south in this section and is exposed to the sun during midday. The stream is too wide to be shaded by streamside vegetation. A similar situation exists further downstream between Reynolds Creek and Singe Creek.

Big Bend Creek's cool water significantly reduced the temperature in Steamboat Creek. Main stem temperature dropped from 75° F. to 70° F. when Big Bend Creek's 64° F. water entered.

Canton Creek, the second largest tributary, did not influence the temperature of Steamboat Creek. Most of the large temperature increases in Canton Creek also occur in the main stream.

How can we judge or predict what the impact of tributaries will be on a stream like Steamboat Creek? The easiest way is with a mixing ratio which weights the contribution of each tributary by its discharge. Such a ratio can be written

$$\text{Adjusted temperature} = \frac{Dm\ Tm + Dt\ Tt}{Dm + Dt}. \qquad (1)$$

The adjusted temperature is the temperature of the main stem after the tributary enters; Dm and Dt are the discharges of the main stem and tributary; and Tm and Tt are the temperatures of the main stem

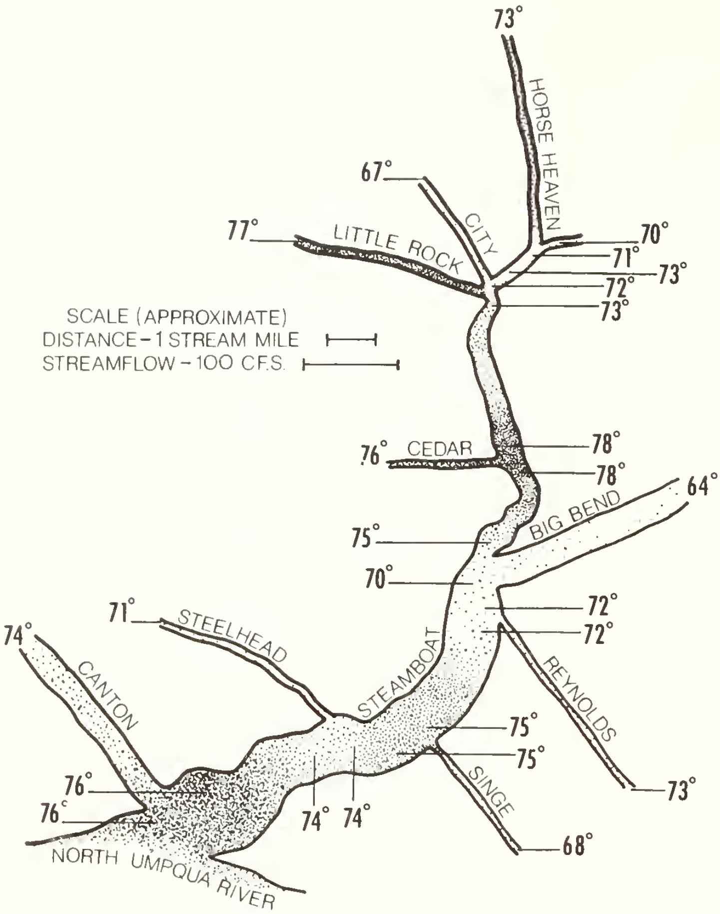

Figure 2.--Maximum water temperatures (degrees F.) on Steamboat Creek and tributaries, July 27, 1969.

and tributary. This enables prediction of the temperature a tributary must reach before the main stem temperature increases or decreases to a given value. An example is given in table 1 for Steamboat Creek tributaries.

Equation 1 tells us that since the impact of a tributary is proportional to its discharge, small tributaries must have much higher temperatures before they influence a larger main stream. This is borne out in table 1. The tributaries furthest upstream have the highest potential effects, since these tributaries contributed a larger percentage to the flow of Steamboat Creek at the point of confluence. For example, the flow rate of Singe Creek and City Creek on July 27 were nearly identical (2.5 c.f.s. and 2.3 c.f.s., respectively). If the temperature of City Creek were 6° F. greater than Steamboat Creek, we would expect a 1° F. increase in Steamboat Creek. Singe Creek, located further downstream where Steamboat Creek is much larger, must be 23° F. warmer in order to increase the main stem's temperature 1° F.

The accuracy of equation 1 can be checked using the measured temperatures shown in figure 2 and the measured discharges in table 1. Combining upstream discharge and temperature with tributary discharge and temperature produces approximately the measured downstream temperature below each tributary.

Table 1.--*Effectiveness of Steamboat Creek tributaries in changing the temperature of Steamboat Creek*

Tributary	Tributary discharge, July 27	Steamboat Creek discharge, July 27[1/]	Percent of Steamboat Creek discharge[1/]	Temperature increase necessary to change Steamboat Creek 1° F.
	----------*C.f.s.*----------			*Degrees F.*
Horse Heaven Creek	7.3	5.0	146	1.7
City Creek	2.3	12.3	19	6.3
Little Rock Creek	3.0	14.6	21	5.9
Cedar Creek	2.2	17.6	12	9.0
Big Bend Creek	31.6	19.8	160	1.6
Reynolds Creek	3.7	51.4	7	14.9
Singe Creek	2.5	55.1	5	23.0
Steelhead Creek	5.0	57.6	9	12.5
Canton Creek	25.1	62.6	40	3.5

[1/] Above confluence of Steamboat Creek and tributary.

Management implications.--This technique of predicting the downstream impact of a tributary has many management implications. Which streams have the greatest potential impact on temperature both positively and negatively? Where should temperature control operations be concentrated? What are the expected cumulative effects of changes in many tributaries? These are but a few of the questions which can be answered quickly using this technique.

Impact of Logging on Temperatures in Tributaries of Steamboat Creek

Assessing the downstream impact of a tributary is important. Equally important, however, is assessing whether water temperature changes will occur within the tributary as a result of logging. The small tributary often forms the backbone of an anadromous fishery. In Oregon, these small streams provide the majority of the spawning and rearing sites for the fry. Thus, onsite impacts are just as important as downstream impacts. The objective of this portion of the study was to catalog the impact of various degrees of shade removal on stream temperature. Study sites included situations with no streamside cutting, complete exposure of the stream by clearcutting, clearcutting with provision of an uncut area immediately downstream as with an alternate block system of harvest, and stream protection using a thin buffer strip (table 2).

No cutting.--This situation represents a "control" condition which provides a rough benchmark for judging the normal temperature patterns in small streams in the Steamboat Creek watershed. On three of the tributaries studied, water temperatures at the upstream end of the section represent *undisturbed* forest conditions. In the three streams, the

Table 2.--*Forest cover and maximum water temperatures in tributary streams, Umpqua National Forest*

Stream (tributary to)	Volume flow	Flow direction	Period of record	Forest cover	Distance	Maximum temperatures: Upstream	Maximum temperatures: Downstream	Maximum temperatures: Chan
	---*C.f.s.*---				---*Feet*---	-----------*Degrees F.*	--------	
Francis Creek (Canton Creek)	0.3-0.9	SE.	June 17-Sept. 30, 1969	Undisturbed for total distance.	9,980	58	59	+1
			July 15, 1970	Buffer strip, 55,000 bd. ft., 3 percent of volume of clearcut.	1,680	58	59	+1
Pass Creek (Canton Creek)	5.1-15.3	ESE.	June 17-Sept. 30, 1969	Undisturbed upstream; two clearcuts on south side separated by undisturbed area of 1,225 feet.	1,290	58	66	+8
		ESE.	July 29-Sept. 30, 1969	Below the two south side clearcuts; clearcut to north, uncut to south.	1,265	65	64	-1
Deep Creek (Steamboat Creek)	.05-.10	N.	July 29, 1969	Undisturbed for approximately 1,000 feet upstream; then clearcut unit; 60 percent slash coverage through 1968 clearcut; ground water inflow.	1,900	56	60	+4
			Aug. 16, 1969	Buffer strip below clearcut; 30 feet wide; dense understory effective shade.	375	60	59	±0
Zinc Creek (South Umpqua)	.2-.3	N.	Aug. 28-Sept. 12, 1969	Several clearcut units upstream, nearest about 1,000 feet; 1950 clearcut to west; 1965 clearcut to east; some shade.	2,200	57	65	+8
			Sept. 4-12, 1969	Uncut forest downstream from clearcuts provides effective shade; ground water inflow.	1,300	64	60	-4
Deep Cut Creek (Jackson Creek)	.04-.05	S.	Aug. 2-26, 1969	Nearest clearcut units upstream 1-1/2 miles on mainstream, 1/2 mile on East Fork; thin buffer 50 feet wide with dense streamside vegetation.	550	60	61	±0
			Aug. 2-26, 1969	Tractor stripped area; no vegetation.	150	61	74	+13
Steelhead Creek (Steamboat Creek)	2.3	SSW.	Aug. 26-Sept. 12, 1969	Undisturbed upstream; thin buffer 30-foot average width; old growth plus 5-year-old alder; very little shade.	1,200	62	65	+3
Little Rock Creek (Steamboat Creek)	1.0-1.9	E.-SE	July 11-Sept. 9, 1969	Several clearcuts upstream, nearest 2,000 feet above upstream point; clearcut with 5-year-old alder.	1,100	72	76	+4
			July 11-Sept. 9, 1969	Thin buffer below clearcut, average 47 feet wide; old-growth Douglas-fir; sparse understory.	2,150	76	76	±0
Cedar Creek (Steamboat Creek)	11.4-2.2	ESE.	July 26-Aug. 22, 1969	North Fork--40 percent logged above clearcut; bottom of large clearcut below junction of North and South Forks.	4,200	69	83	+14

highest maximum, 62° F., was recorded on Steelhead Creek which drains in a southwesterly direction. Francis Creek and Pass Creek, the other two undisturbed streams, flow southeasterly. Although higher maximums might be recorded during prolonged periods of hot weather, this variation is probably representative of undisturbed conditions on small forested streams. There is some indication that undisturbed north flowing streams tend to be cooler than south flowing streams, but there is insufficient evidence from this study to support this.

Clearcutting.--Complete exposure of streams, as expected, produced the greatest temperature increases. Temperatures were measured above and below a clearcut which exposed 1,100 feet of stream on Little Rock Creek. Water temperature increased from 72° to 76° F. in this reach. The high upstream temperature (72° F.) was the residual effect of several other clearcuts along the stream above the clearcut studied.

The highest absolute temperature--83° F.--was recorded downstream from a large clearcut on Cedar Creek.

A similar effect was noted in Zinc Creek. An even sharper increase occurred in a 150-foot stretch of Deep Cut Creek, which was completely cleared of vegetation during road construction. In this very small stream, direct exposure to the south resulted in a 13° F. increase from 61° to 74° F. The importance of even short sections of open stream on water temperatures was noticed in the slash-covered section of Deep Creek, another very small stream. A 4° F. increase was measured in a 60-foot fireline and skid trail across the streambed, 2° F. increase where another 30-foot fireline crossed the stream, and 4° F. increase in a 10-foot diameter sump. Cool 51° F. ground water inflow reduced total change through the 1,900-foot, slash-covered section to 4° F.

Clearcutting in alternate blocks.--Clearcutting in alternate blocks allows for gradual removal and replacement of shade along any one stream. The theory here is that the cooler, shaded environment will reduce the high water temperatures to some acceptable level. The cooling effect of shade was examined with two types of studies--one focusing on environmental processes, the second on empirical observation.

Cedar Creek was selected as the site for studying the influence of the shaded environment on heated streams. The measurement site was within an uncut block of timber just downstream from a large clearcut. Water temperature approached 80° F. each day of the study. An energy balance was used to assess the gains and losses in heat for the stream as it moved from the clearcut into the shade. Methods used in this study have been reported elsewhere (Brown 1969).

The energy balance for Cedar Creek is shown in figure 3. Global radiation, the energy received from the sun, is reduced considerably by the forest canopy. The net radiation represents the energy absorbed by the stream. Additional energy is gained from the surrounding air (convection). Some of this energy is dissipated by evaporation; most of the energy is stored, however. This means that the stream will not cool in this reach but continue to warm very slowly. For most temperature measuring devices, the apparent change in water temperature would be zero.

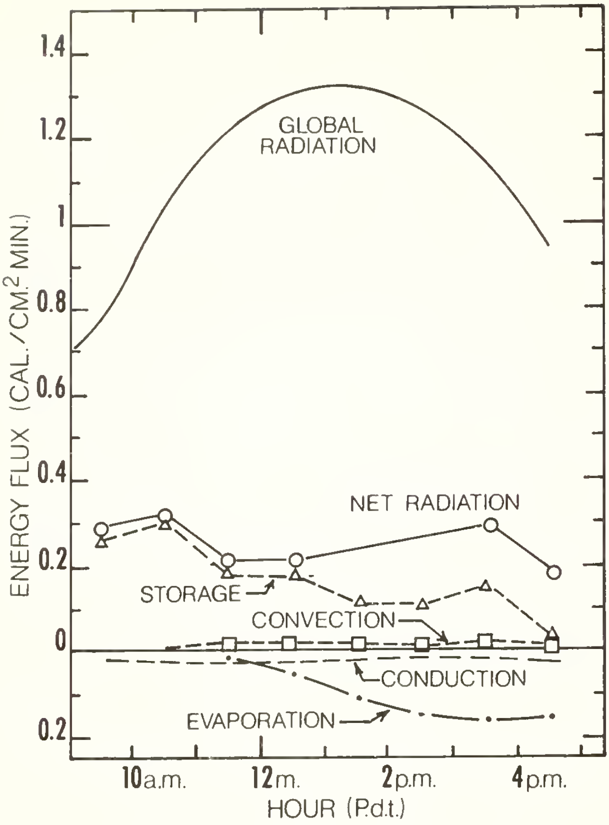

Figure 3.--An energy balance on a shaded reach of Cedar Creek during a clear day in July 1969.

Measurements of water temperature change in the 600-foot reach showed no significant reduction in temperature.

Measurements in shaded reaches of streams at various locations tend to support the "no change" conclusion from the study described above. Temperature changes in the shaded reaches of Francis Creek, Pass Creek, and Deep Creek are + 1° F., which is about the limit of precision for the instruments used (table 2).

Large temperature reductions, such as that measured on Zinc Creek (table 2), are generally the result of cold ground water entering the reach. Ground water temperatures average between 45° and 50° F.; it takes very little of this water to reduce surface water temperatures by 1° F. This is particularly true on small tributary streams. If, for example, a stream heated to 80° F. with a discharge of 1 c.f.s. has ground water inflow with a temperature of 45° F., equation 1 shows that only 1/34 c.f.s. (0.029) of this ground water will reduce the surface water temperature by 1° F. Such a small addition of water cannot be detected using normal current meter techniques.

Clearcutting with a buffer strip.--An excellent technique for controlling water temperature during logging is a buffer strip. Earlier studies (Brown 1969, Brown and Krygier 1970) indicated the importance of shade and the effectiveness of buffer strips in other areas for temperature control. The measurements reported above in areas of no cutting and in shaded areas below cutting units confirm this hypothesis. Again, two types of measurements were made to verify the effectiveness of buffer strips in the Steamboat Creek watershed.

A radiation balance was evaluated within a buffer strip on Little Rock Creek (fig. 4). This radiation balance

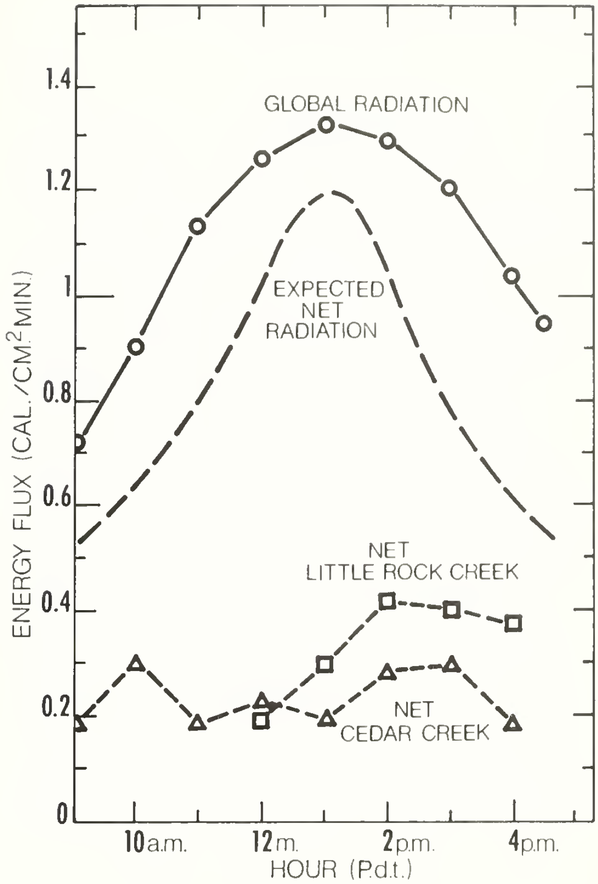

Figure 4.--Net all-wave radiation measured in a shaded reach of Cedar Creek and within a shaded buffer strip on Little Rock Creek during clear days in July 1969.

illustrates why even a thin buffer strip is effective in controlling temperature. The global radiation is the incoming solar radiation on the 2 clear days when the net radiation measurements were made. The "expected" net radiation is the portion of this incoming energy that would have been absorbed by the streams had no trees been present. This expected net radiation was greatly reduced by the streamside buffer strip on Little Rock Creek, almost as much as by the uncut block of timber bordering Cedar Creek. Such low levels of net radiation suggest that very little change would occur within the reach of Little Rock Creek protected by the buffer strip. The buffer strip on Little Rock Creek contained 75,000 board feet of timber, about 7 percent of the volume removed from the adjacent 55-acre clearcut.

Temperature measurements were made above and below the buffer strip on Little Rock Creek and the buffer strip left on Francis Creek. The temperature change in both instances was near zero (table 2). A 1,680-foot buffer strip on Francis Creek (fig. 5) contained only 55,000 board feet, 3 percent of the volume removed from the adjacent 29-acre clearcut. The effectiveness of this buffer strip was due, in large measure, to the excellent shade provided by understory vine maple. The understory remained intact as a result of careful felling and balloon yarding.

Management implications.--The studies of temperature and logging along the tributaries of Steamboat Creek provide forest-land managers with some important insights for temperature control.

Figure 5.--Balloon logging on Francis Creek clearcut area showing the buffer strip over the creek between the unit and the road. (Note balloon used for logging.)

Small streams shaded by forest vegetation tend to have temperature patterns with very little daily or seasonal fluctuation. In undisturbed streams daily variation in water temperature for a given stream may be less than between streams of different aspects. Complete exposure of a small stream by clearcutting can cause large changes in this temperature pattern. These conclusions support the conclusions of many earlier studies.

Forest-land managers can't count on shade to cool heated water. Where water temperature is critical, large temperature changes should be avoided in the first place. This can be achieved during logging by providing a buffer strip of vegetation that shades the stream. For small streams, understory species can provide shade as effectively as merchantable timber.

Predicting Temperature Change--A Field Check of Existing Models

A model for predicting temperature on small streams was described by Brown (1969) and later simplified for the special case of predicting the effect of clearcutting on stream temperature (Brown 1970). The purpose of this portion of the study was to check the accuracy of this simple model in the Steamboat Creek watershed and, if acceptable, use it to estimate the effectiveness of buffer strips for temperature control.

The simpler model for predicting the maximum change produced by clear-cutting (Brown 1970) is:

$$\Delta T = \frac{A \times H}{D} \times 0.000267 \qquad (2)$$

where

ΔT = maximum change in stream temperature in degrees F. produced by completely exposing the stream,

A = surface area of the exposed section of stream in square feet,

H = maximum heat input varying with travel time and sun angle (available in Brown (1970)),

D = discharge, c.f.s.

The term H varies in the Steamboat Creek watershed from 4.0 to 4.5 B.t.u./ft.^{2}/min. The constant 0.000267 converts water from cubic feet per second to pounds per minute so that ΔT will be in degrees Fahrenheit. Predictions using this simple model are shown in table 3.

This table illustrates some of the shortcomings of this method as well as its potential value. The prediction on Pass Creek was within 3°-4° F. of the measured value. On this stream, the method was used to estimate the additive impact of two clearcuts separated by an uncut block of timber to the south (fig. 6). No adjustment was made for cooling in this portion, in accordance with findings reported earlier.

The prediction made for the clearcut in Little Rock Creek was much too high. Subsequent studies in 1970 revealed two possible sources of error. The first was an insufficient number of cross sections for estimating width. In 1969, measurements made at 100-foot intervals suggested that the average width was 16.8 feet. Discharge was 0.96 c.f.s. In 1970, measurements of width at 15-foot intervals suggested that the average width was 12.3 feet even though discharge was 1.11 c.f.s. Overestimation of width, and thus surface area, or underestimation of discharge will produce an overestimation of the maximum temperature change.

A second source of error in the prediction for Little Rock Creek was estimation of the value for the heat input, H. The simplified method assumes that all heat exchange can be accounted for by this term. Earlier work (Brown 1969) suggested that where streambeds were solid rock as on Little Rock Creek, significant amounts of energy would be absorbed by the bed. Energy budget measurements on Little Rock Creek in July 1970 confirmed this loss of heat. Roughly 17 percent of the net radiation was dissipated in this manner. Thus, the value for H should not be 4.1 but 3.4 B.t.u./ft.^{2}/min.

Combining these new measurements for a short stretch of Little Rock Creek, a prediction was made for the upper 640 feet of the area exposed by the clearcut. When an average width of 12.3 feet, discharge of 1.11 c.f.s., and a heat load of 3.4 B.t.u./ft.^{2}/min. was used, a predicted increase of 5.4° F. was obtained. The measured temperature increase was 4° F.

The predicted increase of 34° F. without the thin buffer strip on Little Rock Creek is too high (table 3). Problems with width estimation and heat flow into the streambed are applicable here also.

Table 3.--***Stream temperature increase predictions***

Stream and date of data	Forest cover	Exposed stream channel		Surface area	Discharge	Travel time		Sun angle	Predicted increase	Measured increase	Comments
		Length	Average width								
		------*Feet*------		*Sq. ft.*	*C.f.s.*	*Hours*		*Degrees*	------*Degrees F.*------		
Steelhead Creek, Aug. 15, 1969	30 feet wide, thin buffer.	1,200	13.6	16,320	2.34	2/3	[1]4.2	61	8	4	Buffer about 50 percent effective.
Pass Creek, July 8, 1969	Alternate clearcut and leave on south side of stream.	1,386	12	16,632	2.06	1	[1]4.5	70	10	6-7	Appears reasonable.
Deep Cut Creek, Aug. 27, 1969	50 feet wide, thin buffer with dense understory.	550	4.4	2,420	.04	2	[1]4.1	57	74	±0	Unreasonable increase.
Little Rock Creek Aug. 21, 1969	Clearcut with 5-year-old alder.	1,100	16.8	18,480	.96	1-1/2	[1]4.1	59	21	6	Predicted value high.
1970[2]	Same	640	12.3	7,872	1.11		[1]3.4		5	4	
Aug. 21, 1969	Thin buffer, sparse understory.	2,150	14.4	30,960	.96	3	[1]4.0	59	34	6	Predicted value high.

[1] Values for maximum heat input varying with travel time and sun angle (*H*).
[2] Revised predictions.

The thin buffer on Steelhead Creek seems to be about 50 percent effective in preventing any temperature increase. This buffer contains an old-growth Douglas-fir overstory, average width, 30-foot, with a sparse understory of mixed hardwoods and conifers, especially at the lower end of the unit.

The predicted temperature increase on Deep Cut Creek is unreasonable. Problems in estimating all values in equation 2 become acute on such small streams. Discharge is difficult to measure, as is travel time for the average water molecule. Flow patterns in small pools become obscure, and minor amounts of ground water inflow can significantly decrease the water temperature. Accurate predictions from the simplified model may be impossible in such circumstances.

A final source of error implicit in the simplified method is its use for exceptionally long stretches of stream. Certainly, the capacity of a small stream for absorbing heat is not infinite. As stream temperature increases, more energy will be dissipated by convection and evaporation. As water temperature approaches air temperature, an equilibrium will be reached. This phenomenon is described in Edinger et al. (1968). For very long stretches, the simple method of estimating *H* by assuming that solar

Figure 6.--Pass Creek showing two clearcut units to the south (right) separated by an undisturbed strip. Temperature prediction made for the stream between points 1 and 2.

heat exchange represents total heat exchange is no longer applicable. Thus, the best results using this method will be obtained by using it on short, less than 2,000-foot, stretches of stream.

Management implications.--Predicting the effect of clearcutting on temperature can be a useful tool even with these limitations. With understanding of the principles illustrated by equation 2 and careful measurement of the important factors, accurate predictions can be obtained. The potential utility of the simplified method was illustrated on Pass Creek, on Little Rock Creek using better estimates of width and heat load, and on Steelhead Creek for judging the effectiveness of different densities of streamside vegetation.

Combined with equation 1, the prediction model allows the land manager to estimate onsite and downstream impacts. Where desirable, he can control the impacts, i.e., remove or leave sufficient cover so that maximum temperatures will not exceed a given amount.

RESULTS AND MANAGEMEMEMENT IMPLICATIONS

The results of this study generally are applicable to other forest areas as well as to the Steamboat Creek drainage.

The key to water temperature control is maintaining shade over the stream:

1. Small amounts of energy may penetrate a forest canopy, but normal temperature increases along shaded streams are small.

2. Differences in stream temperature due to natural causes may vary by 4° F. or more.

3. Removing all shade from a stream can increase water temperature 10° F. and more. A stream in one large clearcut had water temperatures of 83° F.

4. Shaded reaches downstream from a clearcut cannot be relied on to cool heated streams. Cooling that does occur can often be attributed primarily to inflow and mixing of cooler ground water.

Small streams are particularly sensitive to changes in shade:

1. For a given heat load and cross section, the change in temperature is inversely proportional to discharge--that is, the smaller the flow, the greater the temperature increase.

2. Exposing 150 feet of one small stream produced a temperature increase of 13° F.

Within a clearcut, water temperature may be controlled by leaving a buffer strip to provide shade. The key to planning buffer strips is recognizing that stream configuration determines buffer strip configuration:

1. Narrow streams may be shaded by brush.

2. Wide streams may require trees of sufficient height and density to effectively shade the stream.

3. When streamside shade is removed, and a relatively quick shade cover is desired, encouragement or propagation of cottonwood, alder, willows, and other fast growing species may shorten the time required to establish a buffer strip. Five-year-old natural regrowth of alder established after the 1964 flood is already providing some shade to small streams.

For any given stream, water temperature could be controlled by removal of shade over time so that temperatures would not exceed a target temperature in any one stretch or downstream.

The forest-land manager can predict water temperature changes that may result:

1. Equation 2 is a simplified method for predicting onsite changes.

2. Equation 1, used in combination with equation 2, can be used to predict downstream changes.

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Stream temperatures were studied in a drainage in which logging operations were typical of much of the commercial forests on the west slopes of the Cascade Range. Changes in water temperature of tributary streams influenced by various degrees of exposure from logging were measured, and a simplified prediction equation was tested.

Keywords: Temperature, watershed management, logging.

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An Analysis of Running Skyline Load Path

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
DEPARTMENT OF AGRICULTURE
FOREST SERVICE
PORTLAND, OREGON

ABSTRACT

This paper is intended for those who wish to prepare an algorithm to determine the load path of a running skyline. The mathematics of a simplified approach to this running skyline design problem are presented. The approach employs assumptions which reduce the complexity of the problem to the point where it can be solved on desk-top computers of limited capacities. The results of this approach are compared with the exact catenary solution.

Keywords: Cable logging, mathematical analysis, logging, skidding (cableway), computer.

1.0 INTRODUCTION

Many logging system designers are now facing the problem of determining the load-carrying capability of the running skyline. There are basically three means for assessing this capability: a graphical-tabular handbook approach as presented by Lysons and Mann,[1/] [2/] a mathematical solution utilizing the large digital computing facilities,[3/] or a mathematical solution utilizing small desk-top computers.[4/]

Although each of these methods is directed to the problem of determining the load-carrying capability of the running skyline, there is a difference in approach. The procedures presented in references 1, 2, and 3 determine load-carrying capability under a given condition of deflection, whereas the procedure of reference 4 determines deflection, and ultimately a load path, for a specified load. The mathematical features of this latter approach to the problem are discussed in this paper.

2.0 MATHEMATICAL PROBLEM

To apply digital computers, either large facilities or small desk-top units, to skyline design problems, the skyline must be described mathematically. This description depends upon a clear statement of the mathematical problem, indicating the physical parameters and system characteristics that can be considered as known information. Such a statement of the running skyline problem can be made (refer to the cable-carriage configuration of fig. 1). The haulback, main, and grapple-opening lines are considered anchored at specific points, (a) and (b). These points are known to be separated horizontally by the span distance L and vertically by the elevation difference h. The carriage, located at (c), a known distance d from the anchor point (a), is supporting a known log load suspended free of the ground. The gross payload, W_G, is the sum of the carriage and log weights, and it is supported by the cable system at point (c). The operating tension, T_A, in the haulback at the left support is equal to the maximum allowable tension for this line, which is usually one-third of the breaking strength. The haulback line is a continuous line from the anchor point (a), running through the carriage and the block at (b), then back to the carriage where the other end is anchored. The weights of the main line, grapple-opening line, and haulback are specified. In the mathematical description, the main line and grapple-opening line are considered to function as one line, and the combined weight of both lines, w_3, is used. This approximation introduces negligible error and also makes the results applicable to running skyline cable configurations without grapple-opening lines or to those systems where the grapple-opening line remains slack and carries a negligible portion of the load.

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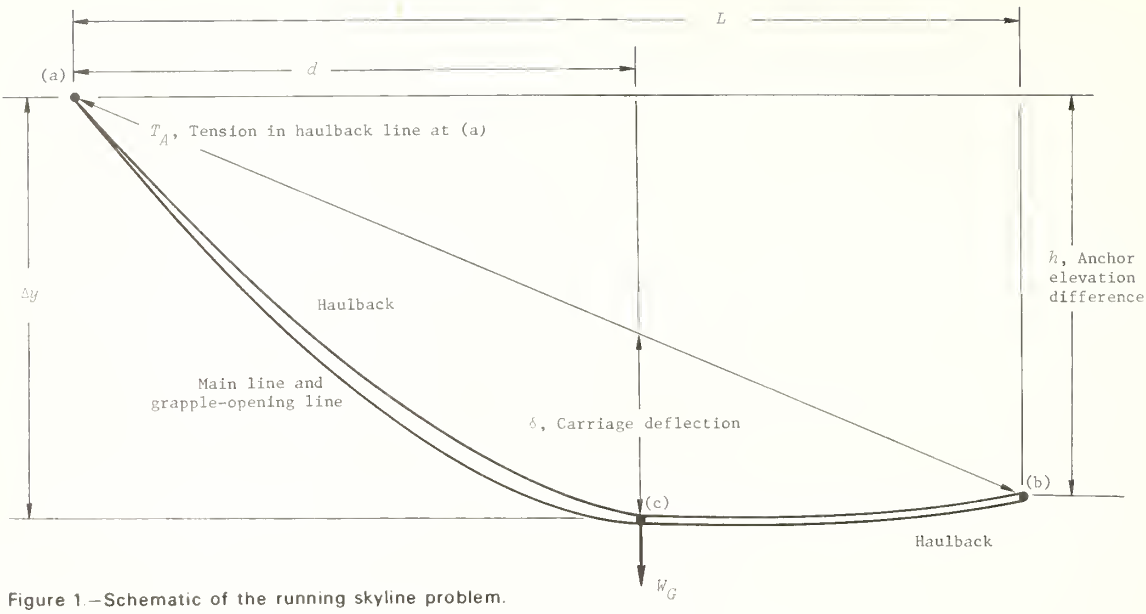

Figure 1.—Schematic of the running skyline problem.

The problem, as stated above, can be solved for the displacement, Δy, necessary to support the payload W_G at the point (c), while maintaining the operating tension T_A in the haulback line. When this problem is solved at a succession of points through the span of the skyline, a curve connecting these points is referred to as the load path of the carriage. This is the desired result of the analysis.

2.1 Problem Formulation

If the catenary description[5/] of this cable configuration was used in the problem formulation, a set of nonlinear, transcendental equations would result. A convenient solution of these would exceed the capacity of the desk-top type of computing facility. Since it is desired to provide a solution to the running skyline problem on a desk-top facility, another more simplified approach must be used.

The problem formulation employed in this paper consists of a force and moment balance approach, with simplifying assumptions about the weights and geometry of the cable segments. The problem is formulated as having known geometry, and load path is determined by an iterative technique designed around this formulation. The accuracy of the results is compared with results derived from a catenary formulation.

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2.2 Force Balance Formulation

The relationship between cable forces and geometry can be derived by considering the equilibrium of components of the running skyline system. The equations are written from force and moment balances for all line segments and for the skyline carriage (see fig. 2). For example, line segment 1 can be described by the vertical force balance on the line segment

$$V_1^a = R_1 + V_1^c ,$$

the horizontal force balance on the line segment

$$H_1 = \text{constant} ,$$

and the moment balance about the carriage

$$V_1^a = R_1 \frac{e_1}{d} + H_1 \frac{\Delta y}{d} .$$

In these expressions, R_1 represents the weight of the cable segment concentrated at a horizontal distance e_1 from the carriage, and the other forces and distances are described in figure 2.

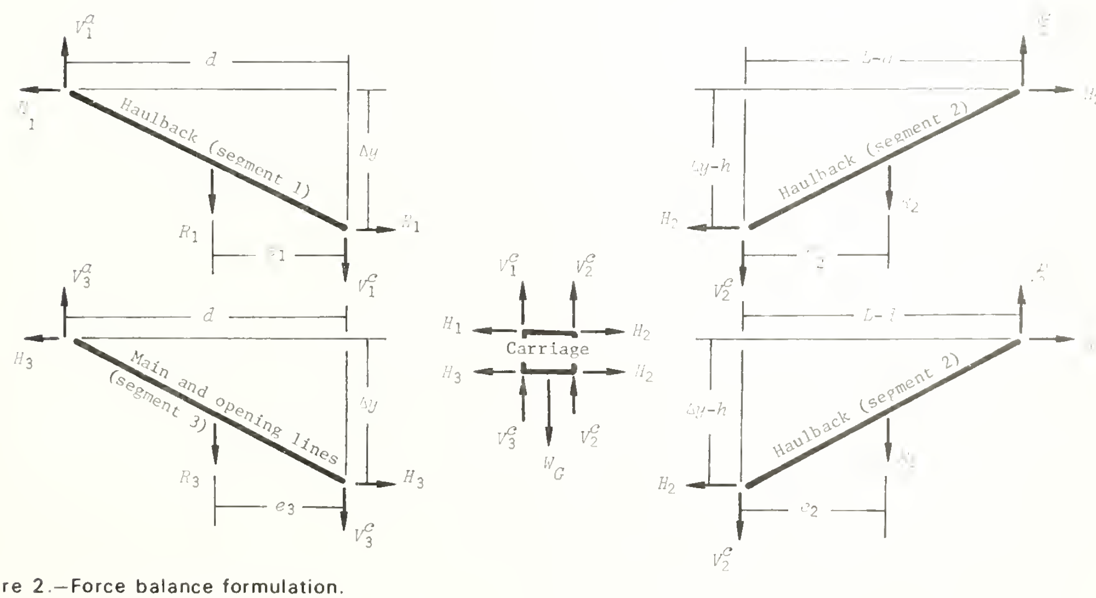


Figure 2.—Force balance formulation.

Line segments 2 and 3 can be described by similar expressions. These equations and the horizontal and vertical force balance equations on the carriage can be combined to provide direct solution for the horizontal tensions in each line segment. These expressions, listed in the order for solution with the necessary intermediate values, are

$$H_1 = \frac{-R_1 t_1 (t_2 - 1) + [(R_1 t_1 (t_2 - 1))^2 - (1+t_1^2)((R_1 (t_2 - 1))^2 - (T_1^c)^2)]^{1/2}}{(1+t_1^2)} ,$$

$$H_2 = \frac{-R_2 t_3 (t_4 - 1) + [(R_2 t_3 (t_4 - 1))^2 - (1+t_3^2)((R_2 (t_4 - 1))^2 - (T_2^c)^2)]^{1/2}}{(1+t_3^2)} ,$$

and

$$H_3 = 2H_2 - H_1 ,$$

where

$$t_1 = \Delta y/d ,$$

$$t_2 = e_1/d ,$$

$$t_3 = \Delta y - h/L - d ,$$

$$t_4 = e_2/L - d ,$$

T_1^c, tension in haulback segment 1 at carriage = $T_A - w_1 \; \Delta y$,

T_2^c, tension in haulback segment 2 at carriage = $T_A - w_1 \; \Delta y$,

and

w_1 is the weight per foot of the haulback.

The values of horizontal tension derived from these equations can be substituted in earlier expressions to determine the load-carrying capability of the skyline.

This formulation of the problem provides an approach for direct solution; however, the expressions presume knowledge of the line weights R and moment arms e of each line segment. Since these are determined by the weight distribution and the length and shape of each line segment, an iterative procedure is required for solution. However, with the approximations discussed in the next section, the iterations can be avoided and a direct solution is provided.

2.3 Force Balance Formulation With Straight-Line Approximations

As discussed in section 2.1, skylines are most accurately described as catenaries. With the geometry of the catenaries known, the weights R and moment arms e of each segment could be accurately determined and the equations of section 2.2 could be used for direct solution. The catenary lengths and shapes, however, are not known until solutions for tensions in each line have been established. Therefore, an exact solution would require iterations involving assumed tensions which provide catenary geometry, line weights, and moment arms, followed by computation of tensions to be compared to the values originally assumed.[6/] This procedure can be simplified by approximating the catenary geometry by straight-line segments between anchor points. The line segments would be envisioned as straight, rigid members with the uniform weight distribution of the cables and would be pinned at (a), (b), and (c). This assumption allows the line segment weights and moment arms to be expressed as

$$R_1 = w_1((d)^2 + (\Delta y)^2)^{1/2} ,$$

$$e_1 = d/2 ,$$

$$R_2 = w_2((L-d)^2 + (\Delta y-h)^2)^{1/2} ,$$

$$e_2 = (L-d)/2 ,$$

$$R_3 = w_3((d)^2 + (\Delta y)^2)^{1/2} ,$$

and

$$e_3 = d/2 .$$

If this assumption is made, the algebraic expressions of section 2.2 can be used to solve the problem directly. An iterative procedure is still required to establish the Δy which matches the gross payload of the skyline; however, the procedure is straightforward. The technique for determining Δy is discussed in the next section. The error of this approximation is presented in section 3.0.

2.4 Iteration For Δy

As discussed in the previous section, a good approximation to the running skyline problem can be formulated, based on known geometry. Since our problem is to determine geometry, specifically Δy, an iterative procedure based on successive solutions of the known geometry problem must be designed to determine the Δy which yields an appropriate gross payload W_G. This procedure, if designed for use with a desk-top computer, should require as little storage and as few instructions as possible. Such a procedure is suggested in this section.

6/ Ward W. Carson and Charles N. Mann. A technique for the solution of skyline catenary equations. Pac. Northwest Forest & Range Exp. Sta. USDA Forest Serv. Res. Pap. PNW-110, 18 p., illus., 1970.

The iterative procedure determines Δy from the known relationship between Δy and W_G and a specified value of $(W_G)_{INPUT}$. The procedure was designed to insure convergence for all physically reasonable data and requires a minimum of instructions and storage in the process. The procedure depends upon an initial computation of W_G corresponding to the chord value of Δy. This will never be the correct value for Δy; however, it serves as a minimum in the iterations that follow.

A second $(\Delta y, W_G)$ pair is generated by choosing a δ corresponding to 1 percent of the skyline span and computing W_G. With this pair and the previous pair computed for the chord value of Δy, a linear relationship can be used to generate new estimates for Δy. The relationship, derived from the illustration in figure 3, is

$$(\Delta y)_I = \{(\Delta y)_{CALC} - (\Delta y)_{CHORD}\} \frac{(W_G)_{INPUT} - (W_G)_{CHORD}}{(W_G)_{CALC} - (W_G)_{CHORD}} + (\Delta y)_{CHORD}$$

where

$(\Delta y)_{CALC}$ = the last value of Δy used in the calculations,

$(\Delta y)_{CHORD}$ = the value of Δy at the skyline chord,

$(W_G)_{INPUT}$ = the input value of gross payload,

$(W_G)_{CALC}$ = the last value of W_G computed,

$(W_G)_{CHORD}$ = the value of W_G computed with $(\Delta y)_{CHORD}$,

and

$(\Delta y)_I$ = an estimate for $(\Delta y)_{SOLN}$ which is used in the next computation of W_G.

This is the equation controlling the values of Δy used in the iterative procedure. For each pass through the calculations, the computed value of W_G is compared with $(W_G)_{INPUT}$. When these are within 1 percent of each other, the calculations are terminated and the value of Δy used to generate W_G is taken as the solution to the problem.

2.5 Numerical Example

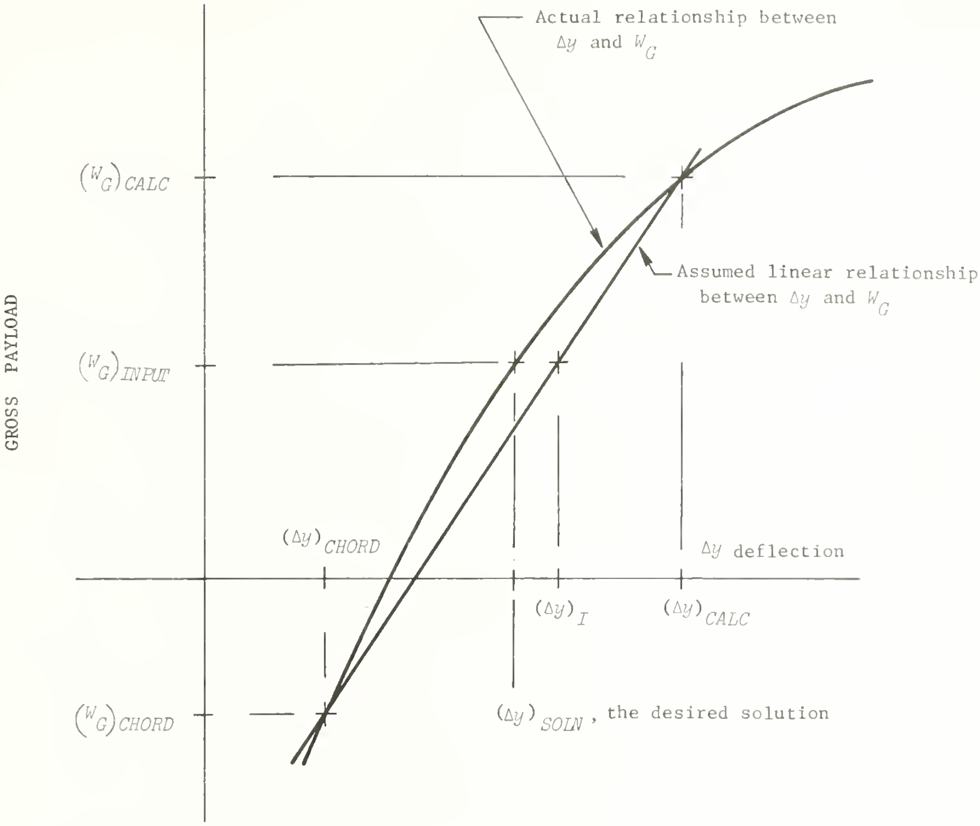
To demonstrate the procedure used to determine load-carrying capability, a numerical computation associated with the example of section 2.0 is discussed here. The geometry of figure 1 and the equipment specified provide the following input

L, skyline span = 800 feet,
h, elevation difference of anchors = 150 feet,
w_1, weight per foot of haulback = 1.42 pounds per foot,
w_3, weight per foot of main and grapple-opening lines combined = 2.84 pounds per foot,

and

T_A, operating tension of haulback = 26,500 pounds.

Figure 3.— Δy-W_G relationship.



For this example, the Δy for $(W_G)_{INPUT}$ = 25,000 pounds when the station location of d = 270 feet is determined.

The first step in the iterative procedure to determine the Δy is to establish $(\Delta y)_{CHORD}$ and $(W_G)_{CHORD}$. These are

$$(\Delta y)_{CHORD} = d\,\frac{h}{L} = 50.625$$

which leads to

$$(W_G)_{CHORD} = -1{,}350.837 \text{ pounds.}$$

The second estimate for Δy is taken as $(\Delta y)_{CHORD}$, plus 1 percent of the span. In this case,

$$(\Delta y)_2 = (\Delta y)_{CHORD} + L/100 = 58.625 \text{ feet.}$$

This gives a gross payload of

$$(W_G)_{CALC} = 970.412 \text{ pounds.}$$

With these two pairs of Δy, W_G, the equation of section 2.4 is used to predict the third estimate of Δy, namely,

$$(\Delta y)_3 = 141.441 \text{ feet.}$$

This gives a gross payload of

$$(W_G)_{CALC} = 25{,}290.21 \text{ pounds.}$$

Another application of the section 2.4 equation gives the final result

$$\Delta y = 140.45 \text{ feet}$$

and the corresponding gross payload of

$$W_G = 25{,}000.26 \text{ pounds}$$

which is close enough to $(W_G)_{INPUT}$ to be regarded as a solution.

Therefore, the solution for these conditions when the station $d = 270.0$ feet is

$$\Delta y = 140.45 \text{ feet.}$$

The four iterations required to arrive at this result are typical. This rapid convergence indicates that the linear relationship in section 2.4 is a good assumption.

3.0 ACCURACY OF THE STRAIGHT-LINE APPROXIMATION

The object of the analysis presented in the previous sections was to determine the load path geometry for specified skyline equipment, ground profile, and gross payload W_G. The accuracy of the approximation proposed in section 2.3 should then be discussed in terms of the geometric error of this solution compared to the results of the catenary formulation. This error can be defined as

$$E\text{, percent error} = \frac{\delta_{FB} - \delta_{CAT}}{\delta_{CAT}} \times 100$$

where

δ_{FB} = the carriage deflection as computed by the force balance formulation containing the straight-line approximations

and

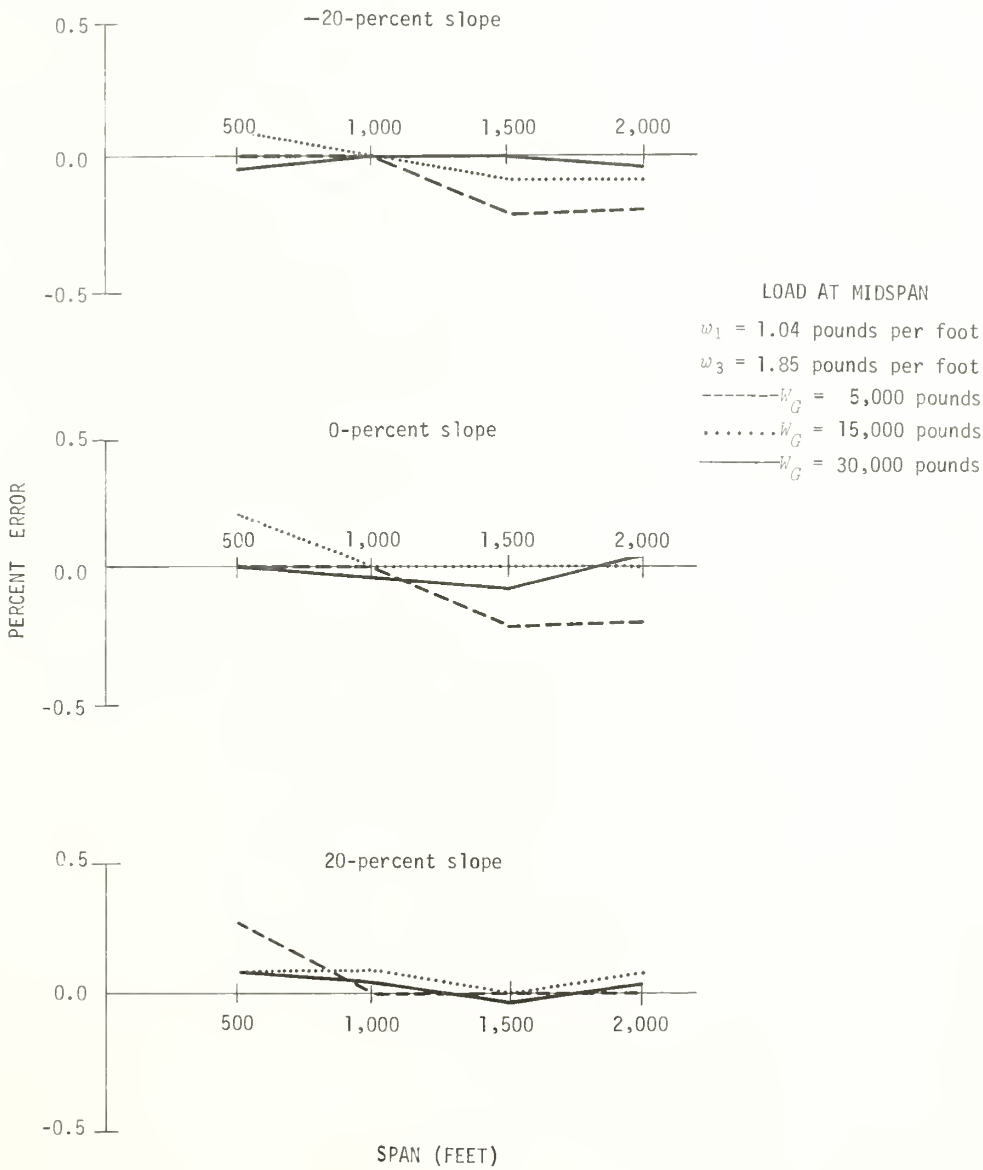
δ_{CAT} = the carriage deflection as computed by the catenary formulation.

This error is influenced by the variables of span L, station d, slope S, line weights per foot w_1, w_2, and w_3, and gross payload W_G. Figure 4 displays the error for a range of these variables. Although a more thorough coverage of the variable ranges would be required for a full study of accuracy, the low errors presented in these figures establish this solution as sufficiently accurate for practical applications of the running skyline system.

4.0 CONCLUSIONS

The approximate force balance solution to running skyline problems provides a method by which these problems can be solved on a desk-top computer with limited storage capability. Carson et al. (see footnote 4) gives the details of applying this solution with a typical desk-top computer/plotter system. Section 3 shows that this approximate solution is always within 1 or 2 percent of the exact catenary solution for the range of practical running skyline problems.

Figure 4.—Percent error in straight-line approximation.



Carson, Ward W., and Charles N. Mann.
1971. An analysis of running skyline load path. USDA Forest Serv. Res. Pap. PNW-120, 9 p., illus. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

The mathematics of a simplified approach to running skyline problems is presented, and the simplified solution is compared with the exact catenary solution. This approach allows practical design of running skylines with desk-top computer/plotters.

Keywords: Cable logging, mathematical analysis, logging, skidding (cableway), computer.

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

USDA FOREST SERVICE RESEARCH PAPER PNW-121

Techniques for Inventorying Manmade Impacts in Roadway Environments

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FOREST SERVICE

Abstract

Four techniques for inventorying manmade impacts along roadway corridors were devised and compared. Ground surveillance and ground photography techniques recorded impacts within the corridor visible from the road. Techniques on large- and small-scale aerial photography recorded impacts within a more complete corridor that included areas screened from the road by vegetation. Techniques were compared on the basis of type and quality of data obtained, types of maps produced, area covered, and relative cost and time requirements.

Keywords: Environment, roadside improvement, landscape management, photography.

INTRODUCTION

The public may encounter more environmental blights in driving than in any other pursuit. This is not new. Over 40 years ago a sociologist (Joad 1928) wrote, "One arrives after a motor journey all liver and no legs; one's mind asleep, one's body tired. One is bored, irritable, and listless. Whatever beauties the landscape might offer are hidden behind forbidding lines of advertising billboards." Now, however, we have over 3 million miles of rural roads and highways and nearly 87 million registered automobiles. Passenger vehicles are driven approximately 835 billion miles each year, with perhaps two or more times as many passenger miles (U. S. Bureau of the Census 1970). Thus the indiscriminate blighting of roadway corridors has a major and a growing impact on the visual quality of environmental experiences.

These visual effects have often been overlooked or disregarded for technical or economic reasons (Twiss and Litton 1966), but there is growing public resistance to such neglect (see, for example, DeBell 1970). As per capita space decreases because of increased population, mobility, and demand for conflicting land uses, consideration of the total environment becomes increasingly important. As a first step toward identifying problem areas and perhaps opportunities to reduce conflicts between landscape uses, we developed and tested inventory methods to measure the kind and extent of manmade alterations on the roadside landscape. In emphasizing the development of methodology, we did not limit our attention to blights but included a variety of other man-caused impacts on the landscape.

Our objectives were to compare costs, advantages, and limitations of four techniques for inventorying these impacts along roadways and to illustrate ways of summarizing and displaying the pattern, kind, severity, and possible amelioration of these impacts. The four techniques studied should be viewed only as selected possibilities. They by no means include all the possibilities for inventorying roadway environments.

RELATED STUDIES

A number of other studies have addressed related problems. Philip Lewis (1962, 1964, 1965) incorporated ecological factors into the general planning process along with highways, buildings, vegetation, and interesting views. Soils were also surveyed to determine the forms of recreation suited to specific areas. By superimposing various survey data with overlay maps, Lewis (1964) showed that major resources were concentrated in linear patterns which he called "environmental corridors." Twiss and Litton (1966) developed procedures for evaluating and inventorying specific attributes of the landscape, with emphasis on topographic form, spatial definition, compositional types, and/or perceptual qualities. They suggested that concern is shifting from proper land use to proper landscape use. Litton (1968) illustrated procedures by making landscape inventories. Sargent (1967) developed a scenery classification scheme to rate landscape qualities based on distance, variety, and eyesores. Burke et al. (1968) also developed a scenery classification scheme based on the "characteristic landscape."

Computers are now increasingly popular for assistance in evaluating landscapes. Amidon and Elsner (1968) developed a program for plotting areas visible from a selected location, with vegetation disregarded. However, vegetation can be considered in computer-drawn perspective views of landscape and vegetation patterns as they would appear from any selected point.[1/] These drawings not only show how vegetation may shield an undesirable impact but also indicate the visual effects of such proposed impacts as clearcut logging--given various sizes, shapes, and positions.

Because studies for improving roadway corridors have generally focused on natural scenery or road alinement and design, we have emphasized procedures for inventorying manmade impacts that often affect the visual quality of existing roadway corridors. We therefore included some impacts that often are a pleasing complement to the natural landscape--farming, for example. We did not judge the desirability of manmade alterations nor did we attempt to determine their effects on potential viewers.

TECHNIQUES

Initially, 25 miles of Washington State Highway 530 were inventoried (1) to determine the usefulness of aerial photographs for field recording, (2) to identify problems with inventorying, and (3) to explore alternative means for inventorying. This showed aerial photographs of 1:20,000 scale to have more detail than needed and, because of the large number of photos necessary, to be awkward to handle in recording data under field conditions.

Based upon this preliminary work, four inventory techniques were devised and tested on a 12-mile section of U.S. Route 2 in Washington. These were ground surveillance, ground photography, and large- and small-scale aerial photography.

The two "ground" techniques were applied within a *visual corridor* defined such that only impacts visible from the roadway were recorded. If an impact was hidden by vegetation or terrain, it was not tallied.

The two aerial photography techniques, on the other hand, were applied within a *topographic corridor*. This is the corridor that would be visible from a highway if only topographic relief restricted site distance. Impacts within the topographic corridor were therefore tallied even if obscured from the roadway by vegetation.

Ground Surveillance Inventory

In the ground surveillance inventory, impact data were gathered by a two-man crew traveling along the highway. One person recorded impact data on topographic maps (15-minute quadrangle sheets) while the other drove.

[1/] *An excellent example was developed by Michimasa Kojima. Unpublished paper available at the Univ. Wash. Coll. Forest Resour., Seattle.*

Impacts were recorded by type and frequency. *Type* included farming, logging, utility lines, advertisements, railroads, roads, mining, dumps, buildings, air or stream pollution, and towns. *Frequency* indicated whether the impact was seen constantly or intermittently for a given section of road. Possible amelioration such as screening, zoning, educating the public, and relocation also was recorded for each impact. The road mileage (to the nearest tenth) was recorded each time an impact came into view or dropped from view, defining one or more sections of road as affected by each impact.

A computer program was developed to summarize data. This provided a record of the miles of roadway from which each impact type was visible. It also summarized amelioration possibilities, computed a net and gross mileage of roadway from which impacts could be seen, and gave the percentage of the total road involved.[2/] Such calculations aid in comparing one road with others, as in selecting the best of several highways for a scenic route or entrance corridor for a park.

Ground Photography Inventory

The ground photography technique was similar to ground surveillance procedures in that data were collected for a visual corridor by on-the-ground procedures. However, data were recorded primarily on film. This created a permanent record of the landscape for future comparisons.

Inventorying consisted of taking four wide-angle 35-millimeter photographs every two-tenths of a mile along the highway--one straight ahead, one 90° to the right, one straight back, and one 90° to the left of the photo point. If vision were unobstructed, this would provide a nearly complete record of the visible landscape (see fig. 1). The only field note-keeping necessary was to record the road sector location, film frame number, and direction of picture. This facilitated identification and location of each photo point when photos were analyzed. Our data showed that several impacts were overlooked on the photos, but this appeared due to interpretation rather than "blind" areas between photo points.

If a large region were inventoried, a four-camera system mounted on top of a vehicle would speed the fieldwork, and the technique used in this study was designed to simulate such a four-camera system. However, 86 percent of total cost was for film and processing which contributed to a poor comparative cost position for the ground photography technique.

The "office" portion of this inventory technique was very similar to the "field" procedure of the ground surveillance technique. The film negatives were printed--24 frames on an 8- by 10-inch sheet of photographic paper. The interpreter then examined photos under a magnifying glass as if he were actually traveling the highway (fig. 2). Data were coded and summarized by computer as in the ground surveillance inventory.

[2/] *Net mileage equals the miles of roadway from which any impact can be seen. The road mileage affected by each impact was included in gross mileage. Therefore, gross mileage could exceed the total road mileage in the inventory.*

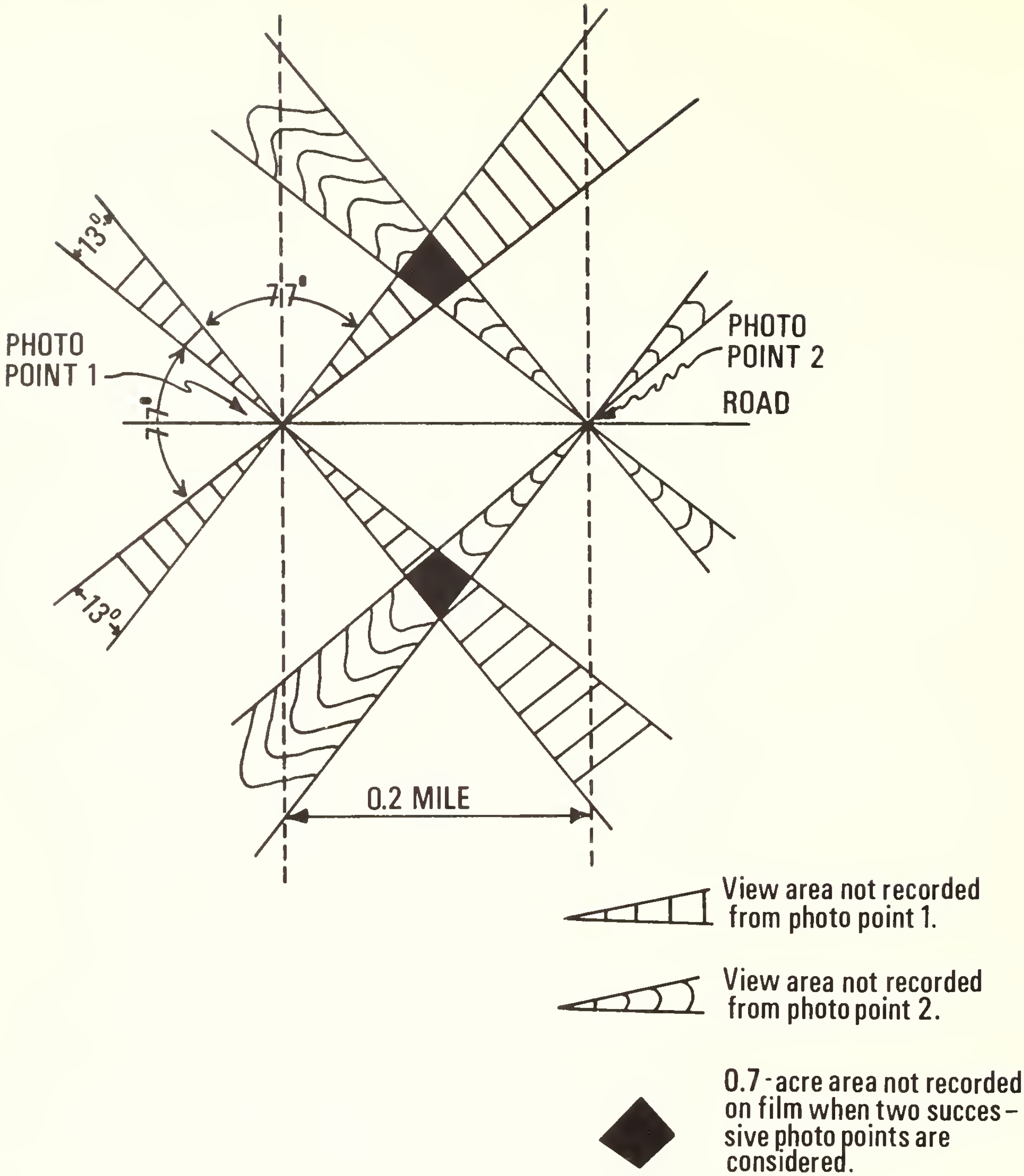

Figure 1.—Diagram showing theoretical area covered by two photo points. The 77° is one of four camera view areas that is recorded at one photo point. The 13° indicates one of four landscape areas that is not recorded on film as a result of using a 28 millimeter, wide-angle lens. When two photo points are considered, much of the "lost" area from one point is subsequently recorded from the other point. Calculations show the actual area "lost" between any two points two-tenths of a mile apart is 1.4 acres.

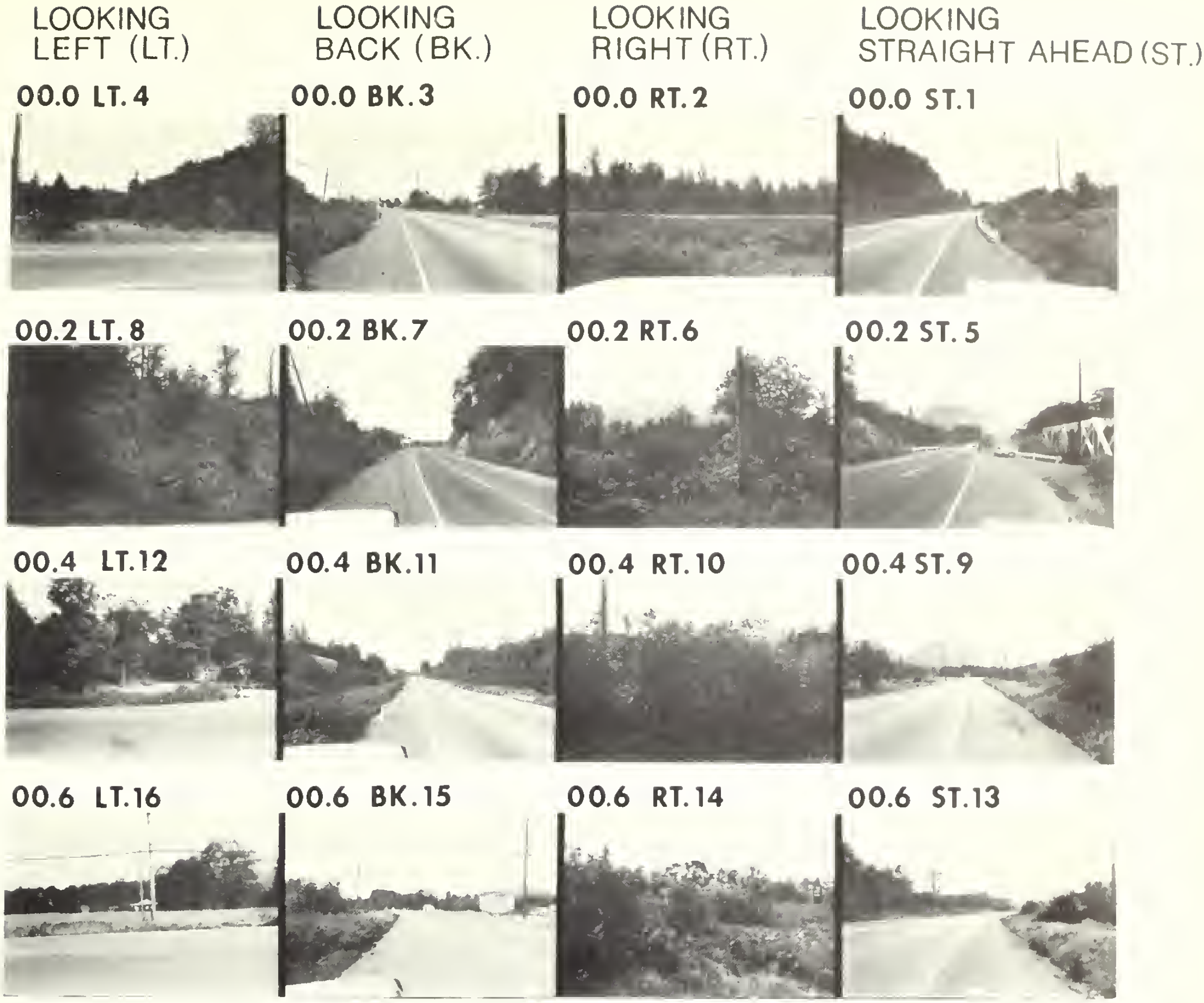

Figure 2.–A portion of a 35-millimeter "proof sheet" used to measure manmade alterations within the visual corridor along U.S. Route 2. Photographs should be read from right to left. Each group of four represents a photo point two-tenths of a mile from the last photo point. The notations above each frame give the photo point relative to the start of the inventory, the view direction, and the photo frame number.

Large-scale Aerial Photography

Initially, large-scale photographs (1:24,000) were tested to determine if impacts could be inventoried from them. To determine whether or not impacts could be seen from the roadway, a "floating line" technique (same principal as the "floating dot" technique described in most elementary aerial photogrammetry texts) was tried on stereo-paired photographs during a preliminary inventory. This was found too time-consuming if every impact on a large-scale inventory were checked, especially when the "floating line" crossed more than one stereo pair. It is applicable, however, for checking individual points.

Because of the difficulty in establishing lines of sight from aerial photos, the question of whether or not impacts could be seen from the road was ignored in an attempt to develop a more workable aerial photo technique.

Based on initial work with standard aerial photos, an inventory technique was devised using "blueline" photo enlargements (scale 1:24,000). Each of these measures approximately 18 by 18 inches and each covers a township. These give adequate detail, and their large size, scale, and the identification of many features compensate for their lack of stereo viewing. Section lines and numbers are indicated, and many towns, roads, streams, and lakes are labeled.

Photo enlargements with these characteristics may not be readily available outside the State of Washington, in which case photo mosaics or other large-scale photos comparable to the blueline enlargements would have to be substituted.

In the inventory, the topographic corridor was drawn on the blueline photographs after its location was estimated from inspection of contour lines on a topographic map. In some instances, contour profiles were constructed to find the most distant point that was potentially visible from the roadway. Impacts within the corridor were then located and identified on the photographs. The area was calculated in acres for these impacts, except for roads and railroad rights-of-way, which were measured in miles.

Small-scale Aerial Photography

Because large-scale aerial photographs can be cumbersome to handle and often have unnecessary detail for interpreting impacts, we also tested small-scale photos. Fortunately, earth satellite simulation photos were available, through the Washington State Department of Natural Resources. These photos had been taken for appraising effectiveness of U.S. Geological Survey Earth Resources Observation Satellite (EROS) for natural resource surveys.

The photos were taken in mid-May of 1969 from an altitude of approximately 36,500 feet, using an extreme wide-angle lens. This provided coverage of 250 to 300 square miles on each 5- by 5-inch photograph, giving a photo scale of approximately 1:250,000. Stereo coverage was taken using "false" color film (Ektachrome Infrared Aero).[3/]

[3/] *Mention of product by name is for identification only and does not imply endorsement by the U.S. Department of Agriculture.*

For the inventory, the analyst began by sketching the topographic corridor on the photos. This was sketched under stereo-viewing and guided primarily by direct observation but with frequent use of the "floating line" technique mentioned earlier. Impacts within the corridor were then located, identified, marked, and labeled on the photos.

COMPARISON OF THE TECHNIQUES

The four inventory techniques investigated were compared on the basis of the type and quality of data obtained, the types of maps that resulted, area covered, and costs and time required.

The number of discernible impact types varied from seven for the small-scale aerial photography technique to 12 for the ground surveillance and ground photo techniques. But in the actual inventories, only four to eight impact types were observed. For the ground surveillance and ground photography techniques, each of the original 12 impact types could have been identified had they been present.

On the photographs used for the large-scale aerial photography technique, some of the impacts easily recorded from the ground were not discernible. For example, utility poles and powerlines were distinguishable only on cleared rights-of-way. Roadside advertisement was also difficult or impossible to interpret from aerial photos. As it was very difficult to distinguish between commercial or noncommercial buildings, no distinction was made.

Of the original 12 impacts, 10 could have been inventoried by the large-scale photographs. These were farming, logging, powerline rights-of-way, roads, mining, dumps, railroads and airports, buildings, some types of air and water pollution, and towns.

In the small-scale aerial photography technique only seven of the 12 original impacts could have been adequately identified--farming, logging, powerline rights-of-way, mining, dumps, water pollution, and towns. Utility poles and lines along highways could not be seen on the photos, but the cleared rights-of-way for power transmission lines were visible. No mining or dumps were recorded in this inventory, but they would be visible provided they covered an area 100 to 200 feet across.[4/] An open pit mine or large area of tailings would be necessary for mining to show.

Map Presentation

The type of map used for recording impacts is arbitrary, but the most direct graphic procedures for each technique will yield very different pictures.

For the ground surveillance and the ground photography techniques, impacts were most easily presented on a topographic quadrangle map. For the large-scale aerial photo technique, it was easiest to map impacts directly on the blueline aerial photo enlargements. For the small-scale aerial photo technique, it was most convenient to sketch directly on the photographs (for example, see fig. 3).

[4/] *Unpublished paper by H. Gyde Lund, "Determining the usefulness of space photography for forest fire science," 10 p., Coll. Forest Resour., Univ. Wash., 1969.*

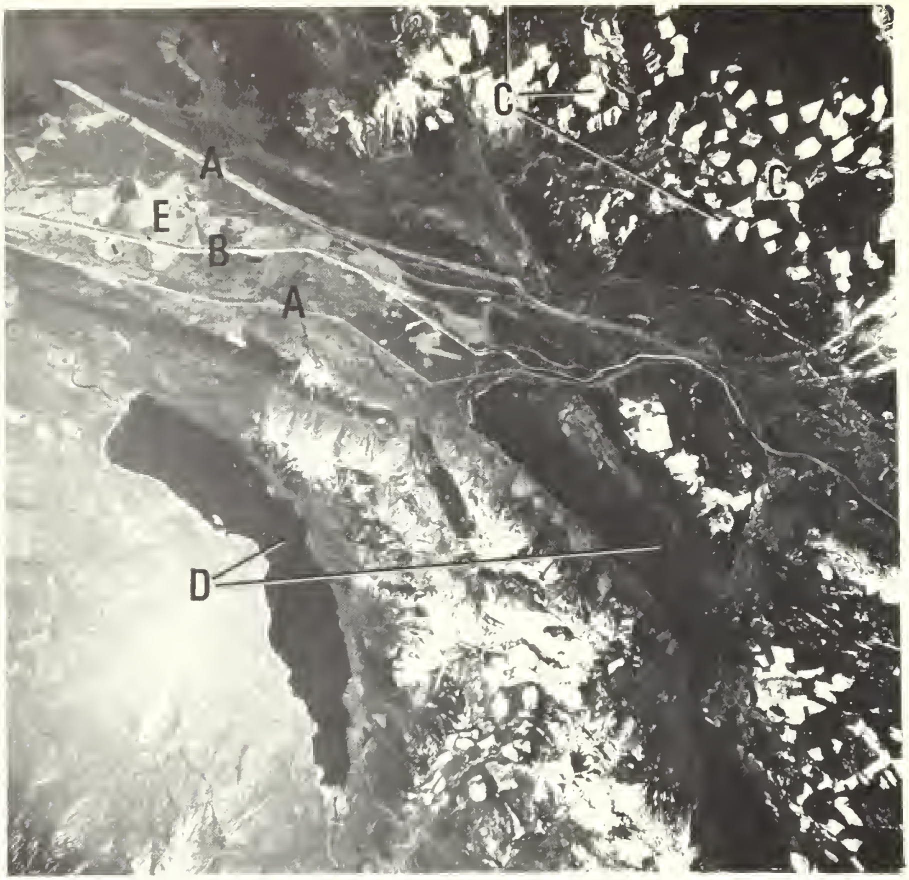

Figure 3.—Actual size of the satellite-simulated "false color" photograph printed in black and white. View is similar to the inventory area. Powerline rights-of-way (A), roads (B), logging areas (C), lakes (D), and agricultural lands (E) are easily seen without magnification. (Photo courtesy of State of Washington Department of Natural Resources.)

Inventory acreages differed substantially depending on inventory method. The topographic corridor, used for the aerial photo techniques, covered approximately 3-1/2 times as much area as the visual corridor, used for the on-the-ground techniques. On the large-scale photos, the topographic corridor acreage measured was 17 percent greater than on the small-scale photos, and the visual corridor acreage for the ground surveillance was 14 percent greater than for the ground photography.

Impact Data

For the two ground techniques, impacts were summarized by the computer, by gross mileage, net mileage, and amelioration possibilities.

To indicate the biases involved in the ground surveillance and ground photography techniques, differences in the gross mileage for eight impact types were compared. Ground photo mileages were subtracted from ground surveillance mileages. For the 10.3

miles of highway examined, the ground photography technique gave slightly more mileage than the ground surveillance technique:

Impact	Ground surveillance minus ground photo
	(Miles)
Logging	5.3
Utility poles, lines	1.2
Advertisements	.8
Mining	-.1[5/]
Railroads	.7
Buildings (commercial)	-.2
Buildings (noncommercial)	.1
Towns	-.2

This is consistent with the more intense and continuous data collection of the ground surveillance technique. The greatest difference was in logging and resulted primarily from misinterpretation of the older logging areas, which, on photos, do not differ markedly in contrast from surrounding area.

Data interpreted from the large-scale and small-scale aerial photography techniques are summarized below. Because only farming, logging, towns, and powerline rights-of-way were identified on the small-scale photos, techniques can be compared for only these four impact types. For farming impacts, measurements obtained from small-scale aerial photography were 9 percent less than measurements obtained from large-scale aerial photography. For logging, the acreage measured on small-scale aerial photos was about 5 percent less.

Impact	Large-scale (1:24,000)	Small-scale (1:250,000)
	Acres	
Farming	813	740
Logging	1,405	1,331
Towns	179	228
Buildings	13	--
Powerlines	563	--
Unknown	140	--
	Miles	
Railroads	15.3	--
Roads	79.8	--
Powerline rights-of-way	16.0	20.8

5/ The minus sign results from the algebraic sum of ground surveillance minus ground photo. For example, there was more "mining" recorded by ground photo than by ground surveillance.

Because logging areas are often along ridges, they are subject to measurement error resulting from misplaced corridor boundaries. This is especially true on small-scale aerial photography where a small error in boundary placement may account for large acreages.

Towns showed the greatest difference between acreages for the two aerial photo inventory techniques. Twenty-one percent more acreage was measured by the small-scale aerial photography technique than by the large-scale. This large measurement difference resulted from misinterpretation of the small-scale, "false" color photographs. More knowledge of town boundaries and greater experience in photo interpretation should help reduce this error.

For powerlines, 23 percent more miles was recorded from the small-scale than from the large-scale photos. This resulted primarily because part of a powerline was located on the same ridge as the topographic corridor. On the small-scale photos, 5 miles of powerline were interpreted as within the topographic corridor; but on the large-scale photos, the line was judged as outside the corridor.

Cost and Time Expenditures

Cost data for the four inventory techniques are not directly comparable. The amount and nature of the information obtained varies considerably from one technique to another. Therefore, inventory objectives as well as inventory costs may dictate procedures. Costs can be divided into labor costs and equipment or special services costs:

Technique	Materials and equipment[6]	Man-minutes[7]	Total cost[8]
	Amount per mile		
Ground surveillance	$0.42	29.0	$1.87
Ground photography	3.35[9]	32.0	4.95[9]
	3.03[10]		4.63[10]
Large-scale aerial photo	.49	17.0	1.35
Small-scale aerial photo	1.74[9]	9.5	2.22[9]
	1.14[10]		1.62[10]

Labor costs for the two ground techniques were about equal, but materials and equipment costs for ground photography greatly exceeded those for ground surveillance. Labor, materials, and equipment costs for small-scale and large-scale aerial photography may fluctuate greatly.

6/ *Includes cost of transportation, film and processing, computer time, air photos, and miscellaneous.*

7/ *Includes field and office labor and keypunching.*

8/ *All labor figured at $3 per hour, excluding overhead and administration.*

9/ *Camera-stereoscope costs were amortized over a 500-mile inventory.*

10/ *Camera-stereoscope costs not included, assuming cost absorbed elsewhere.*

Cost depends on several factors. As the size of the inventory increases, costs per mile may drop, especially if equipment can be amortized over a greater number of miles. Equipment and photo-processing costs could vary greatly depending on their availability and ownership.

DISCUSSION AND CONCLUSION

For inventory of visual impacts along roadways, the choice of method will generally depend on cost, detail needed, and availability of photos, maps, and equipment. The ground surveillance technique and the two aerial photo techniques are each suited to operational use for inventories of visual impacts in roadway corridors. Ground photography tends to undermeasure the total impacted area and is more costly than ground surveillance procedures. However, it provides a permanent record of the landscape, permitting examination of landscape changes over time.

Inventory techniques can be selected or modified to suit specific needs. Thus, if the view from the road is important to inventory objectives, some version of the ground surveillance technique would be appropriate. For example, to take advantage of Federal matching funds under the Highway Beautification Act, a State highway commission might need information on all impacts visible from the road. On the other hand, in determining where to put additional powerlines, a governmental unit might decide that powerlines should be concentrated wherever possible to leave other areas unblemished. Then an aerial photo inventory technique would be adequate for determining where existing powerlines and other manmade developments were currently concentrated.

Ground surveillance data can be recorded and presented on maps, aerial photos, or photo mosaics. The recency of maps and photos may dictate the choice. Aerial photos are generally more up-to-date than available maps, especially U.S. Geological Survey topographic maps which may not be updated for decades. During this time, many cultural features will change. As an example, the most recent topographic maps available for the study reported here were dated 1957, whereas the most recent "blueline" and small-scale photos were dated 1966 and 1969, respectively.

For some purposes, the detail on photo mosaic index sheets may be sufficient for an inventory conducted primarily in the office, with fieldwork only to calibrate and improve office interpretations of impacts. Each photo mosaic index sheet is a photo reduction of approximately 200 9- by 9-inch aerial photographs assembled in mosaic form. Such sheets measure 20 by 20 inches, have a scale of approximately 1:63,000, cover about 300 square miles, and can be purchased for $2.50 to $3 each.

Color photography, in either true or "false" color, costs about 1-1/2 times as much as standard black and white aerial photos. The major advantage of color, especially "false" color, is the increased differentiation it provides among small variations in ground objects. However, the added expense is not likely to be justified unless the photographs are already available.

Whatever the combination of procedures and techniques, inventory of visual impacts is important. We now have a steady and indiscriminate encroachment of unfortunate visual impacts along roadway corridors. If this continues, most of these corridors will be reduced to scenic monotony and mediocrity.

Ideally, unavoidable scenic blemishes would be concentrated in the fewest possible "visual sewers," thereby protecting the scenic quality of all other roadway corridors. Thus truck routes, powerlines, pipelines, etc. might be assigned to the least scenic routes. This ideal will probably never be reached. However, public sentiment seems to be growing for more careful land use and zoning that can at least prevent the worst of all possible worlds. The techniques reported here can help to define both scenic problems and opportunities and can provide data for those who must determine what patterns of use--among those still possible--would be most desirable.

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The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

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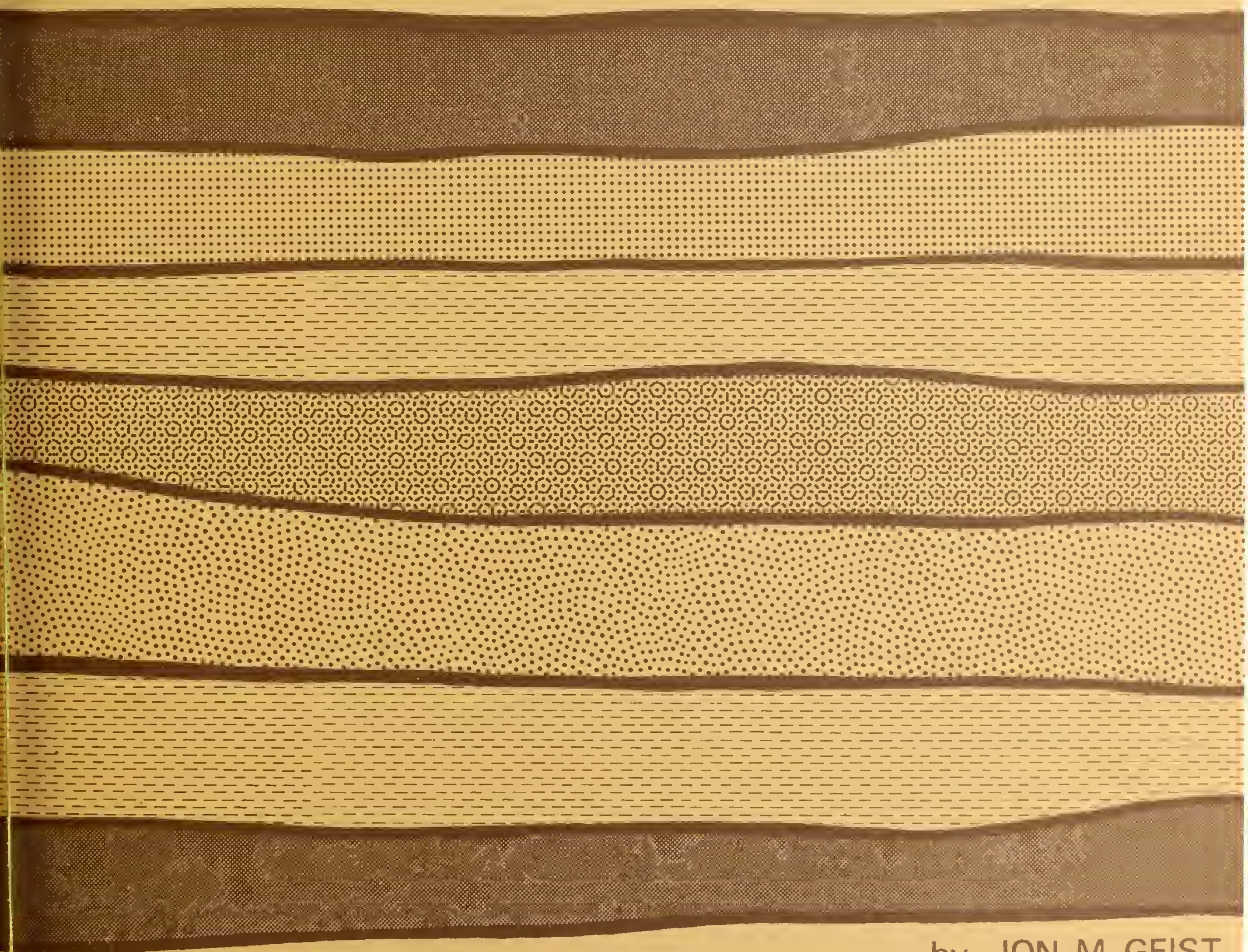
1971
USDA FOREST SERVICE RESEARCH PAPER PNW-122

ORCHARDGRASS RESPONSES TO FERTILIZATION OF SEVEN SURFACE SOILS FROM THE CENTRAL BLUE MOUNTAINS OF OREGON



by JON M. GEIST

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE

ABSTRACT

Growth responses to application of all combinations of N, P, and S on four forest and three grassland soils showed that a significant N-S interaction existed for all seven soils. For two grassland soils, a significant response to phosphorus was obtained in combination with nitrogen and sulfur. The volcanic-ash-derived soils and the Klicker soil had the highest potential yield responses to fertilization.

Fertilization programs involved with soils which have chemical properties similar to these studied should consider only fertilizer sources which contain both N and S in all cases, and N, S, and P for certain grassland soils.

Keywords: Fertilization (plants), soil fertility, nitrogen, sulphur.

INTRODUCTION

The beneficial and detrimental effects of fertilizers in today's highly intensive land management activities are the sources of enthusiasm and concern for their use tomorrow. Proper and appropriate use of fertilizers leads to increased yields, increased profits, improved esthetics, or other benefits. Misuse of fertilizers may lead to environmental depletion of various forms. Therefore it is imperative that the land manager be well informed on both of these use effects prior to fertilizer application on the landscape to be treated.

Little published information exists about the fertilizer response characteristics of upland forest and grassland soils of northeastern Oregon and southeastern Washington. No research has been directed toward identifying specific nutrient deficiencies which might exist in this area. Hedrick et al. (1965) noted large dry matter and protein yield increases for numerous grasses through fertilizer application on a Couse soil in the Wallowa Mountains foothills. Variation in fertilizer benefits was found among species studied and among clipping treatments. Pumphrey (1961, 1963) has studied agricultural crops and soils in relation to plant nutritional requirements.

Predictive quantified knowledge about fertilizer requirements is needed today in relation to many land management activities including forest trail stabilization, increasing timber production, increasing summer forage for livestock, improving logging rehabilitation practices, road cut and fill stabilization, and other erosion and sediment reduction programs.

Several steps are necessary in a research program leading to this prediction capability. The first of these is establishing what nutrient deficiencies may exist for the soil or soils in question. Assays of soil fertility have been made in other areas using biological techniques (Youngberg and Dyrness 1965, Johnson 1969). This method is generally successful and offers an opportunity to compare a number of fertilizers in various combinations over a short period of time using minimal manpower and money. Care in extrapolating these data to the field is necessary, although this also has been successful (Vlamis, Stone, and Young 1954; Wagle and Vlamis 1961).

This study was aimed at determining the major nutrient deficiencies in seven soils found in the Blue Mountains of Oregon.

METHODS

Surface soil material (0- to 6-inch depth) of seven soil series was collected from locations on the Starkey Experimental Forest and Range, 30 miles southwest of La Grande in Union County, Oregon. Several samplings were from locations of soil survey representative profiles.[1/] The soil series were Couse, Klicker, Albee, Anatone (series designation for this soil is currently under reinterpretation but

[1] Soil Survey, Starkey Experimental Forest and Range, Union and Umatilla Counties, Oregon. (Mimeogr.) USDA Soil Conserv. Serv., and USDA Forest Serv. 32 p., 1960.

was mapped as Rock Creek in 1957), Ukiah, Tolo (volcanic ash over a buried B horizon), and another volcanic ash-derived soil. The latter soil series was included in the Tolo series originally but has since been removed from that classification and the new series has not been renamed.[2] This soil was derived from volcanic ash which overlies relatively unweathered basalt bedrock. Characteristics of these soils and their associated vegetation have been documented (Strickler 1965, Geist and Strickler (1970).

Field-soil sample materials were air-dried and passed through a 1/4-inch screen. A subsample of each soil was screened through a 2-millimeter sieve and analyzed chemically prior to the planting process. The gravel content (1/4-inch to 2-millimeter size) of the subsample was determined by weight. The chemical analyses included pH (1:2 in 0.01 M $CaCl_2$), organic matter (Walkley-Black method, Jackson 1958, p. 219-221), extractable K (U.S. Salinity Laboratory staff 1954, p. 100-101), total nitrogen by Kjeldahl (Jackson 1958, p. 187-190), and available P by the sodium bicarbonate method (Watanabe and Olsen 1965).

Fertilizer treatments imposed on each soil were 0 and 100 parts per million each of nitrogen, phosphorus, and sulfur singly and in combination in three replications of a 2 by 2 by 2 by 7 balanced factorial design. Two thousand grams of soil were used in 6-inch pots and de-ionized water was added periodically by weight to maintain moisture tensions in the 1/10- to 1/3-bar range. Plastic bag liners prevented soil and moisture loss, and filler material was used below the bags to equalize the height of the soil surface at the top of the pots. The fertilizer treatment sources were ammonium nitrate, sodium sulfate, and monocalcium phosphate. These were mixed into the dry soil material before initial watering and planting. Seven seeds of Latar orchardgrass (*Dactylis glomerata* L.), a species commonly used in revegetation and soil stabilization, were planted in each pot and were later thinned to five plants. Planting was done January 8, 1970, and plants were harvested 55 days later on March 5.

Mature plants were clipped at the soil surface at harvest, dried for 90 minutes at 100° C., further dried at 60° C. for 24 hours, and then weighed (Mayland 1968).

RESULTS

The chemical analyses of the surface soils used as experimental material indicated that there were sizable differences among the soils in both chemical and physical status (table 1). Extractable potassium values indicated adequate levels for plant growth in all cases, and pH values differed little among soils. Other analyses will be discussed in relation to greenhouse experimentation.

Combined Factorial Analyses for All Soils

The initial statistical analyses of treatment effects on plant growth were made for all soils combined, and table 2 is a summary of the analysis of variance. Significance is shown for main effect factors; this is

[2] Personal communication, Grant Lindsay, Soil Conserv. Serv., Baker, Oreg.

Table 1.--*Chemical and physical properties of the surface soils used in the fertilizer study*

Series sampled	pH	Organic matter	Total nitrogen	Gravel content	Extractable K	Available P
		-----------Percent-----------			*Meq./100 g.*	*P.p.m.*
Grassland soil:						
Albee	5.6	2.73	0.14	19	0.6	10.4
Anatone (Rock Creek)	5.4	3.87	.19	24	.6	8.4
Ukiah	5.5	4.70	.21	19	1.2	19.6
Forest soil:						
Couse	5.5	9.63	.35	22	1.1	21.8
Klicker	5.8	5.83	.17	37	1.8	25.2
Tolo	5.5	2.24	.07	12	1.3	87.0
Ash over basalt	5.4	2.94	.09	16	.9	66.6

Table 2.--*Summary table of analysis of variance of orchardgrass dry matter production for all soils and the various combined treatment effects*

Source	Degrees of freedom	Mean squares	F value
Replication	2	1.67	--
Soils (So)	6	35.03	1/96.83
Nitrogen (N)	1	204.16	1/564.32
Sulfur (S)	1	267.02	1/738.07
Phosphorus (P)	1	13.83	1/38.23
Interactions:			
SoN	6	10.54	1/29.13
SoS	6	4.74	1/13.10
SoP	6	1.02	2.82
NS	1	190.72	1/527.17
NP	1	6.33	1/17.50
SP	1	2.19	6.05
SoNS	6	4.58	1/12.66
SoNP	6	.61	1.69
SoSP	6	.86	2.38
NPS	1	5.36	1/14.82
SoNSP	6	.46	1.27
Error	110	.36	--

1/ Significant at the 0.01 level.

influenced by the significant interactions shown in the lower portions of the table and not necessarily due to the main effect influence alone. For example, the test of significance of the nitrogen treatment alone involves comparison of the means of all treatments containing nitrogen (including combinations as NS and NPS) as opposed to those lacking nitrogen. Because of significant interaction effects (NS, NPS, etc.), one cannot deduce the influence of nitrogen when no other elements are added. Discussion of individual soils indicates further interaction effects in the data.

The statistical tests indicated significant N and S fertility differences among soils as evidenced by their NS interaction response, and their response to N and S (SoN and SoS, respectively). Over all soils, significant interactions were noted for NS, NP, and NPS sources. The reader can note these effects in later comparisons among individual soil response patterns.

The general conclusion from the above results hence is that fertilizer combinations of N and S or N, P, and S are desirable when looking at the average response over all the soils being studied. The discussion below explains which soils would potentially benefit from these treatment combinations.

Factorial Analyses of Individual Soils

Results of treatment effects on grass growth for individual soils have been conveniently placed into grassland and forest soil groups. Bar graphs which illustrate the replicate means of grass growth for all treatment combinations are presented. Exemplary photographs of plant growth on some of the soils and treatments have been included with the graphical data. Height growth can be compared using the 6-inch interval scale behind the plants. One should note gray tonal differences in the foliage which are readily visible among the treatments and are a reflection of the coloration symptoms exhibited by the nutrient deficient plants. The greatly increased tillering which occurred in conjunction with growth responses is apparent in some photographs but was not quantified.

GRASSLAND SOILS

Within the grassland group, grass growth on the Anatone (Rock Creek) and Albee soils showed very similar responses to treatment combinations (figs. 1 and 2). The factorial analyses of variance for the two soils were nearly identical, and both showed significant F-values for all sources tested as shown for the Anatone soil (table 3). The earlier discussion about significant interactions and their relation to main effect tests is amplified when one compares these statistical tests to actual treatment means (fig. 1). Even though the effect of nitrogen alone caused a slight depression in yield, the statistical test of the overall effect of nitrogen on the Anatone soil was significant. This was apparently due to the significant NPS interaction (table 3, fig. 1).

The significant NPS interaction for the Anatone and Albee soils indicates the necessity of using all three fertilizer elements for maximum growth. These were the only soils in either group exhibiting a significant benefit due to phosphorus additions. This would be expected because of their comparatively low analytical level of available phosphorus (table 1). These soils had similar gravel content, hence a similar dilution effect on nutrient content. Field responses to

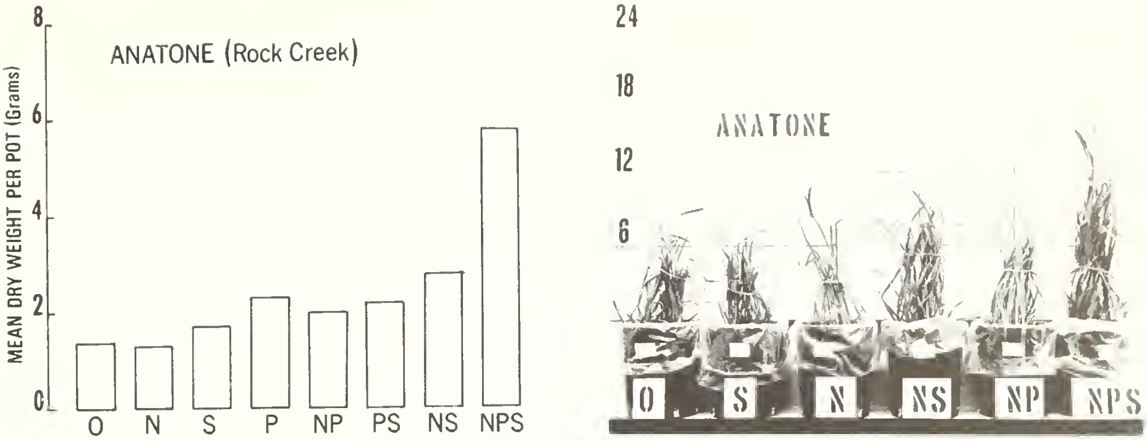


Figure 1.—Mean dry matter produced by each fertilizer treatment combination on the Anatone (Rock Creek) soil. The photograph illustrates plant growth with certain treatments.

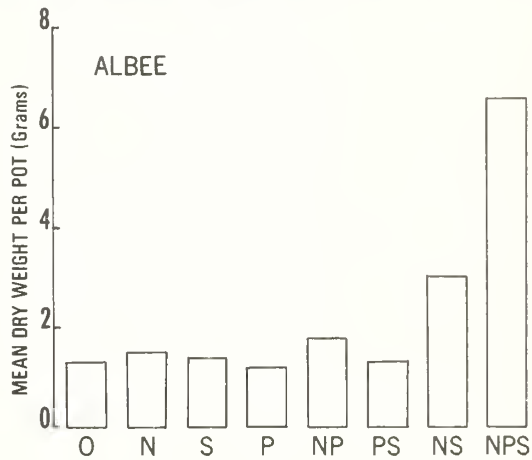


Figure 2.—Mean dry matter produced by each fertilizer treatment combination on the Albee soil.

Table 3.--*Analysis of variance of grass growth on the Anatone (Rock Creek) soil*

Source	Degrees of freedom	Mean squares	F value[1/]
Replication	2	0.64	--
Nitrogen (N)	1	6.82	53.47
Sulfur (S)	1	11.20	87.77
Phosphorus (P)	1	9.62	75.40
Interactions:			
NS	1	9.88	77.40
NP	1	1.81	14.22
PS	1	1.60	12.54
NPS	1	2.66	20.89
Error	14	.12	--

[1/] All are significant at the 0.01 level.

P fertilization should be expected in the 5-10 p.p.m. soil analysis range; however, a response at twice these soil levels (20 p.p.m.) is not uncommon with potted plants in the greenhouse.[3]

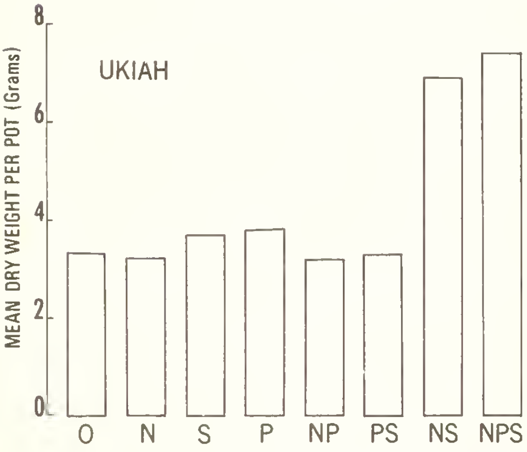
The third soil in the grassland group was the Ukiah. Statistical analyses again showed a significant nitrogen-sulfur interaction, but there was no significant effect due to phosphorus. There is also a much higher unfertilized level of growth than found for the other two soils (fig. 3). The latter may be indicative of a higher and better balanced nutrient regime in the Ukiah soil, which had a considerably higher available P level (table 1).

FOREST SOILS

The Klicker and Couse grass yields showed considerable similarity in their responses to treatments (figs. 4 and 5). There were small-yield increases over the control due to sulfur (S and PS); however, the only meaningful increases were due to the NS and NPS treatments. Factorial statistical analysis indicated a significant (0.01 level) NS interaction response but a nonsignificant effect due to phosphorus for both soils. A tendency for an NPS interaction (F-value = 4.82) was noted in the Klicker yields, hence the greater effect of P. Although analysis for P was higher for the Klicker than the Couse soil, the dilution effect of a greater gravel content in the former was apparently offsetting (table 1).

Both soils derived from volcanic ash exhibited highly significant nitrogen-sulfur interactions with no detectable effects of the phosphorus treatment (figs. 6 and 7). The difference in effects from nitrogen applied alone might be attributed to a lower sulfur level in the Tolo soil which would negate benefits from N applications. These two soils showed the highest potential responses to fertilization among all soils and would each require both nitrogen and sulfur for maximum yield benefits. In contrast,

[3] Personal communication, F.S. Watanabe, USDA Agr. Res. Serv., Dep. Agron., Colo. State Univ., Fort Collins.



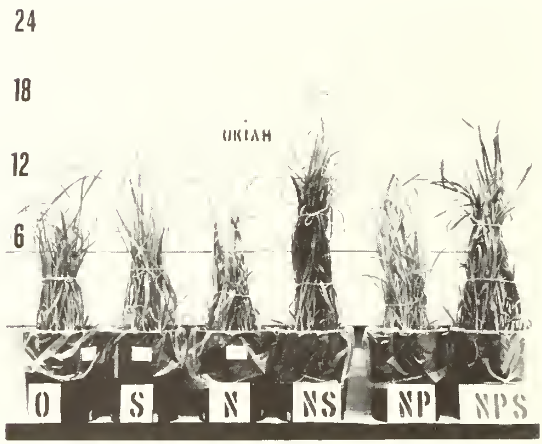


Figure 3.—Mean dry matter produced by each fertilizer treatment combination on the Ukiah soil. The photograph illustrates plant growth with certain treatments.

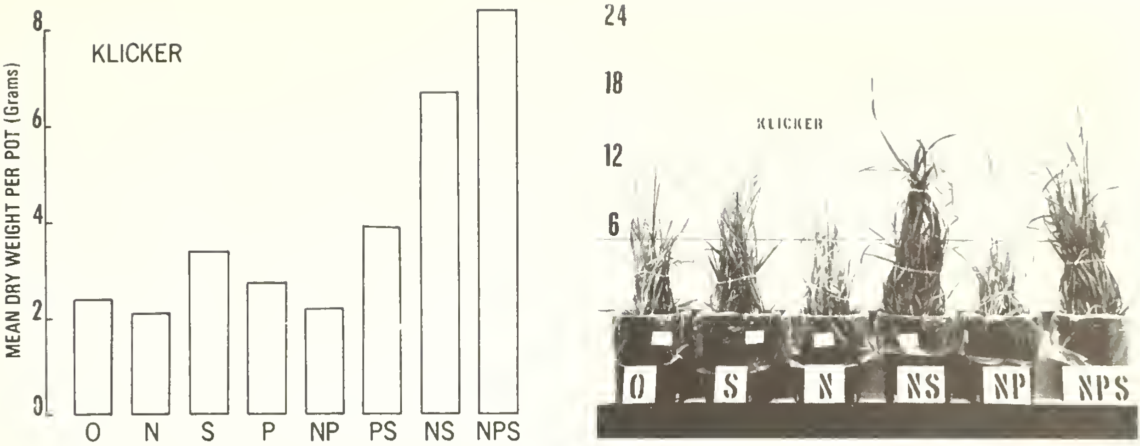


Figure 4.–Mean dry matter produced by each fertilizer treatment combination on the Klicker soil. The photograph illustrates plant growth with certain treatments.

both soils were comparatively low in general fertility status except for available phosphorus values which were quite high (table 1), and their unfertilized yields were the lowest of all soils.

General Trends

Differences in levels of dry matter produced among soils for unfertilized and fertilized treatments are readily evident (fig. 8). Differences in growth responses (over the control) are easily viewed. Under the NPS and NS treatments, the responses to fertilization were highest on the volcanic ash soils and the Klicker soil. Total production for the NPS treatment was similar among these three and the Couse soil. It is obvious here that the benefits of using nitrogen alone are negative on most soils and insignificant on all soils. Growth responses from phosphorus applications were significant in only two instances (Anatone and Albee grassland soils) and then only in combination with nitrogen and sulfur. The necessity of using nitrogen and sulfur together in all cases is thus emphasized.

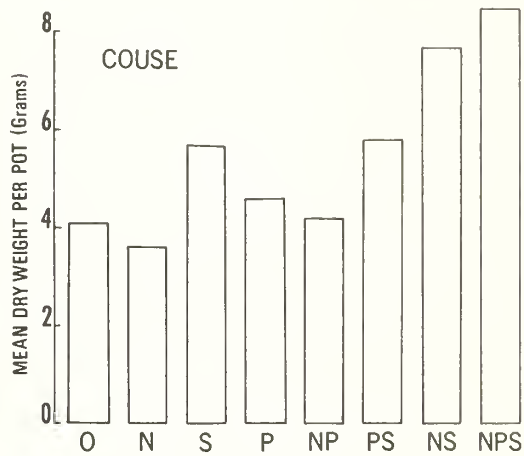


Figure 5.–Mean dry matter produced by each fertilizer treatment combination on the Couse soil.

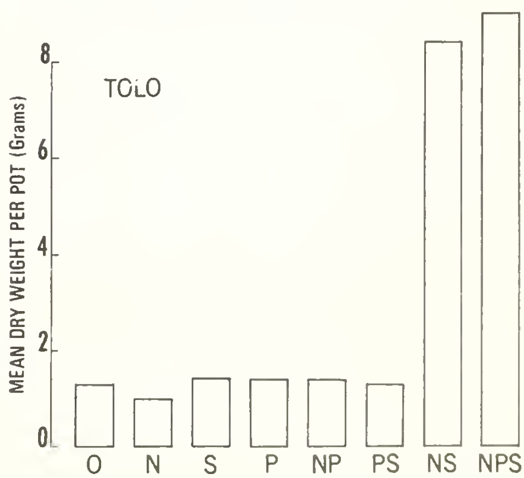


Figure 6.–Mean dry matter produced by each fertilizer treatment combination on the Tolo soil.

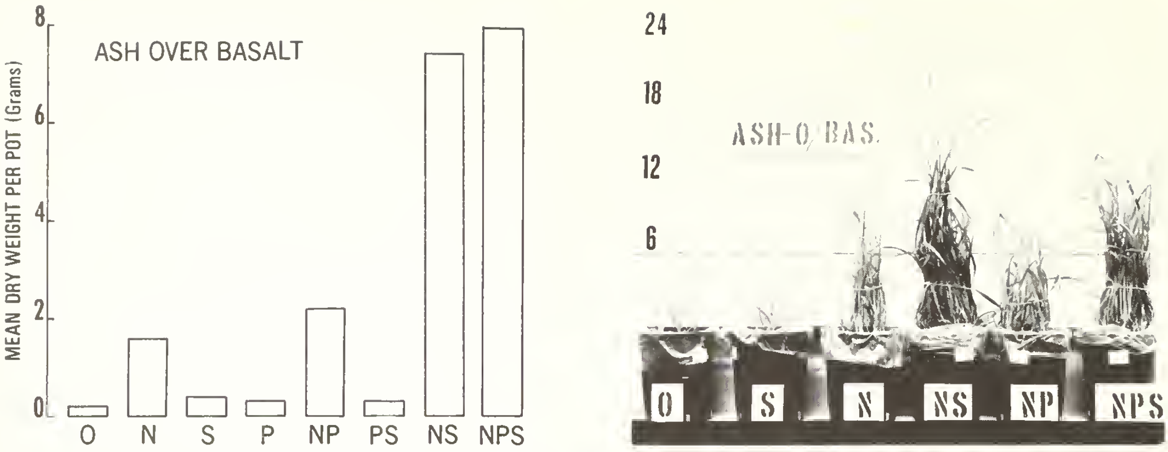


Figure 7.—Mean dry matter produced by each fertilizer treatment combination on the ash over basalt soil. The photograph illustrates plant growth with certain treatments.

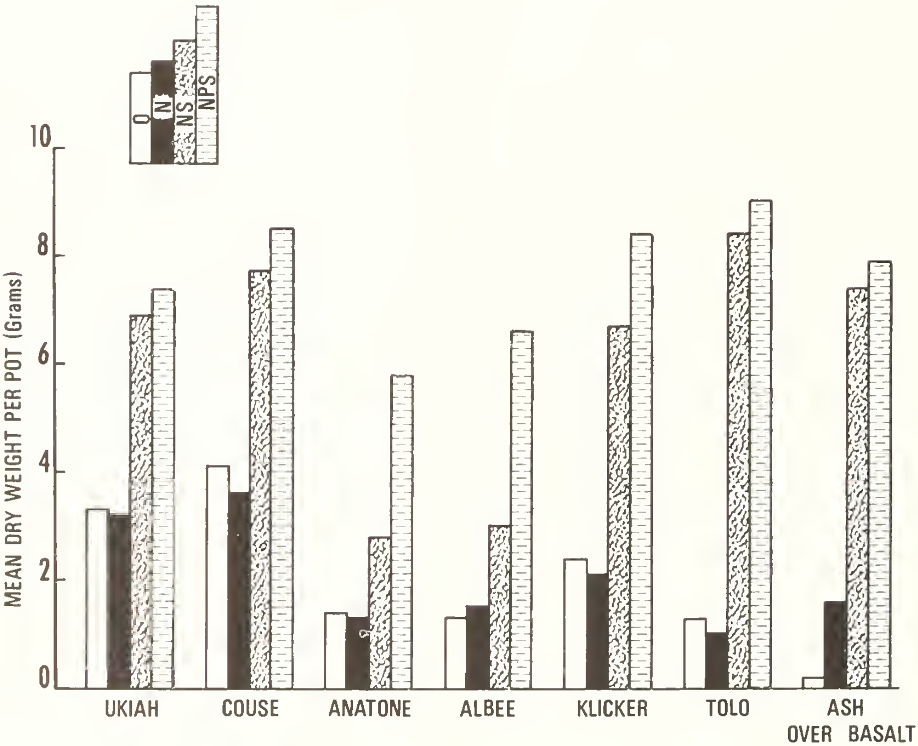


Figure 8.—Growth of orchardgrass on unfertilized and fertilized seven study soils (arranged from left to right in increasing order of response to NPS over control).

DISCUSSION

Implications of the results may be immediately apparent to many forest landowners and administrators because of current trends in the use of fertilizers in various land management activities. A number of the fertilizer materials commonly used today are nitrogen sources only (ammonium nitrate, urea) or contain nitrogen and phosphorus only (ammonium phosphate nitrate, diammonium phosphate). Any of these fertilizers would be a poor choice for use on soils with characteristics similar to those studied here because all of them lack sulfur. Where fertilizer is considered appropriate, use of materials containing both nitrogen and sulfur (ammonium sulfate, ammonium nitrate sulfate, etc.) on all such soils is recommended because of the consistent N-S interactions found. Phosphorus may be necessary in addition to N and S on the Anatone (Rock Creek) and Albee soils. If a complex of soils is to be fertilized, then a fertilizer containing all three elements may again be necessary.

Looking at the results from an economic standpoint, one can see that the greatest potential return should come from fertilization of soils derived from volcanic ash and the Klicker soil. Extrapolation of greenhouse results to the field are difficult at best and are complicated by possible limiting interactions with other site characteristics such as soil moisture, temperature, slope, and aspect. An assessment of potential hazards related to environmental quality must be made as well. Hence, one should evaluate all these factors in order to decide how and where a fertilizer program will be of benefit.

Since these results apply to orchardgrass, the effects of similar treatments on other grass and tree species are largely still in question. However, some published comparisons of grass species performance have been made. Hedrick et al. (1965) studied the yield response of a number of grass and grass-legume species on a Couse soil in the Wallowa Mountains foothills. Fertilized (60 pounds of N, 18 pounds of P, and 24 pounds of S per acre) yields of most grass species was double that of unfertilized yields the first year, but there was no significant residual effect of fertilizers the second year. Grass-legume mixtures responded poorly both years. These investigators noted considerable differences in yields of the various species, as did Pumphrey (1971) who compared the yield increases of 27 grasses grown in fertilized plots on a Tolo soil. Treatments in the latter study consisted of annual spring applications of N, P, and S (60, 10, and 11 pounds per acre, respectively) for 4 continuous years. The average annual increase in dry matter produced for all species was 1,800 pounds per acre, with three grasses showing an average increase of over 2,500 pounds per acre. Unfertilized Latar orchardgrass produced a 4-year average of 1,280 pounds per acre as opposed to 3,120 pounds per acre with fertilizer. Pumphrey speculated that the response was due to the combined effect of the N and S applied, and the results reported here support him (fig. 6).

A number of questions are raised by these results in relation to their possible use in future management. Certainly the results offer a much clearer idea than before as to the nutrient elements to consider in a fertilizer program. However, they offer little idea as to appropriate rates, most advantageous source, how the elements should be proportioned, proper time of application, etc. Further research is needed.

SUMMARY

Interaction responses to fertilization of orchardgrass grown in surface soils collected from seven soil series indicated that both nitrogen and sulfur were necessary to gain significant benefit from additions of either element. Fertilizer sources containing N but lacking S (e.g., urea, ammonium nitrate, potassium nitrate) are not recommended for use on soils with fertility characteristics similar to those studied. The results also showed that for two soils (both grassland soils) the maximum benefit from fertilizing was potentially attainable only by adding phosphorus with nitrogen and sulfur. No other significant phosphorus responses were noted.

Among the seven soils studied, the Klicker and volcanic-ash-derived soils indicated the highest potential yield response to fertilization and should thus give the greatest economic return if site and climatic factors are not otherwise limiting. Soil moisture availability, soil depth, soil temperature, and other factors together with an environmental impact assessment must also be evaluated before a management decision can be made about fertilizer use.

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1971
USDA FOREST SERVICE RESEARCH PAPER PNW–123

RIMARY PRODUCTIVITY OF A OUNG *Tsuga heterophylla* STAND ND SOME SPECULATIONS ABOUT OMASS OF FOREST COMMUNITIES ON THE OREGON COAST

Takao Fujimori

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This research was conducted by Mr. Fujimori when he was working as a research associate at Corvallis, Oregon, in cooperation with Pacific Northwest Forest and Range Experiment Station and Oregon State University.

ABSTRACT

A 26-year-old *Tsuga heterophylla* stand on the Oregon coast had a total biomass and current net annual production of 231.1 and 36.2 metric tons per hectare, respectively.

Keywords: Stand increment estimate, forest appraisal, ecosystem, *Tsuga heterophylla*.

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INTRODUCTION

Studies of primary productivity in forest communities are important not only in themselves but also as essential components of cycling or total ecosystem studies. Many new data on primary productivity have been reported worldwide, some of which have been organized and summarized in general reviews by Kira and Shidei (1967), Tadaki and Hachiya (1968), and Whittaker (1970). At least around the middle latitudinal zone of the northern hemisphere, considerable data on net production have been accumulated. Surprisingly, however, little information has appeared concerning coniferous forest communities in western North America, world famous for high productivity.

In this paper, I report my investigation of net production and production structure of *Tsuga heterophylla* based on analysis of a stand which appeared to be at the peak stage of production in its life cycle. In addition, I have speculated on the factors responsible for the rather large accumulations of biomass in forest communities in this region.

ENVIRONMENT AND FEATURES OF THE EXPERIMENTAL STAND

The experimental stand is located along the Oregon coast in the northwestern United States. Climatic data from a weather station nearby are shown in table 1. Annual temperature differences are minimal, neither excessively hot in summer nor cold in winter. Annual precipitation is high except during the summer; but even during summer months, frequent fog and low clouds compensate for the dry period. Isaac (1946) reported that moisture from fog adds as much as 26 percent to annual precipitation. Soils in the study area are relatively deep, fine textured, and fertile Sols Bruns Acides developed from tuffaceous siltstone (Franklin et al. 1968). The silt loam to silty clay loam A and B horizons are generally 100 to over 150 centimeters in thickness. Although acid (about pH 5. 1), the soils are high in organic matter and nitrogen.

The experimental stand lies within the highly productive *Picea sitchensis* Zone (Franklin and Dyrness 1969). Constituent tree species in this Zone are *Picea sitchensis* , *Tsuga heterophylla* , *Pseudotsuga menziesii* , *Thuja plicata* and *Abies grandis*, but only the first three are common in the vicinity of the experimental area. *Alnus rubra* is found on recently disturbed land.

The stand which occupied the experimental area before harvesting was composed of mature *Tsuga heterophylla*, with some *Picea sitchensis*. In 1951 and 1952, it was thinned, eventually resulting in a 1-acre opening. The understory trees then grew rapidly within this opening to form a new stand which was used in the experiment. The area undoubtedly received considerable shade from the sides until the surrounding trees were clearcut in 1962. According to stem analyses, constituent trees are from 19 to 32 years old. The stand is already closed, dense, competitive, and an understory is absent. No management or treatment has been carried out since this new stand formed. Based on figure 1 (Meyer 1937) and stand characteristics, this stand is believed to be at the stage of maximum yearly productivity in the development of *Tsuga heterophylla* forest communities.

Stand characteristics are:

Tree age	19-32 years
Stand density	6,627 trees per hectare
Total basal area	49.4 square meters per hectare
Mean d.b.h. (diameter at breast height)	7.1 centimeters
Mean tree height	10.0 meters
Mean clear stem length	4.2 meters

Table 1.--*Climatic data from near the experimental stand in Oregon and a station in the temperate zone in Japan*

Item	Otis, Oregon	Aomori, Japan
Elevation (meters)	49	4
Latitude	45°02'	40°49'
Temperature (degrees centigrade):		
Average annual	10.3	9.1
January average	5.3	-2.7
January average minimum	2.2	-6.7
July average	15.5	20.4
July average maximum	20.9	24.5
Index of warmth	65.4	73.8
Index of coldness	0	-24.3
Precipitation (millimeters):		
Average annual	2,995	1,305
June to August	196	329
Hours of sunshine:		
April to September	1,511	1,145
October to March	720	575

Remarks: (1) The data from Otis are mean values from 1951-60, and those from Aomori are from 1931-60.

(2) Index of warmth is the summation of the accumulated temperatures over 5° C. in each month for 1 year. Index of coldness is accumulated temperatures below 5° C.

(3) The data concerning hours of sunshine from Otis are from just the experimental area and are the mean value from 1936 to 1952.

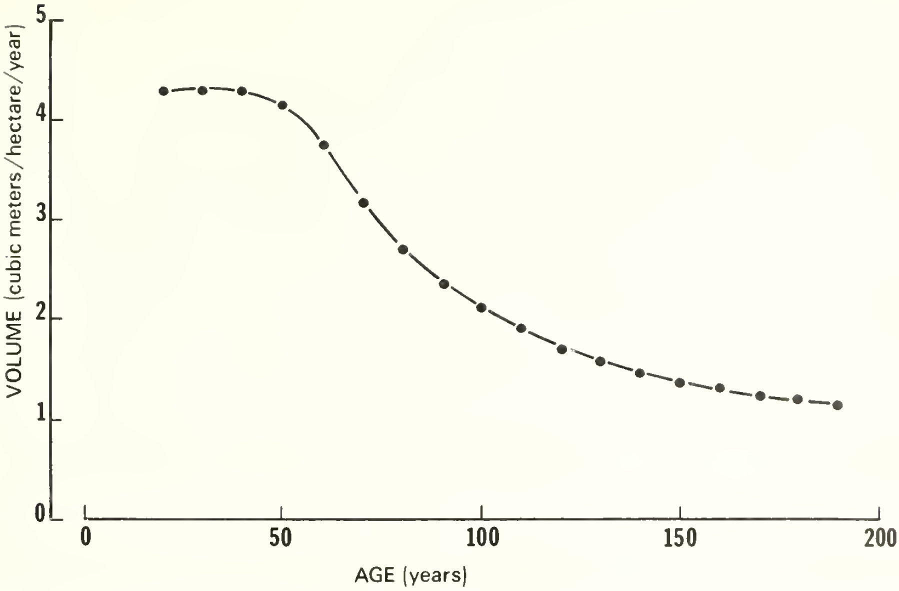

Figure 1.--Periodic annual volume (stem) increment of *Tsuga heterophylla* on highly productive sites in the Pacific Northwest (Meyer 1937).

METHOD

Most fieldwork was carried out between April 20 and May 5, 1970. An 83-square-meter sample plot was selected which included 55 trees. Ten sample trees then were selected in direct proportion to the frequency distribution of d.b.h. and tree height in the stand and were cut down. Each component was measured by the stratified clip method. Since this method was devised by Monsi and Saeki (1953), it has been used mainly by Japanese workers. By use of this method, sample trees are divided into vertical strata of a certain interval (50 cm. in this work) from base to tip. Tree components are measured within each vertical stratum. Adoption of this method makes it easy to describe and illustrate vertical stand structure profiles in experimental stands. As the angles of branches from the stem were regarded as nearly at right angles (90°), a leaf-bearing branch, from base to tip, was placed in the same 50-centimeter stratum, even if the tip was in another stratum.

In general, the net production in 1969 (Pn) is defined as the total amount of the annual biomass increment at the time of investigation (y_N) plus the biomass lost to litterfall and grazing during 1969 (L_N and G_N, respectively) (Kira and Shidei 1967).

$$Pn = y_N + L_N + G_N \qquad (1)$$

Since measurements of L_N and G_N are difficult to obtain and are considered relatively small when compared with y_N, they were disregarded, and Pn was defined as follows in this report:

$$Pn = y_{NS} + y_{NB} + y_{NL} + y_{NR} \qquad (2)$$

where y_{NS}, y_{NB}, y_{NL}, and y_{NR} indicate the biomass increment produced during 1969 in stems, branches, leaves, and roots.

Stem increment was calculated by the common method of stem analysis. This method was also adapted to the measurement of branch increment (Fujimori 1970). Three to five sample branches were chosen from each stratum in direct proportion to the branch size frequency distribution. Each sample branch was cut into 5- to 30-centimeter segments from bough to twigs in proportion to its length and thickness, and its annual growth rings were examined with a magnifying glass. Total branch increment was determined by multiplying total branch biomass in each stratum by the growth rate of the branch, as determined from the samples, in its respective stratum. Leaf increment was obtained by weighing fresh leaves which had developed during the recent year. Since direct measurement of the root increment is difficult, it was estimated from the product of root biomass and the growth rate of aboveground nonphotosynthetic organs. This calculation is based on the assumption that growth rates of roots are equivalent to those of aboveground nonphotosynthetic organs. This method is probably rough, but more accurate methods for estimation of root increment were not available.

Small samples of tree components were taken to the laboratory for analyses and were ovendried (80° C.). All weight values are expressed as dry in this report.

Area on one side of the leaf was determined by the product of leaf weight and ratio of leaf area per unit of leaf weight in each stratum. Light intensity was measured using Weston Illumination Meters, Model No. 756.[1/]

The allometric method has been developed for estimating biomass values for tree components per unit area from sample trees (Ogawa et al. 1965, Kira and Shidei 1967). Although the allometric method is regarded as the most precise method for estimating values per unit area, the following method provides values regarded as sufficiently accurate and is easier (Ando 1962, Fujimori and Yamamoto 1967). This simpler method assumes that the ratio of the sum of biomass in sample trees to that of whole trees per unit area is in proportion to the ratio of respective basal areas. In effect,

$$y = y'\frac{G}{G'}, \qquad (3)$$

where y, y', G, and G' represent the total amount of biomass per unit area, biomass of the sample trees, the total basal area per unit area, and basal area of sample trees, respectively. In this report, biomass values for tree components per unit area were estimated by this method.

RESULTS

Production Structure

The vertical distribution of the total aerial biomass for each tree component in the experimental stand is shown in figure 2. In general, the canopy structure of tolerant tree species is deeper than that of intolerant species. The canopy structure of this stand is that of a typical tolerant species. The vertical distribution of biomass increment is shown in figure 3.

1/ Use of brand names does not imply endorsement by the U.S. Department of Agriculture.

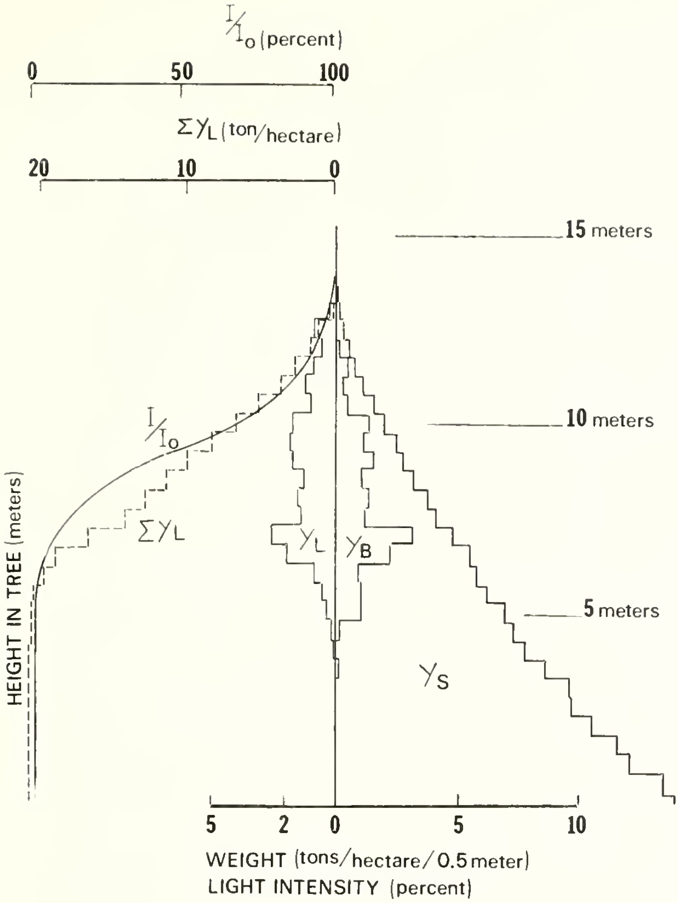

Figure 2.—Vertical distribution of leaf weight (y_L), branch weight (y_B) stem weight (y_S), and relative light intensity ($\frac{I}{I_o}$) in the experimental stand.

The characteristic of light penetration through the forest canopy is a most important factor for determining rates of photosynthesis and the distribution of photosynthetic organs in the forest community. A strong relationship can be observed between the distribution of accumulated leaf weight and relative light intensity (figs. 2 and 3); their distribution and that of stem increment are similar (fig. 3). The characteristics of these relationships have been pointed out by Monsi and Saeki (1953), Tadaki and Shidei (1960), and Shinozaki et al. (1964).

Monsi and Saeki (1953) have shown how the course of light extinction through the plant canopy can be calculated using Beer-Lambert's formula:

$$I = I_o e^{-KF} \qquad (4)$$

where I and I_o denote the light intensity under the total leaf area per unit area from the tip to a certain stratum level (F) and the incident light intensity and K denote the extinction coefficient. The F value at the bottom of canopy is called leaf area index (LAI), i.e., total leaf area within the entire canopy per unit area. Since I, I_o, and LAI were measured, K was calculated using formula 4. The values of I/I_o (percent), LAI (ha./ha.), and K in this stand were 0.79, 7.65, and 0.63. When F is substituted for leaf weight, K becomes 0.23. The I/I_o of this stand is extremely small, demonstrating that *Tsuga heterophylla* is very tolerant.

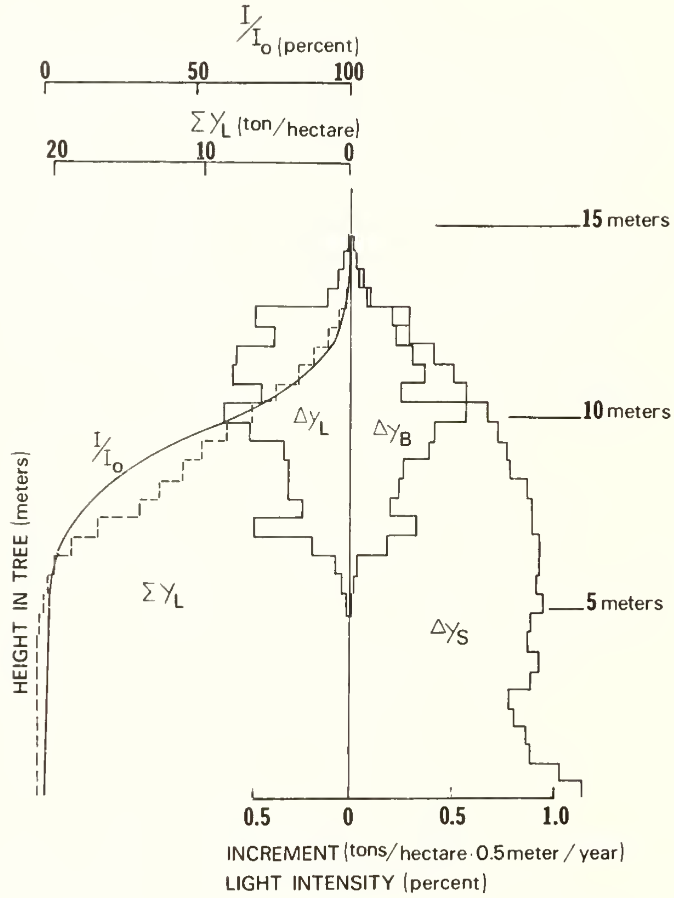

Figure 3.- Vertical distribution of leaf increment (Δy_L), branch increment (Δy_B), stem increment (Δy_S), and relative light intensity ($\frac{I}{I_o}$) in the experimental stand.

Values Per Hectare

Accumulated biomass and net production are 231.1 and 36.2 metric tons per hectare respectively (table 2). The ratio of biomass in the stem to the whole tree (0.65) is quite high for a young stand, which suggests this stand is in a fully stocked, competitive condition.

Table 2.--*Dry weights of forest components (metric ton per hectare) in experimental stand*

Component	Accumulated biomass	Current net annual production
Stem	150.9	20.4
Branch	20.7	4.3
Leaf	21.1	6.0
Root	38.4	5.5
Whole	231.1	36.2

The annual biomass increment (net annual production) is very high, not only for coniferous forests but also for other forests types which have been analyzed in eastern Asia and perhaps even in the world (Tadaki and Hachiya 1968) (fig. 4). Figure 1 shows the periodic annual volume stem increment of *Tsuga heterophylla* in the high site conditions of the study area. When increments of leaf, branch, and root are added to this graph, the peak of the curve will shift to the left to some extent, suggesting that around 20-30 years in this stand might be regarded as the highest stage of production.

Zavitkovski and Stevens[2] reported that net production of *Alnus rubra* in similar coastal Oregon areas is 26.0 tons per hectare per year in its highest stage of production. Although the method they used seems questionable in part, this value suggests high productivity even in deciduous broadleaf forest communities in this area.

DISCUSSION

Large accumulations of biomass predominate in pure or mixed forest communities of *Pseudotsuga menziesii*, *Picea sitchensis*, and other species, as well as those of *Tsuga heterophylla* in the coastal northwestern America. I would like to speculate briefly on two possible causes for the existence of such large biomasses--high productivity per unit period of time and a comparatively long continuous period at a certain level of productivity during the lifespan of a forest. As for the first cause, the data in this report suggest high yearly productivity of forest communities in this area during early stages of growth.

Relationships between photosynthesis, respiration, and environmental factors, especially climatic conditions, must be the key elements in this situation. Climatic data collected near the experimental stand and, for comparison, from Aomori, Japan, located in a temperate zone of deciduous broadleaf forest but where *Tsuga* and *Abies* forest communities are also common, are shown in table 1.

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[2] J. Zavitkovski and R. D. Stevens. Primary productivity of red alder ecosystems. (Ecology, in press.)

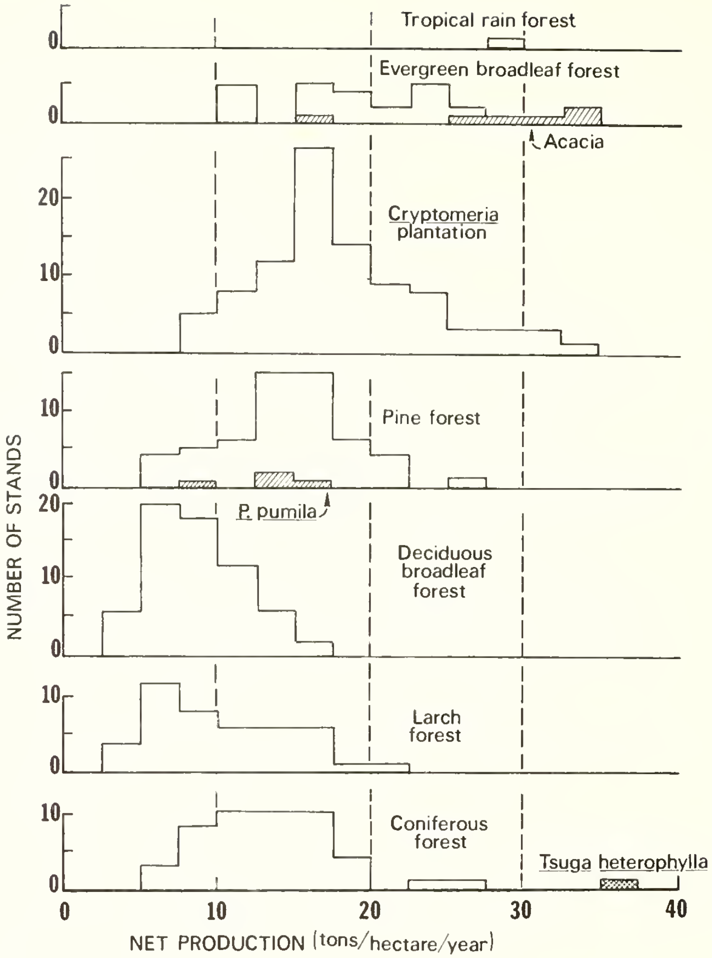

Figure 4.-- Estimates of net production in various forest types (most of these were summarized by Tadaki and Hachiya (1968); these data are limited to forests in Japan except for those for tropical rain and *Tsuga heterophylla* forests)

In the experimental area, accumulated hours of solar radiation during the summer are comparatively high (table 1), because clear weather is common and days are long promoting photosynthesis by forest communities. On the other hand, despite the frequent clear weather, temperatures do not rise so high as to excessively increase respiration rates (table 1). Consequently, the ratio of net production of photosynthate to gross production (net plus respiration loss) is probably comparatively high because temperatures are close to optimum for net production (Negisi 1966).

Mild temperature changes, especially warmth during winter, must be another important factor. The index of coldness in the Oregon coast is zero, which means there is no month with a mean temperature less than 5° C., whereas the index of coldness in Aomori is -24.3° C. (table 1). In spite of this fact, it is reported that there is no measurable biomass increment in western Washington and Oregon trees during winter (Dimock 1964). This must be an effect of day length, since cessation of growth in fall and winter is usually conditioned by shorter days as well as lower temperatures, and the accumulated hours of sunshine during winter are only half as much as during summer (table 1). However, during winter, even though biomass increment has not been detected, there is a possibility that some photosynthesis is occurring. Appreciable net photosynthesis by *Pseudotsuga menziesii* has been reported during winter in western Washington, and this must contribute significantly to stored food reserves which accumulate prior to the flush of spring growth (Helms 1965). Furthermore, the forest trees on the Oregon coast are less subject to severe coldness, which often weakens the vigor of forest communities, and also drastic temperature changes in spring and autumn, which often prevent normal or rapid growth of trees. All of these environmental influences hasten and prolong productivity.

Concerning the long, continuous period at a certain level of productivity, I would speculate. The climate in this area is mild, and drastic changes of weather, such as might weaken the vigor of forest communities, are infrequent. In particular, strong winds which disturb or weaken forest communities are uncommon in this area compared with many other temperate regions. Root systems of forest communities here are comparatively deep[3/] because of genetic and environmental factors. The latter probably include favorable soil conditions (Franklin et al. 1968) and a summer dry period which encourages deep root penetration. It is proposed that the ratio between above- and below-ground components becomes unbalanced as trees grow; i.e., the root system is too small to support the aerial biomass, thereby limiting size of trees. From this viewpoint, infrequent strong winds and deep root systems may be important factors in permitting large biomass accumulations.

The largest minus factor to the growth of forest trees on the Oregon coast must be the lack of rainfall during summer (table 1), even though the fog and low clouds provide partial compensation. The growth rates of trees decline considerably after mid-July in comparison with those recorded between May and mid-July (Dimock 1964).

Genetic factors are also important in understanding the existence of tree species capable of growth to such large sizes. Reportedly, the potentially large species around this region were able to survive the Glacial Age without major gene pool depletion (Silen 1962). Trees in this region thus escaped the direct effects of glaciers by migrating geographically to the south or north, as the climate varied and glaciers advanced or receded.

Large numbers of advanced ecological data will have to be accumulated in the future to substantiate these speculations and assumptions. Meanwhile, this study provides a profile of biomass accumulation and distribution in a young coniferous forest ecosystem; as such, it provides one set of data which can be combined with further studies of production in other age classes or of processes for fuller understanding of ecosystem function and development.

[3/] Unpublished data on file at Forestry Sciences Laboratory, Pacific Northwest Forest and Range Experiment Station, Corvallis, Oregon.

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USDA FOREST SERVICE RESEARCH PAPER PNW-124

Partial Cutting of Western Hemlock and Sitka Spruce in Southeast Alaska

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ABSTRACT

This study of response to partial cutting over a 17-year period in a 96-year-old stand of western hemlock-Sitka spruce at Karta Bay, Alaska, showed that crop trees left after partial cutting were able to increase or maintain about the same rate of diameter growth as before thinning, but growth in diameter of trees in an unthinned stand followed the normal pattern of decline.

Opening the stand stimulated epicormic branching, thus reducing quality of trees in the future. Partially cut plots became well stocked with conifer regeneration, mostly western hemlock.

Keywords: Thinning, rotation age, western hemlock, *Tsuga heterophylla,* Sitka spruce, *Picea sitchensis.*

CONTENTS

INTRODUCTION

In the Pacific Northwest and Alaska, clearcutting is the harvesting method generally used with even-aged management of western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and Sitka spruce (*Picea sitchensis* (Bong.) Carr.). But there may be situations where the forest manager would want to harvest a rotation-aged stand by some method other than clearcutting. Examples would be in areas where esthetic considerations limit clearcutting or where selected crop trees are to be retained in the stand for production of high-quality saw logs. Studies made elsewhere (Staebler 1957, Griffith 1959, Williamson 1966, Malmberg[1/]) show that young western hemlock and Sitka spruce respond well to thinning, and that these species have great potential for producing stands with high volumes of wood over a rotation.

In southeast Alaska, even-aged stands of western hemlock and Sitka spruce are typically dense. At an age of about 100 years, these stands contain some 12,000 cubic feet of wood per acre in trees averaging 12 inches in diameter at breast height. Diameters of largest trees are 20-25 inches, and there are few quality saw logs (Taylor 1934). In 1950, a study was begun to investigate the effect of partial cutting in such stands. One objective, as reported earlier (Godman 1951), was to determine the volume that could be removed and the time required to remove it. Selected crop trees were left for future sawtimber harvest. A second objective, herein described, was to evaluate the effects of partial cutting on stand growth, epicormic branching, and regeneration establishment.

The study originally had two replications of three treatments. Unfortunately, one of the replications had to be abandoned in 1962 when an adjacent blowdown changed conditions of light on the plots. Because one set of plots was lost, no statistical comparisons could be made between treatments. What is presented here is a case study of six small populations, and no inferences can be made beyond these plots with any stated probability. Analysis of these plots does provide some insight into the probable effects of partial cutting on stand growth, epicormic branching, and regeneration establishment.

METHODS

In the summer of 1950, three 1/2-acre plots were established in a 96-year-old stand of western hemlock and Sitka spruce at each of two locations at Karta Bay (fig. 1). The plots were on a Karta-Wadleigh soil complex (Gass et al. 1967). At each location one plot was thinned to 120 crop trees per acre, one was thinned to about two-thirds of the original basal area, and one was left unthinned (table 1). Thinning was essentially from below, but all wolf trees and poorly formed trees were also cut. Volumes removed ranged from 1,930 to 4,420 cubic feet per acre, with an average of 2,880.

There were noticeable differences between plots (table 1). Area 1 plots had higher site indices, fewer trees, and larger average diameters of trees than plots in

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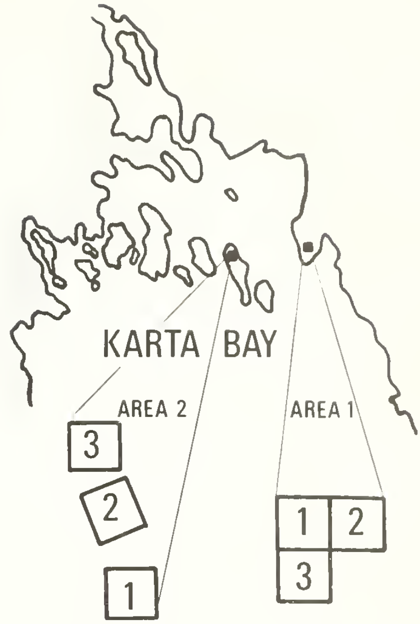
[1/] D. G. Malmberg. Early thinning trials in western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) related to stand structure and product development. Ph. D. dissertation on file at University of Washington, 138 p., illus., 1965.

Table 1.–*Plot statistics for 96-year-old western hemlock and Sitka spruce stand thinned in 1950, Karta Bay, Prince of Wales Island, Alaska*

(Per acre basis)

Area	Plot	Treatment	Site index	Before thinning			After thinning				Trees removed			
				Average d.b.h.	Trees	Basal area	Average d.b.h.	Trees	Basal area	Hemlock crop trees	Average d.b.h.	Trees	Basal area	Basal area cut
				Inches	*Number*	*Sq. ft.*	*Inches*	*Number*	*Sq. ft.*	*Percent*	*Inches*	*Number*	*Sq. ft.*	*Percent*
1	1	120 crop trees	130	16.3	236	341	18.5	120	224	70	13.6	116	117	34.3
	2	Two-thirds of basal area	121	14.2	306	337	15.7	174	234	88	12.0	132	103	30.6
	3	Unthinned	121	15.7	262	351	15.7	262	351	84	0	0	0	0
2	1	120 crop trees	109	11.1	562	379	15.8	120	164	22	9.4	442	215	56.7
	2	Two-thirds of basal area	116	13.4	424	413	16.8	172	263	64	10.4	252	150	36.3
	3	Unthinned	113	13.0	378	346	13.0	378	346	53	0	0	0	0

Figure 1.--*Location of thinned plots at Karta Bay, Prince of Wales Island, Alaska.*



area 2. After thinning, 70 to 88 percent of the trees in area 1 were hemlock, whereas 22 to 64 percent in area 2 were hemlock. Thirty-one to 34 percent of the basal area was removed from area 1 plots and 36 to 57 percent from plots in area 2.

At the time of thinning, there were no markets for pulp timber, so the felled trees were limbed and bucked and left on the ground. A 1/10-acre subplot (66 feet square) at the center of each thinned plot was cleared of logs and slash so that growth of advanced and new regeneration would not be hampered (fig. 2). All trees on the thinned plots and selected crop trees on the unthinned plots were remeasured in 1956 and 1960. Total growth of all trees on the unthinned plots was not determined in 1956 or 1960. In 1962, the timber adjacent to the plots in area 1 (fig. 1) was blown down causing such a change in light conditions that those plots were abandoned.

Figure 2.--*One-half-acre plot thinned to two-thirds of basal area in 1950, as it appeared in 1967. A 1/10-acre subplot was cleared of logs and slash so that growth of advanced and new regeneration would not be hampered. Plot 2, area 2, Karta Bay, Prince of Wales Island, Alaska.*

In 1967, the three plots in area 2 were again remeasured and two increment cores were extracted at right angles to each other from all crop trees on plots 1 and 3. Cores were not taken from trees on plot 2 as this plot had been maintained as a permanent growth plot since 1928. The increment cores from plots 1 and 3 were used to obtain estimates of tree diameters during the period 1928-50 so that trends in growth before thinning could be determined. Height measurements were seldom taken in past years and no analysis was made of changes in tree form. Only diameter and basal-area growth were considered.

The first 33-foot section[2/] of each Sitka spruce crop tree in area 2 was inspected in 1967 to determine if thinning noticeably stimulated epicormic branching. The number of epicormic branches on each tree was tallied in two classes--branches of one-half inch or smaller and those of more than one-half inch in diameter.

To determine changes in regeneration after partial cutting, we divided the 1/10-acre cleared subplots into 100 1-milacre (6. 6 feet square) plots. In the spring of 1951, the number and species of seedlings on each milacre plot were counted. Seventeen growing seasons later (1967), seedlings were again counted by species on each milacre plot and the height of the largest spruce and hemlock on each was measured.

An estimate of crown cover was made in 1967 from 25 vertical ground photos taken on each plot. Canopy cover was estimated from photos by superimposing a 50-dot grid on the photos and recording the percentage of dots falling on foliage, boles, and branches.

RESULTS

Diameter Grcwth

Before thinning, rate of growth of crop trees on the three plots in area 2 were similar (table 2). Over the first 10 growing seasons following thinning, 1951-60, crop trees on thinned plots showed greater growth than similar crop trees on the unthinned plots. Differences in growth between trees on thinned and unthinned plots were even more striking during the period 1961-67 (table 2). Hemlock and spruce showed similar response to treatment.

Trees on the plot thinned to 120 trees per acre increased their average rate of diameter growth for the first 10 growing seasons following thinning. Diameter growth during the next seven growing seasons decreased somewhat but remained above the pre-thinning level.

Trees on the plot thinned to two-thirds of basal area maintained their rate of diameter growth at about the 1928-50 level for the first 10 years following thinning. During the next 7 years, diameter growth of these trees decreased to below the pre-thinning level. Growth of similar trees on the unthinned plot has declined since 1950 (table 2).

[2/] Includes a 1-foot stump and first 32-foot log.

Table 2.–*Average diameter and diameter growth on thinned and unthinned plots at Karta Bay, Prince of Wales Island, Alaska*

Treatment	Plot	Area	Average diameter of crop trees at end of growing season				Average annual diameter growth of crop trees by period		
			1927	1950	1960	1967	1928-50	1951-60	1961-67
			Inches						
Thinned to 120 trees per acre	1	1	--	18.5	19.6	--	--	0.11	--
	1	2	13.7	15.8	17.0	17.7	0.09	.12	0.10
Unthinned (comparison of 120 crop trees per acre)[1/]	3	1	--	17.5	18.2	--	--	.07	--
	3	2	14.8	16.8	17.6	17.9	.09	.08	.04
Thinned to two-thirds of basal area	2	1	--	15.7	16.4	--	--	.07	--
	2	2	14.8	16.8	17.7	18.2	.09	.09	.07
Unthinned (comparison of two-thirds of basal area)[2/]	3	1	--	17.4	18.0	--	--	.06	--
	3	2	13.8	15.6	16.2	16.5	.08	.06	.04

1/ Includes only those trees on the control plots that would have been left had the plots been thinned to 120 trees per acre.

2/ Includes only those trees on the control plots that would have been left had the plots been thinned to two-thirds of the original basal area.

Basal Area Growth

Basal area growth on thinned plots was surprisingly good (table 3). Information gathered from the plots in area 2 shows that trees on the thinned plots more than doubled the net basal area increment of trees on the unthinned plot. This is principally due to the natural mortality of 27 trees on the unthinned plot between 1950 and 1967. There was no mortality among selected crop trees on the unthinned plot. The mortality took place in the smaller diameter classes where there was a net loss to basal area growth. Because of the loss in the smaller diameter classes, net growth for all trees on the plot was less than net growth on selected crop trees (table 3). Unfortunately, we do not know total basal area growth for trees on the unthinned plot in area 1.

In the 17 years, 1951-67, no trees died in area 2 on the plot thinned to two-thirds of basal area, and one tree died on the plot thinned to 120 crop trees per acre. Between 1951 and 1960 in area 1, two trees were windthrown on the plot thinned to 120 crop trees per acre, and one tree was windthrown on the plot thinned to two-thirds of basal area. Four of the selected crop trees on the unthinned plot died.

Epicormic Branching

Percent of spruce crop trees with epicormic branching in area 2 in 1967 was positively correlated with thinning intensity (table 4). The heavier the 1950 thinning, the greater the epicormic branching by 1967. In 1967, on the plot thinned to 120 crop trees per acre, 62 percent of the spruce had epicormic branches compared with 32 percent for the unthinned plot. The number of epicormic branches in the first 33-foot tree section of affected trees was similar on all plots.

Regeneration

Regeneration response after thinning was studied on the three plots in area 2. In 1951, the year after thinning, established seedlings were more numerous on the unthinned plot than on thinned plots (table 5), probably because many seedlings on the thinned plots were destroyed during thinning. All the seedlings present were hemlock. By 1967, however, fewer than half of the seedlings on the unthinned plot remained, but on both thinned plots, seedlings were 19 and 47 times more numerous than in 1951 (figs. 2 and 3). This change in relative number of seedlings from 1951 to 1967 was associated with conditions of light. In 1967, crown cover on the unthinned plot was 94 percent, but on the thinned plots, crown cover was 76 and 83 percent.

Reduction of crown cover on thinned plots improved conditions for spruce regeneration. By 1967, spruce accounted for 15 and 20 percent of the regeneration on thinned plots, but no spruce regeneration was observed on the unthinned plot. Hemlock seedlings were taller on the thinned plots than on the unthinned plot. The difference in average height of hemlock and spruce is due principally to difference in age of the two species; many of the hemlock were already established before thinning, but spruce became established only after the stands were thinned.

Table 3.–*Basal area growth and mortality on thinned and unthinned plots at Karta Bay, Prince of Wales Island, Alaska*

(Per acre basis)

Treatment	Plot	Area	Net growth				Mortality			Gross growth		
			1928-50	1951-60	1961-67	1951-67	1951-60	1961-67	1951-67	1951-60	1961-67	1951-67
			Square feet									
Thinned to 120 trees per acre	1	1	--	17.2	--	--	8.2	--	--	25.4	--	--
	1	2	39.9	22.1	15.4	37.5	2.4	0	2.4	24.5	15.4	39.9
Unthinned (comparison of 120 crop trees per acre)[1]	3	1	--	6.0	--	--	8.9	--	--	14.9	--	--
	3	2	41.4	16.1	4.7	20.8	0	1.8	1.8	16.1	6.5	22.6
Thinned to two-thirds of basal area	2	1	--	18.6	--	--	1.2	--	--	19.8	--	--
	2	2	61.4	28.4	10.4	38.8	0	0	0	28.4	10.4	38.8
Unthinned (comparison of two-thirds of basal area)[2]	3	1	--	3.8	--	--	12.9	--	--	16.7	--	--
	3	2	51.4	19.0	7.2	26.2	0	1.8	1.8	19.0	9.0	28.0
Unthinned (all live trees)	3	2	82.9	[3] 13.2	3.5	16.7	--	--	--	--	--	--

1/ Includes only those trees on the control plots that would have been left had the plots been thinned to 120 crop trees per acre.

2/ Includes only those trees on the control plots that would have been left had the plots been thinned to two-thirds of basal area.

3/ Estimate based on straight line interpretation of excess tree basal area in 1949 and 1967, assuming constant basal area growth over the period.

Table 4.–*Size and number of epicormic branches in the first 33-foot section of Sitka spruce crop trees, area 2, Karta Bay, Prince of Wales Island, Alaska, 1967*

Plot	Treatment	Spruce on 1/2-acre plot	Epicormic branching of Sitka spruce: Spruce with epicormic branches	Branches by average size in first 33-foot tree section: ≤ 1/2 inch	> 1/2 inch
		Number	*Percent*	*Number*	*Number*
1	120 crop trees per acre	47	62	3.4	3.9
2	Two-thirds of basal area	31	42	3.8	5.0
3	Unthinned	42	32	4.1	4.5

Table 5.–*Regeneration condition on thinned and unthinned plots, Karta Bay, Prince of Wales Island, Alaska*

Timber stand description				Regeneration condition							
				1951			1967				
Plot number	Treatment	Basal area (1950)	Crown cover (1967)	Seedlings per acre	Species of seedlings		Seedlings per acre	Species of seedlings		Average height of dominant seedlings	
					Hemlock	Spruce		Hemlock	Spruce	Hemlock	Spruce
		Sq. ft.	*Percent*	*Number*	-----*Percent*-----		*Number*	------*Percent*------		-------*Feet*------	
1	120 trees per acre	164	76	480	100	0	22,650	80	20	4.7	1.2
2	Two-thirds of basal area	263	83	1,330	100	0	25,070	85	15	6.8	2.3
3	Unthinned	346	94	3,840	100	0	1,700	100	0	2.7	--

Figure 3.--*Half-acre control plot as it appeared in 1967. The ground was covered with a thick layer of duff and litter; hemlock and spruce regeneration was sparse. Plot 3, area 2, Karta Bay, Prince of Wales Island, Alaska.*

In 1967, both thinned plots supported a dense understory of tree seedlings, mostly western hemlock. Red huckleberry (*Vaccinium parvifolium* Smith), swordfern (*Polystichum munitum* (Kaulf.) Presl.), and other understory plants were present in small numbers on all plots. On both thinned plots, a deep carpet of feather mosses covered the ground except under dense thickets of seedlings. In contrast, on the unthinned plot, the ground was largely covered with about 8 inches of duff and litter. Moss was scarce, and the hemlock seedlings were spindly and lacked vigor. Most seedlings were located along the western edge of the plot where lighting from the more open adjacent stand was greatest.

DISCUSSION

Over the 17 years following cutting, these 96-year-old stands responded well to thinning. The partial cut apparently removed many trees that would have died during the 17-year period, plus many more that would have contributed little toward increasing stand volume. Crop trees on thinned plots, even at the advanced age of 96 years, were able to make some use of the additional growing space.

Growth of individual trees on the plot thinned to 120 trees per acre was stimulated by thinning, and trees on the plot thinned to two-thirds of basal area were able to maintain their diameter growth at about the prethinning level. Diameter growth on the unthinned plot followed the normal pattern of decline.

With sawtimber as the product objective, quality is important. Sitka spruce is a slow natural pruner, and as stands are opened, epicormic branching increases (Herman 1964). Production of quality wood would require artificial pruning in partially cut stands both to remove persistent branch stubs and to control epicormic branching. Even then it would take 4 to 12 years or more for production of clear wood over smooth branch cuts (Harris 1966).

The study was not designed to compare regeneration after partial cutting and clearcutting although, in considering the use of partial cutting as an alternative to clearcutting, this question would certainly arise. We do not consider regeneration to be a problem on sites having Karta and Wadleigh soils and gentle topography. Based on reconnaissance in young stands that have developed after clearcutting, we would expect dominant trees to be 20 to 30 feet tall and 3 to 6 inches in diameter 18 years after clear-cutting, with spruce comprising roughly 50 percent of the basal area. Thus, regeneration would probably be better had the stand been clearcut.

Blowdown on the study plots was not a serious problem. However, hemlock and spruce are shallow-rooted species, and many existing young-growth stands originated following blowdown of the previous stand. The treated plots at Karta Bay were damaged only slightly by wind during the 17-year study, and although plots in area 1 were abandoned after a blowdown of adjacent timber, this blowdown did not result from partial cutting. The plots at Karta Bay were only one-half acre in size and were well protected by the surrounding stand. How large tracts of partially cut timber might be affected by strong winds is unknown.

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USDA FOREST SERVICE RESEARCH PAPER PNW-125

Habitat Characteristics of the Silver Lake Mule Deer Range

J. Edward Dealy

Pacific Northwest Forest and Range Experiment Station
Forest Service, U. S. Department of Agriculture
Portland, Oregon 1971

ABSTRACT

Twenty-one ecosystems of the Silver Lake mule deer range in northern Lake County, Oregon, are described by site, vegetation, and soil. Discussions are included on ecosystem interrelationships, habitat value for game, and habitat manipulation. A field key to ecosystems has been developed using vegetation characteristics easily identifiable on the ground.

Keywords: Ecosystem, habitat, mule deer, vegetation, soils, site class.

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Contents

Introduction

Mule deer *(Odocoileus hemionus hemionus)*[1] (Ingles 1965) in central Oregon are a migratory group of animals. They roam a vast mountainous summer range and crowd into a relatively small winter range when adverse climatic conditions dictate. Most of the deer ranges in central Oregon are grazed by livestock, either cattle or sheep or both together. Excessive populations of animals compete for food. Prolonged competition can produce changes in diet, nutrition, fecundity, and range conditions. To prevent or reduce this competition, a wide variety of facts must be gathered concerning the animals and their environment.

This paper presents an analysis of 21 habitats present on the Silver Lake deer range in northern Lake County, Oregon. Treatment includes analysis of site, vegetation, and soils on both the summer and transition (summer-winter range boundary) ranges and discussion of vegetation types for suitability as mule deer habitat. This descriptive work is one of the first steps in developing realistic management plans for maximum sustained and compatible mule deer-livestock production.

Information presented here is directly applicable to the Silver Lake deer herd range. Data can be used as guides for management of deer herd ranges in central and south central Oregon and elsewhere in the western United States under similar conditions.

Experience and personal judgment are critical ingredients which must be combined with the information presented here for each ecosystem. Remember, most of this area is deer summer range which, taken as a whole, is not generally a problem area for forage, though through careless disregard it could become such.

In general, suggested values and recommendations for game habitat development should be given secondary priority on high producing timber sites. However, I would expect timber specialists to be sensitive to compatible game habitat improvement suggestions. On low or marginal sites for tree growth, timber production may become secondary in management priorities.

Setting aside large summer range "scab flats" of low sagebrush for deer and antelope use may help make the difference between does being in good enough condition to carry twin fetuses through a bad winter to birth and beyond or being in poor condition and losing one or both young (Fichter 1962, Julander et al. 1961). Setting aside scattered small

[1] *Scientific and common names of animals and plants are listed in the appendix.*

meadow, spring, or aspen areas for game use may also help strengthen tl general health of game populations as they prepare themselves for winte

These suggestions are only examples of many such consideratio which must be studied in relation to livestock needs and other priorities order to maintain balance in a total management plan.

Ecological Studies Related to Central Oregon Vegetation

Daubenmire (1952) has done considerable work on forest vegetation eastern Washington and northern Idaho. He developed a classification which he included the following zones as those of primary importanc (1) *Pinus ponderosa*, (2) *Pseudotsuga menziesii*, (3) *Thuja plicata/Tsug heterophylla*, and (4) *Picea engelmannii/Abies lasiocarpa*. Available sc moisture increased from (1) through (4). It was pointed out that *Populi tremuloides* came into *Pinus ponderosa* stands as a seral species where hig water tables occurred.

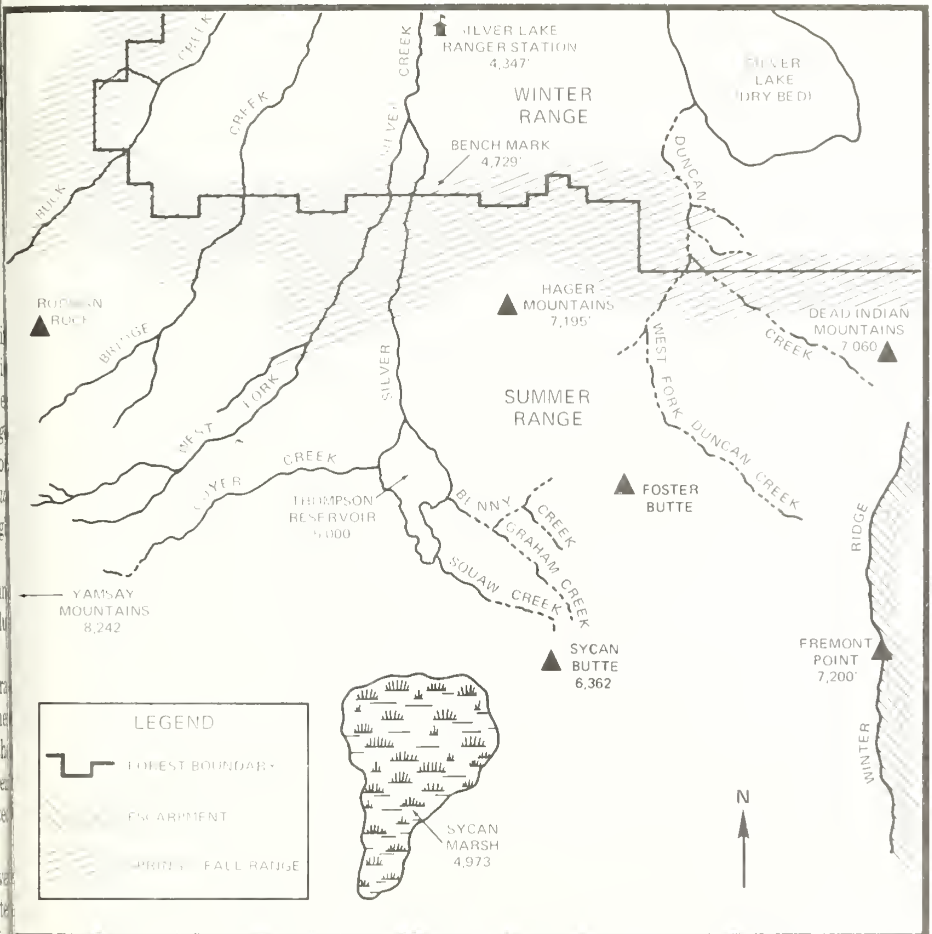
McMinn (1952), studying soil moisture in the northern Rocky Moun tains, concluded that soil moisture is the most important factor influ encing distribution of vegetation types.

Rummell (1951) compared two areas of *Pinus ponderosa* in centra Washington. They were similar; but one had been grazed, and the othe was protected by natural barriers. Density of herbaceous species in th ungrazed area was over twice that of species on the grazed site. Howeve pine saplings averaged 85 per acre under 4 inches d.b.h. on the ungraze area and 3,291 per acre on the grazed site.

Dyrness (1960) studied vegetation and soil-site relationships near Silve Lake in a region of pumice soils. Six plant communities and their site were sampled intensively in an area where basic information was lackin and where management felt a real need for understanding the productiv capacity and management limitations of the resource. Of the six com munities, five were dominated by *Pinus ponderosa* and one by *Abies con color*. The dominant shrub species varied from *Purshia tridentata* unde *Pinus ponderosa* in the driest of the communities to *Ceanothus velutinu* under *Abies concolor* which characterized the most moist site.

Dyrness effectively correlated serious bark beetle infestations an mistletoe occurrence with specific plant communities. He found that th *Pinus ponderosa/Purshia tridentata/Festuca idahoensis* association o Shanahan soil was accompanied by a high bark beetle hazard and *Pinu ponderosa/Ceanothus velutinus* community on the Lapine pumice soil wa closely correlated with large-scale mistletoe infestations.

In describing and interpreting a seral stage of the *Abies concolor/ Ceanothus velutinus* association, *Pinus ponderosa/Ceanothus velutinus*, Dyrness suggests that because the pine reaches a particularly high produc tivity on this site, cutting practices might well favor its maintenance fo several rotations.



Map of the Silver Lake area of Oregon showing main topographic features and the division of summer, winter, and spring-fall ranges for mule deer.

Area Description

The Silver Lake deer herd range is located in northern Lake County, Oregon, and lies between Ranges 11 and 16 East, and Townships 27 and 33 South. It includes several hundred thousand acres, of which approximately one-fourth is winter range and the remainder summer range. The summer-winter range boundary (transition range) fluctuates yearly according to the depth and duration of winter snowpacks.

A major portion of the summer ranges lies within the timbered area of northern Lake County. From east to west it sweeps gently down the back

Silver Lake deer range, looking south. Mountains in the background illustrate the summer range and its topography.

of 7,000-foot Winter Ridge, an upthrust escarpment 20 miles long, to a low of 4,700 feet and then gradually climbs to 8,242-foot Yamsay Mountain 30 miles away. From north to south it follows the Winter Ridge-Yamsay Mountain trough from the timber's edge near Silver Lake south for approximately 15 miles, rising from 4,700 feet to 5,500 feet. Hager Mountain, a cone, rises to 7,000 feet out of the trough center near the north edge of the range.

Numerous seasonally ponded meadows, seasonal streams, and year-round springs are scattered throughout the area. Several year-round streams are present. Water is adequate (although probably not optimal) for big game needs throughout the summer range.

The general vegetation complex includes the forest types of *Pinus ponderosa*, *P. contorta*, *P. ponderosa-Abies concolor*, *A. concolor*, *Populus tremuloides*, and *Cercocarpus ledifolius* (Hitchcock et al. 1955); wet and dry meadows, high elevation burns grown primarily to dense *Artemisia tridentata*, and rocky *Artemisia arbuscula* flats.

A narrow transition area, where use is governed by weather, lies between the summer and winter range from approximately 4,700- to 5,000-foot elevation. During severe winters of deep snow, deer generally move below 4,700 feet using the transition area primarily during the fall migration and again in the spring when moving back to the summer range. However, during most years the animals use it most of the winter. The vegetation complex includes the lower edge of the *Pinus ponderosa* communities, *Purshia tridentata*-bunchgrass, mixed *Artemisia tridentata-P. tridentata*, *Cercocarpus ledifolius*, *A. arbuscula*-bunchgrass, and the ecotone of *P. ponderosa-C. ledifolius-P. tridentata-Juniperus occidentalis-A. tridentata.*

The climate is typical of the intermountain West — — warm dry summers, crisp dry early falls, moderately severe winters with moderate snows generally occurring in January and February, and moderate, late spring rains. Annual precipitation at Silver Lake, in the middle of the winter range, averages 10 inches annually. Precipitation in the summer range varies from about 12 to 30 inches annually. Killing frosts may occur in any month of the year. However, they do not normally occur during July or August.

Day temperatures commonly reach 90° to 95° F. during July and August. The mean January and July temperatures at Silver Lake are approximately 28° and 64° F., respectively. Maximum and minimum temperatures have been recorded at 105° and −35° F. (U. S. Department of Agriculture 1941).

According to Knox (1968), soils in the study area include Grey-Brown Podzolic, Prairie (Brunizems), Chernozem, Chestnut, Regosol, Alluvial, and Humic Gley. Soils in the area are derived from residual parent material consisting primarily of flow basalt. There are localized areas of tuffs and tuff breccias overlying basalts in the lower elevation transition areas. Also, in the same lower areas there are localized occurrences of pumice deposits overlying basalts and tuff.

Methods

Vegetation was typed on the ground with the aid of aerial photographs. Type lines were placed as best as could be judged, in the center of ecotones. Then plots were located at random on photographs and finally on the ground. Plots were rejected if they landed in inclusions obviously not of the type, such as drainageways, another type, or in areas of geological change. These variants were accepted as small enough in area and minor enough in ecological impact to eliminate the need for sampling.

Vegetation sampling of most ecosystems included composition of a understory species from basal area cover, tree basal area, crown cover of shrubs and trees, shrub and tree density, and percent ground cover of moss, litter, rock, and bare soil. Frequency of species occurrence w recorded at each plot — — all data being used plus a careful search of th macroplot and an area within 100 feet in all directions.

Vegetation was measured by a nested plot sampling system. Th system involved establishing large plots (macroplots) 100 feet long by 5 feet wide, restricted random location of four 50-foot transects within th plot, and systematic location of ten 1- by 2-foot observation plo (microplots) along each transect (Poulton and Tisdale 1961).

Basal cover for all species was estimated as a percent of the total 1- b 2-foot plot. This same information was used to calculate compositio Basal area of all trees within each 50- by 100-foot plot was taken fro d.b.h. measurements. Crown cover of shrubs was estimated by using th line intercept method (Canfield 1941), and tree crown cover was est mated using the densiometer (Lemmon 1956). Crown intercept of *Cercocarpus ledifolius* was taken through an adaptation of the densi meter (Dealy 1960).

Due to time limitations, a few plant communities were sampled by a dominance rating rather than composition system for determining relativ importance of various species within each vegetation layer: tree, shru grass, and forb. The rating consisted of five levels for each vegetation lay (Tansley and Chipp 1926) as follows:

5. Very abundant — dominant in its own vegetation layer.
4. **Abundant** — codominant with at least one other species in its own vegetation layer.
3. **Frequent** — common, can stand in one spot and see it wherever yo turn.
2. **Occasional** — must walk around to observe it. Not readily notic able.
1. Rare — must hunt through vegetation to find it.

Other vegetation, soil, and site data were taken as described for a plant communities.

Soils data were taken from pits dug next to each vegetation plo Standard soil description procedures and nomenclature of the Soil Co servation Service Soil Survey Manual were followed (U. S. Department of Agriculture 1951). Complete profile descriptions were not taken on a communities. Some of the less important communities were sampled onl for texture of the A and B horizons, solum depth, restrictive layers, drai age, surface and solum stoniness, pH, parent materials, and depth of roc concentration.

The site characteristics recorded at each plot location were slop aspect, elevation, position on slope, and macrorelief. General use intensit by animals and geographical location were also recorded.

Key to Plant Communities

The Silver Lake deer's summer range ecosystems have been identified in a field key according to vegetation characteristics easily identifiable on the ground. The key is dichotomous in arrangement with ecosystems being separated first on the most broad and obvious vegetative characteristics as is necessary to separate similar ecosystems or phases within an ecosystem.

The first and most obvious separations are tree from nontree communities and shrub from nonshrub communities. The next most obvious separations are between tree species where the ecosystems exhibit single species overstories and between shrub species where there are single shrub communities. From this point, the key continues the separations through characteristics which are based primarily on plant species that should be easily identified by people working in this general area. The final confirmation of identification should be a close agreement between the keyed-out ecosystem label and the corresponding description.

There will be situations or sites which will not key out. These will include ecotones, localized and sharply divergent geological formations including most streamside areas, and a few vegetation complexes of minor extent and value. The latter could not be covered due to time and manpower limitations, but examples are *Abies concolor*, *Tsuga mertensiana*, and some *Pinus contorta* communities.

A. Communities with tree cover — Page

  B. Cover dominated by broadleaf trees

    C. Tree cover dominated by *Populus*

      Shrub cover present, big sagebrush common to abundant —

        10. *Populus tremuloides/Artemisia tridentata/Bromus carinatus* 48

      Shrub cover sparse or absent —

        11. *Populus tremuloides* colonies on meadows or streambanks 53

    C. Tree cover dominated by *Cercocarpus*

      Understory dominated by *Festuca idahoensis* —

        13. *Cercocarpus ledifolius/Festuca idahoensis* 60

      Understory has *Festuca idahoensis* codominant with *Agropyron spicatum*. Soil surface rocky —

        12. *Cercocarpus ledifolius/Festuca idahoensis-Agropyron spicatum* . . 55

B. Cover dominated by coniferous trees Page

D. Tree cover and reproduction of *Pinus ponderosa* only, or other species scarce

E. Shrub cover dominated by *Purshia tridentata*

F. *Purshia tridentata* a sparsely scattered stand, *Festuca idahoensis* the dominant understory species —

2. *Pinus ponderosa/Purshia tridentata/Festuca idahoensis: Festuca idahoensis* phase 15

F. *Purshia tridentata* common to abundant and the dominant understory species

Festuca idahoensis the dominant grass —

1. *Pinus ponderosa/Purshia tridentata/Festuca idahoensis* 10

Carex rossii dominant —

3. *Pinus ponderosa/Purshia tridentata/Festuca idahoensis: Carex rossii* phase 19

E. Shrub cover not dominated by *Purshia tridentata*

Shrub cover dominated by *Artemisia tridentata.*

Dominant grass is *Bromus carinatus* —

6. *Pinus ponderosa/Artemisia tridentata/Bromus carinatus* 30

Shrub cover dominated by *Arctostaphylos patula* or codominant with *Purshia tridentata* —

4. *Pinus ponderosa/Arctostaphylos patula/Festuca idahoensis* 23

D. Tree cover and reproduction not of "*Pinus ponderosa* only, or other species scarce"

G. Tree cover dominated by *Pinus contorta*

Festuca idahoensis common to abundant —

8. *Pinus contorta/Festuca idahoensis* 40

Festuca idahoensis absent to rare —

9. *Pinus contorta/Danthonia californica* 45

G. Tree cover mixed species

Pinus ponderosa and *Abies concolor* mixed overstory, sometimes *A. concolor* mostly as abundant to dominant reproduction under *P. ponderosa* —

7. *Pinus ponderosa-Abies concolor/Festuca idahoensis* 35

Pinus ponderosa and *Cercocarpus ledifolius* mixed —

5. *Pinus ponderosa-Cercocarpus ledifolius/Festuca idahoensis* 28

Ecosystems

1 *Pinus ponderosa / Purshia tridentata / Festuca idahoensis* Ecosystem

Physical Description

Site. — This is the largest single ecosystem on the summer range. It characterized by gentle to rolling topography at elevations from 4,700 t 6,500 feet. Slopes range from 0 to 10 percent, and all aspects are repre sented.

Vegetation. — It is characterized by an overstory of *Pinus ponderos* with reproduction occurring in patches. Basal area averages 166 squa feet per acre, including reproduction above 5.5 feet, and average densit of stems under 10-inch d.b.h. is 2,932 per acre.

The shrub layer is dominated by *Purshia tridentata* with 16-percer composition and 100-percent frequency of occurrence. *Chrysothamnu viscidiflorus*, *Haplopappus bloomeri*, and *Mahonia repens* also occu commonly.

Grasses are dominated by *Festuca idahoensis*, with *Carex rossii* an *Stipa occidentalis* major components of this layer. These species an *Sitanion hystrix* occurred on every macroplot. The only forbs occurrin with 100-percent frequency were *Achillea millefolium*, *Fragaria virginian* and *Microsteris gracilis*. In the table are average vegetative characteristic for all species. *Abies concolor* moves in at high elevations and on nort facing slopes. *Pinus contorta* becomes established because of disturbanc or other localized site influences, *Populus tremuloides* and meadow appear in moist sites, and *Artemisia arbuscula* appears on rocky, shallow soil openings. Inclusions of *Cercocarpus ledifolius* and *Juniperu occidentalis* occur on shallow rocky soils and at the dry edge of the type

Soil. — The soil occurring in this ecosystem has been tentatively classi fied as a Tournquist loam.[2] It commonly contains basalt stones an boulders throughout the solum, which averages 30 inches in depth with A

[2] *C. T. Youngberg, unpublished field notes. Soils Dep., Oreg. State Univ., Corvallis.*

and B horizons averaging 10 and 20 inches, respectively. Drainage is good and roots are abundant to 12 inches and common to 20 inches.

Soil texture varies from loam in the A1 to light clay loam in the A3 and from loam to clay in the B horizon. The pH in the A1 and A3 horizons averages 5.9 and 6.1, respectively.

Discussion

Ecosystem. — Evidence indicates that this ecosystem is in a high good to excellent condition and can be considered relatively stable. *Pinus ponderosa*, the only major overstory species, occurs in all age classes, and there is no indication of other species moving into the stand.

The composition levels at which *Purshia tridentata* and *Festuca idahoensis* occur have very likely been influenced by deer and livestock use, both cattle and sheep. *Festuca idahoensis* in this ecosystem is the least preferred of the forage species we normally consider important. Conversely, *P. tridentata* is probably the species most preferred by deer, sheep, and cattle. It is suspected that percent composition of *P. tridentata* is low due to the long history of heavy use in combination with soil moisture stresses in a site apparently fully occupied.

In this ecosystem, the ability of *Purshia tridentata* to recover after disturbance is open to question. Since *P. tridentata* is relatively fire intolerant, it is possible that before the advent of effective fire control, the understory physiognomy was *Festuca idahoensis* (such as in the fescue phase of this ecosystem). This might have been considered a "fire climax" or something similar in the past but might now more reasonably be thought of as a successional stage which, without further disturbance, can be expected to progress toward the "*P. tridentata-F. idahoensis*" physiognomy. The premise that fire control allowed *P. tridentata* to increase in this ecosystem, in the face of an *F. idahoensis* dominated understory, must necessarily include the idea that *P. tridentata* can compete successfully with *F. idahoensis*. If the premise is true one can conclude, perhaps with some danger, that natural *P. tridentata* reestablishment after logging is to be expected. Even though this conclusion is probably valid, the long period of time evolved in the reestablishment would be unacceptable to land and game managers. This process will most likely involve an increase of *Chrysothamnus viscidiflorus* and *Haplopappus bloomeri* before *P. tridentata* can reestablish itself.

Habitat value. — Food and cover value is considered high. The *Pinus ponderosa/Purshia tridentata/Festuca idahoensis* association is the single most important plant community for deer on the summer range. In addition to being the largest and one of the most widespread communities, it is also a high forage producer. Forbs and grasses provide a moderate variety of early season food, and *P. tridentata* provides the bulk of summer and fall forage. *P. ponderosa* reproduction of 2,932 stems per acre commonly occurs in a clumped pattern and provides good hiding cover and fair protection from heat and insects.

Average site-vegetation characteristics of the *Pinus ponderosa/Pursh* *tridentata/Festuca idahoensis* ecosystem[1]

Number of plots: 8 Condition class: high good to excelle

Site and vegetation	Understory composition	Frequency
	Percent	
Bare soil, 1 percent surface area	--	100
Rock, 3 percent surface area	--	100
Litter, 94 percent surface area	--	100
Moss, 0.5 percent surface area	--	100
Total vegetation, 1.5 percent surface area	--	100
Purshia tridentata, 7 percent crown cover	16	100
Chrysothamnus viscidiflorus	.7	63
Mahonia repens	.4	25
Haplopappus bloomeri	.1	25
Ceanothus prostratus	T	13
Festuca idahoensis	49	100
Carex rossii	13	100
Stipa occidentalis	5	100
Sitanion hystrix	4	100
Poa nervosa	4	100
Poa sandbergii	.4	25
Koeleria cristata	T	13
Achillea millefolium	2	100
Fragaria virginiana	1	100
Microsteris gracilis	1	100
Hieracium cynoglossoides	.7	75
Lupinus caudatus	.6	75
Lomatium triternatum	.5	50
Antennaria geyeri	.5	37
Balsamorhiza sagittata	.4	63
Viola purpurea	.1	37
Paeonia brownii	.1	25
Arnica cordifolia	.1	25
Senecio integerrimus	T	13

(— *Continued*)

Number of plots: 8 Condition class: high good to excellent

Site and vegetation	Understory composition	Frequency
	Percent	
Castilleja sp.	T	13
Sidalcea oregana	T	13
Collinsia parviflora[2]	.2	25
Cryptantha ambigua[2]	.2	13

T = trace.

[1] Averages for trees are:

	Basal area in square feet per acre	*Stems per acre <10 inches d.b.h.*	*Percent frequency*	*Percent crown cover*
Pinus ponderosa	166	2,932	100	60
Cercocarpus ledifolius	T	9	50	T
Juniperus occidentalis	T	3	50	T

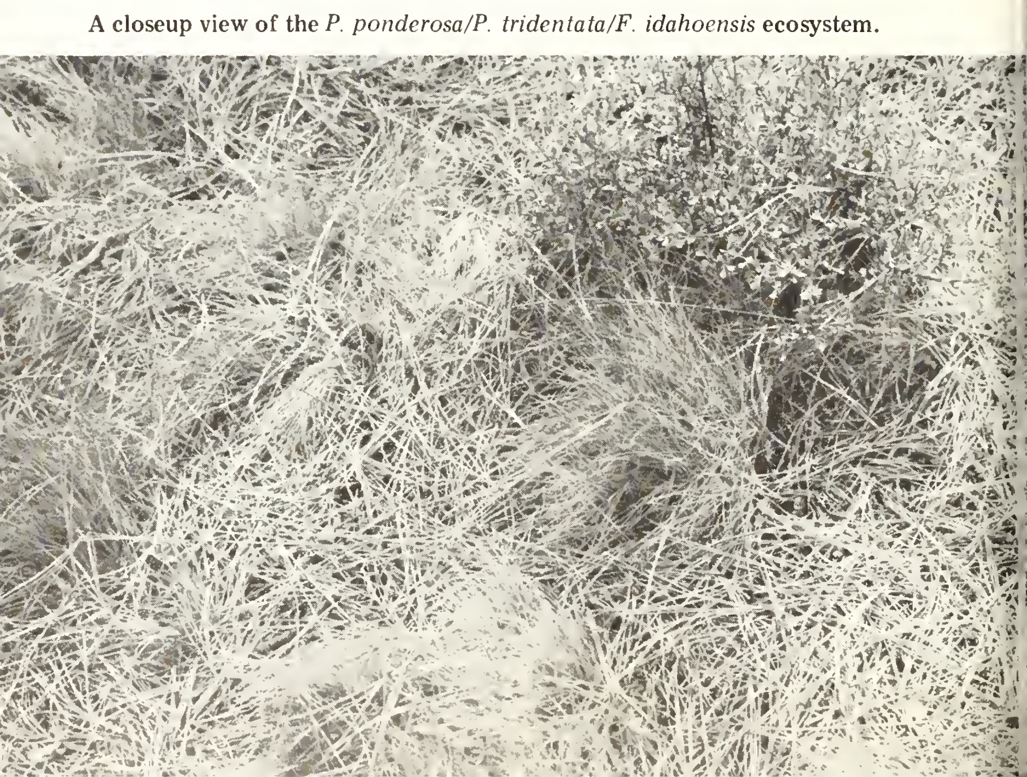
[2] Annuals.

Habitat manipulation. — Overstory removal on a selective basis with minimal disturbance of *Purshia tridentata* would not materially reduce the protection values and would probably increase forage values only in the form of early season grasses and forbs. *P. tridentata* would be expected to show a short- rather than long-term increase in production. This is based on two reasons. First, game and livestock demands on this shrub come during the growing season, demands which take part of the reserve strength which might otherwise be used for crown expansion. Second, the remaining overstory and pine reproduction will expand to reoccupy the site and reestablish the light and soil moisture competition present before logging. Any management practice or treatment which will favor use of *Festuca idahoensis* is desirable in this association, and any rehabilitation after fire or logging should favor *P. tridentata* unless a way is found to use *F. idahoensis* properly.

As was mentioned under ecosystem discussion, natural reestablishment of *Purshia tridentata* after logging is expected to be slow and therefore unacceptable on areas important for deer or livestock. After severe understory disturbances, rehabilitation of *P. tridentata* will require some type of site preparation.

A general view of the *Pinus ponderosa/Purshia tridentata/Festuca idahoensis* ecosystem. Note the scattered clumping of *P. ponderosa* reproduction.

A closeup view of the *P. ponderosa/P. tridentata/F. idahoensis* ecosystem.



2 *Pinus ponderosa / Purshia tridentata / Festuca idahoensis* Ecosystem: *Festuca idahoensis* Phase

Physical Description

Site. — This ecosystem has the same gross site characteristics as the *Pinus ponderosa/Purshia tridentata/Festuca idahoensis* ecosystem which we will name the parent ecosystem.

Vegetation. — The vegetation is similar to that in the parent ecosystem, differing primarily in amounts of *Purshia tridentata* and *Festuca idahoensis*. The understory aspect is grass rather than shrub. *Pinus ponderosa* has a crown cover of 53 percent, compared with 60 percent in the parent. This species has 100-percent frequency of occurrence. *P. tridentata* has a composition of 0.9 percent and a frequency of 100 percent. The only other shrub occurring on sample plots was *Haplopappus bloomeri*. *F. idahoensis* is the dominant grass, having 62-percent composition and 100-percent frequency. *Carex rossii*, *Stipa occidentalis*, *Sitanion hystrix*, *Poa nervosa*, and *Bromus carinatus* are all common components of the understory.

There are four forbs which occur with 100-percent frequency, *Lupinus caudatus*, *Microsteris gracilis*, *Fragaria virginiana*, and *Hieracium cynoglossoides*.

Soil. — This is a well-drained, moderately deep loam. It varies from a loam in the A horizon to clay loam in the B2. The A horizon averages 10 inches deep and the B averages 24 inches. The $B2D_r$ horizon is a clay mixed with weathered basalt fragments. The zone of root concentration is 0 to 19 inches. Large basalt boulders may be present in the solum and may be visible on the surface.

Discussion

Ecosystem. — There is no readily apparent answer to the scarcity of *Purshia tridentata* in this phase of the community. The soil moisture-holding capacity appears, due to a textural difference, to be slightly less here than in the parent ecosystem. Here the A horizon is a loam and the B

Average site-vegetation characteristics for the *Festuca idahoensis* phas
of the *Pinus ponderosa/Purshia tridentata/Festuca idahoensis* ecosysten

Number of plots: 6 Condition class: poc

Site and vegetation	Understory composition	Frequency
	Percent	
Bare soil, 0.2 percent surface area	--	100
Rock, 3.6 percent surface area	--	100
Litter, 94.9 percent surface area	--	100
Moss, 0.1 percent surface area	--	83
Total vegetation, 1.2 percent surface area	--	100
Purshia tridentata, 2 percent crown cover	.9	100
Haplopappus bloomeri	.1	17
Festuca idahoensis	62	100
Carex rossii	17	100
Stipa occidentalis	5	100
Sitanion hystrix	2	100
Poa nervosa	1	100
Bromus carinatus	.1	33
Lupinus caudatus	4	100
Microsteris gracilis	4	100
Fragaria virginiana	1	100
Achillea millefolium	.8	67
Hieraceum cynoglossoides	.7	100
Silene sp.	.7	83
Balsamorhiza sagittata	.3	17
Antennaria geyeri	.1	33

[1] Averages for trees are:

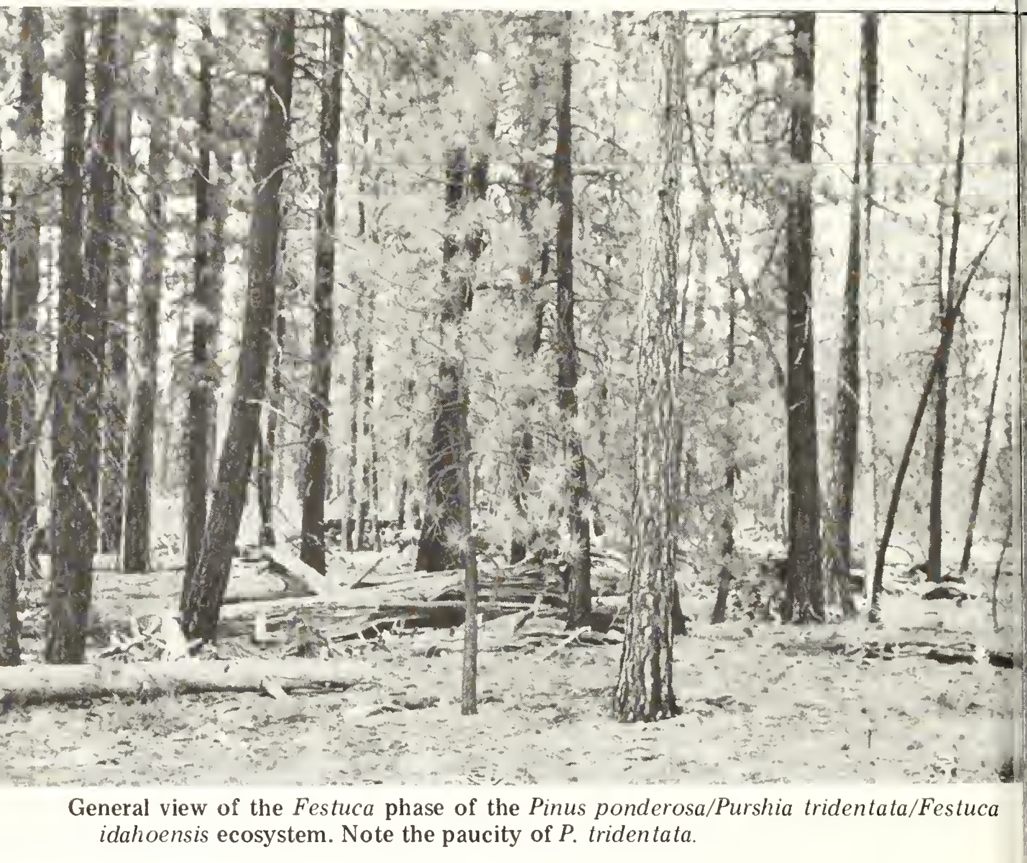
	Basal area in square feet per acre	*Stems per acre <10 inches d.b.h.*	*Percent frequency*	*Percent crown cover*
Pinus ponderosa	180	1,940	100	53

ıorizon ranges to clay loam. In the parent ecosystem the A ranges from oam to clay loam and to clay in the B. Less available moisture is also ndicated by the reduction of total vegetation basal area from 1.5 percent n the parent ecosystem to 1.2 percent in this phase. Tree and shrub rown cover reduction followed the same trend, varying respectively from 50 and 7 percent for the parent to 53 and 2 percent in the phase. The rend was followed in percent composition. Respective shrub composition ercentages for the parent and phase were 16 and 1. Forbs showed no hange in composition. Grass composition percentages showed a reverse rend, 75 percent for the parent and 87 percent for the phase.

Although there are no obvious indications that animal use has caused he reduction in shrub cover and increase in grass, it cannot be discounted vithout more intensive study. Fire may have produced the grass physiog- omy. This is extremely difficult to determine since fire scars are common n both this and the parent ecosystem. In any case, rapid natural improve- ıent of the shrub stand will be doubtful.

Habitat value. — Food and cover value is considered poor. In com- aring this phase with the parent ecosystem, the two principal differences re effective hiding cover and forage production. Hiding cover is thinner ere as indicated by 1,940 *Pinus ponderosa* seedling and sapling stems per cre compared with 2,932 for the parent ecosystem. Forb production is pproximately the same, but *Purshia tridentata* production is reduced ıore than 70 percent from that indicated in the parent ecosystem. Pro- uction of grass and grasslike species increased in this phase, but the bulk f it, *Festuca idahoensis* and *Carex rossii*, has little importance as deer orage except as new green growth in late spring and early fall.

Habitat manipulation. — See parent ecosystem. If understory reseeding desired and if the overstory cut is sufficient to make expansion of the nderstory feasible, then *P. tridentata* should be considered the priority pecies to be reseeded for wildlife.



General view of the *Festuca* phase of the *Pinus ponderosa/Purshia tridentata/Festuca idahoensis* ecosystem. Note the paucity of *P. tridentata*.

Closeup of the *Festuca* phase of the *P. ponderosa/P. tridentata/F. idahoensis* ecosystem.

3 *Pinus ponderosa / Purshia tridentata / Festuca idahoensis* Ecosystem: *Carex rossii* Phase

hysical Description

Site. — This ecosystem has the same gross site characteristics as the *inus ponderosa/Purshia tridentata/Festuca idahoensis* ecosystem which ill be referred to as the parent ecosystem.

Vegetation. — The vegetation differs from that of the parent primarily y exhibiting only half as many *P. ponderosa* stems per acre, less crown over and basal area of the same species, more *P. tridentata*, and a decided ominance of *Carex rossii* in the grass-forb layer.

The tall shrub *Arctostaphylos patula* is present in trace amounts here ut is absent in the parent, and the mat-forming shrub *Ceanothus rostratus* is present as a trace in the parent but absent here. Changes in e forb complement were primarily in composition with one exception, e addition of the perennial *Apocynum androsaemifolium* in this phase.

Soil. — The soil in this phase, like that in the parent, is tentatively clasfied as a Tournquist loam. However, it is shallow (22 inches) compared ith the parent (30 inches). Textural differences of the B horizon are mall, tending to be heavier in the phase and with more stone and gravels roughout the profile than that of the parent. A representative profile is:

1 1-0. Pine litter.

1 0-2 inches. Brown (7.5 YR 5/4) dry, dark reddish brown (5 YR 3/2) moist; loam; weak, very fine granular; loose; very friable, slightly sticky, slightly plastic; pH 6.3; roots abundant.

3 2-11 inches. Dark reddish brown (5 YR 5/4) dry, dark reddish brown (5 YR 3/4) moist; light clay loam; weak, fine granular; slightly hard; friable, slightly sticky, slightly plastic; pH 6.3; roots abundant.

1 11-15 inches. Dark reddish brown (5 YR 3.4/4) moist; clay loam; weak, fine subangular blocky; firm, sticky, plastic with thin patchy clay flows on the ped surfaces; pH 6.3; roots common.

3 15-22 inches. Dark reddish brown (4 YR 3/4) moist; clay; moderate fine subangular blocky; extremely hard; extremely firm, very

sticky, very plastic with thick continuous clay flows on the ped surfaces; pH 6.2; roots few.

CD2 22-24 inches +. Weathered basalt. There are numerous basalt stones throughout the full solum.

Discussion

Ecosystem. — This appears to be a variant of the *Pinus ponderosa/Purshia tridentata/Festuca idahoensis* ecosystem due to subtle environmental changes, probably moisture, primarily. There is evidence of past fires in this stand of vegetation. Charred remains of trees and a partial stand of mature timber with a patchy understory of sapling and pole size timber indicate disturbance.

Habitat value. — Value is moderate for both forage and cover. Although density of quality browse (*Purshia tridentata*) is very high, acreage is small. Cover is below average for *Pinus ponderosa* with stems per acre being 1,435 here, compared with 2,932 in the parent, and 1,940 in the *Festuca* phase.

Habitat manipulation. — Suggestions for habitat manipulation and rehabilitation follow those for the parent ecosystem. However, the density of *Purshia tridentata* is so great (3,834 stems per acre) that with some care in logging, the residual stand may be adequate for deer and livestock requirements.

The *Carex rossii* phase of the *Pinus ponderosa/Purshia tridentata/Festuca idahoensis* ecosystem has a denser stand of *P. tridentata* than any other ecosystem discussed.

inus ponderosa/Purshia tridentata/Festuca idahoensis ecosystem; *Carex rossii phase*[1]

umber of plots: 6 Condition class: good

Site and vegetation	Understory composition	Frequency
	- - - - - - - - *Percent*	- - - - - - - -
are soil, 4.2 percent surface area	--	100
ock, 1.4 percent surface area	--	100
itter, 93 percent surface area	--	100
oss, 0.2 percent surface area	--	67
tal vegetation, 1.2 percent surface area	--	100
rshia tridentata, 11 percent crown cover; 3,834 stems per acre	37	100
honia repens, 108 stems per acre	.1	33
rysothamnus viscidiflorus, 9 stems per acre	.1	17
plopappus bloomeri, 18 stems per acre	T	50
ctostaphylos patula, 38 stems per acre	T	33
rex rossii	46	100
ipa occidentalis	8	100
stuca idahoensis	7	100
anion hystrix	4	100
a nervosa	3	100
eleria cristata	T	17
hillea millefolium	2	100
stilleja sp.	.6	50
crosteris gracilis	.4	83
necio integerrimus	.4	83
ola purpurea	.4	67
lsamorhiza sagittata	.4	50
agaria virginiana	.3	83
matium triternatum	.3	50
pinus caudatus	.1	83
racium cynoglossoides	.1	50
tennaria geyeri	.1	33
nica cordifolia	.1	33

(— Continued)

Number of plots: 6 Condition class: goo

Site and vegetation	Understory composition	Frequency
	- - - - - - - - *Percent*	- - - - - - - -
Apocynum androsaemifolium	.1	17
Pterospora andromeda	T	17
Sidalcea oregana	T	17
Cryptantha ambigua[2]	1	100
Collomia tenella[2]	1	50
Collinsia parviflora[2]	.3	100
Lithospermum sp.[2]	.3	17
Gayophytum nutallii[2]	.1	83

T = trace.

[1]Averages for trees are:

	Basal area in square feet per acre	*Stems per acre <10 inches d.b.h.*	*Percent frequency*	*Percen crown cover*
Pinus ponderosa	120	1,435	100	45
Juniperus occidentalis	.3	11	100	T
Cercocarpus ledifolius	1	9	50	.2
Abies concolor	T	1	17	T

[2]Annuals.

4 *Pinus ponderosa / Arctostaphylos patula / Festuca idahoensis* Ecosystem

Physical Description

Site. — This ecosystem occupies approximately 10,000 acres within the study area, primarily on the slopes of 7,000-foot Hager Mountain but with a small amount occurring on Dead Indian Mountain which is near the north end of Winter Ridge. The typical ecosystem occurs at elevations from 4,900 to 6,500 feet and on slopes from 5 to 25 percent. At the higher elevations and steep slopes it occurs on northwest to east aspects, whereas it may be found on others at lower elevations and on moderate slopes.

Vegetation. — Dominant species which typify this ecosystem are *Pinus ponderosa*, *Arctostaphylos patula*, and *Festuca idahoensis*. In some areas *Ceanothus velutinus* becomes an important shrub component. In the tree layer, *Abies concolor* varies from a codominant position with *P. ponderosa* to a minor component.

Basal area of all vegetation averages 1.2 percent for the ecosystem. Grasses make up a much smaller part (34 percent) of the composition here than in any other ecosystem. Due to a small sample size, data in the table should be used cautiously.

Soil. — The soil is a well-drained loam varying from 25 to 30 inches in depth with an A horizon averaging 11 inches and a B horizon averaging 15 inches. Texture is loam for the A horizon, and the B horizon ranges from silty clay loam to clay loam. The pH ranges from 5.0 to 6.0 in the A horizon and from 5.5 to 6.0 in the B. Root concentration is in the upper 14 inches. Percentage of rock on the solum surface and in the solum averages less than 5 percent. Litter cover and bare ground average 95 and 3 percent, respectively.

Discussion

Ecosystem. — The occurrence of *Abies concolor* in the *Pinus ponderosa* stand identifies this community as a successional stage of the *P. ponderosa-A. concolor/Festuca idahoensis* ecosystem. Another indication

Average vegetation-site characteristics of the *Pinus ponderosa/Arctostap ylos patula/Festuca idahoensis* ecosystem[1]

Number of plots: 3 Condition class: high go

Site and vegetation	Dominance rating	Understory composition	Frequenc
		- - - - - - - - *Percent* - - - -	
Bare soil, 3 percent surface area	--	--	100
Rock, 0.1 percent surface area	--	--	100
Litter, 95.6 percent surface area	--	--	100
Moss, 0.1 percent surface area	--	--	100
Total vegetation, 1.2 percent surface area	--	--	100
Arctostaphylos patula, 10 percent crown cover	5	22	100
Ceanothus prostratus, 8 percent crown cover	3	13	66
Haplopappus bloomeri	3	.7	100
Purshia tridentata	3	T	100
Ceanothus velutinus, 0.3 percent crown cover	2	T	66
Amelanchier alnifolia	1	T	33
Chimaphila umbellata	1	T	33
Symphoricarpos albus	1	T	33
Festuca idahoensis	5	22	100
Sitanion hystrix	3	10	100
Poa nervosa	2	1	66
Carex rossii	3	.9	100
Stipa occidentalis	2	T	100
Balsamorhiza sagittata	3	11	66
Hieracium cynoglossoides	4	8	100

(— Continued)

Number of plots: 3 Condition class: high good

Site and vegetation	Dominance rating	Understory composition	Frequency
		- - - - - - - - Percent	- - - - - -
Achillea millefolium	3	4	66
Fragaria virginiana	4	2	100
Castilleja sp.	3	1	66
Eriophyllum lanatum	3	.9	100
Apocynum androsaemifolium	3	.9	66
Lupinus sp.	3	.9	66
Agoseris sp.	2	T	66
Anaphalis margaritacea	1	T	33
Delphinium sp.	1	T	33
Lilium colombianum	1	T	33
Pterospora andromeda	1	T	33
Sidalcea oregana	1	T	33

T = trace.

[1]Averages for trees are:

	Dominance rating	*Basal area in square feet per acre*	*Stems per acre<10 inches d.b.h.*	*Percent frequency*	*Percent crown cover*
Pinus ponderosa	5	157	917	100	48
Abies concolor	3	2	69	100	2
Cercocarpus ledifolius	3	1	78	66	T
Pinus contorta	2	T	T	33	T
Juniperus occidentalis	1	T	T	33	T
Prunus emarginata	1	T	T	33	T

Pinus ponderosa/Arctostaphylos patula/Festuca idahoensis **ecosystem.**

of their relationship is the occurrence in the parent ecosystem of dead remnants of *Arctostaphylos patula* which were crowded out by dense patches of tree reproduction.

This successional community varies widely in both species and composition; particularly noticeable is the variation in shrubs and forbs.

Habitat value. — This ecosystem is of moderate value as deer habitat. It provides only a small portion of the summer deer range because of its restricted location and limited acreage. Total summer forage is not so great as in the habitats where *Purshia tridentata* is more prominent. However, forbs comprise a greater proportion of the forage here than in the *Pinus ponderosa/P. tridentata/Festuca idahoensis* association.

Hiding cover is high due to the patchy but dense *Abies concolor* and *Pinus ponderosa* reproduction.

Habitat manipulation. — Selective logging would probably produce a

Ground cover closeup of the *P. ponderosa/A. patula/F. idahoensis* ecosystem.

temporary increase in herbaceous forage, but the long-range value would be small.

Logging with severe site disturbance would precipitate a substantial increase in most understory species, probably with a resultant increase in deer concentrations. We might expect *P. tridentata* to suffer in relation to other shrubs. Where *Festuca idahoensis* is dominant we can expect it to hold its own in relation to *Carex*, *Stipa*, and *Sitanion*. Where other species are codominant, it will probably be outproduced. It is doubtful that pine plantings or seedings would be seriously disturbed in this situation as the summer range is not normally the range of short food supply. However, if animal damage did occur, then consideration should be given to large clearcuts in order to more easily absorb the deer numbers or to a selective cutting with reliance on natural regeneration and a less attractive situation for deer concentrations.

5 *Pinus ponderosa-Cercocarpus ledifolius Festuca idahoensis* Ecosystem

This is an ecosystem which may occur anywhere in the drier portions of the *Pinus ponderosa/Purshia tridentata/Festuca idahoensis* ecosystem. Soil is normally a shallow phase of that under the adjacent *P. ponderosa/Purshia tridentata/Festuca idahoensis* ecosystem. In this study area, it would be the Tournquist loam; although near the lower edge of the forest, it may occur on other soils derived from pumice and volcanic ash.

Pinus ponderosa is dominant, with *Cercocarpus ledifolius* an important but secondary species. *Juniperus occidentalis*, *Purshia tridentata*, *Artemisia tridentata*, and *Chrysothamnus viscidiflorus* are minor components of the stand. *Festuca idahoensis* is the strong dominant in the grass-forb layer with *Carex rossii*, *Sitanion hystrix*, *Agropyron spicatum*, and *Stipa occidentalis* other less important species. Commonly occurring forbs are *Achillea millefolium* and *Eriophyllum lanatum*.

Habitat value is low due to limited acreage and low browse availability. Primary value of the ecosystem is cover.

Pinus ponderosa-Cercocarpus ledifolius/Festuca idahoensis ecosystem. Note the paucity of shrubs.

A close view of the ground cover in the *P. ponderosa-C. ledifolius/F. idahoensis* ecosystem illustrating *F. idahoensis* dominance.

6 *Pinus ponderosa / Artemisia tridentata / Bromus carinatus* Ecosystem

Physical Description

Site. — This ecosystem occupies several thousand acres at elevations between 6,000 and 7,200 feet with a slight westerly aspect. This is an area where the runoff from heavy snowpacks appears to produce numerous intermittent drainageways or seasonal streambeds.

Vegetation. — *Pinus ponderosa* dominates the overstory and is mixed with very small numbers of *Pinus contorta* and *Abies concolor*. Tree reproduction, although sparse, includes all three species with *P. ponderosa* outnumbering the others tenfold. The shrub layer is characterized by a dominant stand of *Artemisia tridentata* with *Symphoricarpos albus* and *Eriogonum microthecum* commonly distributed throughout.

Bromus carinatus and *Poa nervosa* are about equally abundant and together account for about 31 percent of the total composition. Lesser amounts of *Sitanion hystrix*, *Stipa occidentalis*, and *Carex rossii* complete the grass and sedge component of this ecosystem.

Forbs are less prominent than grasses. About 15 species combine to make 10 percent or less of the vegetal composition. *Collinsia parviflora*, an annual, makes up nearly half of the forb component, and the other half is composed primarily of *Achillea millefolium*, *Lathyrus* sp., and *Fragaria virginiana*.

Soil. — The soil is a moderately deep, well-drained loam with gravels common throughout the solum. Depth averages 24 inches and roots are concentrated in the upper 8 inches but common to 20 inches. Stones account for 1 percent of the soil surface and vary from less than 5 percent to 60 percent of the solum volume.

The A horizon has a loam texture, a pH of 5.8, and averages 12 inches in depth. The B horizon is a clay loam, 12 inches deep, and the pH is 5.8 to 6.0. The typical profile description is as follows:

A11 0-3 inches. Dark brown (7.5 YR 3/2)[3]; brown (7.3 YR 4/4 crushed) loam; dark reddish brown (5 YR 3/2) moist; loam; weak

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[3] *In this profile, colors will be dry unless otherwise noted.*

fine granular structure; very friable, slightly sticky and slightly plastic; abundant very fine and fine roots; slightly acid reaction (pH 5.8); abrupt, smooth boundary. (2 to 4 inches thick.)

A12 3-7 inches. Dark brown (7.5 YR 3/2); brown (7.5 YR 4/4 crushed) loam; dark reddish brown (5 YR 2/2) moist; loam; weak fine subangular blocky structure; very friable; slightly sticky, slightly plastic; common very fine, fine and medium roots; slightly acid reaction (pH 5.8); clear, smooth boundary. (3 to 5 inches thick.)

A3 7-12 inches. Brown (7.5 YR 4/2) dark reddish brown (5 YR 3/3) moist; loam; strong, medium subangular blocky structure; firm; sticky, plastic; common, very fine, fine, and medium roots; slightly acid reaction (pH 5.8); abrupt, smooth boundary. (4 to 6 inches thick.)

B1 12-18 inches. Brown (7.5 YR 4/4) dark reddish brown (5 YR 2/2) moist; clay loam; strong, medium subangular blocky structure; firm; sticky, plastic; common fine and medium roots; slightly acid reaction (pH 5.8); clear, smooth boundary. (5 to 7 inches thick.)

B2 18-24 inches. Dark brown (7.5 YR 3/2) moist; pinkish grey (7.5 YR 7/2) on dry surfaces broken across peds; thin clay films on ped surfaces; clay; strong, medium angular blocky structure; extremely firm; very sticky, very plastic; uncommon fine, medium and large roots; neutral reation (pH 6.0); clear, smooth boundary.

24-28 inches +. Light brown (7.5 YR 6/4); strong brown (7.5 YR 5/6) moist; abundant partly decomposed igneous materials; few medium roots.

Permeability is estimated as moderate and runoff as slow to medium. Erosion hazard is low to medium. Effective rooting depth includes the full horizon under natural vegetation.

Discussion

Ecosystem. — We think of *Artemisia tridentata* as occurring primarily in the low rainfall, high desert areas rather than the high elevation, high precipitation area of this ecosystem. However, *A. tridentata* is the dominant shrub in the general area of upper Winter Ridge. This ecosystem seems to be a relatively stable one. Reproduction varies from pure *Pinus ponderosa* to a mixture of *P. ponderosa*, *P. contorta*, and very sparse *Abies concolor*. Ecotones occur between this plant community and *A. concolor*, *P. contorta*, *Populus tremuloides*, and *Artemisia arbuscula* in the same general elevation range, and *P. ponderosa/Purshia tridentata/Festuca idahoensis* community at the lower elevation perimeter.

Habitat value. — Value is moderate to high for deer and livestock due to the wide variety of summer forbs which are available. Tree reproduction is very sparse and provides little protective cover.

Habitat manipulation. — Clearcutting does not seem desirable for this ecosystem. Observations in the general area indicate that fire results in a successional stage of dense *Artemisia tridentata* and forbs, making successful reforestation difficult. Reforestation should always be accomplished as rapidly as possible after a burn. In addition, following burns or selective logging, consideration should be given to seeding forbs, native and introduced, for game and livestock use rather than grass and browse. Forbs are probably better competitors than browse with the vigorous and dense *A. tridentata* stands observable on all burns in the area and may also be more desirable as summer forage.

Average vegetation-site characteristics of the *Pinus ponderosa/Artemisia tridentata/Bromus carinatus* ecosystem[1]

Number of plots: 5 — Condition class: good

Site and vegetation	Understory composition	Frequency
	Percent	
Bare soil, 14 percent surface area	--	100
Rock, 1 percent surface area	--	80
Litter, 83 percent surface area	--	100
Moss, zero percent surface area	--	0
Total vegetation, 2 percent surface area	--	100
Artemisia tridentata	45	100
Eriogonum microthecum	2	60
Symphoricarpos albus	1	80
Ribes cereum	.1	20
Bromus carinatus	17	100
Poa nervosa	14	80
Sitanion hystrix	6	100
Stipa occidentalis	1	80
Carex rossii	1	60
Achillea millefolium	2	80
Lathyrus sp.	1	80

(— *Continued*)

Number of Plots: 5 Condition class: good

Site and vegetation	Understory composition	Frequency
	Percent	
Fragaria virginiana	1	40
Aster sp.	.6	40
Lupinus sp.	.6	40
Hieraceum cynoglossoides	.1	60
Agoseris sp.	.1	20
Arnica cordifolia	.1	20
Balsamorhiza sagittata	.1	20
Eriophyllum lanatum	.1	20
Penstemon sp.	.1	20
Sidalcea oregana	.1	20
Silene sp.	T	20
Collinsia parviflora[2]	5	100
Polygonum douglasii[2]	.6	60
Collomia grandiflora[2]	.1	40

T = trace.

[1] Averages for trees are:

	Basal area in square feet per acre	*Stems per acre <10 inches d.b.h.*	*Percent frequency*	*Percent crown cover*
Pinus ponderosa	139	97	100	47
Pinus contorta	2	10	60	T
Abies concolor	T	4	20	T
Juniperus occidentalis	T	T	20	T

[2] Annuals.

Dense *Artemisia tridentata* is serious competition to other species of the open canopied *Pinus ponderosa/A tridentata/Bromus carinatus* ecosystem.

Grasses are well used by cattle in the *P. ponderosa/A. tridentata/B. carinatus* ecosystem.

7 *Pinus ponderosa-Abies concolor/Festuca idahoensis* Ecosystem

Physical Description

Site. — This ecosystem ranges in elevation from approximately 5,000 to 7,000 feet and includes moderate slopes of a northerly aspect averaging 7 percent. This includes the upper three-quarters of the *Pinus ponderosa* communities where slope aspect and/or elevation provide conditions which are suitable.

Vegetation. — Overstory is a mixture of *Pinus ponderosa* and *Abies concolor* in varying proportions but is generally dominated by mature pine. *A. concolor* dominates tree reproduction on all plots sampled, and *Pinus contorta* occurs on about 25 percent of the plots.

The shrub layer, which is characterized by *Mahonia repens* and *Purshia tridentata*, is a minor component from the standpoint of composition; however, frequencies of both these species are above 50 percent.

Principal forbs (100-percent frequency) are *Hieracium cynoglossoides*, *Fragaria virginiana*, and *Arnica cordifolia*.

Grasses and sedges are second only to trees in basal area composition, with *Festuca idahoensis* dominant. Other species that occurred with 100-percent frequency are *Carex rossii*, *Stipa occidentalis*, *Sitanion hystrix*, and *Poa nervosa*.

Soil. — The soil is a Tournquist loam (tentative) which is over 30 inches deep. The A1 of 2 inches and A3 of 7 inches are dark reddish brown loams, the B1 of 8 inches is a dark red gritty heavy loam, the B21 of 9 inches is a dark clay loam, and the B22 of 4 inches is a dark red stony clay. The B31, beginning at 30 inches, contains well-weathered basalt fragments.

This is a well-drained soil with roots concentrated in the upper 17 inches and common to 26 inches. Surface rock makes up only one-half of 1 percent of the soil surface area and less than 5 percent of the solum volume. Permeability is estimated as good and runoff is slow. Erosion hazard is low. Effective rooting depth is the full horizon under natural vegetation.

Average vegetation-site characteristics of the *Pinus ponderosa-Abies concolor/Festuca idahoensis* ecosystem[1]

Number of plots: 7 Condition class: high good

Site and vegetation	Understory composition	Frequency
	- - - - - - - - *Percent*	- - - - - - - -
Bare soil, 1.7 percent surface area	--	100
Rock, 0.3 percent surface area	--	100
Litter, 96.4 percent surface area	--	100
Moss, 0.1 percent surface area	--	100
Total vegetation, 1.5 percent surface area	--	100
Mahonia repens	2	57
Purshia tridentata	1	86
Arctostaphylos patula	.3	29
Festuca idahoensis	39	100
Carex rossii	21	100
Stipa occidentalis	6	100
Poa nervosa	4	100
Sitanion hystrix	4	100
Bromus carinatus	1	43
Danthonia californica	.6	14
Fragaria virginiana	4	100
Arnica cordifolia	4	100
Hieraceum cynoglossoides	1	100
Achillea millefolium	1	71
Lupinus caudatus	1	71
Paeonia brownii	1	71

(*— Continued*)

Number of plots: 7 **Condition class: high good**

Site and vegetation	Understory composition	Frequency
	Percent	
Senecio integerrimus	1	71
Sidalcea oregana	1	57
Lomatium triternatum	.8	29
Microsteris gracilis	.8	29
Phacelia sp.	.8	29
Balsamorhiza sagittata	.7	43
Antennaria geyeri	.4	14
Collinsia parviflora[2]	2	57
Cryptantha ambigua[2]	.8	43
Epilobium minutum[2]	.4	43
Lithospermum sp.[2]	.4	14

T = trace.

[1]Averages for trees are:

	Basal area in square feet per acre	*Stems per acre <10 inches d.b.h.*	*Percent frequency*	*Percent crown cover*
Abies concolor	54	2,941	100	
Pinus ponderosa	151	458	100	66
Pinus contorta	3	130	29	
Juniperus occidentalis	T	T	14	T

[2]Annuals.

Discussion

Ecosystem. — The dominance of *Abies concolor* reproduction in the understory of this ecosystem indicates the future dominance of the species in the mature stand, assuming no major disturbance. Past management practices have favored *Pinus ponderosa* dominance by selective logging of the *A. concolor* whenever feasible.

This ecosystem illustrates clearly the influence of moisture and temperature changes on vegetation. Subtle changes of elevation, aspect, and slope result in obvious changes in composition of conifer regeneration throughout the study area. Wherever these influences produce better moisture and temperature conditions, the *Pinus ponderosa/Purshia tridentata/Festuca idahoensis* community gives way to the mixed conifer of the one under discussion. *P. tridentata* decreases, *Mahonia repens* becomes more prominent, and forbs change both in species and in composition.

Habitat value. — Value is considered high, primarily due to the excellent protective cover and the summer forage supplied by forbs. This

Pinus ponderosa-Abies concolor/Festuca idahoensis **ecosystem. Note the dense conifer reproduction, primarily of** *A. concolor.*

ecosystem exhibits the highest density in conifer stems per acre under 10 inches d.b.h. of any described in this study, amounting to 3,530. Forage supplied by forbs, although not significantly greater here than in other ecosystems, is palatable over a longer period of time because of the cooler temperatures and higher moisture conditions prevailing on these sites.

Habitat manipulation. — After logging or burning, we can expect an increase in *Arctostaphylos patula*. In rehabilitating these sites, there is a great opportunity for experimentation with legumes and other forbs. It may be desirable to convert the native forb components, some of which are used very little if any, to introduced species both suitable to the site and highly palatable to deer. Additional benefits that might accrue from forb development — as compared with shrub development — are reduced competition with tree regeneration and improvement of the habitat for ruffed grouse *(Bonasa umbellus sabini)* (Gabrielson and Jewett 1940).

If a rehabilitation program is considered and grasses, particularly fescue, are dominating the site, scarification may be necessary.

Understory view of *P. ponderosa-A. concolor/F. idahoensis.*

8 *Pinus contorta / Festuca idahoensis* Ecosystem

Physical Description

Site. — This is a relatively small ecosystem which occurs from 5,000 to 6,000 feet in elevation with moderate to level topography, slopes averaging 3 percent and aspects ranging from north to northeast. It can occur in a meadow edge situation. Downed logs with evidence of fire are common throughout.

Vegetation. — *Pinus contorta* is dominant in both overstory and reproduction. *Pinus ponderosa* and *Abies concolor* are common in very small numbers. *P. ponderosa* was present in all the macroplots but was not recorded in any microplots, whereas *A. concolor*, with four times as many stems per acre, was more widely distributed.

The shrub layer consisting of *Purshia tridentata* and *Chrysothamnus viscidiflorus* is very sparse.

Festuca idahoensis is dominant in the grass stratum, making up over half of the total understory. The next three most prominent species in order of abundance are *Carex rossii*, *Sitanion hystrix*, and *Stipa occidentalis.* Other grasses include *Poa nervosa*, *Danthonia californica*, and *Bromus carinatus.*

The primary forbs in order of abundance are *Microsteris gracilis*, *Fragaria virginiana*, *Lupinus* sp., *Viola purpurea*, *Lomatium triternatum*, *Achillea millefolium*, and *Arnica cordifolia.* Among others of equal forage value but much less common are *Sidalcea oregana*, *Hieraceum cynoglossoides*, *Penstemon* sp., and *Trifolium* sp.

Soil. — This is a well-drained loamy soil with root concentrations in the upper 15 inches and roots common to 28 inches. Surface rock makes up 0.2 percent of the soil surface and less than 5 percent of the solum volume. The A horizon is a dark reddish brown loam approximately 10 inches deep. The B horizon is 18 inches thick and ranges from a dark reddish brown heavy loam to a clay loam.

Discussion

Ecosystem. — The community appears to be a fire-produced seral stage which is progressing to an overstory of *Abies concolor.* The trend is indi-

Pinus contorta/Festuca idahoensis ecosystem illustrating logs from old burn and good hiding cover for game. Note absence of shrub cover.

Pinus contorta/Festuca idahoensis ecosystem ground cover illustrating the strong dominance of *F. idahoensis.*

Average vegetation-site characteristics of the *Pinus contorta/Festuca idahoensis* ecosystem[1]

Number of plots: 6 Condition class: good

Site and vegetation	Understory composition	Frequency
	Percent	
Bare soil, 1.8 percent surface area	--	100
Rock, 0.2 percent surface area	--	83
Litter, 96.8 percent surface area	--	100
Moss, 0.1 percent surface area	--	33
Total vegetation, 1.1 percent surface area	--	100
Purshia tridentata	.3	83
Chrysothamnus viscidiflorus	.3	17
Festuca idahoensis	55	100
Carex rossii	7	100
Sitanion hystrix	5	83
Stipa occidentalis	4	100
Poa nervosa	2	67
Danthonia californica	.9	50
Bromus carinatus	.5	33
Microsteris gracilis	9	100
Fragaria virginiana	4	100
Lupinus sp.	2	83
Viola purpurea	2	67
Achillea millefolium	1	83
Lomatium triternatum	1	83
Arnica cordifolia	1	67
Sidalcea oregana	.8	67
Hieraceum cynoglossoides	.5	33
Thalictrum sp.	.4	17

(— *Continued*)

Number of plots: 6		Condition class: good
Site and vegetation	Understory composition	Frequency
	Percent	
Trifolium sp.	.4	17
Silene sp.	.3	33
Penstemon sp.	.2	33
Potentilla sp.	.2	33
Zigadenus sp.	.2	33
Antennaria rosea	.2	17
Geum ciliatum	.2	17
Geum sp.	.2	17
Paeonia brownii	.2	17
Potentilla glomerata	.2	17
Gayophytum nutallii[2]	.4	33
Collomia tenella[2]	.2	17
Epilobium minutum[2]	.2	17
Lithophragma sp.[2]	.2	17

T = trace.

[1]Averages for trees are:

	Basal area in square feet per acre	*Stems per acre <10 inches d.b.h.*	*Percent frequency*	*Percent crown cover*
Pinus contorta	144	1,653	100	77
Pinus ponderosa	5	87	100	T
Abies concolor	.2	322	100	T
Juniperus occidentalis	T	2	17	T

[2]Annuals.

cated first by the young stand of shade-tolerant *A. concolor* which averages 322 stems per acre and second by the evidence of fire history. The trend is further indicated by the occurrence of *Bromus carinatus* and *Danthonia californica*, which are not found in the drier *Pinus ponderosa/Purshia tridentata/Festuca idahoensis* association but occur within the more mesic *P. ponderosa-A. concolor/F. idahoensis* association.

There may be an interaction of cold air drainage in situations of low or "pocket" topography. However, with both *Abies concolor* and *Pinus ponderosa* reproduction present, it would have to be minor enough for *P. contorta* to ameliorate temperatures sufficiently in the spring to allow the other conifers to establish themselves.

Habitat value. — Value to game is fair due to low acreage. It is valuable primarily in the area of protection and secondarily in forage in the form of a high variety of forbs. A dense stand of over 2,000 young trees per acre provides game with good protection from heat, insects, and all other sources of harassment during the late spring, summer, and fall seasons. In that respect, this community compares quite closely with the *Pinus ponderosa/Abies concolor/Festuca idahoensis* community.

Habitat manipulation. — Overstory removal would reduce protection values for game but increase forage values for both game and livestock. With severe ground disturbance favoring a dominance of grasses and *Pinus contorta*, it would be necessary to scarify the soil before *P. ponderosa* or forbs could be planted.

When this ecosystem occurs in a meadow edge situation with an interaction of cold temperature, it may be best to log, forgo rehabilitation, and allow a natural succession to follow, gambling that intensified management of the future will allow us to thin at the proper time to produce a valuable crop of *P. contorta.* If rehabilitation is desirable in this situation, advice should be sought in order to plan what may be a difficult program. In any case, from a game standpoint, this ecosystem presents a better opportunity for grass and forb rehabilitation than for shrubs. Forbs, particularly, would supply needed succulents for both deer and grouse.

9 *Pinus contorta / Danthonia californica* Ecosystem

Physical Description

Site. — This ecosystem is characterized by a low site which we might describe as one step above a meadow. It is a typically moist site, possibly with a cold air drainage pattern. This situation may occur at any elevation range within the study area.

Vegetation. — It is characterized by an overstory of *Pinus contorta* with sparse and scattered reproduction. Basal area averages 128 square feet per acre, including reproduction above 5.5 feet, and average density of stems under 10-inch d.b.h. is 620 per acre.

There is no shrubby understory.

The grass layer is dominated by *Danthonia californica*, with five other grasses and grasslike species of a total of 13 being major components of the stand.

The forb dominant is *Antennaria corymbosa*. Other important forbs are *Aster* sp., *Trifolium* sp., *Achillea millefolium*, and *Fragaria virginiana*. Forbs of minor but consistent occurrence include *Sidalcea oregana*, *Geum macrophylum*, and *Potentilla gracilis*. Due to a small sample size, data in the table should be used with caution.

Soil. — The soil is a moderately deep and moderately well-drained clay loam. There is less than 5 percent of the soil surface covered with stone, and stone comprises less than 15 percent of the solum volume. Roots are concentrated in the upper 12 inches.

Discussion

Ecosystem. — This is a small, highly variable ecosystem that is obviously responsive to moisture gradients which account for its irregular vegetation patterns. It is very possibly a result of invasion of *Pinus contorta* into a dry meadow type. A relatively high moisture table and/or a

Pinus contorta/Danthonia californica ecosystem[1]

Number of plots: 2 Condition class: goo

Site and vegetation	Dominance rating	Frequency
	Percent	
Bare soil, 5 percent surface area	--	100
Rock, <5 percent surface area	--	100
Litter, 85 percent surface area	--	100
Moss, 5 percent surface area	--	100
Total vegetation, <5 percent surface area	--	100
Danthonia californica	5	100
Carex sp.	3	100
Deschampsia elongata	3	100
Juncus sp.	3	100
Koeleria cristata	3	100
Muhlenbergia filiformis	3	100
Poa sp.	2	100
Scirpus sp.	2	100
Sitanion hystrix	1	100
Stipa occidentalis	1	100
Danthonia unispicata	1	50
Deschampsia danthonioides	1	50
Festuca idahoensis	1	50
Antennaria corymbosa	5	100
Achillea millefolium	3	100
Aster sp.	3	100
Fragaria virginiana	3	100
Trifolium sp.	3	100
Agoseris sp.	2	100
Geum macrophyllum	2	100
Potentilla gracilis	2	100
Sidalcea oregana	2	100

(— *Continued*)

Number of plots: 2 | Condition class: good

Site and vegetation	Dominance rating	Frequency
	Percent	
Penstemon sp.	2	50
Arnica cordifolia	1	50
Circium sp.	1	50
Geum sp.	1	50
Phacelia sp.	1	50
Potentilla glandulosa	1	50
Linanthus harknessii[2]	1	50

[1]Averages for trees are:

	Dominance rating	*Basal area in square feet per acre*	*Stems per acre <10 inches d.b.h.*	*Percent frequency*	*Percent crown cover*
Pinus contorta	5	128	620	100	50

[2]Annual.

cold drainage appear to be why this ecosystem is characterized by *P. contorta* rather than *P. ponderosa*, the typical species in adjacent but higher and drier ecosystems.

Habitat value. — The value of this ecosystem is low, primarily due to the relatively small acreage available to game in this summer range. However, wherever it occurs, both deer and grouse find succulent mid- and late summer forbs available.

Habitat manipulation. — If a market were to develop in the area for *Pinus contorta*, then clearcutting, maintenance as a meadow, and managing for livestock grazing would be desirable, particularly considering the scarcity of meadow acreage in this area. It may be desirable in some locations to fence small portions of the ecosystem as game areas to encourage both deer and grouse development.

10 *Populus tremuloides / Artemisia tridentata / Bromus carinatus* Ecosystem

Physical Description

Site. — This ecosystem occurs between 6,000- and 7,100-foot elevation with level terrain or west-facing slopes of less than 5 percent in areas with numerous intermittent drainageways and heavy winter snowpacks. Topography is smooth to rolling, and the ground surface is moderately rough.

Vegetation. — The overstory crown cover is unmistakably *Populus tremuloides* (24 percent) with an occasional, scattered *Pinus ponderosa*. *Artemisia tridentata* is the most abundant species in the shrub stratum. Other shrubs with wide ecosystem distribution but much less prominence are *Eriogonum microthecum* and *Symphoricarpos albus*. *Ribes cereum* and *Haplopappus bloomeri* complete the shrub list.

Grasses are dominated by *Bromus carinatus* (18-percent composition), followed by *Sitanion hystrix* and *Poa nervosa*. Perennial forbs occurring on all plots are *Aster* sp. and *Lathyrus* sp. Also common are *Agoseris* sp., *Thalictrum* sp., and *Eriophyllum lanatum*. The only annual which occurs with 100-percent frequency is *Collinsia parviflora*.

As this community is heavily used by livestock during the summer, the understory appears ragged and trampled. Obviously, species composition represents something less than pristeen conditions.

Soil. — This is a deep, well-drained, medium-textured soil developed in basalt residuum. The surface horizon (8-10 inches thick) ranges from brown to dark brown and from silt loam to loam.

The solum is 28 inches plus with roots concentrated in the upper 10 inches but common throughout the profile. Permeability is estimated as moderately rapid and runoff as slow to medium. Erosion hazard is medium. The following soil profile description is representative of the soil under this vegetation community:

O1 1-0 inch. *Populus tremuloides* and *Artemisia tridentata* litter.

A1 0-2 inches. Dark brown (7.5 YR 3/2) moist; loam; moderate fine granular structure; very friable; slightly sticky, slightly plastic; many very fine, fine, medium, and large roots; slightly acid (pH 6.2); many stones and boulders (50 percent horizon volume); clear, smooth boundary. (1 to 3 inches thick.)

A3 2-9 inches. Dark brown (7.5 YR 3/2) moist; loam; moderate medium subangular blocky structure; very friable; slightly sticky, slightly plastic; many very fine, fine, medium, and large roots;

slightly acid reaction (pH 6.0); many stones and boulders (50 percent horizon volume); clear, smooth boundary. (6 to 9 inches thick.)

B1 9-20 inches. Very dark brown (10 YR 2/2) moist; clay loam; moderate medium subangular blocky structure; friable; sticky, plastic; common fine, medium, and large roots; slightly acid reaction (pH 6.0); many boulders (50 percent of horizon); clear wavy boundary; this horizon has inclusions from the A3 as a result of rodent activity and/or old root channels. (9 to 12 inches thick.)

B2 20-28 inches +. Strong brown (7.5 YR 5/6) moist; clay loam; moderate medium subangular blocky structure; friable; sticky, plastic; common fine, medium, and large roots; slightly acid reaction (pH 6.0); many boulders (50 percent of the horizon).

Discussion

Ecosystem. — This ecosystem occurs in areas within the conifer communities where soil-site conditions have been naturally altered to provide localized mesic conditions which meet the requirements of *Populus tremuloides*. Both game and livestock use are heavy, resulting in serious abuse to understory species. Because the environment is localized and transitional with concentrated shade and succulent forage, animals of all kinds tend to congregate here as they do in the even more moist *P. tremuloides* groves on streambanks and at spring locations. There is more bare soil here than in any other ecosystem sampled.

Habitat value. — The value of this habitat for deer is limited due to the small area involved but varies with proximity of conifer types. Where it occurs in association with the open *Pinus pondcrosa/Artemisia tridentata/Bromus carinatus* association but remote from other cover, its value is moderate due to both the cover provided by *P. tremuloides* and succulent forage provided. Where it is near *P. contorta* thickets or *Abies concolor* communities, the protective cover advantage is less important as is the difference in forage types.

A potential value which is generally ignored is that for grouse and other small animal species. This is high due to the excellent variety of forage and cover which could be developed with proper management.

Habitat manipulation. — The variety and quality in forage and cover which is available to game should put this ecosystem in a low multiple use category for logging the occasional *Pinus ponderosa* which might occur in the overstory. Opportunity exists for deer and grouse habitat improvement by fencing some of the more strategically located areas, probably scarifying the soil, and seeding the understory, if necessary, to legumes and other desirable forbs. This would eliminate severe livestock damage in fenced areas, allow deer use, and provide habitat which would encourage the increase of grouse and other small animals. Consideration should also be given to water development in the form of guzzlers for both deer and grouse.

Average vegetation-site characteristics of the *Populus tremuloides/Artemisi*
tridentata/Bromus carinatus ecosystem[1]

Number of plots: 5 Condition class: fai

Site and vegetation	Understory composition	Frequency
	- - - - - - - - *Percent* - - - - - - - -	
Bare soil, 30 percent surface area	--	100
Rock, 1 percent surface area	--	100
Litter, 67 percent surface area	--	100
Moss, zero percent surface area	--	0
Total vegetation, 2 percent surface area	--	100
Artemisia tridentata, 20 percent crown cover	39	100
Eriogonum microthecum	9	80
Symphoricarpos albus, 3 percent crown cover	3	80
Ribes cereum	1	40
Haplopappus bloomeri	T	20
Bromus carinatus	18	100
Sitanion hystrix	6	100
Poa nervosa	5	60
Stipa occidentalis	4	20
Deschampsia elongata	1	40
Melica bulbosa	.1	20
Aster sp.	3	100
Agoseris sp.	1	60
Thalictrum sp.	1	60
Lathyrus sp.	.7	100
Lupinus caudatus	.4	40

(— Continued)

Number of plots: 5 Condition class: fair

Site and vegetation	Understory composition	Frequency
	Percent	Percent
Potentilla glomerata	.4	40
Achillea millefolium	.2	40
Castilleja sp.	.2	20
Eriophyllum lanatum	.2	60
Lomatium triternatum	.2	20
Hieracium cynoglossoides	.1	40
Delphinium sp.	.1	20
Hydrophyllum capitatum	.1	20
Sidalcea oregana	.1	20
Collinsia parviflora[2]	5	100
Polygonum douglasii[2]	1	80
Collomia grandiflora[2]	.1	40
Linanthus harknessii[2]	.1	20

T = trace.

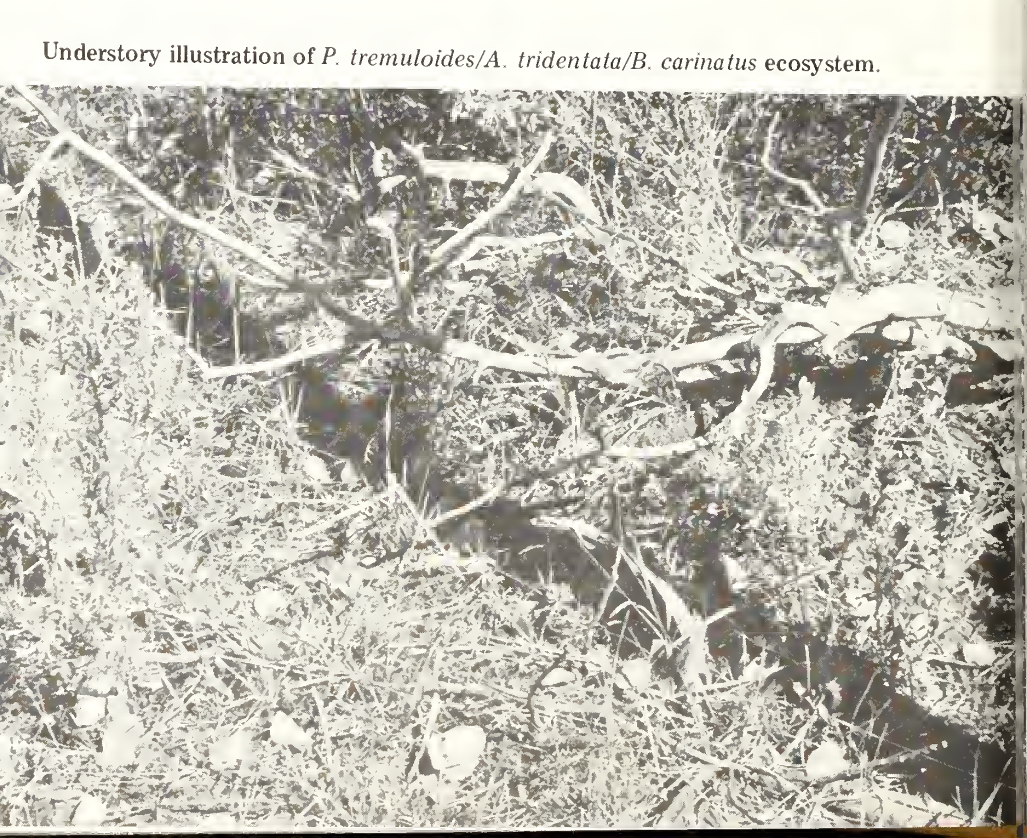
[1] Averages for trees are:

	Basal area in square feet per acre	*Stems per acre <10 inches d.b.h.*	*Percent frequency*	*Percent crown cover*
Populus tremuloides	34	435	100	24
Pinus ponderosa	1	10	80	.1
Abies concolor	T	2	20	T

[2] Annuals.

Populus tremuloides/Artemisia tridentata/Bromus carinatus ecosystem.

Understory illustration of *P. tremuloides/A. tridentata/B. carinatus* ecosystem.



11 *Populus tremuloides* Colonies

The *Populus tremuloides* colonies in the mule deer's summer and transition range characteristically occur on stream banks, around springs, or on moisture seeps and comprise a very small acreage. Because water is more available, these colonies are even more attractive to grazing animals than the ecosystem discussed above and subject to the same abuse. Possibilities for improving them are also the same.

Habitat Value

Habitat potential is similar to that in the *Populus tremuloides/ Artemisia tridentata/Bromus carinatus* community. However, in these colonies there is little if any shrub cover. It appears that protection from livestock can result in an increase of cover due to aspen suckering. Thus, hiding cover for deer can approach that which can be attained in the *P. tremuloides/A. tridentata/B. carinatus* community through fencing.

Overall view of a *Populus tremuloides* colony. Note the understory vegetation cropped short by deer and cattle.

A close view of ground vegetation under a *P. tremuloides* canopy.

12 *Cercocarpus ledifolius / Festuca idahoensis-Agropyron spicatum* Ecosystem

Physical Description

Site. — This ecosystem occurs at the lower edge of the *Pinus ponderosa/Purshia tridentata/Festuca idahoensis* ecosystem and is characterized by topography at elevations from 4,700 to 5,600 feet and by slopes ranging from less than 5 to 40 percent. Exposure aspects are northeast and northwest in the Silver Lake study area. As topography is cut abruptly by ridges and hillocks, aspects change within very short horizontal distances.

Most of the *Cercocarpus ledifolius* occurs in a transition area between the lower edge of the *Pinus ponderosa* forest and the upper edge of the high desert shrub steppe. It also occurs, but in smaller amounts, as inclusions in the pine type, sometimes as belts around scab or *Artemisia arbuscula* flats, and as a dominant on various sites throughout the high desert of eastern Oregon.

Mean annual precipitation is approximately 12 inches with two-thirds falling as snow and rain during the winter and the rest as rain in the fall and spring, except for 5 percent which falls during the 3 summer months.

Vegetation. — This ecosystem is characterized by a dense, patchy cover of *Cercocarpus ledifolius* averaging 36 percent, with an occasional *Juniperus occidentalis* and *Pinus ponderosa*. The understory is primarily *Festuca idahoensis* and *Agropyron spicatum* with *Artemisia tridentata* and other shrubs increasing where *C. ledifolius* crown cover is absent. Other shrubs include *Chrysothamnus viscidiflorus*, *C. nauseosus*, *Ribes cereum*, and *Purshia tridentata*.

Balsamorhiza sagittata and *Achillea millefolium* are the principal forbs. The annual, *Bromus tectorum*, was 11 percent of the composition, more than any of the forbs or perennial grasses except the codominants *Festuca idahoensis* and *Agropyron spicatum*.

Soil. — The soil is a well-drained, moderately deep stony loam on rolling to steep topography. Surface area of bare soil and rock averaged 5 and

Average vegetation-site characteristics of the *Cercocarpus ledifolius/Festu* *idahoensis-Agropyron spicatum* ecosystem[1]

Number of plots: 5 Condition class: good to high go

Site and vegetation	Understory composition	Frequency
	- - - - - - - - *Percent*	- - - - - -
Bare soil, 5 percent surface area	--	100
Rock, 26 percent surface area	--	100
Litter, 63.5 percent surface area	--	100
Moss, 2 percent surface area	--	100
Total vegetation, 3.5 percent surface area	--	100
Artemisia tridentata, 3 percent crown cover	4	100
Chrysothamnus viscidiflorus	1	80
Chrysothamnus nauseosus	T	60
Ribes cereum	T	20
Purshia tridentata	T	20
Festuca idahoensis	37	100
Agropyron spicatum	24	100
Sitanion hystrix	9	100
Poa sandbergii	8	100
Koeleria cristata	2	80
Bromus carinatus	.5	40
Bromus tectorum[2]	11	80
Balsamorhiza sagittata	3	80
Achillea millefolium	.1	60
Microsteris gracilis	.1	40
Astragalus stenophyllus	.1	20
Erigeron sp.	.1	20
Lupinus caudatua	.1	20
Collinsia parviflora[2]	T	20

T = trace.

[1]Averages for trees are:

	Basal area in square feet per acre	*Percent frequency*	*Percent crown cove*
Cercocarpus ledifolius	--	100	36
Junipcrus occidentalis	T	80	.5
Pinus ponderosa	T	80	.1

[2]Annual.

26 percent, respectively. Stone in the solum averages 60 percent of the volume. Solum development is in mixed colluvium and weathered basalt. A representative profile is:

A11 0-3 inches. Dark reddish brown (5 YR 2/2) moist; gravelly loam; weak fine granular structure; very friable; slightly sticky and slightly plastic; abundant very fine and fine roots and common medium to large roots; medium acid reaction (pH 6.0); angular cobbles 30 percent of the volume; clear, wavy boundary. (2 to 5 inches thick.)

A12 3-9 inches. Dark reddish brown (5 YR 2/2) moist; gravelly loam; weak fine granular structure; very friable, slightly sticky, slightly plastic; abundant very fine, fine, and medium roots and common large roots; medium acid reaction (pH 6.0); angular cobbles 30 percent of the volume; clear, wavy boundary. (5 to 8 inches thick.)

B21 9-14 inches. Dark reddish brown (5 YR 3/2) moist; heavy gravelly loam; moderate, fine granular structure; very friable; slightly sticky and slightly plastic; common very fine, fine, medium and large roots; slightly acid reaction (pH 6.5); angular cobbles 60 percent of the volume; clear, wavy boundary. (4 to 7 inches thick.)

B22 14-21 inches. Reddish brown (5 YR 4/4) moist; clay loam; moderate fine subangular blocky structure; sticky and plastic; uncommon fine, medium and large roots; slightly acid reaction (pH 6.5); angular cobbles 60 percent of the volume; clear, wavy boundary. (5 to 9 inches thick.)

IIC 21 inches +. Gravelly clay, mixes with weathered basalt fragments and cracked basalt rock.

This is a well-drained soil with moderate permeability. Runoff is estimated as medium, and erosion hazard is moderate to high. Effective rooting depth includes the entire profile under natural vegetation.

Discussion

Ecosystem. — This is an ecosystem in good to very good condition with little evidence of abuse by livestock. Deer have highlined the mature *Cercocarpus ledifolius*, and both deer and sheep have kept the few young plants severely hedged. Grass appears almost untouched; however, green regrowth is used readily by deer during the fall, winter and spring periods and should be considered an important part of their diet. The shrub layer has been relatively undisturbed except for *Purshia tridentata* which amounts to only a trace of total composition.

The greatest pressure animals have on this ecosystem seems to be that of continued extreme use of *Cercocarpus ledifolius* with two results: (1) the highlining of mature plants which probably has little adverse effect

Cercocarpus ledifolius/Festuca idahoensis-Agropyron spicatum **ecosystem. Note the relatively open canopy.**

on the maintenance or survival of the species and (2) the suppression of young plants by producing a low-hedged or "pincushion" growth form. This heavy utilization does not suppress germination or establishment of young plants. They escape detection in the tall bunchgrass and winter snows until they are 6 to 12 inches tall and have a strong competitive root system and well-branched top.

Because this community lies between the conifer forest and high desert steppe, it might be considered more a part of an ecotone than a separate ecosystem. However, the consistency and reliability with which it occurs in the position described, and the marked and abrupt change that is exhibited at its upper and lower edge, make it a very real and unique ecosystem.

Habitat value. — Although this is of relatively small acreage, it is in a position contiguous with the other *Cercocarpus ledifolius* ecosystems and, therefore, in combination they become a very valuable habitat for deer particularly during the fall, winter, and spring periods. The greatest value

Understory view of *C. ledifolius/F. idahoensis-A. spicatum* **ecosystem. Note the prominence of** *A. spicatum.*

is hiding cover, followed by forage. This relationship might be reversed with rehabilitation.

Habitat manipulation. — When a *Cercocarpus ledifolius* plant attains the stature of a tree and is highlined, it no longer provides forage but does continue to be a valuable source of seed. Attempts have been made to push these trees over so that deer can utilize the forage in their tops, but the trees usually die. Studies are underway to determine if pruning the tops will stimulate sprouting on the lower part of the main stem, within reach of deer.

When rehabilitation is necessary after fire, *Cercocarpus ledifolius* should be seeded exclusively until more information is gathered concerning its ability to compete with other species. Reseeding on most sites will probably be limited to hand or aerial methods due to steepness and rockiness. Until more information is available on seed stratification, seeding should be done in late fall. Overstory removal should not be deliberate on steep sites due to erodable soils.

13 *Cercocarpus ledifolius/ Festuca idahoensis* Ecosystem

Physical Description

Site. — This ecosystem is characterized by mountainous terrain c northeast to north-northwest exposures with slopes from less than 5 to 2 percent and at elevations from 4,700 to 5,400 feet.

Vegetation. — This vegetation, although similar in many respects t that of the *Cercocarpus ledifolius/Festuca idahoensis-Agropyron spicatur* ecosystem, differs mainly in its much denser stand of *C. ledifoliu* (66-percent crown cover), fewer shrubs, and the large amount of *F idahoensis* in the composition (80 percent). The shrubs, represente mainly by *Artemisia tridentata* and *Chrysothamnus viscidiflorus*, ar largely restricted to openings in the dense *C. ledifolius*.

The following grasses combined comprise 14 percent of the composi tion: *Agropyron spicatum*, *Sitanion hystrix*, *Koeleria cristata*, and *Po sandbergii*. Forbs that are frequently encountered include *Hieraceun cynoglossoides* and *Microsteris gracilis*.

Soil. — Because this and the *Cercocarpus ledifolius/Festuca idahoensis Agropyron spicatum* eocsystems are contiguous, they are subjected tc very similar climatic conditions and are derived from the same parent material (mixed colluvium and weathered basalt). They appear to be only slight variations of the same soil. The primary difference is the much smaller volume of cobbles in the A horizon of this unit (5 percent as com- pared with 30 percent). A representative profile is:

A11 0-4 inches. Very dark brown (10 YR 2/2) moist; loam; weak, fine granular structure; slightly sticky and slightly plastic; common large, medium, and many fine and very fine roots; few fine and very fine tubular and interstitial pores; medium acid reaction (pH 6.0); cobbles 5 percent of the volume; clear, smooth boundary. (3 to 5 inches thick.)

A12 4-10 inches. Very dark brown (10 YR 2/2) moist; loam; weak, fine granular structure; slightly sticky, slightly plastic; common large verage vegetation-site characteristics of the *Cercocarpus ledifolius/Festuca idahoensis* ecosystem[1]

umber of plots: 5 | Condition class: good to high good

Site and vegetation	Understory composition	Frequency
	- - - - - - - - *Percent*	- - - - - - - -
are soil, 3 percent surface area	--	100
ock, 3 percent surface area	--	100
tter, 73.5 percent surface area	--	100
oss, 17 percent surface area	--	100
otal vegetation, 3.5 percent surface area	--	100
rtemisia tridentata, 3 percent crown cover	2	80
hrysothamnus viscidiflorus	T	40
melanchier alnifolia	T	20
ibes cereum	T	20
etradymia canescens	T	20
estuca idahoensis	80	100
itanion hystrix	6	80
gropyron spicatum	5	100
oeleria cristata	2	80
oa sandbergii	1	100
romus carinatus	.6	40
arex rossii	T	20
romus tectorum[2]	.6	40
ieraceum cynoglossoides	1	100
licrosteris gracilis	1	80
goseris sp.	.2	60
riophyllum lanatum	.2	60
chillea millefolium	T	20
alsamorhiza sagittata	T	20
rigeron sp.	T	20
ollinsia parviflora[2]	.2	60
ryptantha ambigua[2]	.2	40
lontia perfoliata[2]	T	20

T = trace.

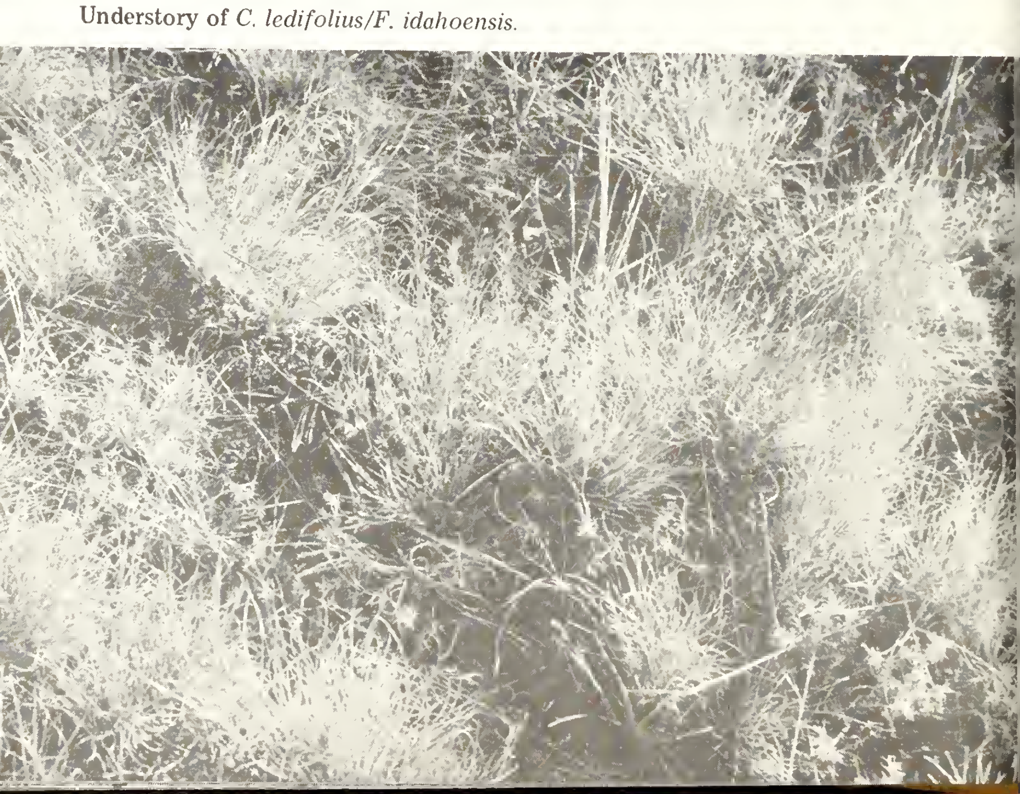
[1] Averages for trees are:

	Basal area in square feet per acre	*Percent frequency*	*Percent crown cover*
inus ponderosa	T	100	T
ercocarpus ledifolius	--	100	66
uniperus occidentalis	T	60	1

[2] Annuals.

Cercocarpus ledifolius/Festuca idahoensis ecosystem. Note surprisingly dense stand of *F. idahoensis* under this heavy canopy.

Understory of *C. ledifolius/F. idahoensis.*



and medium and many fine roots; few fine and very fine tubular and interstitial pores; medium acid reaction (pH 6.0); cobbles 5 percent of the volume; clear, wavy boundary. (4 to 7 inches thick.)

B21 10-16 inches. Dark brown (7.5 YR 3/2) moist; clay loam; moderate, fine, subangular blocky structure; sticky and plastic; common large, medium and fine roots; common fine and very fine pores; medium acid reaction (pH 6.0); stone 65 percent of the volume; clear, wavy, boundary.(4 to 8 inches thick.)

B22 16-24 inches. Dark brown (7.5 YR 3/2) moist; clay loam; sticky and plastic; moderate, fine, subangular blocky structure; common large and medium roots; few fine and very fine pores; medium acid reaction (pH 6.0); stone 65 percent of the volume; clear, smooth boundary. (7 to 9 inches thick.)

IIC 24 inches +. Weathered basalt gravels and slightly weathered, cracked basalt rock.

This soil is well drained. Permeability is estimated as medium, runoff is medium, and erosion hazard is moderate. Effective rooting depth includes the entire profile under natural vegetation.

Discussion

Ecosystem. — This community is in good to high good condition with no evidence of abuse by livestock and only moderate abuse by deer. Sheep are trailed through this area, but use is light, and only a minor amount of *Cercocarpus ledifolius* is available. Deer have highlined the *C. ledifolius* stand which was tall enough that very little damage resulted. This stand is relatively even-aged, and young plants are few. Lack of regeneration is not believed to be a result of heavy deer use but of lack of openings in an almost closed community.

Habitat value. — Although acreage is relatively small, its contiguous occurrence with other *Cercocarpus ledifolius* ecosystems in the winter-summer range transition zone, its potential production of highly preferred deer browse, and its value as cover make it an important habitat.

Habitat manipulation. — The same comments concerning manipulation of the *Cercocarpus ledifolius/Festuca idahoensis-Agropyron spicatum* ecosystem apply to this one.

14 *Purshia tridentata / Festuca idahoensis* Ecosystem

Physical Description

Site. — This eocsystem occurs on the deer's transition range betwe the summer and winter ranges. It is characterized by gentle to rolli benchland which rims a portion of the Silver Lake Valley. Slopes ran from 0 to 5 percent.

Vegetation. — It is characterized by a dominant aspect of *Pursh tridentata* with *Artemisia tridentata* and *A. arbuscula* commonly occurri throughout the stand. Other shrub species occurring consistently a *Chrysothamnus viscidiflorus* and *C. nauseosus.*

There is an occasional *Juniperus occidentalis* and *Cercocarpus ledifoli* occurring in this ecosystem; however, composition, basal area, and crow cover data indicate that these species are of minor importance.

The strong dominant in the grass layer is *Festuca idahoensis. P sandbergii, Stipa thurberiana, Sitanion hystrix,* and *Agropyron spicatu* are other grasses which occur consistently and prominently.

Antennaria rosea, Erigeron sp., *Astragalus purshii,* and *Arabis* sp. ar forbs which occur consistently throughout the stand. Others which ar common but irregular are *Eriophyllum lanatum* and *Crepis* sp.

Soil. — This is a well-drained, moderately deep loam. The A horizo averages 6 inches in depth and is slightly acid. The B1 is a stony clay loan the B2 is a stony clay, and both are slightly acid. Stones in the solu average 35 percent by volume, and the zone of root concentration is 0 t 12 inches. Inclusion of approximately 10 percent of the shallow soil unde the *Purshia tridentata-Artemisia arbuscula/Stipa thurberiana* ecosyster occurs here.

Discussion

Ecosystem. — This is the relatively narrow transition belt between th high desert steppe and the forest. Here variability is high, and it migh seem that successful ecosystem definition would be unreasonable. How ever, in unraveling vegetation, soils, and sites, there seems to be enoug uniformity to justify the effort, especially since this is a very critical are for deer management.

This ecosystem has a long history of both heavy livestock use and mod erately heavy to heavy deer use. Livestock use has been primarily from late spring through summer and deer use during the late fall, winter, and

Purshia tridentata/Festuca idahoensis ecosystem[1]

Number of plots: 3 Condition class: fair to good

Site and vegetation	Understory composition	Frequency
	- - - - - - - - *Percent*	- - - - - - - -
Bare soil, 37 percent surface area	--	100
Rock, 1 percent surface area	--	100
Litter, 43 percent surface area	--	100
Moss, 17 percent surface area	--	100
Total vegetation, 2 percent surface area	--	100
Purshia tridentata, 3 percent crown cover	29	100
Artemisia tridentata	13	100
Artemisia arbuscula	9	100
Chrysothamnus nauseosus	4	100
Chrysothamnus viscidiflorus	4	100
Festuca idahoensis	13	100
Poa sandbergii	7	100
Stipa thurberiana	6	100
Sitanion hystrix	4	100
Agropyron spicatum	2	100
Carex rossii	.9	100
Koeleria cristata	.5	66
Melica bulbosa	.4	66
Stipa occidentalis	.2	66
Bromus tectorum[2]	5	100
Antennaria rosea	.6	100
Erigeron sp.	.4	100
Arabis sp.	.2	100
Astragalus purshii	.2	100
Crepis sp.	.1	66
Eriophyllum lanatum	.1	66
Penstemon sp.	.1	33
Achillea millefolium	.1	33
Eriogonum sp.	.1	33
Lomatium triternatum	.1	33

T = trace.

[1] Averages for trees are:

	Basal area in square feet per acre	*Percent crown cover*	*Percent frequency*
Juniperus occidentalis	T	66	T
Cercocarpus ledifolius	T	66	T

[2] Annual.

spring periods. The combination of these uses has resulted in *Pursh tridentata's* exhibiting a sculptured crown. Also the native grasses ha been overused to the point where *Bromus tectorum* composition h climbed to 5 percent, a figure higher than those of 67 percent of tl native grasses present.

In analyzing the use history and composition, it seems reasonable t conclude that this ecosystem is in a successional stage. Enough soil do not appear to have been lost through erosion to change the potential c the site.

Habitat value. — The value of this ecosystem is high due to both i position in a critical deer range and its productivity for deer forage. Avai able in this one ecosystem is a variety of four usable shrub species. Two c these species are very desirable (*Purshia tridentata* and *Artemisi arbuscula*), and two provide variety during times of plenty and emergenc forage when times are hard (*A. tridentata* and *C. viscidiflorus*). *A arbuscula* is particularly valuable during the spring period after it puts ou new leaders.

There are two grass species which provide excellent forage during th fall and spring periods and even some green regrowth during the winte periods when snow cover is lacking (*Poa sandbergii* and *Bromus tectorum*).

Habitat manipulation. — This and other ecosystems in the deer's transition range should be given high priority for deer management when manipulation becomes necessary. Any livestock use or rehabilitation plans should hold to the objective of providing a combination of shrub and herbaceous forage. *Purshia tridentata* and *Artemisia arbuscula* could both be reseeded since it is suspected that this ecosystem as well as *P. tridentata-A. arbuscula/Stipa thurberiana* have specific soil microsites for each species. Site preparation will probably be necessary in many situations before seeding. It may be more reasonable to encourage *Bromus tectorum* and *Poa sandbergii* or similar responsive grass species for this situation rather than *Festuca idahoensis*, *S. thurberiana*, and *Agropyron cristatum*, etc. The latter commonly produce forage later in the spring than deer prefer and/or have more old standing litter hiding the fresh growth than deer are willing to chew through. This litter can be dealt with in sites where management is for grass only by manipulation with livestock; however, on shrub ranges it becomes very difficult to use livestock (although not unreasonable in some situations) where both they and deer prefer the same shrub species.

Unless fire or some other disaster disturbs this ecosystem, it may be necessary to use cattle to remove standing litter from perennial grasses in the spring **before** new growth begins on shrub species. Then any shrub forage used by cattle will be last year's (that which deer did not use during the preceding winter), and new growth will be reserved for next winter's needs. Soil compaction must be watched carefully as this soil is susceptible.

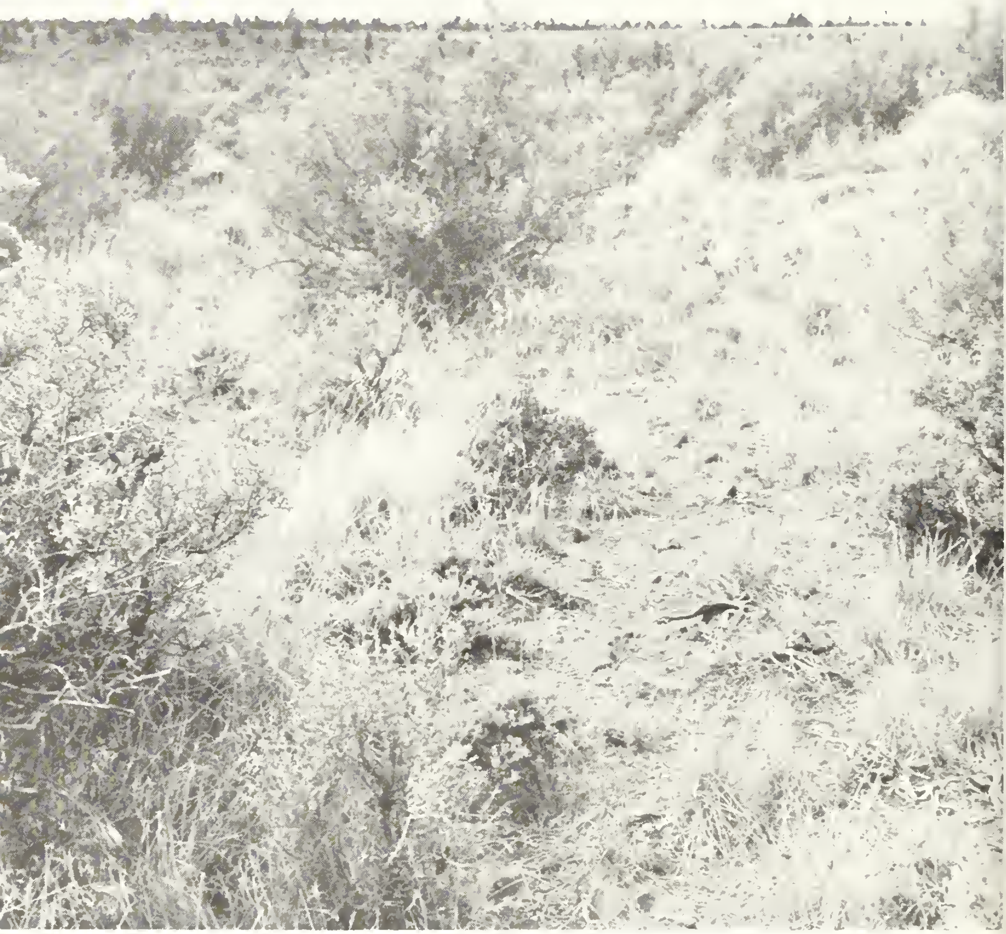
15 *Purshia tridentata-Artemisia arbuscula / Stipa thurberiana* Ecosystem

This ecosystem occurs on the upper portion of the deer's winter range near the lower edge of the pine forest. Slope is less than 5 percent. The soil is shallow, stony, and heavy and only moderately well drained.

Purshia tridentata and *Artemisia arbuscula* are strong shrub dominants with *Chrysothamnus viscidiflorus* and *C. nauseosus* occurring as minor components, increasing in importance with a reduction in condition class. The dominant grass is *Stipa thurberiana* with *Sitanion hystrix* and *Poa sandbergii* being major competitors. Other grasses include *Koeleria cristata*, *Agropyron spicatum*, and *Bromus tectorum*. The dominant forb is *Antennaria rosea*. Other important forbs are *Astragalus* sp., *Erigeron* sp., and *Lomatium triternatum*. This vegetation seems to be only in fair condition due to a long history of heavy use by livestock.

Normally in central Oregon, *Purshia tridentata* and *Artemisia arbuscula* are strange companions since *P. tridentata* requires a considerably deeper and better drained soil than does *A. arbuscula*. Here they grow together in apparent harmony. Preliminary tests indicate that these two species are growing on two distinct microsites. *A. arbuscula* occurs on those which have a layer restrictive to roots at approximately 15 to 20 inches, and *P. tridentata* occurs on sites where this restrictive layer has failed to form. Thus, what appears to be an *A. arbuscula* stand with *P. tridentata* randomly scattered throughout may rather be a vegetation mosaic where the species are growing on distinctly different soil sites. The major cementing agent which seems to be restricting drainage and root penetration has been identified as silica.

This ecosystem is an important component of the deer's transition range and during most years provides valuable grass regrowth in the fall and grass regrowth and shrub forage in both the winter and spring periods.



Purshia tridentata-Artemisia arbuscula/Stipa thurberiana ecosystem. Note the *A. arbuscula* plants in the interspaces.

16 Artemisia tridentata-Purshia tridentata / Festuca idahoensis Ecosystem

Physical Description

Site. — This is a large ecosystem situated in the mule deer's summer-winter range transition belt just below the *Pinus ponderosa* and *Cercocarpus ledifolius* forest edges at an elevation range from 4,500 to 4,700 feet. During the greater number of years, this ecosystem provides winter habitat for the deer. Slopes range from level benches to those of 15 percent and exposures may be east, north, or west.

Vegetation. — It is characterized by an aspect of *Artemisia tridentata* peppered with *Purshia tridentata* in a crown cover ratio of approximately 2 to 1. There is a small but consistent amount of *Chrysothamnus viscidiflorus* throughout the stand, and *C. nauseosus* and *Tetradymia canescens* occur only sporadically.

Perennial grasses are dominated by *Festuca idahoensis* and *Sitanion hystrix*, with the annual *Bromus tectorum* having as high a place in composition as either perennial. All three grasses occur with 100-percent frequency. Other important perennials in the grass layer which occur consistently are *Carex rossii*, *Stipa occidentalis*, and *Agropyron spicatum*.

Forbs are of relatively minor importance, occurring with less than 1-percent composition in total. The most consistently occurring perennials are *Lupinus* sp. and *Astragalus* sp.

Soil. — The soil is a deep, well-drained sandy loam derived primarily from pumice. Fine pumice gravels are common in the upper 2 feet, and pumice gravels and stones up to 8 centimeters in diameter are common from 21 inches to 4 feet. There is some colluvium in the profile, with basalt gravels and stones common in the upper 12 inches.

The A horizon has a sandy loam texture, a pH of 6.0 to 6.4, and averages 12 inches in depth. The AC horizon is also a sandy loam, has a pH of 6.4, and is 17 inches deep. The typical description is as follows:

A11 0-3 inches. Gray brown (10 YR 5/2)[4]; dark reddish brown (5 YR 3/2) moist; sandy loam; moderate, medium platy structure; soft;

[4] *In this profile colors will be dry unless otherwise noted.*

Artemisia tridentata-Purshia tridentata/Festuca idahoensis ecosystem

Number of plots: 4 Condition class: low goo[d]

Site and vegetation	Understory composition	Frequency
	Percent	
Bare soil, 21 percent surface area	--	100
Rock, 1 percent surface area	--	100
Litter, 61 percent surface area	--	100
Moss, 12 percent surface area	--	100
Total vegetation, 5 percent surface area	--	100
Artemisia tridentata, 12 percent crown cover	10	100
Purshia tridentata, 7 percent crown cover	4	100
Chrysothamnus viscidiflorus	1	100
Chrysothamnus nauseosus	.5	25
Tetradymia canescens	.5	25
Sitanion hystrix	23	100
Festuca idahoensis	19	100
Carex rossii	7	100
Stipa occidentalis	4	100
Agropyron spicatum	2	100
Poa sandbergii	2	100
Stipa thurberiana	2	75
Koeleria cristata	1	75
Bromus tectorum[1]	23	100
Astragalus sp.	.2	100
Lupinus sp.	.2	100
Eriogonum sp.	.1	50
Chaenactis douglasii	T	50
Collinsia parviflora[1]	.1	100
Cryptantha ambigua[1]	.1	100
Epilobium minutum[1]	T	100
Polygonum douglasii[1]	T	75

T = trace.

[1]Annuals.

nonsticky; nonplastic; abundant very fine and fine roots; slightly acid reaction (pH 6.0); clear, sharp boundary.

A12 3-12 inches. Dark reddish brown (5 YR 3/3) moist; sandy loam; weak, medium subangular blocky structure; very friable; nonsticky, nonplastic; common fine and medium roots; abundant fine gravels of pumice and few of basalt; slightly acid reaction (pH 6.4); clear gradual boundary.

AC11 12-21 inches. Light brown (7.5 YR 6/4); dark reddish brown (5 YR 3/4) moist; sandy loam; weak, medium, subangular blocky structure; very friable; nonsticky, nonplastic; common fine and medium roots; common fine to medium pumice gravels; very slightly acid reaction (pH 6.4); clear gradual boundary.

AC12 21-29 inches. Light brown (7.5 YR 6/4); yellowish red (5 YR 4/6) moist; sandy loam; weak, medium, subangular blocky structure; very friable; nonsticky, nonplastic; common fine and medium roots; common fine to medium pumice gravels; very slightly acid reaction (pH 6.4); clear gradual boundary.

C1 29-39 inches. Pink (5 YR 7/4); yellowish red (5 YR 4/6) moist; sandy loam; weak, medium subangular blocky, breaking to single grain structure; very friable, nonsticky, nonplastic; common fine roots; common medium to large pumice gravels to 6 cm. in diameter; very slightly acid reaction (pH 6.4); clear gradual boundary.

C2 39-45+ inches. Yellowish red (5 YR 4/6) moist; sandy loam; hard; nonsticky, nonplastic; common large pumice gravels and stones to 8 cm. in diameter; very slightly acid reaction (pH 6.4).

Discussion

Ecosystem. — The composition relationship among species is primarily a result of heavy past use by both livestock and deer. We might expect *Purshia tridentata* to have a higher composition figure and *Artemisia tridentata* a lower one under better conditions or less past use, since *P. tridentata* is highly preferred for forage over *A. tridentata*. The high figures for *Bromus tectorum* and *Sitanion hystrix* as compared with *Festuca idahoensis* and *Agropyron spicatum* also indicate a history of past overuse by foraging animals. Here, too, reverse trends in composition might be expected under better use management. Also the climate and soil indicate that this ecosystem has a higher potential for *P. tridentata*, *F. idahoensis*, and *A. spicatum* than is indicated by present composition figures.

This ecosystem grades into an ecotonal mixture of *Juniperus occidentalis*, *Cercocarpus ledifolius*, and *Pinus ponderosa* with a varying but continual mixture of present shrubs under a more favorable moisture regime, but it grades out of *P. tridentata* and into a dominant stand of *A. tridentata* with a decrease of moisture.

Habitat value. — Value is considered high, primarily due to available shrub forage during the winter period. This ecosystem is positioned in

Ground vegetation of the *A. tridentata-P. tridentata/F. idahoensis* ecosystem. Note the disturbed appearance of the ground surface and the high incidence of broken and trampled shrub stems.

what is generally considered the "transition range," i.e., the spring-fall range. However, in the past 12 years, this area has been accessible for the greater part of most winters and during that time has never been unavailable during an entire winter.

An added value provided by this ecosystem is the cover protection from winter winds. Shrubs are tall enough to provide considerable wind protection during daily feeding forays and provide adequately protected daybeds for rest except during severe storms.

Habitat manipulation. — Since this, along with adjacent transition and winter range ecosystems, provides highly critical forage and cover for deer, any deliberate vegetation manipulation should be based on plans carefully developed by both land and game management agencies.

Studies in progress indicate that rehabilitation of the shrub stand

ieneral view of the *Artemisia tridentata-Purshia tridentata/Festuca idahoensis* ecosystem.

hould favor *Purshia tridentata.* A study of *P. tridentata* seeded after a ›urn, being conducted in this immediate area (Dealy 1970), found that ıfter 2 years of treatment the shrub response was greater from browsing ›rotection than from elimination of vegetation competition. Any shrub ehabilitation project may need site preparation and should provide some ype of protection from animal use for from 3 to 5 years. This protection ould be accomplished either physically by fencing or by a large enough ıcreage of rehabilitation to absorb the intense use with minimal damage. rotective fencing costs per acre are not unreasonable when considering ,000-acre blocks or larger.

Rehabilitation after wildfire is difficult primarily due to a limited availıbility of *Purshia tridentata* seed on short notice. In this case it would be lesirable to seed with a mixture of seed from any available species which ıre suitable for the area and for deer forage.

17 *Artemisia tridentata / Stipa occidentalis-Lathyrus* Ecosystem

Physical Description

Site. — This ecosystem is characterized by a narrow range in elevation from 6,500 to 7,000 feet and by gentle slopes of 5 percent or less. It includes portions of the upper slopes of Winter Ridge and aspects ranging generally from south through west. Microrelief is broken only by intermittent waterways which are shallow, narrow, and apparently the result of spring melt from typically heavy winter snowpacks.

Vegetation. — *Pinus contorta* occurs erratically in patches throughout this community. *Pinus ponderosa* was not recorded on or near any sample plots but occurs as rare, overmature individuals which are significant to the ecological interpretation of the community.

Artemisia tridentata is the dominant shrub with 57-percent composition and 100-percent frequency of occurrence. All other shrubs are minor in importance and occurrence. They include *Chrysothamnus viscidiflorus*, *Symphoricarpos albus*, *Eriogonum microthecum*, and *Ribes cereum*.

The grass and sedge component (19-percent composition) is the smallest sampled with the exception of the *Pinus ponderosa/Arctostaphylos patula/Festuca idahoensis* ecosystem. *Stipa occidentalis* is dominant (6-percent composition) and *Carex rossii* is a close second (5 percent). Other important grasses include *Poa nervosa*, *Sitanion hystrix*, *Bromus carinatus*, and *Melica bulbosa*.

Perennial forbs are represented by a greater number of species here than in any other community described. They also comprise a larger part of the composition (16 percent) than in any community except the *Artemisia arbuscula/Danthonia unispicata*. *Lathyrus* sp., *Achillea millefolium*, and *Senecio* sp. are most prominent. Annuals make up 40 percent of the total forb component. Those most commonly found are *Collinsia parviflora*, *Linanthus harknessii*, *Epilobium minutum*, and *Polygonum douglasii*.

Soil. — The soil is a moderately deep, well-drained loam over a residuum of weathered basalt. Depth of the solum averages over 30 inches. Surface area of bare soil and area of surface stone average 25 and 3 per-

A tall, dense stand of *Artemisia tridentata* indicates high moisture in the *A. tridentata/ Stipa occidentalis-Lathyrus* ecosystem.

A. tridentata/S. occidentalis-Lathyrus ecosystem showing grass stand in shrub interspaces. Note young *A. tridentata* in openings.

Average vegetation-site characteristics of the *Artemisia tridentata/Sti*[cut off] *occidentalis-Lathyrus* ecosystem[1]

Number of plots: 5 Condition class: fa[cut off]

Site and vegetation	Understory composition	Frequency
	- - - - - - - - *Percent*	- - - - - - -
Bare soil, 25 percent surface area	--	100
Rock, 3 percent surface area	--	100
Litter, 69 percent surface area	--	100
Moss, trace of surface area	--	60
Total vegetation, 3 percent surface area	--	100
Artemisia tridentata, 32 percent crown cover	57	100
Eriogonum microthecum	T	60
Ribes cereum	T	40
Symphoricarpos albus	T	40
Chrysothamnus viscidiflorus	T	20
Stipa occidentalis	6	100
Carex rossii	5	100
Poa nervosa	3	100
Sitanion hystrix	2	100
Bromus carinatus	2	80
Melica bulbosa	1	80
Agropyron sp.	.1	20
Lathyrus sp.	5	100
Achillea millefolium	3	100
Senecio sp.	2	100
Viola purpurea	1	100
Agoseris sp.	1	80
Delphinium sp.	1	80
Hydrophyllum capitatum	1	80
Trifolium sp.	1	20
Phacelia hastata	.1	100
Arabis sp.	.1	60
Thalictrum sp.	.1	60

— *Continued)*

Number of plots: 5 **Condition class: fair**

Site and vegetation	Understory composition	Frequency
	- - - - - - - - *Percent*	- - - - - - - -
3rodiaea sp.	.1	40
'astilleja sp.	.1	40
Jeranium sp.	.1	40
lieracium cynoglossoides	.1	40
'riophyllum lanatum	.1	20
'ragaria virginiana	.1	20
,omatium sp.	.1	20
,upinus sp.	.1	20
licrosteris gracilis	.1	20
'otentilla sp.	.1	20
lanunculus sp.	.1	20
,ewisia rediviva	T	20
'ollinsia parviflora[2]	3	100
,inanthus harknessii[2]	1	100
'pilobium minutum[2]	1	100
'olygonum douglasii[2]	1	100
'ryptantha ambigua[2]	1	60
'ollomia grandiflora[2]	1	60
Javarretia tagetina[2]	.2	60
Jalium sp.[2]	.2	40

T = trace.

[1] Averages for trees are:

	Basal area in square feet per acre	*Percent frequency*	*Percent crown cover*
'inus contorta	T	40	T

[2] Annuals.

cent, respectively. Stone in the soil averages 70 percent of the volume. Topography is gently sloping. Mean annual precipitation is over 20 inches with two-thirds falling as snow and rain during the winter and the rest as rain in the fall and spring except for approximately 5 percent which falls during the 3 summer months. A representative profile is:

A1 0-3 inches. Brown (10 YR 5/3) dry; dark brown (10 YR 4/3) moist; loam; weak, fine granular structure; very friable; slightly sticky, slightly plastic; many very fine, fine, and medium roots; slightly acid reaction (pH 6.0); many stones and boulders (70 percent of horizon volume); clear, smooth boundary. (2 to 4 inches thick.)

A3 3-14 inches. Brown (10 YR 5/3) dry, dark brown (10 YR 4/3) moist; loam; weak, fine, subangular blocky structure; very friable; slightly sticky, slightly plastic; many fine and medium roots; medium acid reaction (pH 5.8); many stones and boulders (70 percent of horizon volume); clear, wavy boundary. (8 to 14 inches thick.)

B1 14-20 inches. Dark brown (7.5 YR 4/4) moist; clay loam; moderate, medium subangular blocky structure; friable; sticky and plastic; few fine and common medium roots; medium acid reaction (pH 5.8); many stones and boulders (70 percent of horizon volume); clear smooth boundary. (5 to 8 inches thick.)

B2 20-30 inches +. Dark brown (7.5 YR 4/4) moist; clay loam; strong, medium subangular blocky structure; firm; sticky and plastic; few fine, common medium roots; medium acid reaction (pH 5.8); many stones and boulders (70 percent of horizon volume).

Discussion

Ecosystem. — It is fairly obvious that this is a successional stage of an ecosystem similar to, if not the same as, that illustrated by the *Pinus ponderosa/Artemisia tridentata/Bromus carinatus* community. It occurs in the same general elevation range, has the same slope aspects, and has similar soils. It also exhibits remnants of a *Pinus ponderosa* stand in the form of occasional large, old individual trees still growing. In addition, there are scattered stands of *Pinus contorta*, a subordinate species in the *P. ponderosa/A. tridentata/B. carinatus* ecosystem. Charred tree remnants suggest that this seral stage is a result of fire.

In comparing the two communities with respect to composition relationships between species and the incidence of common occurrence of species, we find that in this seral shrub community all tree species except *Abies concolor* are present which are present in the *P. ponderosa* community. Likewise, all shrubs are present, most grasses are present, and the major forbs are present, particularly *Lathyrus* sp. and *Achillea millefolium*. *Artemisia tridentata* is easily the dominant shrub in both communities. Perennial grass-types dominant here are *Stipa occidentalis* and

Carex rossii instead of *Bromus carinatus* and *Poa nervosa*, the two principal species in the pine ecosystem.

When a tree community of 53-percent crown cover is reduced by fire to bare soil on a southwesterly exposure, insolation becomes a critical factor in changing the microsite. It, in combination with a lack of seed source, reduces to remote, the possibility of a reasonably fast recovery to a conifer stand. Apparently *Artemisia tridentata* seed sources survived sufficiently to allow a domination of the site by this species. Since a *Pinus ponderosa* seed source is lacking, and the site is totally occupied by successional vegetation, it appears that unless the site is artificially manipulated the *Artemisia tridentata/Stipa occidentalis-Lathyrus* community will remain dominant for some time. The scattered stand of *P. contorta* suggests that it will, in time, achieve dominance in the ultimate succession to *P. ponderosa* and *Abies concolor*.

Habitat value. — Value of this habitat is medium because it is limited to the upper Winter Ridge area and is small (less than 5,000 acres) in relation to the total study area. Its value lies principally in the availability of abundant perennial forbs during the late spring and early to middle summer. The significance of this forb forage supply is that this community has 16 percent of its vegetal composition in perennial forbs, whereas the *Pinus ponderosa/Artemisia tridentata/Bromus carinatus* ecosystem has only 5 percent.

Habitat manipulation. — Since this ecosystem is part of the mule deer's summer range that in total seems to supply adequate amounts of forage during most years, it should be considered primarily for timber production and secondarily for game production. The convenient rehabilitation of this ecosystem to a *Pinus ponderosa* stand is hampered by the dense and vigorous *Artemisia tridentata* which occupies the site. It is further hampered by the problem of exposure and severe insolation of a south- and west-facing slope devoid of even a thin tree canopy. Any attempt to plant pine will have to be preceded by at least a partial kill of *A. tridentata*, utilizing shrub shade for protection during establishment. A total kill of *A. tridentata* may produce such a severe site that planted tree seedlings cannot survive. Whether any of the species of legumes present has nitrogen-fixing capabilities is not known. However, it is probable that among *Lupinus* sp., *Trifolium* sp., and *Lathyrus* sp. one or more have provided this soil with a supplement of nitrogen which should benefit any conifer planting.

18 *Artemisia arbuscula / Festuca idahoensis* Ecosystem

Physical Description

Site. — This community is one of three dominated by *Artemisia arbuscula*. All occur on rocky openings from the transition range throughout all but the highest parts of the summer range, from elevations of 4,700 to 6,500 feet. These openings vary in size from approximately 5 acres to extended plains over 1 mile across.

Slopes are moderate, seldom exceeding 5 percent. Slope aspects are generally westerly but occasionally northerly, particularly in the transition range.

Vegetation. — Three communities that commonly occur in varying combinations with the one being described here are (1) *Artemisia arbuscula/Koeleria cristata*, (2) *A. arbuscula/Danthonia unispicata*, which will be discussed later, and (3) *Cercocarpus ledifolius/Festuca idahoensis-Agropyron spicatum*, which has been described. The latter commonly occurs around scab flat edges, between *A. arbuscula* and conifer types. The first two and the one under discussion here are treeless communities characterized by a low-growing shrub and an understory of mixed herbaceous species. The only shrub recorded in any of the three is *A. arbuscula*. In this ecosystem it averages 8 inches in height and 26 percent of the composition.

There are fewer forbs here than in any other ecosystem sampled except the two *Cercocarpus ledifolius* ecosystems previously described. *Lomatium triternatum* is the most widely distributed perennial (86-percent frequency), and *Eriophyllum lanatum* has the largest share of the composition (3 percent). Annual forbs, as a group, occur more frequently than perennials.

Soil. — This is a stony loam soil about 18 inches deep. Drainage, although not good, is less restricted than in the other *Artemisia arbuscula* ecosystems.

The A horizon is 6 to 7 inches deep, is a loam, and has a pH of 6.5. The B horizon is 12 to 15 inches, is a clay, and has a pH of 7.0. Root con-verage vegetation-site characteristics of the *Artemisia arbuscula/Festuca idahoensis* ecosystem

umber of plots: 7 — Condition class: good

Site and vegetation	Understory composition	Frequency
	Percent	*Percent*
are soil, 18 percent surface area	--	100
ock, 38 percent surface area	--	100
itter, 37 percent surface area	--	100
loss, 2 percent surface area	--	100
otal vegetation, 5 percent surface area	--	100
rtemisia arbuscula, 14 percent crown cover	26	100
estuca idahoensis	32	100
anthonia unispicata	16	100
oa sandbergii	13	100
itanion hystrix	4	100
oeleria cristata	2	86
riophyllum lanatum	3	57
renaria congesta	.9	29
omatium triternatum	.5	86
rigeron bloomeri	.4	43
goseris sp.	.2	43
licrosteris gracilis	.2	29
rabis sp.	.1	14
alochortus macrocarpus	.1	14
eum ciliatum	.1	14
omatium nudicaule	.1	14
enstemon sp.	.1	14
olygonum douglasii[1]	.4	86
ollinsia parviflora[1]	.2	71
ayophytum nuttallii[1]	.2	29
avarretia tagetina[1]	.2	100
inanthus harknessii[1]	.1	86
pilobium minutum[1]	.1	43
lagiobothrys hispidus[1]	.1	29

[1] Annuals.

centration is in the upper 6 inches. Soil surface coverage by stones ranges from 26 to 75 percent, averaging 38 percent, and volume of stone in the soil mantle ranges from 37 to 63 percent with an average of 50 percent.

There is little obvious difference between this soil and the soil under the *Artemisia arbuscula/Koeleria cristata* ecosystem. Two differences and probably two reasons why this soil supports *Festuca idahoensis* while the other doesn't are the typically deeper A horizon (6 inches instead of 4) and less restrictive B horizon. The *A. arbuscula/Danthonia unispicata* ecosystem has no *F. idahoensis*, but it does have an A horizon depth and B horizon texture equal to this ecosystem. However, *D. unispicatum* replaces *F. idahoensis* in areas of higher moisture.

Discussion

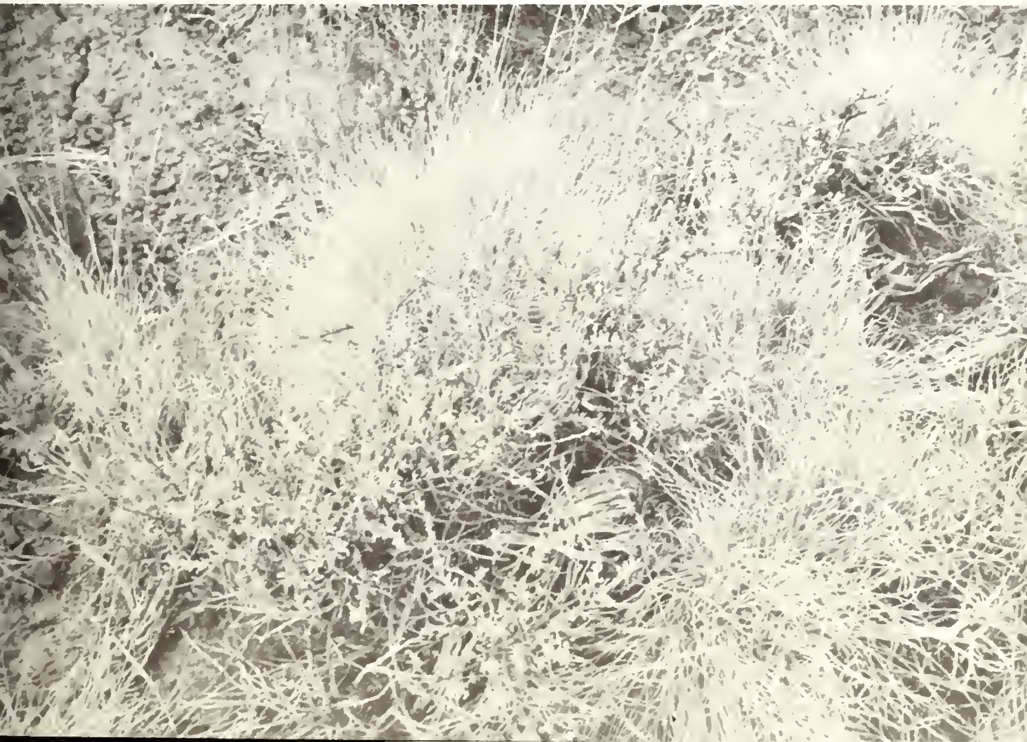
Ecosystem. — The ecosystems which include the rocky or "scab" flat openings create an interesting and complex situation. It is common to have more than one *Artemisia arbuscula* community on a single scab flat. In fact, it is not uncommon to find *A. arbuscula/Festuca idahoensis*, *A. arbuscula/Koeleria cristata*, and *A. arbuscula/Danthonia unispicata* communities all on the same scab flat. Each appears to be an edaphic community. Soil-site factors typical of these scab flat ecosystems are shown below:

Ecosystem	A-horizon depth	Depth to restrictive layer	B-horizon texture	Stoniness in soil	Drainage
	(Inches)	(Inches)		(Percent)	
Artemisia arbuscula/ Festuca idahoensis	6	18	Clay loam	50	Moderatel[y] well draine[d]
A. arbuscula/ Danthonia unispicata	7	18	Clay loam	60	Imperfectl[y] or somewha[t] poorly drain[ed]
A. arbuscula/ Koeleria cristata	4	15	Clay	5	Imperfectl[y] or somewha[t] poorly drain[ed]

The most significant difference between the soil that supports *Festuca idahoensis* and the one supporting *Danthonia unispicata* appears to be in their drainage characteristics. *D. unispicata* generally grows in the lower parts of the flats where surface runoff is channeled or where it collects to form temporary pools. The very low percentage of solum stones, the clay, and the shallow A horizon under *Koeleria cristata* combine to restrict both water and root penetration.

A. arbuscula appears hedged from animal use in the *A. arbuscula/Festuca idahoensis* ecosystem.

Note the grass-shrub competition in the *A. arbuscula/F. idahoensis* ecosystem.



Habitat value. — Habitat value of all the *Artemisia arbuscula* communities is estimated to be high. There is no hiding cover so value is primarily for food. Value for food is high during the spring and early summer where these habitats extend into summer range, because of a good selection of forbs and grasses. Where the ecosystems occur in the transition area between summer and winter range, the food value is derived from *A. arbuscula*, as well as forbs and grasses. *A. arbuscula* is used heavily in central Oregon during the spring as soon as leader growth is sufficient to provide tender forage — about 1 to 2 inches long. New grass is used extensively during late winter and early spring but is relegated to second place when *A. arbuscula* becomes available. By the time deer move up into the summer range many forbs are available, as well as new growth on most shrubs, so that *A. arbuscula* is less important.

A high percentage of scab flat acreage in the Silver Lake mule deer's summer range is also the summer range for a small population of pronghorns *(Antilocapra americana)*. They inhabit *A. arbuscula* openings as far as 17 miles inside the lower edge of the *Pinus ponderosa* zone measured from the closest point of access from the high desert.

Habitat manipulation. — The potential for total forage production on these sites is relatively low due to their rockiness and shallow soil both of which drastically reduce the soil moisture holding capacity and eliminate site preparation as a possibility. Also, soil compaction is a potential hazard because of the combination of soil texture and late spring moisture. These ecosystems should be maintained with as little manmade disturbance as possible, recognizing that there will be a combination of livestock, mule deer, and pronghorn use on these each year. Livestock use should be delayed until the soil is dry enough to prevent significant compaction. Where acreages of scab flats are small in comparison with higher producing conifer types, the flats may suffer abuse.

19 *Artemisia arbuscula / Danthonia unispicata* Ecosystem

Physical Description

Site. — Site characteristics for this community are described under the *Artemisia arbuscula/Festuca idahoensis* unit.

Vegetation. — *Artemisia arbuscula* averages 13 percent of the composition here, half as much as in the preceding unit.

Five grasses occur in this community, two of which make up more than half the composition, and three of which occur frequently but in small amounts. *Danthonia unispicata* is dominant with 28-percent composition and 100-percent frequency, and *Poa sandbergii* is a close second with 23-percent composition and 100-percent frequency. Site conditions vary so that occasionally these two species do change places with each other in dominance. *Sitanion hystrix*, *Koeleria cristata*, and *Stipa thurberiana* complete the list of grasses.

Perennial forbs account for a much larger part of the composition here (25 percent) than in any other community sampled. *Antennaria dimorpha*, with 17 percent, exceeds all other forbs combined. *Erigeron bloomeri*, *Lomatium triternatum*, *L. nudicaule*, and *Sedum stenopetalum* are widely distributed. *Polimonium micranthum* and *Gayophytum lanatum* are the most common annuals.

Soils. — This is a poorly drained, shallow, stony loam with 36 percent of the surface covered by rock and 27 percent bare. The solum contains approximately 60-percent stone by volume. Root concentration is in the upper 7 inches with roots common to 11 inches. Solum development is in mixed aeolian and illuvial material derived primarily from basalt. A representative profile is:

A11 0-3 inches. Dark brown (7.5 YR 3/2) moist; pinkish gray (7.5 YR 6/2) dry; loam; strong fine platy structure, slightly hard; slightly sticky and slightly plastic; abundant very fine and fine roots; medium acid reaction (pH 6.0); angular cobbles 60 percent of the volume; clear, smooth boundary.

Average vegetation-site characteristics of the *Artemisia arbuscula/Danthonia unispicata* ecosystem

Number of plots: 5

Condition class: fair

Site and vegetation	Understory composition	Frequency
	- - - - - - - - Percent - - - - - - - -	
Bare soil, 27 percent surface area	--	100
Rock, 36 percent surface area	--	100
Litter, 33 percent surface area	--	100
Moss, 0.5 percent surface area	--	100
Total vegetation, 3.5 percent surface area	--	100
Artemisia arbuscula, 8 percent crown cover	13	100
Danthonia unispicata	28	100
Poa sandbergii	23	100
Sitanion hystrix	4	100
Koeleria cristata	2	80
Stipa thurberiana	1	60
Antennaria dimorpha	17	100
Microsteris gracilis	3	60
Erigeron bloomeri	1	100
Lomatium triternatum	1	100
Lomatium nudicaule	1	80
Agoseris sp.	.8	60
Sedum stenopetalum	.5	80
Castilleja sp.	.1	60
Achillea millefolium	.1	20
Allium sp.	.1	20
Astragalus sp.	.1	20
Geum ciliatum	.1	20
Trifolium sp.	.1	20
Polemonium micranthum[1]	2	100
Gayophytum lanatum[1]	1	100
Linanthus harknessii[1]	.5	60
Polygonum douglasii[1]	.4	80
Navarretia tagetina[1]	.1	40
Madia glomerata[1]	.1	20

[1]Annuals.

Artemisia arbuscula/Danthonia unispicata ecosystem. These stony, shallow soil ecosystems are fragile and recover very slowly.

Note the limited microsites available for establishment in the *A. arbuscula/D. unispicata* ecosystem.

A12 3-7 inches. Dark brown (7.5 YR 3/2) moist; loam; strong, medium; platy structure; friable; slightly sticky, slightly plastic; abundant very fine and fine roots, and common medium roots; medium acid reaction (pH 6.0); angular cobbles 60 percent of the volume; clear, wavy boundary.

B 7-15 inches. Dark brown (7.5 YR 3/2) moist; clay loam; moderate fine subangular blocky structure; friable; sticky, plastic; common fine and medium roots; medium acid reaction (pH 6.0); angular cobbles 60 percent of the volume.

Discussion

Ecosystem. — See discussion under *Artemisia arbuscula/Festuca idahoensis* community.

Habitat value. — This ecosystem is of moderate value for mule deer habitat. It is relatively small in acreage, has no hiding cover, and has considerably less *Artemisia arbuscula*, a valuable spring food for deer, than other *A. arbuscula* communities but has a high composition of forbs which provide valuable spring and early summer forage.

Habitat manipulation. — See discussion under *Artemisia arbuscula/Festuca idahoensis* community.

20 *Artemisia arbuscula / Koeleria cristata* Ecosystem

Physical Description

Site. — Site characteristics for this community are described under the *Artemisia arbuscula/Festuca idahoensis* unit.

Vegetation. — The shrub component, composed entirely of *Artemisia arbuscula* (59-percent composition), is more than twice as large as either of the two *A. arbuscula* units previously described and exceeds all other units sampled. The mature plants average 8.5 inches in height.

On the other hand, the grass component is less than half as large (25-percent composition) as it is in the other two *Artemisia arbuscula* units. *Poa sandbergii* is dominant (13 percent), and *Koeleria cristata* (7 percent) and *Sitanion hystrix* (5 percent) follow.

Perennial forbs are a smaller part of the composition (6 percent) than annuals (9 percent). *Lomatium triternatum*, *Antennaria dimorpha*, and *Erigeron bloomeri* account for most of the perennial composition. *Polygonum douglasii*, *Collomia tenella*, and *Navarretia tagetina* are prominent annuals. Since only two plots were sampled for this ecosystem, composition and frequency averages have limited reliability.

Soil. — The soil is a poorly drained, shallow heavy loam or clay loam. Stone on the soil surface averages 34 percent and varies from 5 to 95 percent; stone in the soil averages 5 percent of the volume. Soil development is in basalt residuum with the probable influence of localized loess deposits. It occurs on level to gently sloping topography. A representative profile is:

A11 0-1 inch. Loam; moderate fine platy structure; friable; slightly sticky and slightly plastic; abundant very fine and fine roots and common medium roots; slightly acid (pH 6.2); cobbles 5 percent of the solum; clear, smooth boundary.

A12 1-4 inches. Clay loam; moderate medium platy structure; friable; sticky and plastic; abundant very fine and fine roots and common medium roots; slightly acid (pH 6.2); cobbles 5 percent of the solum; clear, smooth boundary.

Average vegetation-site characteristics of the *Artemisia arbuscula/Koeleria cristata* ecosystem

Number of plots: 2 Condition class: fair

Site and vegetation	Understory composition	Frequency
	Percent	*Percent*
Bare soil, 15 percent surface area	--	100
Rock, 34 percent surface area	--	100
Litter, 48 percent surface area	--	100
Moss, 1 percent surface area	--	100
Total vegetation, 2 percent surface area	--	100
Artemisia arbuscula, 26 percent crown cover	59	100
Poa sandbergii	13	100
Koeleria cristata	7	100
Sitanion hystrix	5	100
Carex rossii	.2	50
Juncus sp.	.2	50
Antennaria dimorpha	2	100
Lomatium triternatum	2	100
Erigeron bloomeri	1	100
Achillea millefolium	.3	50
Lomatium nudicaule	.2	100
Agoseris sp.	.2	50
Geum ciliatum	.2	50
Trifolium sp.	.2	50
Polygonum douglasii[1]	4	100
Collomia tenella[1]	3	100
Navarretia tagetina[1]	2	100
Madia glomerata[1]	.3	100
Linanthus harknessii[1]	.2	100

[1] Annuals.

Surface stone in the *A. arbuscula/Koeleria cristata* ecosystem is highly variable.

Severe frost heave hampers the development of plants in the *Artemisia arbuscula/ Koeleria cristata* ecosystem.

B 4-18 inches. Clay; strong, medium subangular blocky structure very sticky and very plastic; clay skins on ped surfaces, and clay skins on stones; uncommon very fine, fine and medium roots medium acid reaction (pH 6.0); cobbles 10 percent of the solum clear, smooth boundary.

C 18-20+ inches. Weathered basalt fragments in a clay matrix; mildly alkaline reaction (pH 7.5).

Permeability of this soil is estimated as slow and runoff, as slow to medium. Erosion hazard is moderate. Extreme pedestaling of both grasses and *Artemisia arbuscula* is evident in many areas. Frost crystals 3 inches high have been observed, and *A. arbuscula* shrubs commonly have 4 to 6 inches of roots exposed.

Discussion

Ecosystem. — This is the third "scab flat" ecosystem dominated by *Artemisia arbuscula*. It should be noted that there is a significantly larger percent composition of *Poa sandbergii* than *Koeleria cristata*. *P. sandbergii* is a species that seems to be in a position between perennial and annual grasses although it is actually a perennial. It begins growth early in the spring before most other perennial grasses and then normally matures and enters the summer with cured forage of no value to game and limited value to livestock. Yearly production on an equal cover basis is less, and varies to a greater degree, than species such as *K. cristata* or *Sitanion hystrix*. Being in this position of a quasiannual, *P. sandbergii* is not considered on a par ecologically with the typical perennial bunchgrasses. Therefore, even though its place in the composition indicates an apparent dominance in the grass layer, it is not considered as such here.

This ecosystem is probably most typical of the flat, stony, shallow soiled "scab flats" of this area — not particularly in species composition, but in the heavy soil and the prominence of *P. sandbergii*. Most scab flats have been severely overused by cattle in this area; therefore this ecosystem exhibits only one of many condition classes which may be encountered. *K. cristata* may commonly be replaced by *Sitanion hystrix*, *Stipa thurberiana*, or any codominant combination.

Habitat value. — The value of this ecosystem is high in combination with other scab flat ecosystems. Value is further discussed in the *Artemisia arbuscula/Festuca idahoensis* ecosystem.

Habitat manipulation. — As has been recommended for the other scab flat ecosystems, no deliberate manipulation (other than reduction of livestock use) of these sites should be attempted. If there are any areas which are large enough in acreage to be managed as separate game allotments (possibly near Sycan Marsh and Murphy Windmill) for mule deer and the pronghorn, then an elimination of livestock use would be an important step towards developing a wide selection of high quality summer range habitats for game.

21 *Artemisia cana/ Muhlenbergia richardsonis* Ecosystem

This ecosystem generally occurs as a ring surrounding seasonally ponded areas, expanding and receding as the water line moves back and forth with long-term changes in the moisture cycle.

Artemisia cana is the only shrub which occurs commonly. Trees and shrubs occurring at the type edge or as inclusions are *Salix* sp., *Populus tremuloides*, *Pinus contorta*, *Artemisia arbuscula*, and *A. tridentata*.

Muhlenbergia richardsonis, *Eleocharis* sp., and *Juncus* sp. form a fairly heavy stand under *Artemisia cana*, with forbs very scarce. There is extreme competition between livestock and deer for the few forbs which do occur.

Acreage as well as game forage in this ecosystem is limited, and therefore the value is low.

Artemisia cana **commonly rings seasonally ponded meadows in the Silver Lake deer range.**

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Appendix

Scientific Names, Authors, and Common Names
of Species Mentioned in the Text

SCIENTIFIC NAMES & AUTHOR	COMMON NAME
Mammals	
Odocoileus hemionus hemionus Raf.	mule deer
Antilocapra americana Ord	pronghorn
Birds	
Bonasa umbellus sabini Douglas	Oregon ruffed grouse
Plants	
Abies concolor (Gord. & Glend.) Lindl. ex Hildebr.	white fir
Abies lasiocarpa (Hook.) Nutt.	subalpine fir
Achillea millefolium L.	yarrow
Agoseris Raf.	agoseris
Agropyron Gaertn.	wheatgrass
Agropyron cristatum (L.) Gaertn.	fairway crested wheatgrass
Agropyron spicatum (Pursh) Scribn. & Sm.	bluebunch wheatgrass
Allium L.	onion
Amelanchier alnifolia Nutt.	Saskatoon serviceberry
Anaphalis margaritacea (L.) B. & H.	common pearleverlasting
Antennaria corymbosa E. Nels.	flattop pussytoes
Antennaria dimorpha (Nutt.) T. & G.	low pussytoes
Antennaria geyeri Gray	pinewoods pussytoes
Antennaria rosea Greene	rose pussytoes
Apocynum androsaemifolium L.	spreading dogbane
Arabis L.	rockcress
Arctostaphylos patula Greene	greenleaf manzanita
Arenaria congesta Nutt.	ballhead sandwort
Arnica cordifolia Hook.	heartleaf arnica
Artemisia L.	sagebrush
Artemisia arbuscula Nutt.	low sagebrush
Artemisia cana Pursh	silver sagebrush
Artemisia tridentata Nutt.	big sagebrush

SCIENTIFIC NAMES & AUTHOR	COMMON NAME
Aster L.	aster
Astragalus L.	milkvetch loco
Astragalus purshii Dougl. ex Hook.	woollypod milkvetch
Astragalus stenophyllus T. & G.	hangingpod milkvetch
Balsamorhiza sagittata (Pursh) Nutt.	arrowleaf balsamroot
Berberis repens Lindl.	low oregongrape
Brodiaea Sm.	brodiea
Bromus carinatus Hook. & Arn.	California brome
Bromus tectorum L.	cheatgrass brome
Calochortus macrocarpus Dougl.	sagebrush mariposa
Carex L.	sedge
Carex athrostachya Olney	slenderbeak sedge
Carex rossii Boott	Ross sedge
Castilleja Mutis ex L.	paintbrush
Ceanothus prostratus Benth.	squawcarpet
Ceanothus velutinus var. *velutinus* Dougl. ex Hook.	snowbrush
Cercocarpus H. B. K.	mountain-mahogany
Cercocarpus ledifolius Nutt.	curlleaf mountain-mahogany
Chaenactis douglasii (Hook.) H. & A.	falseyarrow
Chimaphila umbellata (L.) Bart.	common pipsissewa
Chrysothamnus nauseosus (Pall.) Britt.	tall gray rabbitbrush
Chrysothamnus viscidiflorus (Hook.) Nutt.	tall green rabbitbrush
Cirsium Mill.	thistle
Collinsia parviflora Lindl.	littleflower collinsia
Collomia grandiflora Doug. ex Lindl.	largeflower collomia
Collomia tenella Gray	diffuse collomia
Crepis L.	hawksbeard
Cryptantha ambigua (Gray) Greene	obscure cryptantha
Danthonia californica Boland.	California danthonia
Danthonia unispicata (Thurb.) Munro ex Macoun	onespike danthonia
Delphinium L.	larkspur
Deschampsia danthonioides (Trin.) Munro ex Benth.	annual hairgrass
Deschampsia elongata (Hook.) Munro ex Benth.	slender hairgrass
Eleocharis R. Br.	spikesedge
Epilobium minutum Lindl. ex Hook.	smallflower willowweed
Erigeron L.	fleabane
Erigeron bloomeri Gray	scabland fleabane
Eriogonum Michx.	buckwheat
Eriogonum microthecum Nutt.	slenderbush buckwheat
Eriophyllum lanatum (Pursh) Forbes	woolly eriophyllum

SCIENTIFIC NAMES & AUTHOR	COMMON NAME
Festuca idahoensis Elm	Idaho fescue
Fragaria virginiana Duchesne	blueleaf strawberry
Galium L.	bedstraw
Gayophytum nuttallii T. & G.	nuttall groundsmoke
Geranium L.	geranium
Geum L.	avens
Geum macrophyllum Willd.	largeleaf avens
Geum triflorum Pursh	prairiesmoke avens
Haplopappus bloomeri Gray	rabbitbrush goldenweed
Hieracium cynoglossoides Arv.-Touv.	houndstongue hawkweed
Hydrophyllum capitatum Dougl. ex Benth.	ballhead waterleaf
Juncus L.	rush
Juniperus occidentalis Hook.	western juniper
Koeleria cristata Pers.	prairie junegrass
Lathyrus L.	peavine
Lewisia rediviva Pursh	bitterroot lewisia
Lilium columbianum Hanson	columbia lily
Linanthus harknessii (Curran) Greene	Harkness linanthus
Lithophragma Nutt.	woodlandstar
Lithospermum L.	gromwell
Lomatium Raf.	biscuitroot
Lomatium nudicaule (Pursh) Coult. & Rose	barestem lomatium
Lomatium triternatum (Pursh) Coult. & Rose	nineleaf lomatium
Lupinus L.	lupine
Lupinus caudatus Kell.	tailcup lupine
Madia glomerata Hook.	cluster tarweed
Melica bulbosa Geyer ex Porter & Coult.	oniongrass
Microsteris gracilis (Hook.) Greene	pink microsteris
Montia perfoliata (Donn) Howell	minerslettuce
Muhlenbergia Schreb.	muhly
Muhlenbergia filiformis (Thurb.) Rydb.	pullup muhly
Muhlenbergia richardsonis (Trin.) Rydb.	Richardsons muhly
Navarretia tagetina Greene	northern navarretia
Paeonia brownii Dougl. ex Hook.	Browns peony
Penstemon Mitch.	penstemon
Phacelia Juss.	phacelia

SCIENTIFIC NAMES & AUTHOR	COMMON NAME
Phacelia hastata Dougl. ex Lehm.	whiteleaf phacelia
Picea engelmannii Parry	Engelmann spruce
Pinus contorta Dougl.	lodgepole pine
Pinus ponderosa Laws.	ponderosa pine
Plagiobothrys hispidus Gray	popcornflower
Plagiobothrys scouleri (H. & A.) Johnst.	Scouler popcornflower
Poa L.	bluegrass
Poa nervosa (Hook.) Vasey	Wheeler bluegrass
Poa sandbergii Vasey	Sandberg bluegrass
Polemonium micranthum Benth.	littlebells polemonium
Polygonum douglasii Greene	Douglas knotweed
Populus L.	cottonwood
Populus tremuloides Michx.	quaking aspen
Potentilla L.	cinquefoil
Potentilla glandulosa Lindl.	gland cinquefoil
Potentilla gracilis Dougl. ex Hook.	beauty cinquefoil
Prunus emarginata (Dougl.) Walpers	bitter cherry
Pseudotsuga menziesii (Mirb.) Franco	Douglas-fir
Pterospora andromedea Nutt.	woodland pinedrops
Purshia tridentata (Pursh) DC.	antelope bitterbrush
Ranunculus L.	buttercup
Ribes cereum Dougl.	wax currant
Salix L.	willow
Scirpus L.	bullrush
Sedum stenopetalum Pursh	wormleaf stonecrop
Senecio L.	groundsel
Senecio integerrimus Nutt.	western groundsel
Sidalcea oregana (Nutt.) Gray	Oregon checkermallow
Silene L.	silene
Sitanion hystrix (Nutt.) J. G. Smith	bottlebrush squirreltail
Stipa occidentalis Thurb. ex Wats.	western needlegrass
Stipa thurberiana Piper	Thurber needlegrass
Symphoricarpos albus (L.) Blake	common snowberry
Tetradymia canescens DC.	gray horsebrush
Thalictrum L.	meadowrue
Thuja plicata Donn	western redcedar
Trifolium L.	clover
Tsuga heterophylla (Raf.) Sarg.	western hemlock
Tsuga mertensiana (Bong.) Carr.	mountain hemlock
Viola purpurea Kell.	goosefoot violet
Zigadenus Michx.	deathcamas

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The mission of the PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION is to provide the knowledge, technology, and alternatives for present and future protection, management, and use of forest, range, and related environments.

Within this overall mission, the Station conducts and stimulates research to facilitate and to accelerate progress toward the following goals:

1. Providing safe and efficient technology for inventory, protection, and use of resources.
2. Development and evaluation of alterantive methods and levels of resource management.
3. Achievement of optimum sustained resource productivity consistent with maintaining a high quality forest environment.

The area of research encompasses Oregon, Washington, Alaska, and, in some cases, California, Hawaii, the Western States, and the Nation. Results of the research will be made available promptly. Project headquarters are at:

College, Alaska	Portland, Oregon
Juneau, Alaska	Roseburg, Oregon
Bend, Oregon	Olympia, Washington
Corvallis, Oregon	Seattle, Washington
La Grande, Oregon	Wenatchee, Washington

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