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DEVELOPMENT, INITIATION, AND DESIGN FOR FUTURE MONITORING OF AN UNEVEN-AGED SILVICULTURAL PRESCRIPTION IN THE MIXED SPECIES FORESTS OF WESTERN MONTANA

By

James A. Eaton

B.S., Oregon State University, 1982

Presented in partial fulfillment of the requirements for the degree of

Master of Science

UNIVERSITY OF MONTANA

1985

Approved by:

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Chairman, Board of Examiners

Dean, Graduate School

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Development, Initiation, and Design for Future Monitoring of an Uneven-aged Silvicultural Prescription in the Mixed Species Forests of Western Montana (87 pp.)

Director: Dr. George M. Blake

In the mixed species forests of western Montana, forest managers rarely consider uneven-aged silviculture as a viable alternative. Their skepticism stems from potential undesirable changes in species composition, difficulty in regulating the harvest, and a lack of information on the subject. Opportunities for the application of uneven-aged silviculture exist on fragile sites, visually sensitive areas, and stands exhibiting all-aged structures. Information gleaned from this long-term study will provide forest managers with an alternative silvicultural tool for managing similar stands.

Stand structure goals were defined to convert a previously high-graded stand, exhibiting several age classes, to a balanced uneven-aged stand. The following goals were selected: residual density of 65 ft^2/acre, maximum tree size of 20 inches, q-ratio of 1.4, and a 20-year cutting cycle. Three treatment units were delineated. One was a control and the prescription, with two fuel management schemes, were field tested on the other two. Unit II called for individual-tree selection with full-tree utilization of the nonmerchantable material. Unit III had the same prescription, but it also included a prescribed burn.

The initial entry was directed toward stand improvement and removing the western spruce budworm-ravaged Douglas-fir. Marking guidelines were developed for selection harvest of the crop tree species (predominantly ponderosa pine, with scattered lodgepole pine and western larch). The prescription was initiated during the summer of 1984 in Lubrecht Experimental Forest. Permanent four-tenth acre growth and yield plots and one-three hundredth acre regeneration plots were established to assess changes in species conversion, future growth and yield, and the suitability of the stand structure goals.

The pretreatment average q-ratio of 1.74 was reduced to 1.56 after the first harvest. Approximately 2,300 board-feet (net) of logs and 11 units of hogfuel were removed per acre. Average net income per acre was $100.

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Chapter 1

INTRODUCTION

Federal agencies, private timber companies, and small landowners have excluded forest land from intensive management to protect scenic amenities and fragile sites. Many other stands exhibit multiaged structures resulting from past high-grading and pose a management dilemma. High-grading left the poorest trees on these sites, and encouraged the development of tolerant species. Such stands are typically at low elevations and have good access. These areas are best suited for the application of uneven-aged silviculture.

The decision of which silvicultural system to use in any given stand should be based on management objectives, stand conditions, site, and the silvical characteristics of the species present or desired. Silvicultural systems are classified either as even- or uneven-aged depending upon the type of harvest-regeneration method employed. Stands containing trees of about the same age that develop under full-light conditions without significant border competition are silviculturally classified as even-aged. Stands containing trees of several ages that develop with significant interaction with surrounding trees of different ages are classified as uneven-aged (Hann and Bare 1979).

Even-aged silviculture is most effective in even-aged stands of intolerant species, whereas uneven-aged silviculture is more suited to irregular stands of tolerant species. In mixed species stands, uneven-aged silviculture tends to predominate tolerant species in the reproduction. This tendency can be combatted by concentrating the cutting in the most tolerant species and making the cutting heavy enough to provide the proper environmental conditions for reproduction of the intolerant species.

In the mixed species forests of western Montana, forest managers are reluctant to employ uneven-aged silviculture because of undesirable changes in species composition (Boe 1948), difficulty in regulating the harvest (Alexander and Edminster 1977a), and a general lack of information on the subject. The purpose of this project is to use the individual-tree selection system to convert a high-graded stand to a balanced uneven-aged stand. Individual-tree selection system is the removal of trees in several or all diameter classes on an individual tree basis. The ultimate objective is to provide a stand with trees of different sizes and age classes intermingled on the same site (USDA Forest Service 1973).

Objectives

The objectives of this study are separated into short- and long-term time frames. The short-term objective (initiated during the summer of 1984) was to develop and initiate the uneven-aged silvicultural prescription. Second, procedures for monitoring three long-term objectives were designed. These objectives will answer three questions:

1. Will this silvicultural prescription allow for regeneration of the seral species?

2. What growth and yield can be expected for this stand in the future?

3. Can the prescribed q-ratio (diameter distribution) be created and maintained from the management guidelines specified in the prescription, or will the prescription have to be altered in the future?

Literature Review

Uneven-aged silvicultural research began with the Law of de Liocourt. The law quantified balanced or sustainable diameter distributions with a mathematical expression. The mathematical expression defined the q-value as the ratio of the number of trees between successive diameter classes. The q-value can be estimated for a set of stand inventory data by using the linear regression: $LnN_i = b_o + b_1D_i$ where N_i and D_i are, respectively, number of trees per acre and midpoint of the i^{th} diameter class, and b_o and b_1 are estimates of the regression parameters. For 2-inch diameter classes, $q = e^{-2b_1}$. The relationship generates a geometric series and, when plotted, forms the reverse J-shaped curve (Hann and Bare 1979).

Meyer (1943, 1952) and Hough (1954) expanded upon de Liocourt's work. Meyer combined the balanced diameter distribution with additional information concerning present stand structure and growth, and developed a conversion procedure to estimate future yields. Hough used growth and diameter distribution data to determine a target q-value and a maximum tree size based on the objectives of management and the form of the original diameter distribution. Hough then compared the original diameter distribution to the target q-value to determine the number of trees to be cut in each diameter class.

Duerr and Bond (1952) interjected economics into the conversion procedure by using the criterion of marginal value growth percent to determine optimal stocking on a volume per acre basis. They defined the optimal stocking level as that where marginal value growth equals the alternative rate of return for the forest landowner. Trimble, Mendel, and Kennel (1974) used this idea for a selection system in the northern hardwoods.

Moser (1976) used Leak's (1964) work and facilitated comparisons with stocking levels of even-aged stands by describing a process for determining stand density, as measured by basal area, from a given diameter distribution. Moser's procedure can be used when optimal growing stock levels have been defined for a particular species and one wishes to convert a stand to an uneven-aged stand with the optimal growing stock distributed over a range of diameters.

Recent work by Stage (1973), Adams and Ek (1974), Adams (1976), Moser, Tubbs, and Jacobs (1979), Buongiorno and Michie (1980), Chang (1981), Wykoff, Crookston, and Stage (1982), and Hall and Bruna (1983) have used stand simulators and nonlinear mathematical programming to determine the optimal stand diameter distribution, cutting cycle length, and conversion procedure. Stage's Prognosis Model was designed for even-aged stands. Cut-or-leave designations for specific tree selection can, however, be entered on the input tree records. Designating cut-or-leave trees allows individual-tree selection to be controlled, and the model will calibrate and grow the preferred residual stand. Hall and Bruna created WINNOW to efficiently build and index prognosis stand files and quickly submit the many Prognosis jobs. Stand biological productivity is read from the Prognosis jobs. Stand biological productivity is read from the Prognosis output for each trial cutting cycle. Economic productivity is determined by tree value classes and land expectation value. The tabulated biologic and economic productivity results clearly indicate relations between trial prescriptions, and managers can select the optimum prescription for a specified objective.

Reynolds (1969) provided the only opportunity to objectively look at an uneven-aged silvicultural system that has been in operation for several years. This study has been in progress for over 40 years in the Crossett Experimental Forest in Arkansas. Working with intolerant loblolly and shortleaf pine, Reynolds has shown that it is possible to start with previously unmanaged and, in this instance, badly understocked stands, and develop them to full pine stocking without sacrificing potential income to the landowner.

Two other long-term studies, both in the northeastern United States, presented 20-year results of uneven-aged silvicultural systems. Trimble (1970) looked at individual tree-selection cuttings in stands of Appalachian hardwoods in West Virginia. The 20-year results begin to show how this kind of management affects growth, yield, and species composition. The residual stand produced 300 board feet per acre per year with a dramatic improvement in log quality. Shade-tolerant species doubled in number over the 20-year period. Frank and Blum

(1978) reported 20-year results of the selection system applied to spruce-fir stands in Maine. The results included comparative data from 20 years of experience in managing spruce and fir under the selection system, commercial clear-cutting, and no management situations. The selection system improved log quality and increased the yield of forest products over the other two management options. They also showed that by controlling the seed source one can maintain a desired species composition and promote higher value species. Last, Frank and Blum recommended the selection silvicultural system for spruce-fir stands in the northeast.

Alexander and Edminster (1977b) brought the current research closer to western Montana by describing a procedure for converting old-growth spruce-fir stands with irregular structure to managed uneven-aged stands. Alexander and Edminster's study was located in the central Rocky Mountains. How to determine and calculate residual stand structure goals are outlined. By comparing the optimum stocking curve with the actual stocking curve, diameter classes with surplus trees and those with a stocking deficit can be identified. To bring the stand under management, cutting is concentrated in the surplus diameter classes while the number of trees in diameter classes deficit in stocking are allowed to increase through ingrowth.

Graham and Smith (1983) looked at the individual tree selection method in the grand fir-cedar-hemlock forests of northern Idaho. They presented guidelines for determining the four parameters that describe managed uneven-aged stands: (1) residual basal area,

(2) maximum tree size, (3) diameter distribution, and (4) cutting cycle length.

Previous research on uneven-aged silviculture in the Northern Rocky Mountains was not found. Anderson (1934) employed an economic selection cutting, where only the largest diameter trees of the high-value species were cut. He concluded that net return per acre under this type of cutting was greater than that from clear-cutting. This type of cutting now is recognized as high-grading.

Roe (1947a) looked at the growth rate of selectively cut ponderosa pine stands in the Lick Creek drainage of the Bitterroot National Forest. Marking guides were used to selectively remove most of the more tolerant Douglas-fir and reserve 30 percent of the seral ponderosa pine expected to survive to the next harvest. Residual trees accelerated growth after a selective logging operation. Roe (1947b) further determined an optimum cutting cycle for this same stand. The rate of accretion on the residual stand led him to conclude a 20-year cutting cycle. Roe's work, like Anderson's (1934), concentrated only on sawtimber-size trees, and cannot be regarded as a true uneven-aged silviculture study.

Boe (1948) looked at the composition and stocking of a ponderosa pine stand 35 years after a selection cut. This study looked at the effects of aspect, residual density, and species composition on the regeneration and survival of ponderosa pine and Douglas-fir. The more tolerant nature of Douglas-fir favored its survival on the lighter cuts while ponderosa pine regeneration was more favorable on the heavier cuts. Roe and Squillace (1950) also looked at regeneration after selection cutting in ponderosa pine stands. They concluded that abundant ponderosa pine regeneration is greatly aided by site preparation and proper timing with good seed years and seed fall.

Wellner and Ryker (1973) stated that the selection system has merit in ponderosa pine-Douglas-fir mixtures. They concluded that this type of silvicultural system favors the more tolerant Douglas-fir in the long run. Pfister (1984) believed, however, that the natural trend toward Douglas-fir in these stands may be counteracted by underburning and/or site preparation. Franklin (1978) identified the Rocky Mountain ponderosa pine forest type as having potential for the selection system without undesirable changes in species composition, provided that more tolerant associates are not present in great numbers. No data were provided to support these observations.

Chapter 2

PROCEDURES

Study Area Location

An 18-acre mixed stand of ponderosa pine (*Pinus ponderosa Laws.*), Douglas-fir (*Pseudotsuga menziesii var. glauca*), western larch (*Larix occidentalis Nutt.*), and lodgepole pine (*Pinus contorta Dougl.*), 30 miles east of Missoula, Montana served as the land base for the study. The legal description is T12N, R14W, SE¼, NE¼, Section 15. The stand is on the north side of Montana State Highway 200 immediately inside the western boundary of the Lubrecht Experimental Forest. Lubrecht Experimental Forest, owned by the University of Montana, is located on the west side of the Continental Divide in west central Montana. The 18-acre stand was broken up into three treatment units. Unit I was a 5.2 acre control. The prescription was initiated on units II and III--8.0 acres and 5.2 acres, respectively.

Methods for Short-term Objective

The first step in the prescription process was to complete a 100 percent inventory of the study area. The boundary of the study area was traversed and the area grid surveyed, breaking the study area into one square chain or one tenth acre blocks. Trees were tallied by diameter at breast height (D.B.H.) and species for each block.

Odd-sized sections at the outer edges of the study area were tallied in the same manner and were measured to calculate their area. D.B.H. was measured to the nearest one-tenth inch to facilitate dividing the trees into 2-inch diameter classes for each species. From the inventory information and previous research on uneven-aged silviculture, stand structure goals were defined and the prescription initiated.

As an important preliminary to deciding upon stand structure goals, the stand was sampled for data to establish an age versus diameter relationship. A strong age versus diameter relationship must exist before an uneven-aged silvicultural prescription is implemented. One must know if there are younger aged trees to recruit for future sawtimber harvest, or if the stand is actually even-aged and the different sized trees are a result of various intensities of competition.

Trees less than 6 inches D.B.H. were destructively sampled for total age, breast height age, and diameter at breast height. Larger trees were sampled for these same attributes. In all, 40 trees were sampled. A linear regression analysis with D.B.H. as the independent variable and total age as the dependent variable showed a strong relation between the two variables with a coefficient of determination (r^2) of 0.82, and standard error from regression of 7.71 (Appendix C).

Site index was determined by sampling 25 ponderosa pine and 15 lodgepole pine trees. Sampled trees were all dominant or co-dominant crown class. These trees were chosen across the midrange of diameters. Breast height age was measured with an increment borer, and tree heights were measured using a clinometer. Tree heights were recorded to the nearest foot. This information was fit to the appropriate site index curves (Meyer 1961, Alexander 1966) and an average site index value was calculated.

Physical Characteristics of the Site

Climate

Lubrecht Experimental Forest experiences hot, dry summers where temperatures can reach 105°F in July and August, and cold, snowy winters with temperatures well below zero. Average annual temperature is 39.3°F and average annual precipitation is 17.73 inches with most of the precipitation falling as winter snow. Average snowfall is 51 inches. The long, cold winter results in a rather short frost-free growing season of 132 days (Steele 1981).

Geology and Soils

Areas in Lubrecht below 4,200 feet are underlain by Tertiary basin deposits. The rock types of these areas are poorly to semiconsolidated mudstone, sandstone, and conglomerate. Most of the area underlain by Tertiary basin deposits is covered by an extremely clay-rich impermeable soil containing subangular argillite, siltite, and quartzite fragments. The clay is indicative of bentonitic clay derived from decomposed volcanic glass (Brenner 1968).

The above account is a good description of the soil on the study area. The duff layer is thick (2-4 inches) and varies considerably across the study area. There is a thin A horizon overlying a thicker E horizon of eluviation. The most prominent feature of the soil profile is an extensive illuviated Bt horizon.

Habitat Types

There are four habitat types, as described by Pfister et al. (1977), on the study area. The two that cover the greatest area are Psme/Vaca and Psme/Syal. The Psme/Vaca is confined to microsites of cold air accumulation in the small draws and the more easterly microaspects. The study area can be considered a frost pocket. Where the effects of cold air drainage are somewhat ameliorated on the steeper slopes and more southerly aspects, one finds Psme/Syal.

The third most common habitat type is Psme/Libo. This habitat type is confined to the Douglas-fir thickets. The fourth representative is a very minor component of Psme/Fesc on open southwest facing slopes (see Map 3, Appendix A, habitat type map).

Topography

The topography is gentle undulating slopes between 5 and 30 percent. Elevation is 4,100 feet and the aspect varies from southwest to east on a microscale. There are no major drainages in the study area.

Vegetative and Biological Characteristics of the Site

Timber Stand Description

The 18-acre study area contains four major tree species. The percentage breakdown of their basal areas are ponderosa pine 61 percent, Douglas-fir 37 percent, western larch 1 percent, and lodgepole pine 1 percent. The treatment units themselves were not uniform. The pretreatment basal area per acre averaged 104 ft^2 across the study area (see Tables 1, 2, and 3 for a detailed inventory).

Table 1

Study Area Pretreatment Inventory and Basal Area Comparison:
Unit I--Control, 5.2 Acres

Diameter class	Ponderosa pine	Douglas-fir	Western larch	Total all species
2	478	715	8	1,195
4	222	363	1	586
6	136	214	3	353
8	86	101	2	189
10	34	49	2	85
12	17	29	-	46
14	12	21	-	33
16	18	8	-	26
18	20	7	-	27
20	13	4	-	17
22	11	4	-	15
24	8	1	-	9
26	-	1	-	1
28	1	1	-	2
30	-	0	-	0
32	1	0	1	2
Total basal area (ft^2)	284.8	251.4	8.1	544.3
Basal area/acre (ft^2)	54.8	48.3	1.6	104.7
Percent total basal area/species	52.3	46.2	1.5	100.0

Table 2

Study Area Pretreatment Inventory and Basal Area Comparison:
Unit II--Unburned Treated, 8.0 Acres

Diameter class	Ponderosa pine	Douglas-fir	Western larch	Lodgepole pine	Total all species
2	804	963	2	4	1,773
4	516	495	-	-	1,011
6	341	215	3	-	559
8	198	104	-	-	302
10	105	64	1	-	170
12	38	36	2	-	76
14	25	22	-	1	48
16	25	10	-	1	36
18	16	12	-	-	28
20	19	4	-	-	23
22	10	-	-	-	10
24	4	2	-	-	6
26	-	1	-	-	1
28	3	-	-	-	3
30	-	1	-	-	1
32	-	-	-	-	-
34	2	-	-	-	2
Total basal area (ft^2)	483.7	289.3	2.8	2.6	778.4
Basal area/acre (ft^2)	60.5	36.2	0.4	0.3	97.4
Percent total basal area/species	62.1	37.2	0.4	0.3	100.0

Table 3

Study Area Pretreatment Inventory and Basal Area Comparison: Unit III--Burned Treated, 5.2 Acres

Diameter class	Ponderosa pine	Douglas-fir	Western larch	Lodge-pole pine	Total all species
2	818	560	1	54	1,433
4	429	216	2	60	707
6	213	98	0	26	337
8	148	59	6	7	220
10	62	42	6	2	112
12	54	25	3	1	83
14	18	14	1	1	34
16	16	5	-	-	21
18	11	5	-	-	16
20	12	4	-	-	16
22	11	2	-	-	13
24	8	-	-	-	8
26	5	2	-	-	7
28	2	1	-	-	3
30	1	-	-	-	1
Total basal area (ft^2)	393.6	169.5	8.0	17.4	588.5
Basal area/acre (ft^2)	75.7	32.6	1.5	3.4	113.2
Percent total basal area/species	66.9	28.8	1.3	3.0	100.0

The ponderosa pine component exhibits several age classes ranging from 300-plus-year-old relics to newly established seedlings. The principal age classes are 150-plus-year-old, 40- to 60-year-old poles, and 20- to 30-year-old saplings.

The Douglas-fir component was made up of scattered old-growth and several stagnated thickets of sapling to pole size fir. The most notable feature of the Douglas-fir was the great number of seedlings per acre. Douglas-fir regeneration had a sample mean of 3,945 seedlings per acre compared to only 175 per acre for ponderosa pine.

The lodgepole pine and western larch were minor components of the stand. The lodgepole pine was mainly confined to the north central part of treatment unit III. The majority of the lodgepole pine were 30- to 50-year-old poles. The western larch was scattered throughout the study area. They, too, were mostly in the pole sizes with a few small sawtimber sized trees.

Understory Vegetation

The undergrowth is a low, dense layer of kinnikinnick (*Arctostaphylos uva-ursi*), pinegrass (*Calamagrostis rubescens*), elk sedge (*Carex geyeri*), dwarf huckleberry (*Vaccinium caespitosum*), snowberry (*Symphoricarpos albus*), twinflower (*Linnaea borealis*), and creeping Oregon grape (*Berberis repens*).

Insects and Diseases

The major insect problem is the western spruce budworm (*Choristoneura fumiferana*). Every Douglas-fir in the stand appears to have been defoliated, many repeatedly, by this pest. The ponderosa pine has a minor incidence of the European pine shoot moth (*Rhyacioria Buoliana*). Its damage has been confined to the sapling size ponderosa pines in the stand.

The major disease problem is a high incidence of red-brown butt rot (*Polyporus schweinitzii*). Disease centers were found in several Douglas-fir thickets.

Wildlife

Aside from several nongame species of mammals and birds, the study area is frequented by whitetail deer (*Odocoileus virginianus*). Rocky Mountain elk (*Cervus elaphus nelsonii*) sign also was found.

Stand History

The multiaged character of the stand appears to have come about following several high-grading entries into the stand while it was owned by Anaconda Company in the early 1900s. The last of such entries was in the 1930s. These harvests removed many of the old-growth ponderosa pine and Douglas-fir. Judging from the stumps, Douglas-fir was a more minor component in the stand than it is today. The Douglas-fir thickets range in age from 50 to 80 years, and they likely were established in openings when the overstory was removed. Since the stand has been a part of Lubrecht Experimental Forest, no timber harvest has been recorded.

Site Productivity

Site index curves were developed for even-aged stands of ponderosa pine by Meyer (1961) and Barrett (1978), and for even-aged stands of lodgepole pine by Alexander (1966). Site index for ponderosa pine on the study area was calculated to be 78, base 100 years. This value corresponds to site class IV on a declining scale of 1 to 7. Barrett's site index curves were developed for ponderosa pine in Oregon and Washington; the study area is outside the range of this data. Alexander's curves also were developed for pure, even-aged stands of lodgepole pine. The lodgepole pine in the study area were equivalent to site index 80, base 100 years (see Appendix C, detailed site index calculations).

Site index values for Douglas-fir and western larch were not determined. The Douglas-fir trees have been all defoliated sometime in the past by the spruce budworm, affecting height and diameter growth. A search for nondefoliated trees was futile.

Chapter 3

UNEVEN-AGED SILVICULTURAL PRESCRIPTION

Land Management Objectives

Lubrecht Experimental Forest is maintained as a research area for natural resource disciplines, as well as an outdoor classroom for these students. As such, Lubrecht Experimental Forest is managed to provide research and recreational opportunities while, at the same time, provide a small amount of timber harvest to help defray operating expenses.

The study area is heavily used as a walk-in, day-hike, and hunting area. It is completely visible from Highway 200. These factors combine to impose visual constraints on any type of forest management conducted there.

Silvicultural Objectives

Two silvicultural objectives guided the initial harvest--and will guide subsequent ones:

1. Use the individual-tree selection method to develop a balanced diameter distribution (q-ratio).

2. Promote the establishment and growth of seral species.

The first objective is governed by the selected stand structure goals. Ultimately, this silvicultural system should develop several distinct age classes. Presently the small sawtimber size is understocked. The number of trees in this 10- to 18-inch range will be allowed to increase through ingrowth from the present sapling and pole component of the stand.

The first entry in the prescription concentrates on removing the dead, dying, and deformed trees of the seral species, as well as the western spruce budworm-ravaged Douglas-fir.

Prescribed Uneven-aged Treatment

There are three units (see Map 2, Appendix A, treatment unit map):

Unit I. Control, no treatment; 5.2 acres.

Unit II. Individual-tree selection, full-tree utilization of the nonmerchantable material; merchantability limits were 6-inch top at 33 feet; 8.0 acres.

Unit III. Same treatment as Unit II, but unit III includes a post logging prescribed burn; 5.2 acres.

Table 4 is a projected timetable for units II and III for the next 100 years.

Treatment units were located subjectively on the basis of logging access and burning considerations. Unit I was assigned to be the control because of its greater distance from the logging access road and because it contains the steepest topography of the three units.

Unit III was selected for the prescribed burn because of its location in proximity to natural fire breaks and ease of fire control. This unit is 50 percent surrounded by roads, and the access road at the west boundary effectively cuts off unit III from the rest of the study area. The chance of fire getting into Units I and II is remote. Unit III is almost flat, so topographical effects on the rate of

Table 4

Timetable for the Next 100 Years

Time	Unit II	Unit III
Summer 1984 (year 0) Fall 1984	Initiate prescription: remove 2.2 m/acre*	Initiate prescription: remove 3.2 m/acre Prescribed burn
2004 (year 20)	Continue prescription: remove 1.5 m/acre	Continue prescription: remove 2.0 m/acre Prescribed burn
2024 (year 40)	Continue prescription: remove 1.6 m/acre	Continue prescription: remove 2.0 m/acre Prescribed burn
2044 (year 60)	Balanced diameter distribution met: remove 2.0 m/acre.	Balanced diameter distribution met: remove 2.2 m/acre Prescribed burn if necessary
2064 (year 80)	Maintain balanced diameter distribution: remove 2.5 m/acre	Maintain balanced diameter distribution: remove 2.5 m/acre
2084 (year 100)	Maintain balanced diameter distribution: remove 2.5 m/acre	Maintain balanced diameter distribution: remove 2.5 m/acre

*1 m = 1,000 b.f.

fire spread are nil. Should control problems arise, fire suppression vehicles can drive into the unit.

Marking Procedure

Several investigators have analyzed marking criteria for selectively cutting ponderosa pine (Thompson 1940, Keen 1943, Orr 1945, Pearson 1946) and northern hardwoods (Arbogast 1957, Trimble et al. 1974). The work with ponderosa pine was based on vigor classification. The work with hardwoods was similar in approach and, in the case of

Trimble et al., economics were considered. Salient points in the marking literature were combined and a marking hierarchy developed.

Marking for uneven-aged stands must be done on an area basis. The spacial distribution of diameter classes makes marking on an acre basis impossible. The pretreatment inventory by 2-inch diameter classes was known and the idealized stocking level was calculated. The difference between the actual stocking level and the idealized stocking level showed surplus and deficit diameter classes. Surplus trees were designated as cut trees; occasionally trees were harvested from deficit diameter classes if they were within the marking guidelines.

As the treatment units were traversed, leave trees were tallied and compared to the density goal. This process was repeated until goals were met.

The marking criteria hierarchy follows:

1. Species. Removal of all Douglas-fir, leaving all western larch, ponderosa pine, and lodgepole pine as specified below.

2. Risk. Removal of all ponderosa pine and lodgepole pine that were not expected to live to the next cutting cycle (20 years); removal of all trees leaning 20° from vertical.

3. Cull and defect. Removal of all trees with dead tops, visible defects, and severe insect or disease damage.

4. Form, crown, and branching habits. Removal of all trees with (a) crown ratios less than 40 percent, (b) yellow chlorotic needles, (c) forks below the top of the first log (approximately 33 ft) unless crotch occurs at stump height, and (d) wolf-trees with large, heavy

branches the length of the bole--leaving the most vigorous trees (indicated by straight boles with tight bark, shallow fissures, and advanced natural pruning). The crown position indicates the most dominant individuals to be left in clumpy areas. If several dominants are located close together, the diameter plus four rule[1] applies as does the number of leave trees needed (as tempered by the stand structure goals).

5. Logging damage. Removal of all trees susceptible to logging damage in skid trails and in the felling path of large cut trees, yet leaving 10 percent more trees in the 4- and 6-inch diameter classes to account for logging damage.

Logging Plan

One major concern of extended uneven-aged silviculture is the potential for soil compaction resulting from successive cutting cycles. Soils on the study area are high in clay. Clay soils are most prone to compaction when wet. The logging plan was designed to limit the extent and potential for soil compaction.

Permanent skid trails and landings were designated and this network was used and will be every cutting cycle (see Map 4, Appendix A, skid trail map). The theory here is that one cannot grow trees on 100 percent of the ground to begin with, thus setting aside skid trails and landings where compaction is concentrated will not significantly

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[1]D.B.H. plus four rule of thumb spacing (feet) between trees, e.g., 6-inch trees plus 4 = 10-foot spacing.

reduce the timber growing land base. Approximately one fourth acre of the treated 13.2 acres will be removed from production. Orientation of the skid trails was to facilitate the clumpy nature of the stand. Logistics required skid trails to run favorably downhill and not across a side slope. Equipment operators chose the arterial skid roads where needed. To further limit the potential for soil compaction, all logging activities were/will be confined to the dry summer or early fall months.

One landing was located in each of the two treated units. These landings were placed in natural openings, directly adjacent to the logging access road. The landings were large enough to accommodate logging trucks and chip vans. The skid trail network eventually converged on the appropriate landing.

Logging of the study area was contracted out. The contractors entered the stand from below with a feller-buncher. This machine can shear a 16-inch tree, pick it up, and carry the tree to a bunch. The feller-buncher works well in tight spaces (approximately 8 feet wide) and is extremely mobile. The machine works best facing uphill on moderate slopes (less than 30%), and its tanklike tracks give excellent scarification.

Cutting started at the back of the unit and proceeded toward the landing. All cut trees less than 16 inches were felled and bunched. One crew member stayed with the feller-buncher and cut trees it couldn't reach. The other two crew members cut trees small enough to carry and bunch by hand. Tree butts were oriented toward the landing along the skid trails for transport to the landing. Chipable material was sorted from the merchantable logs.

After the trees less than 16 inches were felled and bunched, the loggers used two farm tractors with grapple systems to skid the trees to the landing. The smaller trees were removed first to reduce damage from harvesting the overstory trees and provide greater mobility for the skidders. At the landing, the chipper was waiting for the nonmerchantable material. The small merchantable logs were whole-tree skidded to the landing where they were limbed and bucked. Branches and tops were run through the chipper.

When the unit had been cleared of bunches, the trees greater than 16 inches were felled. These were limbed in the woods. On unit III these limbs and some of the small tops were left in the woods to fuel the broadcast burn, otherwise the limbs and tops were brought to the chipper.

A rubber-tired grapple skidder yarded the large logs to the landing. Occasionally these large logs were bucked in the woods to avoid damaging the residuals on the way to the landing. The skidder also was used to cold deck the logs. Peelers and sawlogs were separated from stud logs to maximize product conversion value. A self-loading log truck was contracted to do the hauling.

Site Preparation

This prescription relies exclusively on natural regeneration, and sites for seedling establishment must be created. The two treated units used two fuel management treatments to aid in site preparation. Unit II called for 100 percent utilization of the nonmerchantable material, including tops. This was done to reduce the logging slash and remove barriers to seedling establishment.

Unit III was prescribe burned to reduce the fire hazard and duff depth. The intent of the burn was to create favorable sites for tree regeneration, reinstitute the natural fire cycle, and counteract the species conversion to Douglas-fir.

The tracks on the feller-buncher allow for excellent scarification as the machine spins around and shears trees. Percent mineral soil exposed was 17 percent and 12 percent in units II and III, respectively. The higher value in unit II can be attributed to the feller-buncher working on steeper slopes and causing greater ground disturbance. The mineral soil was exposed during the logging process.

Chapter 4

METHODS FOR LONG-TERM OBJECTIVES

The long-term study of uneven-aged silviculture will be continued. A 5-year remeasurement period will be used to assess the three long-term objectives:

1. Will this silvicultural prescription allow for regeneration of the seral species?

2. What growth and yield can be expected from this stand in the future?

3. Can the prescribed q-ratio (diameter distribution) be created and maintained from the management guidelines specified in the prescription, or will the prescription have to be altered in the future?

Plot Establishment and Measurements

Permanent plots were established. There are two types of plots: (1) 4/10-acre growth and yield plots, and (2) 1/300-acre regeneration plots. The growth and yield plots were necessarily large to deal with the variation in tree size.

Two 4/10-acre growth and yield plots were randomly located in each of the three treatment units from a set of all possible plot centers, and aggragating four 1/10-acre blocks (established from the grid survey) to form square 4/10-acre plots. If plot centers fell on a road or other nonrepresentative location, they were rejected. The buffer area was a one-chain wide strip around each treatment unit.

In each growth and yield plot all trees greater than 1.6 inches diameter at breast height (D.B.H.) were numbered and tagged. Trees between 0.6 inches D.B.H. and 1.6 inches D.B.H. were counted and not tagged. When trees grow to be 1.6 inches D.B.H., they will be tagged during subsequent remeasurement periods. Diameter to the nearest tenth inch, height to the nearest foot, and crown ratio in percent were recorded for each tree. Crop trees were selected on the control plots and designated as leave trees as if the control unit was to have the same prescription.

Periodic annual increment was determined from past 10-year radial increments. Sampled trees were selected by first calculating the total basal area represented by each 2-inch diameter class in the growth and yield plots. This was done separately for all crop trees (including those designated in the control unit) and Douglas-fir in the control unit. The number of trees sampled in each diameter class was weighted in proportion to the basal of each diameter class. Random numbers were used to select the sample trees in each diameter class. Ten percent of all crop trees and 10 percent of the Douglas-fir were sampled for 10-year diameter growth.

Five-year height growth on trees less than 5 inches D.B.H. was also measured. From the parameters measured on the growth and yield plots, Meyer's (1952) stand table projection or Stage's (1973) Prognosis Model could be used to predict future volume.

Twenty circular 1/300-acre regeneration plots were randomly located in each of the three treatment units. The plot centers were randomly selected from the set of all possible plot centers established where the rows and columns of the grid survey crossed. The same buffer restriction, and rejection criteria applied here.

The total number of established seedlings on each regeneration plot were recorded by species. Seedlings had to be greater than 6 inches tall and have at least five branch whorls to be considered established. Seedlings up to 0.6 inches D.B.H. were recorded.

The percent exposed mineral soil also was determined from the regeneration plots. Plot measurements were averaged and percent exposed mineral soil was calculated for each treated unit.

Long-term Objective One: Species Composition

The increase or decrease of ponderosa pine regeneration on 1/300-acre regeneration plots will be used to monitor species composition. The mean number of ponderosa pine seedlings per plot was calculated at time zero (M_o), which will be repeated at 5-year intervals thereafter ($\overline{X}_5$, $\overline{X}_{10}$, etc.). The mean number of ponderosa pine seedlings per plot calculated at time zero is assumed the population mean. The population is defined as each individual treatment unit. The means will be tested with a two-tailed Student's t-test where $H_o: M_o \geq \overline{X}_5$ and $H_a: M_o < \overline{X}_5$:

$$\text{t-ratio} = \frac{\overline{X}_5 - M_o}{s/\sqrt{n}}$$

$$\alpha = 0.05$$

$$s = \sqrt{\frac{\sum_{i=1}^{n} (X_i - \overline{X}_5)^2}{n - 1}}$$

where $\overline{X}_5$ = the sample mean at each 5-year interval,

s = the sample standard deviation,

n = the number of plots, and

X_i = the number of ponderosa pine seedlings on plot i.

Reject the H_o if the calculated t-ratio is greater, or more negative, than the two-tailed critical value for t(n - 1) d.f.

A calculation example appears in Table 5. Data for the example are from the initial regeneration survey displayed in Appendix B.

Table 5

Example Calculation of t-test for Species Conversion

Given:

$M_o = 0.5$, $\overline{X}_5 = 1.5$, $\sum_{i=1}^{n} (X_i - \overline{X}_5)^2 = 31.0$, $n = 20$,

$t(n - 1)$ d.f. $= \pm 2.093$, $\alpha = 0.05$, $H_o{:}M_o \geq \overline{X}_5$, $H_a{:}M_o < \overline{X}_5$,

$$s = \sqrt{\frac{31}{19}} = 1.28$$

$$\text{t-ratio} = \frac{1.5 - 0.5}{1.28/\sqrt{20}} = 3.50$$

Conclusion: The calculated t-ratio is greater than the two-tailed critical value for t(n - 1) d.f. (3.50 > 2.093), so reject the H_o and accept the H_a.

Five-year changes may, however, be too slight to warrant using this procedure because the criteria for calling a seedling established require it be at least 5 years (i.e., have five branch whorls). In this case, 10-year or greater changes in species composition will be evaluated using the same procedure.

Accepting an alternative hypothesis of $M_o < \overline{X}_5$ will indicate a statistically significant increase in ponderosa pine regeneration over time zero levels.

Long-term Objective Two:
Future Growth and Yield

Two prediction tools were used. The first utilized Meyer's (1952) stand table projection method. The projection procedure computes a gross volume increase per acre per year based on current stand structure, q-distribution, and average annual diameter growth. The computed volume growth does not include mortality and, as such, is a conservative predictor because no acceleration of growth after release can be included in the projection when the projection period is extended several years.

The second tool used was Stage's (1973) Prognosis Model. Data files for each growth and yield plot, as well as aggregations of plots on the treated and untreated units, were created. The simulations were run for 20 years. Prognosis volume predictions seemed to grossly overpredict the conservative stand table projections. The stand table projection used local volume equations formulated by Champion Timberlands. The volumes per tree removed, calculated from these equations, agreed within 2 percent of the actual scale tickets at the mill. The Prognosis volumes per tree were calculated from equations based on sampling from all over the Northwest, and the predicted volumes were much higher. Summary output from the Prognosis runs are included in Table 7 (p. 34), but much greater confidence is placed in the stand table projection results.

The projection method works best when the entire post treatment inventory or pretreatment inventory is used. This gives a treated versus untreated comparison. Meyer's (1952) method uses a table of gross volume increase in percent of volume by diameter classes for balanced, uneven-aged forests. From the average q-ratio, a percent volume increase for each diameter class is calculated from the average annual diameter growth. The gross volume increase in percent, calculated by Meyer, is displayed in tabular form in Appendix B. A derivation of the gross volume increase in percent also was presented by Meyer.

The magnitude of the volume increase is dependent on the average q-ratio between the number of trees in each successive diameter class. The most reliable projections were calculated when large areas were considered, such as in treated versus untreated options of the entire study area. Individual plot projections were complicated by having widely different numbers of trees in each 2-inch diameter class. This resulted in inconsistent q-values between successive diameter classes and made the average q-value suspect.

The projections for the treated versus untreated options are detailed in Appendix B. Table 6 summarizes the two projections. The treated option projects the growth on units II and III. The untreated option considers the entire study area.

The volume increase for the untreated option is greater because it has a greater number of stems on which to put volume; however, the average volume per tree and the average volume growth per tree are greater for the treated option. This shows the growth being concentrated on fewer stems. Two-inch trees are not considered here because they are too small to sample for diameter growth, and are counted only.

A conservative estimate of volume increase during the next 20

Table 6

Comparisons of Volume Growth for Treated Versus Untreated Options

Volume	Treated option	Untreated option
Current		
Board feet	3,480	6,153
Cubic feet	1,067	1,967
Annual growth		
Board feet	99.2	159.5
Cubic feet	30.8	50.2
Average tree		
Board feet	26.7	21.6
Cubic feet	8.2	6.9
Average growth/tree		
Board feet	0.76	0.56
Cubic feet	0.24	0.18
20-year increase		
Board feet	1,984	3,190
Cubic feet	616	1,004

years on the treated units can be calculated by multiplying the annual gross volume increase per acre by 20. Conversely, the 20-year figure for the untreated stand is an overestimate. This option would result in slower future growth rates and greater mortality as the stand becomes increasingly overstocked.

The projected 20-year volume increase for the treated option is 1,984 board feet per acre. Approximately 1,500 board feet are needed to pay for the logging and hauling costs. This leaves surplus volume to rebuild the stand to the balanced diameter distribution specified by the stand structure goals.

The Prognosis output is summarized in Table 7. The 1984 basal areas and trees per acre were identical for the stand table projection

Table 7

Prognosis Output Summary

Simulation period	Treated option	Untreated option
1984 volume		
Board feet	4,910	9,686
Cubic feet	1,403	2,826
Cubic feet/acre/year	38	85
1994 volume		
Board feet	5,966	12,087
Cubic feet	1,743	3,551
Cubic feet/acre/year	59	84
2004 volume		
Board feet	8,151	15,000
Cubic feet	2,257	4,191

and the Prognosis runs. In comparing the 1984 volume totals, one can see that the Prognosis initial volumes are much higher than the stand table projection initial volumes. By starting each Prognosis simulation with greater volumes, the magnitude of the overprediction increased for each 10-year simulation period.

Future Yield

Approximations can be made regarding future yields 20 and 40 years from now. Yields at the next two entries will come from liquidating the old-growth and, to a much lesser extent, from removing selected trees less than 20 inches in accordance with the marking rules.

Table 8 is a gross approximation of the projected yield for the next two entries from trees greater than 20 inches on the treated units. The current diameter growth for ponderosa pine of one-tenth inch/year was used here. Each tree then would grow 2 inches over the 20-year period. The table is one way of dividing the old-growth into two groups by projecting the current growth rates for 20 or 40 years.

At the third entry (60 years) the harvest will bring the stand to the balanced diameter distribution, and thereafter the harvest will stabilize. Table 9, an extension of Table 8, estimates the projected harvest at 60 years, and subsequent harvests from the balanced stand. The same annual diameter growth of 0.1 inches is assumed.

Table 8

Estimated 20- and 40-year Yields from the Treated Units*

D.B.H.	a†	b	c‡	d‡	e	f	g‡	h‡	i
16	29	41§	-	-	41	84‖	5	616	79
18	19	29	-	-	29	41	-	-	41
20	26	19	5	1,346	14	29	22	5,923	7
22	15	26	16	5,981	10	14	10	3,738	4
24	9	15	10	5,028	5	10	8	4,022	2
26	3	9	6	3,950	3	5	4	2,633	1
28	5	3	2	1,684	1	3	2	1,684	1
30	-	5	3	3,168	2	1	1	1,056	-
32	-	-	-	-	-	2	1	1,301	1
34	2	-	-	-	-	-	-	-	-
36	-	2	1	1,578	1	-	-	-	-
38	-	-	-	-	-	1	1	2,231	-
Totals				22,734				23,204	

*Assume 0.1-inch annual diameter growth.

†Column headings:
a = current inventory
b = projected inventory at 20 years
c = removal at 20 years: number of trees
d = removal at 20 years: volume board feet
e = residual inventory at 20 years
f = projected inventory at 40 years
g = removal at 40 years: number of trees
h = removal at 40 years: volume board feet
i = residual inventory at 40 years

‡These estimated volume removals do not include trees less than 16 inches that would be harvested in accordance with the marking rules.

§Fourteen-inch trees from the current inventory.

‖Twelve-inch trees from the current inventory.

Table 9

Estimated Harvest Volumes from the Treated Units at 60 Years and Thereafter

D.B.H.	a*†	b	c	d	e‡	f	g	h
2	780	900	120	Chip	780	900	120	Chip
4	560	780	223	Chip	557	780	223	Chip
6	400	560	161	Chip	399	557	158	Chip
8	285	400	116	Chip	284	399	115	Chip
10	205	285	81	1,743	204	284	80	1,722
12	150	205	60	2,614	145	204	59	2,570
14	114	150	45	3,445	105	145	40	3,603
16	79	114	40	4,932	74	105	31	3,822
18	41	79	26	4,851	53	74	19	3,545
20	7	41	3	808	38	53	15	4,038
22	4	7	7	2,617	-	38	38	14,205
24	2	4	4	2,011	-	-	-	-
26	1	2	2	1,316	-	-	-	-
28	1	1	1	842	-	-	-	-
30	-	1	1	1,056	-	-	-	-
32	1	-	-	-	-	-	-	-
34	-	1	1	1,578	-	-	-	-
Totals				27,813				32,965

*Column headings:
a = residual at 40 years
b = inventory at 60 years
c = removal at 60 years: number of trees
d = removal at 60 years: volume board feet
e = balanced diameter distribution at 60 years
f = inventory at 80 years
g = removal at 80 years: number of trees
h = removal at 80 years: volume board feet

†Current inventory projected 40 years; trees greater than 14 inches D.B.H. are from Table 8.

‡Residual basal area is 65 ft^2 per acre, maximum tree size is 20 inches, q-ratio is 1.4.

Long-term Objective Three: Q-ratio Maintenance

Plot inventories following each harvest entry will determine if the prescribed q-ratio can be maintained. Evaluating this third long-term objective every 20 years will allow looking at the effects of tree growth and individual-tree selection harvest on the diameter distribution. A 5-year evaluation of this objective will not show the great importance that harvesting selected trees has on creating the desired q-ratio. The procedure described herein also will help track the initial q-ratio as it progresses toward the balanced q-ratio (q = 1.4).

The growth and yield plots in the treated units should provide a representative q-ratio for the entire treated area. These plots were randomly selected before the prescription applied. Unfortunately, these plots have greater stocking, on a volume per acre basis, than the treated area as a whole. The average q-ratio on these four plots are higher than the treated stand's average. A great reduction of the average q-ratio is expected after the next harvest entry. Thereafter the change in the q-ratio will be slight as the stand approaches the balanced diameter distribution.

To analyze the change in the q-distribution, a two-tailed Student's t-test was chosen. The mean q-ratio ($\overline{X}_{20}$) after each subsequent entry will be compared with the initial q-ratio (M_o) at the beginning of the 20-year period where H_o:$M_o \leq \overline{X}_{20}$ and H_a:$M_o > \overline{X}_{20}$.

$$\text{t-ratio} = \frac{\overline{X}_{20} - M_o}{s/\sqrt{n}}$$

$$\alpha = 0.05$$

$$s = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \overline{x}_{20})^2}{n - 1}}$$

where $\overline{X}_{20}$ = the sample mean q-distribution after each subsequent entry,

s = the sample standard deviation,

n = the number of plots, and

X_i = the average q-ratio on plot i.

Reject the H_o if the calculated t-ratio is greater, or more negative, than the two-tailed critical value for t(n - 1) d.f.

A calculation example appears in Table 10.

Once the balanced diameter distribution has been created, this procedure will indicate departures from the balanced state should they occur.

This t-test is performed with a small sample size (n = 4). This fact may reduce the value of the t-test in analyzing changes in the q-ratio.

Table 10

Example Calculation of t-test for q-ratio Maintenance

Given:

$$M_o = 2.18,\ \overline{X}_{20} = 1.70,\ \sum_{i=1}^{n} (X_i - \overline{X}_{20})^2 = .1781,\ n = 4,$$

$$t(n - 1)\ \text{d.f.} = \pm 3.12,\ \alpha = 0.05,\ H_o: M_o \leq \overline{X}_{20},\ H_a: M_o > \overline{X}_{20},$$

$$s = \sqrt{\frac{.1781}{3}} = .244$$

$$\text{t-ratio} = \frac{1.70 - 2.18}{.244/\sqrt{4}} = -3.94$$

Conclusion: The calculated t-ratio is more negative than the two-tailed critical value for t(n - 1) d.f. (-3.94 < -3.182, so reject the H_o and accept the H_a.

Chapter 5

RESULTS AND DISCUSSION

Results

Yield

Trees harvested from the study area will be converted into several products. Logs were cut for sawtimber, plywood, and stud logs. All stems smaller than the merchantability standards, as well as tops from the merchantable trees and most limbs, were chipped for hogfuel. A summary of the volume of logs and chips harvested from the treated units appears in Table 11. See also Appendix B, detailed yield table of what was harvested by unit, species, and size class, and the computer program used to calculate tree volumes by 2-inch diameter classes.

Yield for the merchantable logs are from the actual scale tickets issued by the mills where the logs were delivered. Hogfuel volumes also are derived from the scale tickets. Hogfuel vans are weighed empty and then with a full load. The weight of the hogfuel chips is converted to cubic foot volume by a weight-to-volume conversion factor calculated for the loads coming from the study area.

Economic Evaluation

Total income from the sale of the logs and hogfuel were separated for each treated unit. The value per net thousand board

Table 11

Volume of Harvested Logs and Chips from the Treated Units

Item	Unit II (8.0 acres)	Unit III (5.2 acres)
Total Douglas-fir harvested (board feet, gross)	12,329	9,228
Total ponderosa pine harvested (board feet, gross)	5,101	7,706
Total other species harvested (board feet, gross)	0	16
Total all species harvested* (gross)	17,430	16,950
Net	15,270	14,850
Average volume harvested/acre (board feet, gross)	2,179	3,260
Total units hogfuel (1 unit = 200 ft^3)	95.61	52.81
Units hogfuel/acre	11.95	10.16

*63% of the volume removed was Douglas-fir; 37% was ponderosa pine.

Table 12

Economic Evaluation

Value/M.B.F. (net) = $164.76   Value/unit hogfuel = $15.00

Unit II: 8.0 acres

Total revenue	
Chips, 95.61 units × $15.00/unit	$1,434.15
Logs, 15.27 M.B.F. (net) × $164.76/M.B.F.	2,525.89
Total revenue	$3,950.04
Production costs*	
Falling and bucking†	$1,055.50
Skidding and chipping‡	1,789.00
Loading and hauling, $125/load × 4 loads	500.00
Total costs	$3,344.50
Net income	$ 605.54
Per acre	$ 75.69
Per M.B.F. (net) removed	$ 39.66

Unit III: 5.2 acres

Total revenue	
Chips, 52.81 units × $15.00/unit	$ 792.15
Logs, 14.85 M.B.F. (net) × $164.76/M.B.F.	2,446.69
Total revenue	$3,238.84
Production costs§	
Falling and bucking†	$ 559.00
Skidding and chipping‡	1,467.00
Loading and hauling, $125/load × 4 loads	500.00
Total costs	$2,526.00
Net income	$ 712.84
Per acre	$ 137.08
Per M.B.F. (net) removed	$ 48.00

*340 man hours required to log and haul.

†Includes the Bobcat Feller-Buncher, chainsaws, equipment costs, and labor costs.

‡Includes the John Deere skidder, farm tractor, chipper, chainsaws, equipment costs, and labor costs.

§257 man hours required to log and haul.

Table 13

Residual Stand Structure,* Units II and III Combined

2-inch diameter class	Trees per acre Before treatment	After treatment	Target stand
2	242.9	52.4	52.1
4	130.2	45.3	42.2
6	67.9	33.4	30.2
8	39.5	22.7	21.5
10	21.4	11.4	15.4
12	12.0	6.4	11.4
14	6.1	3.1	7.9
16	4.3	2.2	5.6
18	3.3	1.4	4.0
20	3.0	2.0	2.9
22	1.7	1.1	-
24	1.1	0.7	-
26	0.6	0.2	-
28	0.5	0.4	-
30	0.2	-	-
32	-	-	-
34	0.2	0.2	-
q-ratio	1.74	1.56	1.40
Basal area/acre	104 ft^2/acre	54 ft^2/acre	65 ft^2/acre

*Per acre basis.

feet (M.B.F., net) was calculated by dividing the total income from the logs by the net M.B.F. removed. The value per M.B.F., net is an average for both species. Average percent defect was 12.4.

Detailed time records were kept for all phases of the logging operation as well as equipment costs. These costs were broken down by unit. Loading and hauling costs also were determined for each unit. The economic evaluation is presented in Table 12.

Logging costs in subsequent entries should be lower. This is because the permanent skid trail and landing system has been established, fewer smaller trees will be removed, and the mobility of the logging equipment will be improved when the stand is in a managed state. The percent defect also will decrease as the old-growth is harvested and the stand managed for high quality sawlogs.

Residual Stand Structure

Table 13 illustrates the trees per acre before treatment, after treatment, and in the future target stand. Treated units II and III are combined. The before treatment figures include the Douglas-fir component. The after treatment figures show trees greater than the 20-inch maximum tree size. These trees were left to make up for the stocking deficits in the other size classes.

Stand Structure Goals

Regulation in uneven-aged stands is accomplished by setting three stand structure goals. These goals are to:

1. Maintain a residual density, in terms of basal area, to provide adequate growth and yield.

2. Maintain a maximum tree size.

3. Maintain a diameter distribution (q-ratio) to provide for regeneration, growth, and development of replacement trees.

The three goals are targets, not rigid quotas to be met the first cutting.

Residual Density

The square feet of basal area the stand is cut back to each cutting cycle is the residual density. To arrive at a residual basal area, two crucial factors must be balanced. The first is the desire to open up the stand so as to create favorable sites for natural regeneration. The second is the need to maintain a growing stock that quickly occupies the site, thereby losing no net growth.

In this stand a successful uneven-aged silvicultural prescription is dependent on the natural regeneration of intolerant species. In such an instance, harvest cuttings must be heavy enough to encourage regeneration of these species. This kind of management may result in a relatively low level of total stocking, but it should maintain the crop species in the future stand.

The residual density is dependent on how much the site can carry at full stocking. Stands can be cut back to 60 percent of this full stocking level without losing growth (Marquis 1978). Herein lies a basic premise of uneven-aged silviculture. The productive capacity of the site is maintained by concentrating the growth on fewer high quality stems of several age classes.

Currently, no residual density guidelines exist for uneven-aged stands in the Northern Rocky Mountains. There are, however, available stocking guides for even-aged stands. Where local information of uneven-aged guidelines are absent, these are the only source.

Meyer (1961) showed a stand of similar site index carrying 175 ft^2 of basal area per acre at full stocking. The study area had a pretreatment basal area of 104 ft^2 per acre. The stand at that time was essentially fully occupied but in an uneven-aged condition. In such a state the advanced growth of the smaller trees had become established under a canopy of larger trees. Growing space occupied by each age or size class was being shared. This clearly was not an even-aged situation, and yield tables could be expected to overpredict this site's full stocking level.

Some information was available for selection forests of ponderosa pine. An Arizona study (reported by Marquis 1978) defined the residual basal area per acre as 60 percent of the fully stocked basal area as previously described. A graph illustrated where one enters the diameter of a tree of average basal area and the corresponding residual basal area is read off. The graph listed a residual basal area of 57 ft^2 for the study area.

Dale Hall used residual basal area standards of 45, 60, and 75 ft^2 per acre in a central Idaho ponderosa pine selection study (reported by Foiles 1978). Another study in Arizona (reported by Marquis 1978) used 80 ft^2 per acre for a residual basal area. None of these studies had long-term results, but a residual basal area between 45 and 80 ft^2

per acre was common for moderately productive ponderosa pine sites. A residual density of 65 ft^2 per acre was used for this study.

Maximum Tree Size

Maximum tree size is dependent on site productivity, management objectives, and other uses of a stand. When choosing a maximum tree size, one has to weigh economic timber production of high quality sawlogs against the visual attributes of large, old-growth ponderosa pine.

Strict economic consideration indicates a smaller maximum tree size. WINNOW (Hall and Bruna 1983) lists a 14- to 16-inch tree size for maximum dollar return in selectively cut ponderosa pine stands in Idaho. This size tree is, however, too small to meet the landowner's objective of maintaining the visual quality of the present study area.

Maximum tree size based on financial maturity data is available for many eastern hardwood species. Rate of return information of this sort was provided by Trimble et al. (1974) for several hardwood species. The basic principle of such an approach is to leave trees expected to exceed a minimum acceptable return because of rapid growth or quality improvement. Trees that fall below the minimum acceptable return are deemed financially mature and should be harvested.

Other studies in ponderosa pine selection silviculture have used maximum tree sizes from 20 to 28 inches. The larger maximum tree sizes are reserved for highly productive sites. Given the productivity of the present study area, a 20-inch maximum tree size was chosen. This meant that once a balanced diameter distribution had been created, the stand would be cut back to a 20-inch maximum tree size at each entry. These 20-inch trees then would be allowed to grow for 20 more years before being harvested. In actuality then, trees larger than 20 inches occupy the site at the end of each cutting cycle. When the diameter distribution is balanced, a 20-inch maximum tree size should also retain the visual attributes of large sawlog sized trees on the site.

Q-distribution

The third stand structure goal was the q-ratio used to distribute the residual basal area over the 2-inch diameter classes. Unfortunately, no yield data were available that allowed for calculating the economic trade-offs of different ratios. In the absence of any experience data, or growth and yield information, the best estimate of the number of trees to leave by diameter classes was to use the lowest q-ratio reasonable in terms of existing markets, stand conditions, and funds available for cultural work. Marquis (1978) made a general recommendation of q-ratios between 1.3 and 1.8 for 2-inch diameter classes in previously unmanaged stands. Schubert (1974) used a q of 1.5 in managed stands of ponderosa pine in Arizona. Figure 1 illustrates the stocking curves for various q-ratios.

When the number of trees per acre is plotted over diameter at breast height on semilog paper, the balanced diameter distribution forms a straight line (see Figure 2).

Stands described by small q-ratio have a higher proportion of available growing space in larger trees, fewer trees per acre, and a smaller difference in the number of trees between diameter classes

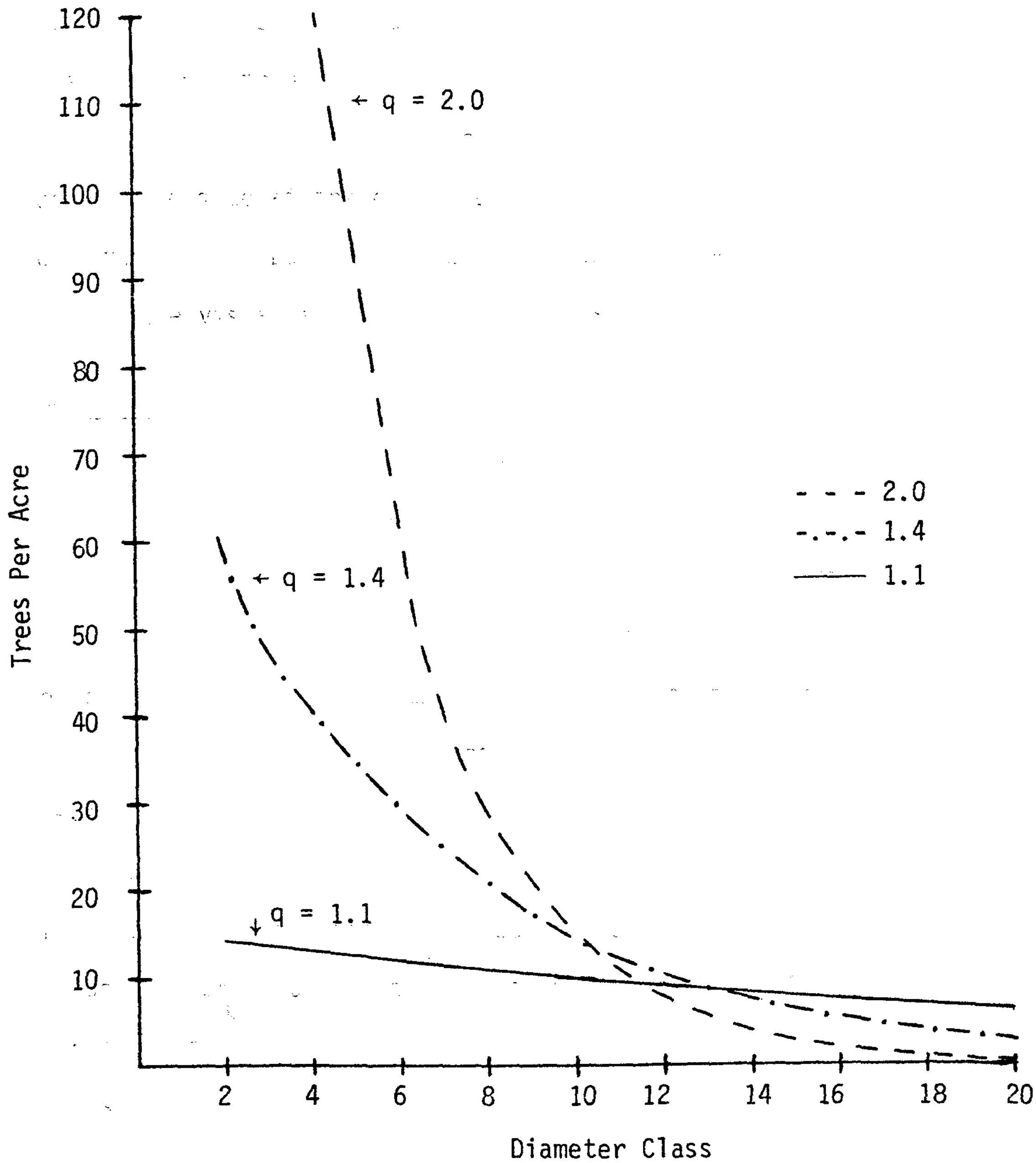

Figure 1. Example of stocking curves for various q-ratios

(Alexander and Edminster 1977a). Conversely, stands described by a higher q-ratio will have their growing stock concentrated in a greater number of smaller trees, more trees per acre, and a greater difference in the number of trees between diameter classes.

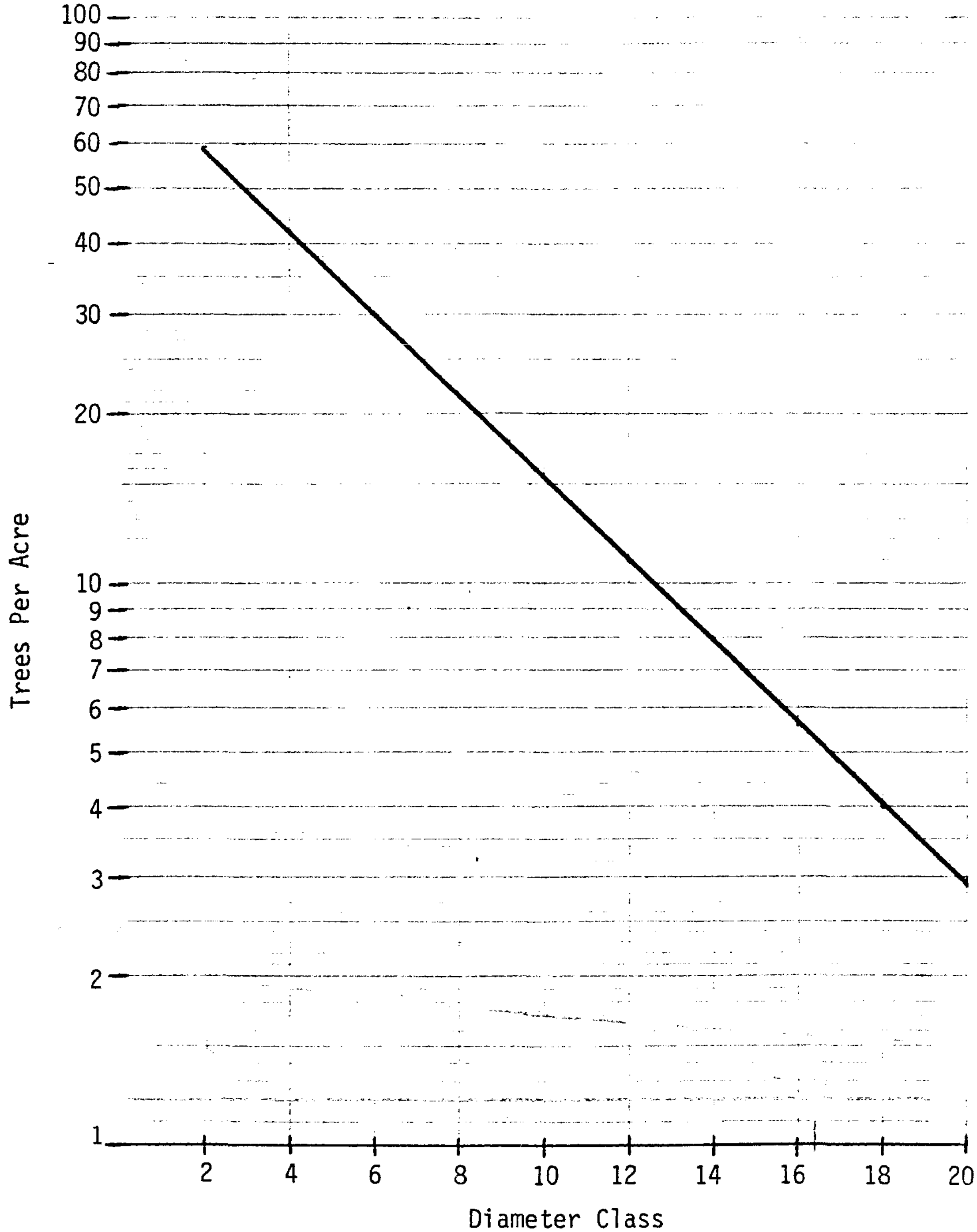

Figure 2. Q-ratio of 1.4 plotted on semilog paper

Q-ratios for managed stands generally range from 1.0 to 2.0. Higher q-ratios have a greater number of smaller trees that need to be regulated. Lower q-ratios result in more large sawtimber sized trees, but a great number of small diameter trees still must be removed at the initial entry. If funds are available for managing the smaller size classes and a market exists for them, lower q-ratios are practical. In this study both conditions were met so a low q-ratio was feasible.

The original diameter distribution of the stand also weighed heavily on the choice of a q-value. A pretreatment inventory indicates the number of trees one has to work with in each diameter class from which a pretreatment q-ratio can be calculated. This is done by summing the quotients between the number of trees in each successive diameter class and averaging the quotients over the number of diameter classes represented. The pretreatment q-value was decreased until there was enough volume to pay for the initial entry without decreasing the number of trees in the middle diameter classes where the stand already was understocked. This q-ratio was 1.4.

Figure 3 shows the basic idea for harvesting in regulated uneven-aged stands. The idealized stocking curve depicts the stand structure goals selected. Comparing the actual to idealized stocking curves shows where surpluses and deficits occur. To bring the stand under management, the number of trees in the diameter classes that are below the idealized stocking curve (deficit) are allowed to increase and cutting is limited to those diameter classes with surplus trees. Enough trees must be left above the curve in the surplus diameter classes to balance the deficit diameter classes below the curve--and this was accomplished by leaving more 4-, 6-, and 8-inch trees, as well as several trees above the 20-inch maximum tree size. The actual

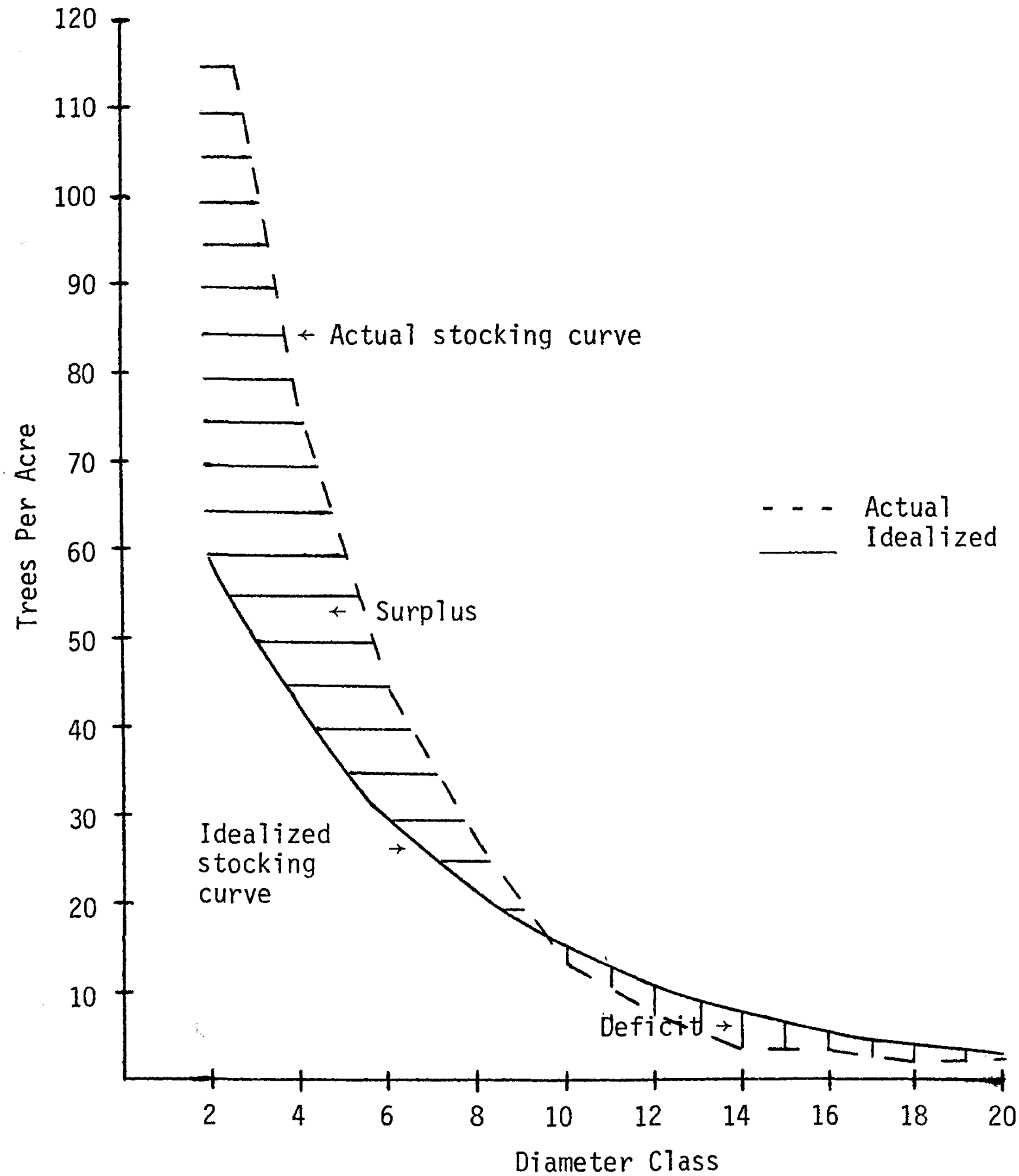

Figure 3. Surplus and deficit diameter classes, exhibited by the idealized and actual stocking curves

calculation of the number of trees in each 2-inch diameter class that forms the idealized stocking curve is shown in Appendix C.

The last parameter needed for a regulated uneven-aged stand was the cutting cycle. A 20-year cutting cycle was chosen. Twenty years was considered adequate time for the residual trees to accrue enough diameter and board feet growth to raise them to the surplus level (Roe 1947b).

The concept of a balanced diameter distribution is paramount to a successful uneven-aged silvicultural prescription. The balanced diameter distribution must be developed to ensure that trees in smaller size classes provide the ingrowth into the sawtimber sizes. Early attempts at uneven-aged management has failed because cutting was concentrated in the large size classes (high-grading) and no thought was given to the development of the smaller size classes. Previously unregulated stands will not be brought under control with one cut or even a series of cuts (Alexander and Edminster 1977b, Foiles 1978).

There were several reasons why the seral species will be promoted in the future. The first and most important was the effect of past defoliation by the western spruce budworm on Douglas-fir growth. Height and diameter growth had been depressed. Past 10-year radial increment was sampled for the crop and noncrop trees across the range of diameters in the study area. The Douglas-fir growth was roughly half that of the other species. Douglas-fir diameter growth averaged 0.45 inches over the last 10 years. The 10-year growth averaged 0.45 inches over the last 10 years. The 10-year diameter increments were 1.02 inches, 1.31 inches, and 0.95 inches for ponderosa pine, lodgepine, and western larch, respectively.

Past 5-year height growth for trees less than 5 inches D.B.H. also were sampled. The influence of the spruce budworm can graphically be seen here. Five-year height growth for Douglas-fir averaged 1.1

feet. Five-year height growth for ponderosa pine averaged 4.2 feet. Ponderosa pine trees sampled for age versus diameter relationship averaged 13 years to breast height. Douglas-fir averaged 27 years. The western spruce budworm was affecting all sizes of Douglas-fir. Carlson et al. (1982) reported that the western spruce budworm does best in storied stands. The larvae fall from the overstory trees onto the understory, and each layer in the canopy can be affected. This situation was graphic on the present study area.

The establishment of the 50- to 70-year-old Douglas-fir thickets coincides with past high-grading and the beginning of the fire exclusion policy. In the absence of frequent low-intensity ground fires, the more tolerant Douglas-fir has become established; close to 4,000 fir seedlings occupy each acre. Without the natural fire cycle, the stand was being converted from faster growing seral species to the slower growing climax species. The Douglas-fir was harvested and the fire cycle reintroduced to halt this species conversion.

That last contributor to the demise of Douglas-fir was the high incidence of red-brown butt rot. The butt rot was centered in the Douglas-fir thickets, and most of the old-growth fir had some degree of this infection.

Complete exclusion of Douglas-fir from the study area is unrealistic. The overstory can be removed and a good part of the understory, but every seedling cannot be uprooted. When these seedlings are 20 years older, they will be cut in the next cutting cycle. There also will be seed movement into the study area from outside the study boundary. This is unavoidable; but, cutting back the Douglas-fir at each entry controls its establishment. Thus its effect on the growth of the crop trees will be minimized.

Overstory-Understory Affects on Tree Growth

In uneven-aged stands trees are suppressed components of the understory at some point in their lives. Large trees--either as individuals, or constituting edges adjacent to groups of small trees, affect growth rates of nearby small trees. Competition for light and space is vertical and horizontal in uneven-aged stands. The presence of vertical competition is the main reason that uneven-aged silviculture is restricted to the more tolerant species. This effect is greatest on poor sites, where competition for water may also limit tree growth.

Curtis (1978) described the height and diameter growth of uneven-aged stands as a pattern showing a prolonged period of slow growth in early life, followed by a later acceleration when the overstory is removed. Barrett (1970, 1982) and Curtis (1978) have shown that ponderosa pine responds favorably to release. Trees 40 to 70 years of age seem to respond the greatest, but even a 100-year-old ponderosa pine will accelerate its diameter and height growth following release (Barrett 1963). Because ponderosa pine responds to release indicates the understory has been suppressed. The acceleration in growth following release is the tree's way of compensating for growth lost while being suppressed. The 20-year cutting cycle attempts to maximize potential growth. Potential growth is realized when trees are not suppressed.

The overstory affect on understory growth can be tempered by using low-density stand structures to promote the establishment of small even-aged groups of the seral species. This is not to be confused with group-selection where the even-aged groups would be much larger. Seed crops in ponderosa pine are infrequent, and the inconsistent nature of environmental conditions enabling germination and establishment combine to cause waves of reproduction. These waves are aided by site preparation, occurring at each harvest entry. Thus distinct age classes, separated by roughly 20 years, are likely to develop.

Fire's Role in Creating Uneven-aged Stand Structure

Historically fire has played an important role in the development of uneven-aged stands. Before the advent of fire exclusion policy, the natural fire cycle in the study stand was approximately 20 years. Fire's role helped create uneven-aged stands by periodically removing newly established regeneration. Faster growing seral species established at the time of the previous fire were large enough to survive the low-intensity fire and developed a distinct age class. The fires also removed the tolerant species from the understory and created receptive seed beds for regeneration of intolerant species. The thick bark of ponderosa pine and western larch assured their survival in the overstory and these species provided seed for the new age class. In this way the seral species were proliferated.

Fire exclusion policy resulted in the increased dominance of the tolerant species. This occurrence added to the vertical continuity of the fuel load (ladder fuels) and increased the potential for destructive crown fires.

Long-term Genetic Implications

Previous high-grading may have been detrimental to the hereditary qualities of the study stand. The pretreatment stand was essentially trees passed over for harvest because they didn't meet the merchantability standards at that time. A poorly managed stand, with high-grading of the better trees and little care in selection among the lower age classes, is very likely to lead to a lowering of genetic quality (dysgenic selection).

Evidence that continued application of uneven-aged silviculture leads to the elimination of fast-growing quality trees, with respect to bole form and tree health, is inconclusive. Assuming the current age versus diameter relationship holds true, the proper application of the individual-tree selection system should ensure a status quo gene pool. Fast-growing quality trees should be recognized and allowed to mature and produce seed. This phenotypic selection does not result in upgrading of the gene pool but perpetuates the current gene pool.

Likelihood that distinct age classes will develop after waves of regeneration become established, may result in cutting some of the better trees to meet q-distribution goals. The timing of these waves of regeneration may not be conducive to creating 2-inch diameter classes. Trees beyond a maximum size will be harvested, not beyond a maximum age. When fast growing trees are not recognized and are, in turn, harvested to meet q-distribution goals, they are lost from the stand.

Treatment Evaluation

The major factor influencing future results and data interpretation is the bias introduced by nonrandom allocation of the treatment units. This bias will have to be considered in any conclusion derived from the study.

Logging damage was minimal on the entire treatment area. Damage mostly was confined to the smaller sized trees. This was expected as a consequence of falling the overstory trees. More leave trees were marked in the 4- and 6-inch diameter classes to account for logging damage. Ponderosa pine has thick bark that serves to minimize cat scaring and this type of damage was greatest on the smaller trees.

The logging procedure used by the crew was extremely helpful in minimizing damage. Smaller trees were cut and yarded out of the stand first. Most of this work was done by the feller-buncher which had complete control over the tree--its shearing and bunching. By removing the understory cut trees first, more room was created to fall the larger, more valuable trees. The designated skid trail system was effective in confining the majority of the soil disturbance to the trails. Logging damage doesn't have to be high in harvesting uneven-aged stands. The most important factor is the logger's ability to understand what the silviculturist wants done, then accepting the challenge and improvising if necessary.

Adherence to the 65 ft^2/acre basal area residual density goal was impossible. The objective was to remove the dead, dying, and deformed seral species, and Douglas-fir at the start of the prescription. Despite dropping below the residual density goal on a stand basis, small sections of the managed area are overstocked. This localized overstocking was necessary to maintain good trees on the site and not fall too far below the residual density goal. These areas remained overstocked even after removing (in some cases) 50 percent of the surrounding trees.

At times the feller-buncher was unable to access the thickets because spacing was too tight. Opening up a thicket too quickly can cause blowdown before the residual trees can increase their root volume and better anchor themselves. It was decided to let the best trees in these thickets prove themselves over the next 20 years. Close attention to spacing will be possible at that time.

The fire succeeded in killing approximately 90 percent of the Douglas-fir regeneration, reduced the duff and litter layers, and created receptive seedbeds for natural regeneration. Ideally, one would like to time a prescribed burn with seedfall to create optimum conditions for germination.

The marking scheme initially worked well. Unfortunately, once all of the dead, dying, and deformed trees were removed, there was little opportunity to use the D.B.H. plus four rule on the crop trees. Strict adherence to the D.B.H. plus four rule would have left the small pole size classes understocked.

Crop trees in the 2-inch diameter class and smaller were not intensively managed to meet q-distribution goals. All trees of this size were left on unit III because the prescribed burn would kill an uncontrollable number of them. In unit II all poor quality trees of this size were removed; however, no spacing criteria were used. Logging damage was especially heavy in the small diameter classes; managing the 2-inch class at this point would have been futile.

The initial harvest of the prescription was successful in starting the process of creating the desired stand structure. The average pretreatment q-ratio was 1.74. After harvest the average q-ratio dropped to 1.56. The stand still has several old-growth ponderosa pine and great diversity of tree ages.

The monitoring of the long-term objectives at each 5-year remeasurement period should provide the necessary information to determine the applicability of uneven-aged silviculture for forest landowners.

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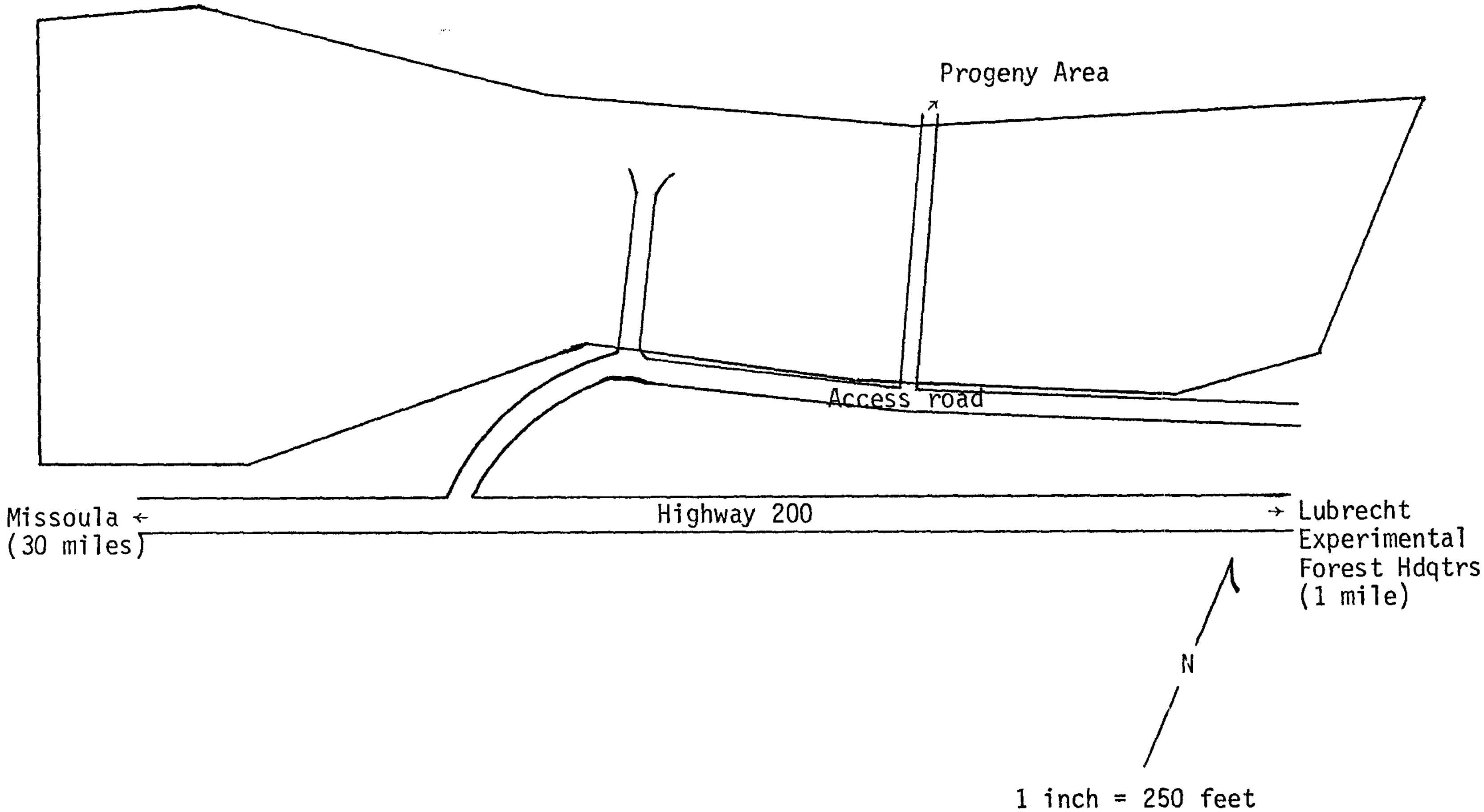
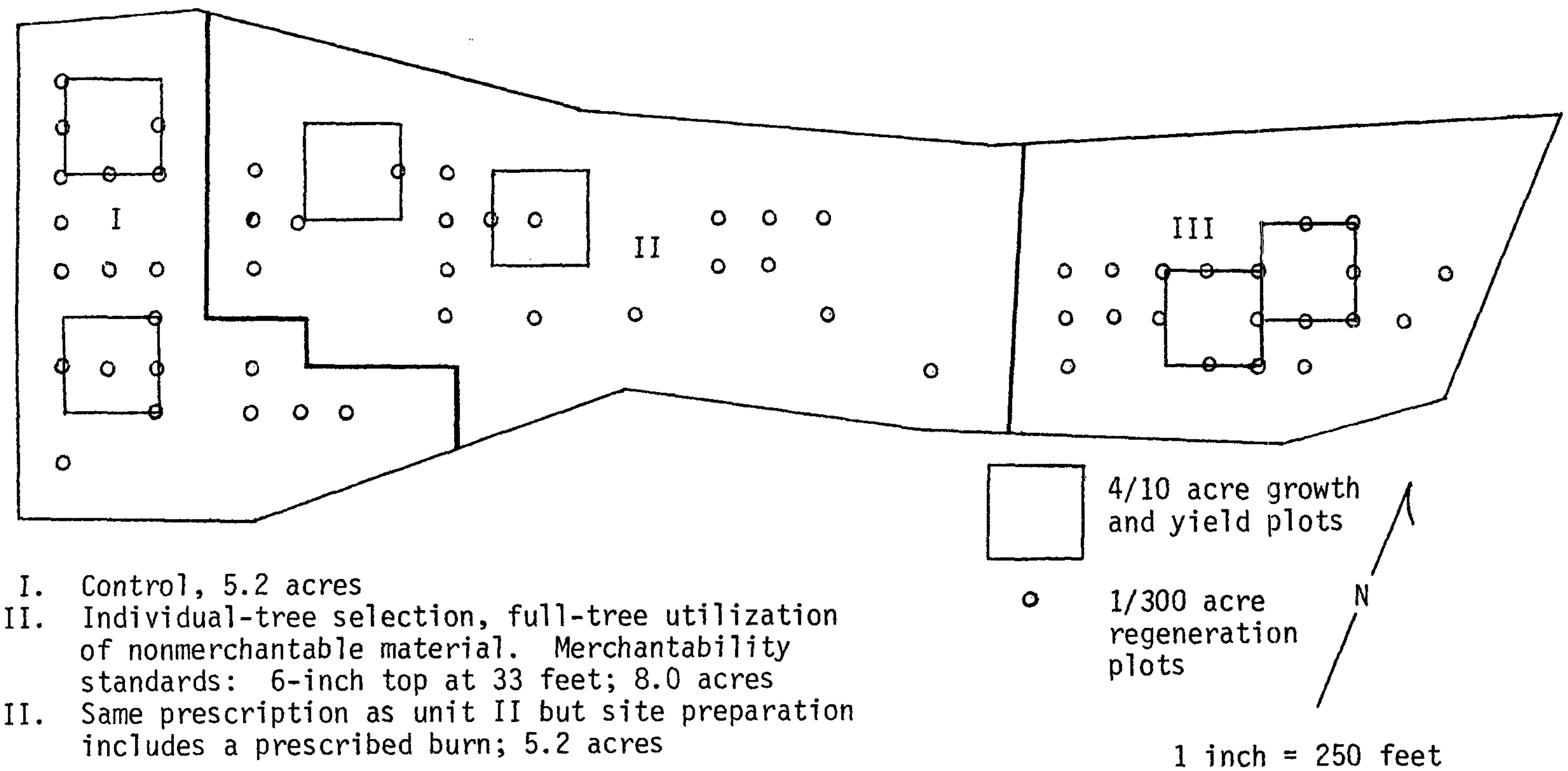
APPENDIX A

Map 1. Study Area



Map 2. Location of Treatment Units and Plots

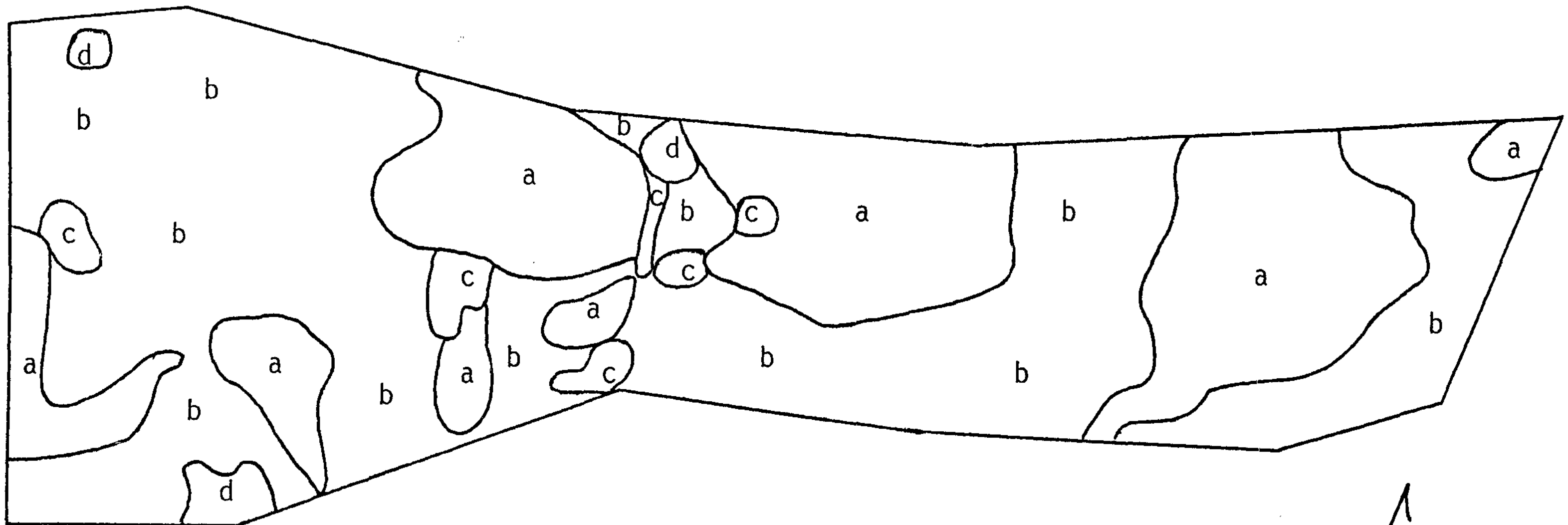


I. Control, 5.2 acres

II. Individual-tree selection, full-tree utilization of nonmerchantable material. Merchantability standards: 6-inch top at 33 feet; 8.0 acres

III. Same prescription as unit II but site preparation includes a prescribed burn; 5.2 acres

Map 3. Habitat Type Map*

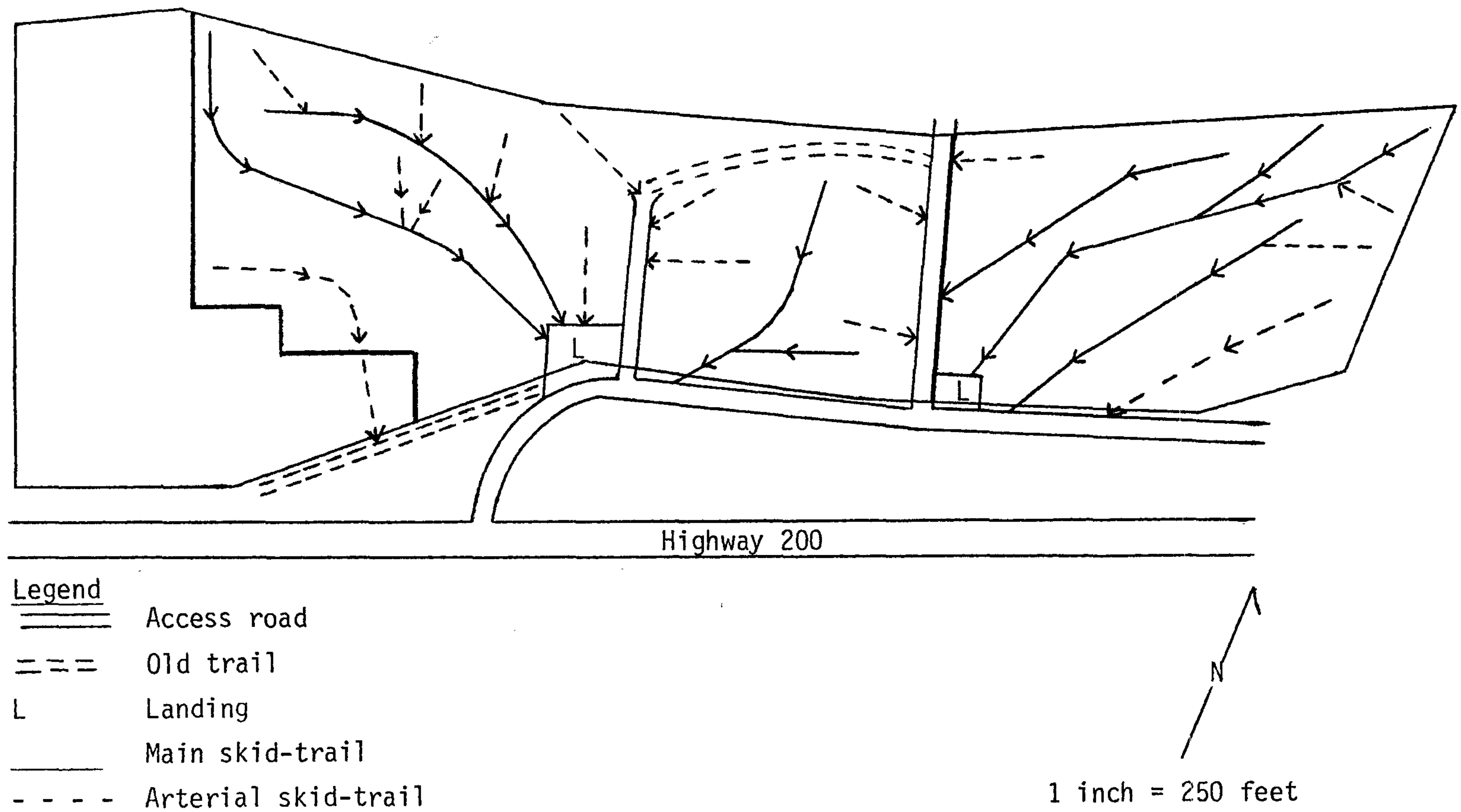


Legend
a. Pseudotsuga menziesii-Vaccinium caespitosum (Psme/Vaca)
b. Pseudotsuga menziesii-Symphoricarpos albus (Psme/Syal)
c. Pseudotsuga menziesii-Linnaea borealis (Psme/Libo)
d. Pseudotsuga menziesii-Festuca scabrella (Psme/Fesc)

1 inch = 250 feet

*After Pfister et al., 1977.

Map 4. Permanent Skid-trail System and Designated Landings



A P P E N D I X B

Table 1

Detailed Yield for Treated Units, Merchantable Volume Removed (Board Feet, Gross): Unit II--Unburned Treated, 8.0 Acres

Diameter class	Ponderosa pine	Douglas-fir	Total all species
8	291	817	1,108
10	366	1,377	1,743
12	175	1,569	1,744
14	383	1,685	2,068
16	740	1,233	1,973
18	747	2,239	2,986
20	808	1,077	1,885
22	747	-	747
24	1,005	1,006	2,011
26	-	658	658
28	-	-	-
30	-	1,056	1,056
Volume removed (bd ft, gross)	5,262	12,717	17,979
Volume removed/ acre (bd ft, gross)	658	1,590	2,248
Percent volume removed/species	29.3	70.7	100.0

Table 2

Detailed Yield for Treated Units, Merchantable Volume Removed (Board Feet, Gross): Unit III--Burned Treated, 5.2 Acres

Diameter class	Ponderosa pine	Douglas-fir	Western larch	Lodgepole pine	Total all species
8	165	464	8	8	645
10	172	904	-	-	1,076
12	436	1,089	-	-	1,525
14	-	1,072	-	-	1,072
16	863	617	-	-	1,480
18	747	933	-	-	1,680
20	808	1,077	-	-	1,885
22	1,495	748	-	-	2,243
24	502	-	-	-	502
26	1,317	1,317	-	-	2,634
28	-	842	-	-	842
30	1,056	-	-	-	1,056
Volume removed (bd ft, gross)	7,561	9,063	8	8	16,640
Volume removed/acre (bd ft, gross)	1,454	1,743	1.5	1.5	3,200
Percent volume removed/species	45.4	54.4	0.1	0.1	100.0

Table 3

FORTRAN Program Used for Volume Calculation

```
CHARACTER*80 TITLE
INTEGER CODE
TYPE 175
FORMAT(1X,'ENTER A TITLE UP TO 80 CHAR,',/,1X,
'(INCLUDE THE TREATMENT AND YEAR OF MEASUREMENT)')
ACCEPT 180, TITLE
FORMAT(A80)
WRITE(5, 185) TITLE
FORMAT(1X,/,1X,A80,//,6X,'DBH',6X,'BA',6X,'PHT',7X,
'PV',GX,'CVTS',6X,'SV6',/)
CODE = 202
DO 1000 N = 2, 40, 2
DBH = FLOAT(N)
D = 0.0
BA = 0.0
PHT = 0.0
PV = 0.0
CVTS = 0.0
TATS = 0.0
T = 0.0
CV4 = 0.0
CV46 = 0.0
CV6 = 0.0
BCR = 0.0
SV6 = 0.0
D = ALOG10(DBH)
BA = 0.005454*(DBH**2)
IF(CODE.EQ.108)PHT = 23.0+3.036*DBH
IF(CODE.NE.108)PHT = 8.1+3.64*DBH
IF(CODE.NE.108)PV = 10**(-1.52198+2.12327*D+0.0138*PHT-0.005612*D*PHT)
IF(CODE.EQ.108)PV = 10**(-0.2771+0.963354*ALOG10(BA*PHT))
IF(CODE.NE.108)CVTS = (10**-2.3582)*(DBH**1.87254)*(PHT**0.89306)
IF(CODE.EQ.108)CVTS = (10**-2.53758)*(DBH**1.87765)*(PHT**1.03312)
IF(DBH.LT.6.0) SV6 = 0.0
IF(DBH.LT.6.0) GOTO 80
TATS = 0.912733/((1.0330*(1.0+1.382937*EXP(-4.015292*(DBH/10.0))))
*(BA+0.087266)-0.174533)
T = CVTS*TATS
CV4 = T*(BA-0.087266)/0.912733
CV46 = EXP(-6.88442+1.39623*ALOG(DBH)+13.2879*ALOG(PHT)/DBH-28.273
*ALOG(PHT)/(DBH**2))
CV6 = CV4-CV46
B4 = T/0.912733
```

(continued next page)

Table 3 (continued)

```
BCR = 1.544187*(DBH**(4.523887*ALOG10(B4)))
*(B4**(-0.231146*ALOG10(DBH)**2))
*(DBH**(-1.100526*ALOG10(B4)**2))*(DBH**(-3.14368))
*(B4**(-0.181216*AALOG10(B4)))
SV6 = CV6*BCR
IF(SV6.LT.0.0)SV6 = 0.0
WRITE(5,300)DBH,BA,PHT,PV, CVTS,SVS
FORMAT(5X,F4.1,2(2X,F7.2),3(2X,F7.2))
TBA = TBA+BA
CONTINUE
STOP
END
```

Table 4

Predicted Volume and Height by Diameter Class for Ponderosa Pine and Douglas-fir

DBH	a*	b	c	d	e
2.0	0.02	15.38	0.20	0.18	0.00
4.0	0.09	22.66	0.98	0.95	0.00
6.0	0.20	29.94	2.59	2.61	0.49
8.0	0.35	37.22	5.25	5.44	7.86
10.0	0.55	44.50	9.24	9.69	21.52
12.0	0.79	51.78	14.80	15.61	43.57
14.0	1.07	59.06	22.22	23.43	76.57
16.0	1.40	66.34	31.76	33.38	123.30
18.0	1.77	73.62	43.72	45.68	186.60
20.0	2.18	80.90	58.37	60.53	269.23
22.0	2.64	88.18	76.02	78.14	373.83
24.0	3.14	95.46	96.94	98.72	502.80
26.0	3.69	102.74	121.44	122.46	658.30
28.0	4.28	110.02	149.79	149.56	842.19
30.0	4.91	117.30	182.27	180.21	1,056.01
32.0	5.58	124.58	219.15	214.59	1,301.01
34.0	6.30	131.86	260.70	252.90	1,578.11
36.0	7.07	139.14	307.16	295.30	1,887.91
38.0	7.88	146.42	358.76	341.99	2,230.75
40.0	8.73	153.70	415.72	393.14	2,606.67

*Column headings: a = basal area (ft^2)
b = predicted height (ft)
c = predicted volume (ft^3)
d = cubic foot volume top and stump
e = Scribner volume to a 6-inch top

Table 5

Number of Established Seedlings at Time Zero

Plot	Unit I		Unit II		Unit III	
	a*	b	a	b	a	b
1	0	1	1	0	1	2
2	3	1	3	0	0	0
3	1	0	1	0	2	1
4	0	0	1	0	0	0
5	21	1	0	0	11	1
6	12	0	2	0	1	0
7	130	0	0	0	0	0
8	3	0	16	4	12	1
9	25	0	0	0	0	0
10	0	1	14	0	0	0
11	0	0	2	1	0	1
12	40	5	23	1	0	0
13	0	0	4	4	3	0
14	10	5	12	0	1	1
15	1	0	3	0	3	0
16	1	0	1	0	1	3
17	3	0	11	0	1	0
18	3	0	0	0	7	0
19	10	0	0	0	0	0
20	0	1	0	0	0	0
Plot mean	13.15	0.75	4.7	0.5	2.15	0.5
Estimated seedlings/acre	3,945	225	1,410	150	645	150
Standard error of estimate (trees/acre)	1,958	102	449	86	243	55

*Column headings: a = Douglas-fir; b = ponderosa pine.

Table 6

Gross Volume Increase in Percent of Volume by Diameter Classes in Balanced Uneven-aged Forests for Different Values of Average Annual Diameter Growth I and Different Values of q

q*	Average annual diameter growth I in inches†								
	0.04	0.06	0.08	0.10	0.12	0.14	0.16	0.18	0.20
1.20	0.4	0.5	0.7	0.9	1.1	1.3	1.5	1.7	1.8
1.22	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
1.24	0.4	0.6	0.9	1.1	1.3	1.5	1.7	2.0	2.2
1.26	0.5	0.7	0.9	1.2	1.4	1.6	1.9	2.1	2.3
1.28	0.5	0.7	1.0	1.2	1.5	1.7	2.0	2.2	2.5
1.30	0.5	0.8	1.1	1.3	1.6	1.9	2.1	2.4	2.7
1.32	0.6	0.8	1.1	1.4	1.7	2.0	2.2	2.5	2.8
1.34	0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.7	3.0
1.36	0.6	0.9	1.2	1.5	1.9	2.2	2.5	2.8	3.1
1.38	0.6	1.0	1.3	1.6	2.0	2.3	2.6	2.9	3.3
1.40	0.7	1.0	1.4	1.7	2.0	2.4	2.7	3.1	3.4
1.42	0.7	1.1	1.4	1.8	2.1	2.5	2.8	3.2	3.6
1.44	0.7	1.1	1.5	1.8	2.2	2.6	3.0	3.3	3.7
1.46	0.8	1.1	1.5	1.9	2.3	2.7	3.1	3.5	3.9
1.48	0.8	1.2	1.6	2.0	2.4	2.8	3.2	3.6	4.0
1.50	0.8	1.2	1.6	2.0	2.5	2.9	3.3	3.7	4.1
1.52	0.8	1.3	1.7	2.1	2.5	3.0	3.4	3.8	4.3
1.54	0.9	1.3	1.7	2.2	2.6	3.1	3.5	4.0	4.4
1.56	0.9	1.3	1.8	2.2	2.7	3.2	3.6	4.1	4.5
1.58	0.9	1.4	1.8	2.3	2.8	3.3	3.7	4.2	4.7
1.60	0.9	1.4	1.9	2.4	2.9	3.3	3.8	4.3	4.8
1.62	1.0	1.5	1.9	2.4	2.9	3.4	3.9	4.4	4.9
1.64	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.6	5.1
1.66	1.0	1.5	2.0	2.6	3.1	3.6	4.1	4.7	5.2
1.68	1.0	1.6	2.1	2.6	3.2	3.7	4.2	4.8	5.3
1.70	1.1	1.6	2.1	2.7	3.2	3.8	4.3	4.9	5.4
1.72	1.1	1.6	2.2	2.7	3.3	3.9	4.4	5.0	5.6
1.74	1.1	1.7	2.2	2.8	3.4	4.0	4.5	5.1	5.7
1.76	1.1	1.7	2.3	2.9	3.5	4.0	4.6	5.2	5.8
1.78	1.2	1.7	2.3	2.9	3.5	4.1	4.7	5.3	5.9
1.80	1.2	1.8	2.4	3.0	3.6	4.2	4.8	5.4	6.1
1.82	1.2	1.8	2.4	3.0	3.7	4.3	4.9	5.5	6.2
1.84	1.2	1.8	2.5	3.1	3.7	4.4	5.0	5.6	6.3
1.86	1.2	1.9	2.5	3.2	3.8	4.4	5.1	5.7	6.4
1.88	1.3	1.9	2.6	3.2	3.9	4.5	5.2	5.8	6.5
1.90	1.3	1.9	2.6	3.3	3.9	4.6	5.3	5.9	6.6
1.92	1.3	2.0	2.6	3.3	4.0	4.7	5.4	6.0	6.7
1.94	1.3	2.0	2.7	3.4	4.1	5.7	5.4	6.1	6.9
1.96	1.4	2.0	2.7	3.4	4.1	4.8	5.5	6.2	7.0
1.98	1.4	2.1	2.8	3.5	4.2	4.9	5.6	6.3	7.1

*Quotient between number of trees in successive 2-inch diam. class.

†Increase percent = $(q^{1/2}-1)100$.

<u>Source</u>: H. A. Meyer, 1952, Structure, growth, and drain in balanced and uneven-aged forests, <u>J. For</u>. 50:87.

Table 7

Stand Table Projection for the Treated Option

a*	b†	c	d	e‡	f§	g§	h	i	j‖	k‖
4	45.30	1.36	.089	2.13	-	.95	-	43	-	.9
6	33.41	1.48	.104	2.50	.49	2.61	16	87	.4	2.2
8	22.65	1.98	.126	3.05	7.86	5.44	178	123	5.4	3.7
10	11.44	1.80	.129	3.13	21.52	9.69	246	111	7.7	3.5
12	6.36	2.05	.140	3.40	43.57	15.61	277	99	9.4	3.4
14	3.11	1.41	.141	3.43	76.57	23.43	238	73	8.2	2.5
16	2.20	1.53	.122	2.95	123.3	33.38	271	73	8.0	2.2
18	1.44	.76	.120	2.90	186.6	45.68	269	66	7.8	1.9
20	1.89	1.66	.102	2.45	269.23	60.53	509	114	12.5	2.8
22	1.14	1.68	.113	2.73	373.83	78.14	426	89	11.6	2.4
24	.68	2.96	.107	2.58	502.8	98.72	342	67	8.8	1.7
26	.23	.61	.125	3.03	658.3	122.46	151	28	4.5	.8
28	.38		.108	2.60	842.19	149.56	320	57	8.3	1.5
34	.15		.115	2.78	1,578.11	252.9	237	38	6.6	1.3
Tot.	130.4						3,480	1,067	99.2	30.8
Ave.		1.62	.117	2.83						

*Column headings:
- a = diameter class
- b = trees/acre
- c = q-ratio
- d = average annual diameter growth (inches)
- e = percent volume increase
- f = volume/tree: board feet
- g = volume/tree: ft^3
- h = volume/acre: board feet
- i = volume/acre: ft^3
- j = gross volume increase/acre/year: board feet
- k = gross volume increase/acre/year: ft^3

†From residual stand structure.

‡From Table 9, Appendix B.

§From Table 7, Appendix B.

‖Percent volume increase multiplied by volume/acre for each diameter class.

Table 8

Stand Table Projection for the Untreated Option

a*	b	c	d†	e‡	f§	g§	h	i	j‖	k‖
4	125.2	1.84	.073	2.00	-	.95	-	119	-	2.4
6	67.9	1.76	.076	2.10	.49	2.61	33	177	.7	3.7
8	38.6	1.94	.093	2.53	7.86	5.44	303	210	7.7	5.3
10	19.94	1.79	.101	2.76	21.52	9.69	428	193	11.8	5.3
12	11.14	1.78	.100	2.70	43.57	15.61	484	173	13.1	4.7
14	6.25	1.27	.109	2.97	76.57	23.43	479	146	14.2	4.3
16	4.51	1.15	.101	2.76	123.3	33.38	555	150	15.3	4.1
18	3.91	1.67	.092	2.50	186.6	45.68	728	178	18.2	4.5
20	2.34	1.13	.086	2.35	269.23	60.53	619	139	14.6	3.6
22	2.07	1.65	.096	2.60	373.23	78.14	784	164	20.4	4.3
24	1.25	2.56	.092	2.50	502.8	98.72	629	123	15.7	3.1
26	.49	1.13	.095	2.58	658.3	122.46	316	59	8.2	1.5
28	.43	4.00	.096	2.60	842.19	149.56	362	64	9.4	1.7
30	.11	1.00	.050	1.35	1,056.01	180.21	116	20	1.6	0.3
32	.11	1.00	.080	2.20	1,301.01	214.59	143	24	3.1	0.5
34	.11		.115	3.15	1,578.11	252.9	174	28	5.5	0.9
Tot.	284.4						6,153	1,967	159.5	50.2
Ave.		1.72		2.48						

*Column headings:
a = diameter class
b = trees/acre
c = q-ratio
d = average annual diameter growth (inches)
e = percent volume increase
f = volume/tree: board feet
g = volume/tree: ft^3
h = volume/acre: board feet
i = volume/acre: ft^3
j = gross volume increase/acre/year: board feet
k = gross volume increase/acre/year: ft^3

†From residual stand structure.

‡From Table 9, Appendix B.

§From Table 7, Appendix B.

‖Percent volume increase multiplied by volume/acre for each diameter class.

APPENDIX C

Table 1

Age Versus Diameter Relationship for Ponderosa Pine

X*	Y†	X	Y	X	Y	X	Y
1.0	27	3.9	38	8.0	40	10.2	49
1.1	17	4.1	38	8.1	48	10.5	52
1.6	20	4.4	36	8.4	55	11.4	80
1.8	25	4.4	37	8.7	49	11.7	75
1.8	28						
2.4	29	4.8	40	8.9	48	12.0	63
2.8	31	5.4	37	9.3	51	12.0	66
2.8	34	6.0	34	9.4	67	12.8	58
3.0	37	7.3	45	9.8	41	14.4	72
3.3	36	7.3	55	9.8	48	19.0	110
3.4	39	7.8	37	10.0	47		

*X = diameter (inches).

†Y = age (years).

Simple Linear Regression: $y = a + b\chi$

$\overline{X} = 7.12$ inches

$\overline{Y} = 45.98$ years

$$\sum_{i=1}^{40} (X_i - \overline{X})^2 = 686.46$$

$$\sum_{i=1}^{40} (Y_i - \overline{Y})^2 = 12{,}542$$

$$\sum_{i=1}^{40} (X_i - \overline{X})Y_i = 2{,}601.2$$

$$\sum_{i=1}^{40} (X_i - \overline{X})(Y_i - \overline{Y}) = 2{,}656$$

$$\hat{b} = \frac{2601.2}{686.46} = 3.79$$

$$\hat{a} = 45.98 - 3.79(7.12) = 18.99$$

$$\hat{Y} = 18.99 + 3.79(\chi)$$

$$r = \frac{2656}{\sqrt{(686.46)(12542)}}$$

$$r = .905$$

$$r^2 = 0.82$$

Unexplained Variation in the Regression Equation

$$S^2_{y \cdot x} = \frac{12542(1 - .82)}{38} = 59.41$$

$$S_{y \cdot x} = 7.71$$

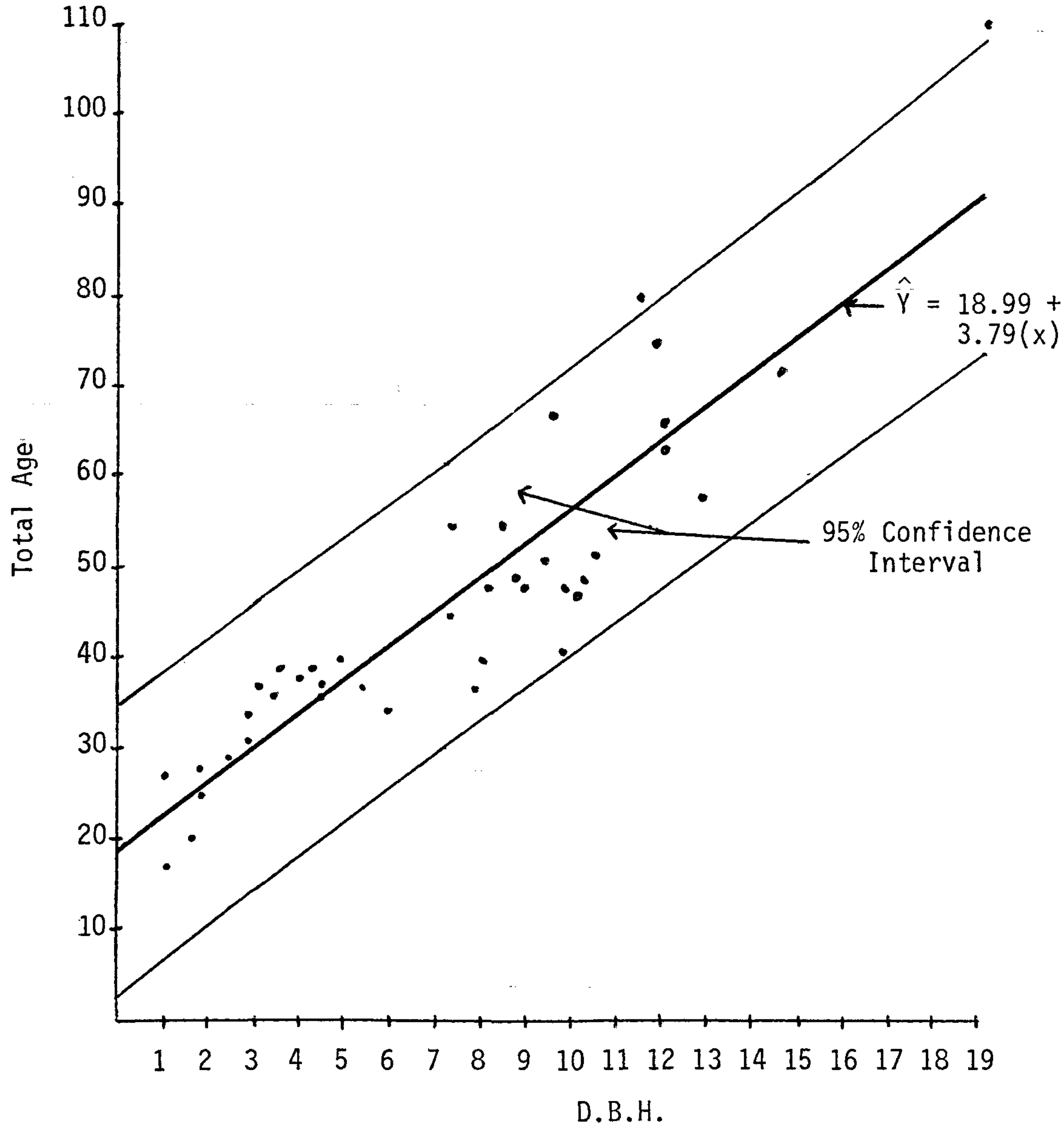


Table 2

Site Index Calculation

Diameter class*	Average height of sample	Average total age of sample	Site index
		Ponderosa Pine	
4	31	36	70†
6	35	39	72†
8	50	47	81†
10	52	48	83†
12	60	56	88†
Meyer's (1961) average site index, base 100 years = 78			
		Lodgepole Pine	
4	32	32	68‡
6	44	40	80‡
8	45	41	80‡
10	46	40	82‡
12	50	40	90‡
14	69	70	85‡
16	67	85	74‡
Alexander's (1966) average site index, base 100 years = 80			

*Approximately 75% of the trees sampled were greater than 8 inches.

†W. H. Meyer, 1961, Yield of even-aged stands of ponderosa pine, USDA Tech. Bull. 630.

‡R. R. Alexander, 1966, Site indexes for lodgepole pine with corrections for stand density: Instructions for field use, USDA For. Serv. Res. Pap. RM-24, Rocky Mountain For. and Rng. Exp. Sta., Fort Collins, CO.

CALCULATION OF THE IDEALIZED STOCKING CURVE

Stand structure goals: residual density = 65 ft^2/acre
maximum tree size = 20 inches
q-ratio = 1.4

Idealized stocking curve is defined as:

$$N_i = Ke^{-D_i[(\ln q)/2]}$$

where N_i = number of trees/acre in the ith diameter class,
K^* = basal area parameter (constant),
e = 2.71828,
D_i = ith diameter class, and
lnq = natural logarithm of q.

Basal area parameter:

$$K = \frac{\text{Residual density}}{\text{Table value* for 20-inch maximum tree size and } q = 1.4} = \frac{65}{0.78523} = 82.778$$

Number of trees in the 2-inch diameter class:

$$N_2 = 82.778(2.71828)^{-2[.3365/2]}$$

$$N_2 = 59.1 \text{ trees/acre}$$

Divide N_2 by 1.4 to get the number of trees in N_4. Follow this relationship until the number of trees in the 20-inch diameter class is calculated:

$$N_{0+2} = \frac{N_o}{1.4}$$

where N_{0+2} = number of trees in the next 2-inch diameter class and
N_o = number of tress/acre in a particular diameter class.

---

*Value in the denominator is from R. R. Alexander and C. B. Edminster, 1977b, Uneven-aged management of old-growth spruce-fir forests: Cutting methods and stand structure goals for the initial entry, USDA For. Serv. Res. Pap. RM-186, Rocky Mountain For. and Rng. Exp. Sta., Fort Collins, CO, Table 2, page 5.

The following table results:

Diameter class	Trees/acre
2	59.1
4	42.2
6	30.2
8	21.5
10	15.4
12	11.0
14	7.9
16	5.6
18	4.0
20	2.9