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Silvicultural prescription for the management of an even-aged larch sapling stand, lower Holland Creek, Condon, Montana

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SILVICULTURAL PRESCRIPTION FOR THE MANAGEMENT OF AN EVEN-AGED LARCH SAPLING STAND LOWER HOLLAND CREEK-CONDON, MONTANA

By

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CHAPTER I

STAND DESCRIPTION

Location

The stand selected for evaluation lies in the lower Holland Creek drainage about two miles west of the scarp face of the Swan Range, and about one and one-quarter miles south of Holland Lake (Figures 1 and 2). The legal description is: NE 1/4, section 10, township 19N, range 16W, P.M.M. Roughly rectangular in shape, the stand is 16 acres in size. The Owl Creek Loop Road borders the stand along its south perimeter. Adjoining along the north and east is a seed-tree cut and along the west, a clearcut.

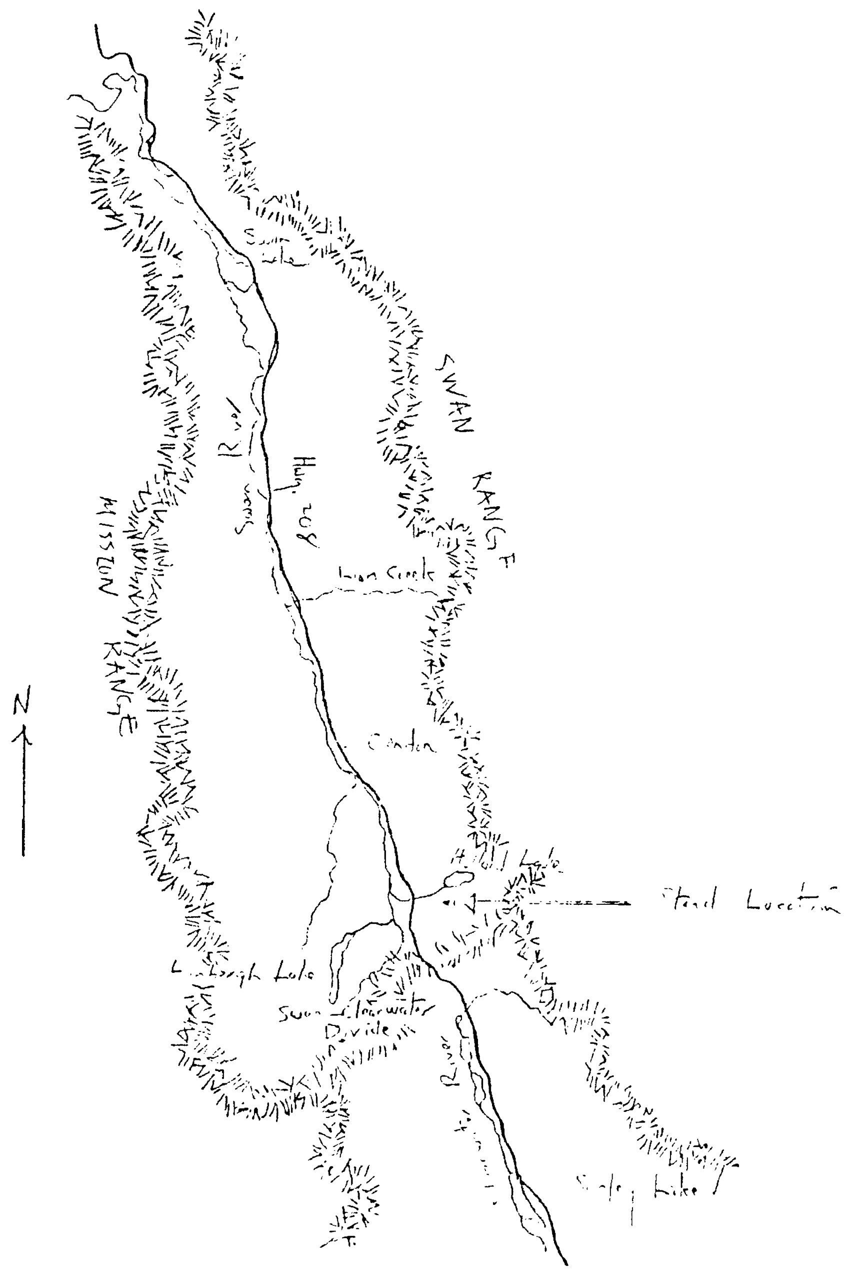
The stand is 2.8 miles east of state highway 208 and approximately 25 miles north of Seeley Lake. With the exception of several small, private holdings, the land surrounding the stand is federally owned, and administered by the Swan Lake Ranger District.

Topographic Features

The stand is located along the lower slope of a long low ridge that inclines gently to the north from the Swan-Clearwater Divide. The elevation is 4320 feet. The slope averages 10% and ranges from 5 to 20%. Slope configuration is typically planar while the predominant aspect is north.

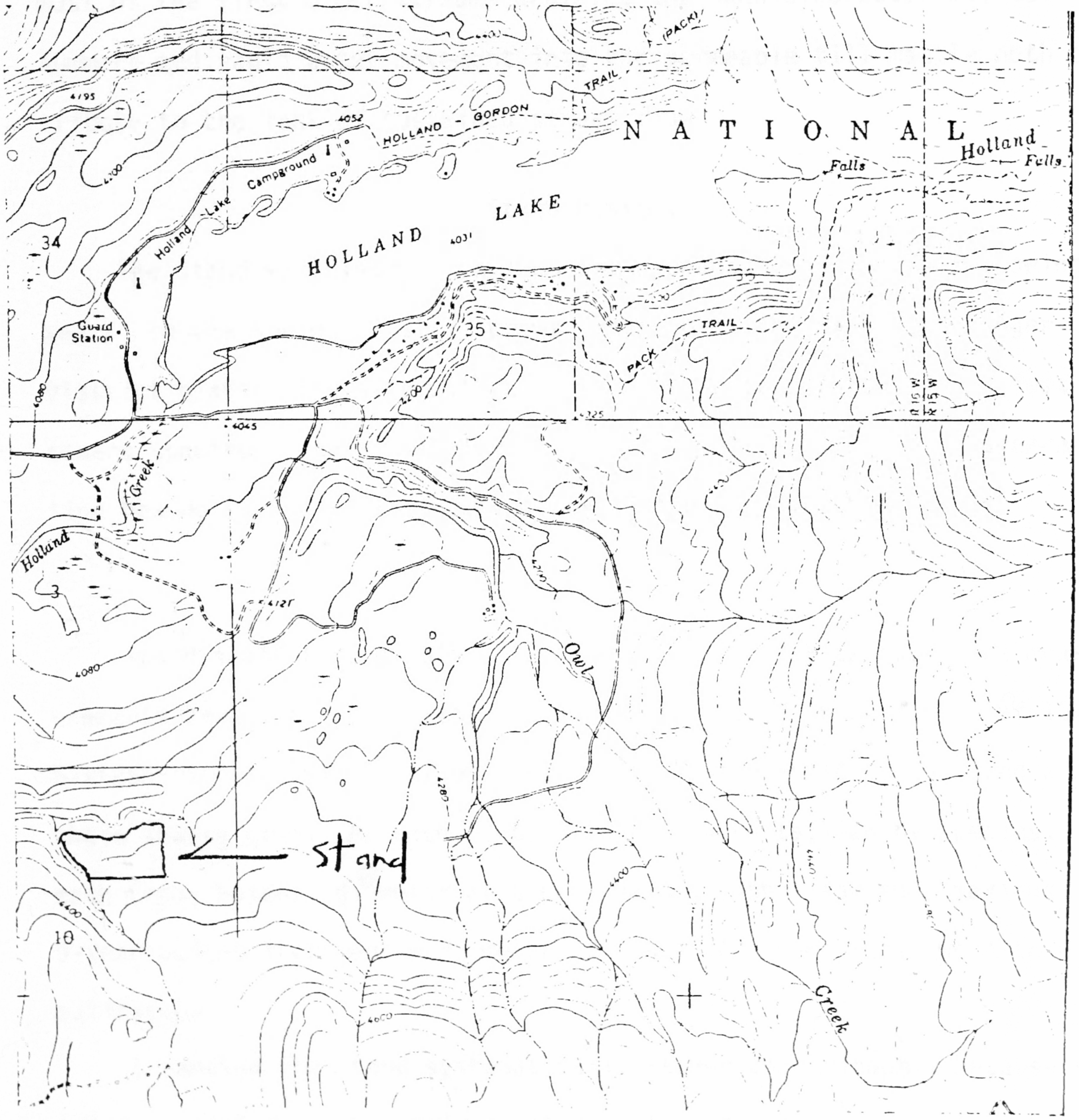
An intermittent stream, a minor tributary of lower Holland Creek,

FIGURE 1



General Vicinity Map

FIGURE 2



Topographic Map Scale: 1:24,000

borders the stand to the west. The stream is usually dry by August as are most of the first order streams draining the Swan-Clearwater Divide. Dry summers and rapid water movement into the permeable till mantle both contribute to the lack of sustained stream flow.

Stand History

The stand was clearcut in 1965 and broadcast burned the following year. In the spring of 1967, crews employed by the Swan Lake Ranger District planted the site with 2-0 stock of western larch at a 6-feet square spacing. The silviculturalist presently in charge of regeneration has no record of the seed source of the planting stock.

Stand Statistics

Stand statistics displayed in the following tables summarize measurements taken in a systematic sample of the stand in September of 1980. Sixteen circular plots, 1/300 acre in size, were established along a 3.2 chain square grid. At each plot, all trees were tallied by species. On each tree, height, diameter at breast height (dbh), and the previous 5-year height increment were measured. Age and crown ratio were then estimated.

I sampled the stand systematically rather than randomly because systematic sampling is not only quicker, but also insures adequate coverage in aggregated populations. Results from several empirical studies indicate that systematic sampling is a more efficient estimator in aggregated populations. Both Kattenberg (1978) and Payandeh and Ek (1971) reported that systematic sampling produced more precise estimates than simple random sampling when sampling intensities were held constant.

TABLE 1

DESCRIPTIVE STATISTICS

Mean number of trees per acre		Coefficient of variation (%)	Standard error of the mean (%)	95% confidence limits (%)
All trees	2934	64	16	2934 ± 34.8
Trees ≥ 1"	1015	34	8.5	1015 ± 18

The precision of the estimate of the mean number of trees per acre is ± 34.8 percent of the 95 percent confidence level. If trees less than one inch dbh are ignored, the precision of the estimate is improved to ± 18 percent at the 95 percent confidence level.

Stand Structure

The site, originally planted exclusively to larch, now supports a species mix (Table 2). A favorable seedbed and available seed from a variety of indigenous species have contributed to this stand's development as a mixed conifer stand. Ages range from 5 to 13 years.

Western larch presently commands a sizable competitive advantage over Douglas fir and Engelmann spruce (Figure 3). These latter two species are confined to the suppressed crown class. The striking difference in height illustrated in Figure 3 between larch and these two more tolerant species is due to the differences in their respective juvenile growth rates as

TABLE 2

TREES PER ACRE BY SPECIES AND AGE

	Species			
	W.L.	D.F.	E.S.	Total
5		323		323
6	77	462	185	724
7		162	46	208
8				
9				
10	384	123	69	486
11				
12				
13	721			721
Total	1182	1290	462	2934

well as differences in age. Larch typically outgrows all competitors (Deitchman and Green, 1965). These differences in height growth rate are most pronounced during the seedling and sapling phase of development. Schmidt (1969) reports that between the ages of ten and fifteen, larch adds height increment at twice the rate of Douglas fir and at almost three times the rate of Engelmann spruce. Classification of species by diameter class closely parallels their distributions by crown class (Table 3).

TABLE 3

TREES PER ACRE BY SPECIES

AND DIAMETER CLASS

	SPECIES			
	W.L.	D.F.	E.S.	Total
.1-.9	167	1290	402	1919
1-1.9	373			373
2-2.9	296			296
3-3.9	346			346
Total	1182	1290	402	2934

Stand Density

Sixty-five percent of the stem total is less than one inch average dbh (Table 3) and 3.5 feet tall (Figure 3). The remaining thirty-five percent, considerably larger, averages 15 feet in height. The degree to which stems in the lower sixty-five percent of the stand diameter distribution exerts competitive influence on trees comprising the upper thirty-five percent is probably negligible (Bella, 1971). The measure of stand density in the following discussion considers only those trees in the upper thirty-five percent of the diameter distribution.

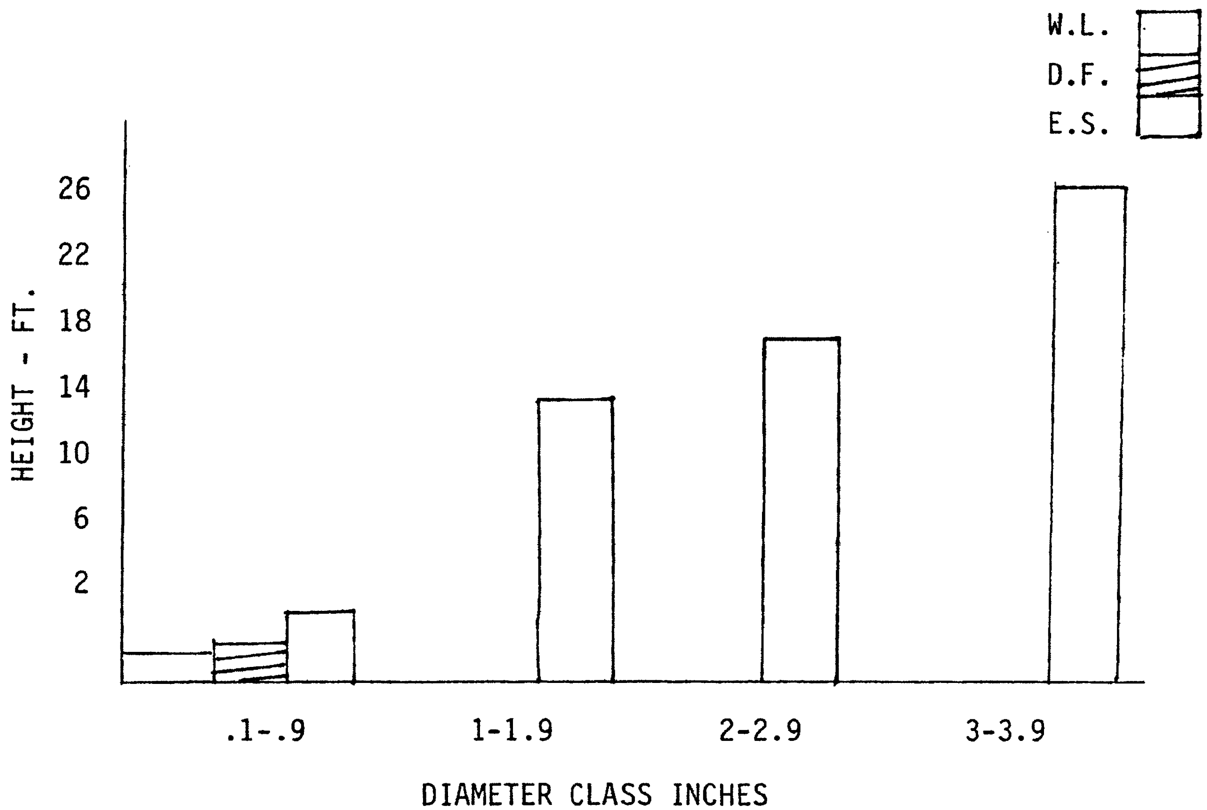
The crown competition factor (CCF) (Krajicek and others, 1961), a diameter based measure of relative density, is an index of the average level of crown competition between neighboring trees. Expressed as a percent, the CCF is the ratio of the growing space currently occupied by the tree of average diameter to the growing space available. At a CCF of 100 percent, trees are on the average utilizing all of the available growing space. Stated another way, crowns of meighboring stems are just touching. Initiation of crown overlap does not necessarily coincide with competition among meighboring trees for light, water, and nutrients.

The CCF of the upper thirty-five percent of the diameter distribution is 65 percent, which means that trees on the average are occupying 65 percent of the growing space available. Trees in the stand are aggregated rather than uniformly distributed so the actual level of competition varies around this mean. Having ample space to grow, dominants and co-dominants are averaging 1.5 feet of leader growth per year and maintaining

FIGURE 3

MEAN HEIGHT BY SPECIES

DIAMETER CLASS



live crown ratios in excess of seventy-five percent. Height of the taller dominants exceeds 20 feet while the diameter of mean basal area is 2.7 inches.

The CCF is computed from an equation predicting crown width as a function of diameter and from the number of trees per acre by diameter class displayed in the stand table (Table 3). The equation is derived from data furnished by Schmidt (Schmidt, unpublished data, 1981) collected in larch sapling stands growing on medium quality sites. Individual data points represent the average of twenty observations. Averaging, which reduces the subsequent residual variation when the regression line is fitted to the data artificially reduces the standard error of the regression. Associated with this reduction is the accompanying inflation of the coefficient of determination.

Crown width (feet) = .384 + 1.88 dbh (inches)

$n = 20$

each data point is the average of 20 observations $\quad r^2 = .96 \quad sy/x = .32$

Coverage of Grasses, Forbs, and Shrubs

A developed sod layer consisting of Calamagrostis rubeacens and Carex Rossii presently covers greater than 50% of the ground surface. Clintonia uniflora, Linnaea borealis, and Pyrola secunda are present in small amounts. Their respective coverages are restricted to moist microsites. Xerŏphyllum tenax and Eplobium augustifolium are the only forbs present in any quantity. Their combined coverage is somewhere between 10 and 15 percent. Shrubs, a minor component, cover less than 10 percent of the area. The four most frequently occurring shrub species are Vaccinium globulare, Symphoricarpus albus, Shepherdia canadensis, and Amelanchier alnifolia.

Has the coverage of grasses increased since the original old growth stand was harvested and the site broadcast burned? Lack of undisturbed old growth stands immediately adjacent prevents direct comparison between uncut and cutover sites. Antos (1980), in a study of successional patterns in grand fir habitat types, reports an increase in grass coverage from 5 percent in undisturbed stands to 30 percent following clearcutting and broadcast burning.

Site Productivity

The lack of suitable site trees rules out direct measurement of site index. Suitable site trees are defined as dominants and codominants free of damage and past suppression. An alternative approach for measuring site productivity is indirect estimation of site index using the habitat type classification (Pfister and others, 1977). According to Pfister, the stand is located within the Xerophyllum tenax phase of the Abies lasiocarpa-Clintonia uniflora (ABLA/CLUN/XETE) habitat type. Pfister reports a site index estimate of 63 for larch and a yield capability, predicted from site index, of 80 cubic feet per acre per year for this habitat type. Pfister's productivity estimates are generated from a very small sample; at each plot only a single site tree was measured for each species present. Pfister never intended the habitat type classification to be used for site stratification. Only when requested by the Forest Service to include productivity estimates, did he add site index statistics. Site index alone is not a reliable estimator of yield capability (Assman, 1970). Stands similar in age growing on the same sites often differ in stocking.

Seeking a more accurate estimator of site index, I measured six larch dominants and codominants in a 73 year old stand about one-half mile to the east but on similar terrain and within the same habitat type. The site index here, 59 on a 50 year base, is significantly lower than the figure reported by Pfister for the ABLA/CLUN/XETE habitat type. The direct estimate may be conservative since initial stand development can significantly reduce the site index for larch. Shrub competition and crowding during seedling and sapling stages of stand development both reduce larch height growth (Schmidt, 1969). Potential height increment, once forfeited, is never regained.

General Vegetation Patterns in the Lower Holland Creek Drainage

The forests growing in the lower Holland Creek drainage are presently dominated by seral species. Even-aged stands of lodgepole pine (*Pinus contorta* var. *latifolia* *Engelm*) that regenerated in the wake of the disastrous 1910 fire, presently cover much of the area north of the Swan-Clearwater Divide. Western larch (*Larix* *occidentalis* Nutt.) and Douglas-fir (*Pseudostsuga* *menziessii* var. *glauca* Franco) are present in these stands as minor associates. Old growth stands, until recently, comprised a prominant timber type, but have been heavily cut during the past twenty years. Of those remaining, Douglas-fir and western larch, both long-lived seral dominants, as well as Engelmann spruce (*Picea* *engelmannii* Parry), are the major tree species.

On most sites, subalpine fir (*Abies* *lasiocarpa* (Hook.) Nutt.) is the climatic climax. Douglas-fir and grand fir (*Abies* *grandis* (Dougl.)

Lindl.) are both present as minor associates in the subalpine fir climax community. Their respective distributions as climax species are restricted to warmer, more moist and warmer, drier sites.

Within the subalpine fir series, the most common habitat types (H.T.) are the Abies lasiocarpa/Clintonia uniflora H.T., Abies lasiocarpa/ borealis H.T. and Abies lasiocarpa/Xerophyllum tenax H.T. These three habitat types grade into one another presumably along a gradient of decreasing soil moisture. At the dry end of this spectrum is the Pseudostsuga menziessii/Linnea borealis H.T. On sites in which grand fir potentially outcompetes subalpine fir, the Abies grandis/Clintonia uniflora H.T. is the most common habitat type.

Fire History

Fire has strongly influenced both the species composition and stand structure of the surrounding stand complex. Age class distributions in seral stands, ranging from highly even-aged to uneven-aged, indicate that fires of varying intensities have occurred. Fires of both moderate and high intensity have maintained seral species in dominant stand positions but each has created a distinctly different stand structure.

High intensity stand-destroying fires create conditions favoring the immediate establishment and development of even-aged stands of western larch and lodgepole pine. The catastrophic fire of 1910 burned over acreages of timberland north of the Swan-Clearwater Divide leaving few survivors in the original overstory. A direct result of this fire is the densely stocked lodgepole pine forest that covers most of the land north of the divide.

Less intense burns killing only a portion of the trees in the overstory have created stands consisting of two different yet intermingled age classes. Fire thinned the overstory, eliminated fuel buildings, and exposed mineral soil (Sneck, 1977). An even-aged lower story has developed from seed dispersed by thick barked survivors as well as from the serotinous cones of lodgepole pine. The resulting stands are similar in configuration to a successful seedtree or shelterwood cut in which the overstory has been left to grow.

Wildlife

I observed both mule deer (Odocoileus heminous) and white tail deer (Odocoileus virginianus) in the Owl Creek drainage during the late summer and early fall. In the same general area, I also observed pellet groups of elk (Cervus canadensis nelsoni). Browsing activity on shrubs growing within the stand appeared to be light. Lack of use was probably due to lack of hiding cover and the close proximity of the stand to a well traveled road. Pileated woodpeckers (Dryocopus pileatus) appeared occasionally while I was cruising old growth stands along the stream bottoms.

Insects and Disease

The only indication of any insect or disease infestation is past severance of terminal shoots on larch by western spruce budworm (Choristoneura occidentalis). Terminal shoots on most trees have been severed at least once, but severed shoots were replaced during the same growing season by upturned laterals. On the majority of trees, the forks have not persisted. As a result, overall crown form remains good and the boles straight. Past defoliation and damage to terminal shoots has likely resulted in some loss in potential height growth. In a five year study of the effects of repeated attacks on form and growth of larch, Schmidt and Fellin (1973) reported average annual height growth losses of 27% on trees whose terminals had been severed. Infestations in mature stands have caused significant reductions in seed production (Shearer, 1980). Spruce budworm larvae feed on developing cones as well as buds and flowers (Fellin and Shearer, 1968).

Larch casebearer (*Coleophora laricella*), first observed near St. Mary's, Idaho in 1957 (Denton, 1958), has since spread throughout almost the entire range of western larch in Montana (Denton, 1979). District foresters reported an outbreak during the summer of 1980 in the Lion Creek drainage about 25 miles north of Holland Lake. There is no sign of casebearer damage either in the stand or in the immediate vicinity.

Mountain pine beetle (*Dendroctonus ponderosae*) is currently epidemic on the Glacier View District of the Flathead National Forest. As of 1980, no outbreaks had been reported in the Seeley-Swan (U.S.D.A., 1981). The extensive stands of 65 year old lodgepole pine are likely to become prime targets if the present infestation on the North Fork of the Flathead spreads south into the Swan Valley.

Lodgepole pine dwarf mistletoe (*Arceuthobium americanum*) is present in surrounding stands in very small amounts. Larch dwarf mistletoe (*Arceuthobium larcis*) may also be present but none was seen during a reconnaissance.

Geology and Soils

The Swan Valley was formed by high angle block faulting of Precambrian rocks (Perry, 1962) and subsequently altered by glaciation (Alden, 1953). The valley bottom is a depositional landscape constructed by the accumulation of drift transported by water and ice. A prominent depositional feature is the moraine of the Holland Creek glacier.

The soils are gravelly loams that developed from parent materials consisting of volcanic ash over quartzite and argillite till. These soils are classified as loamy-skeletal, mixed andic cryocrepts and mapped in the Waldbillig series (U.S.D.A., 1980).

Waldbillig soils developed on two distinctly different lithologies. The surface horizon developed from loess containing a sizable amount of volcanic ash. The underlying horizons developed from till. A profile description taken at a roadcut (Table 4) reflects the lithologic differences. The subsurface horizons are designated by the prefix II.

TABLE 4

HORIZON	DEPTH
Andic	0-9
IIA2	11-28
IIA2B2	29-60

The only significant differentiation within the profile is the abrupt boundary between the andic and IIA2 horizons. These two horizons differ greatly in texture, color, structure, and consistency. The andic is a light brown, gravelly loam having a weak, fine granular structure. The IIA2 is a pink to reddish brown gravelly, sandy loam massive in structure.

The andic is friable when moist and soft when dry, while the IIA2, also friable when wet, is hard and dry. The percentage of coarse fragments increases from roughly 30% of total volume in the andic to approximately 60% in the IIA2B2.

The andic horizon has a number of properties favorable to tree growth. It is typically low in bulk density, high in total porosity, and holds large amounts of water available for use by plants. Cullen and Montagne (1981) measured physical properties by horizon in quartzite tills overlain by volcanic ash. They sampled 18 undisturbed pedons at three locations in the Flathead and Kootenai National Forests. Their findings characterize the andic as much less dense, more permeable, and capable of retaining more water between -1/3 and -15 bars than underlying horizons. Average bulk density is .76 grams/cm3 in the andic and 1.77 grams/cm3 in the IIA2 and IIA+B. Total porosity, inversely related to bulk density, varies from 71 percent of total volume in the andic to 33 percent in the denser IIA2 and IIA+B. Water holding capacity, strongly related to macropore space, shows a similar trend. Water available for plants decreased from 32 percent by weight in the andic to 17.6 and 21.4 in the IIA2 and IIA+B respectively. The andic is a better medium for both rooting and water storage (Figure 4) than either the IIA2 or IIA+B.

The andic horizon typically has a relatively high cation exchange capacity. Cullen and Montagne report average C.E.C. by horizon in quartzite tills. Values range from 17.07 meq./100 grams in the andic to 4.97 and 8.79 meq./100 grams in the IIA2 and IIA+B. Higher C.E.C. values in the andic reflect higher organic matter contents as well as the presence of allophane. An amorphous clay mineral weathered from

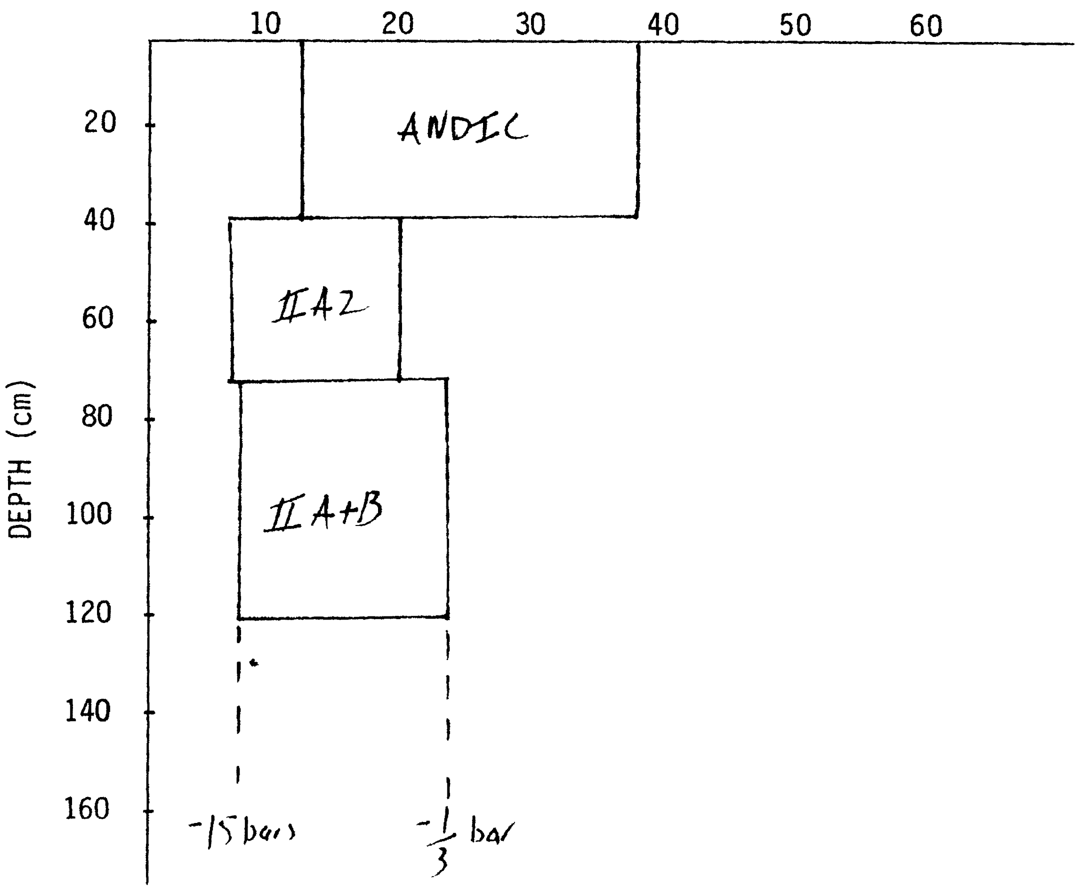
FIGURE 4

AVAILABLE WATER STORAGE CAPACITY

BY HORIZON IN SOILS FORMED

ON VOLCANIC ASH OVER QUARTZITE TILL

SOIL MOISTURE (percent dry weight)



volcanic materials, allophane is a dominant clay mineral in ash-influenced horizons (Klages, 1978). It is highly reactive, has a large surgace area, and forms complexes with organic matter (Wada, 1977).

Soils formed in quartizite till are highly susceptible to compaction by logging equipment (Bates, 1981). In a study determining the relative susceptibilities of different textured soils to compaction, Raney and others (1955) found that medium textured soils compact to the highest densities.

Climate

The climate of the Swan Valley is montane-continental and is strongly influenced by maritime air masses (Foggin, 1980). Moist air masses originating over the Pacific Ocean yield large amounts of precipitation as they are intercepted by the Mission and Swan Ranges. These moist air masses also moderate temperature extremes, especially during the winter.

Seeley Lake, the nearest weather station, receives a yearly average of 22 inches of precipitation. Most of this falls during the winter and spring. June is wet but the remainder of the growing season is warm and dry. The main source of water for tree growth is from moisture stored in the soil at the beginning of the growing season.

Martinsen (1981) measured soil moisture content in valley-bottom soils derived from glacial till at a number of locations in the Swan Valley. Displayed in Figure 5 is a year long record of soil moisture fluctuation recorded at a site having a soil type and moisture regime similar to that in the study site. The soil was recharged to levels at or near field capacity by late fall of 1979. Moisture levels remained constant through April of the following year. The surface horizon began to dry out in May but was recharged by heavy rains in late May. During

TABLE 5

MONTHLY MEAN PRECIPITATION AND TEMPERATURE

SEELEY LAKE (4042 FT. ELEVATION;

27 YEARS OF RECORD)

	J	F	M	A	M	J	J	A	S	O	N	D
Precipitation (inches)	3.35	1.86	1.66	1.37	1.78	2.19	.96	1.14	1.39	1.35	2.2	2.96
Temperature (°F)	26.1	26.3	30.2	39.6	48.6	56.0	62.4	61.2	52.9	43.7	31.3	22.7

Annual Precipitation: 22.2

Annual Temperature: 41.3

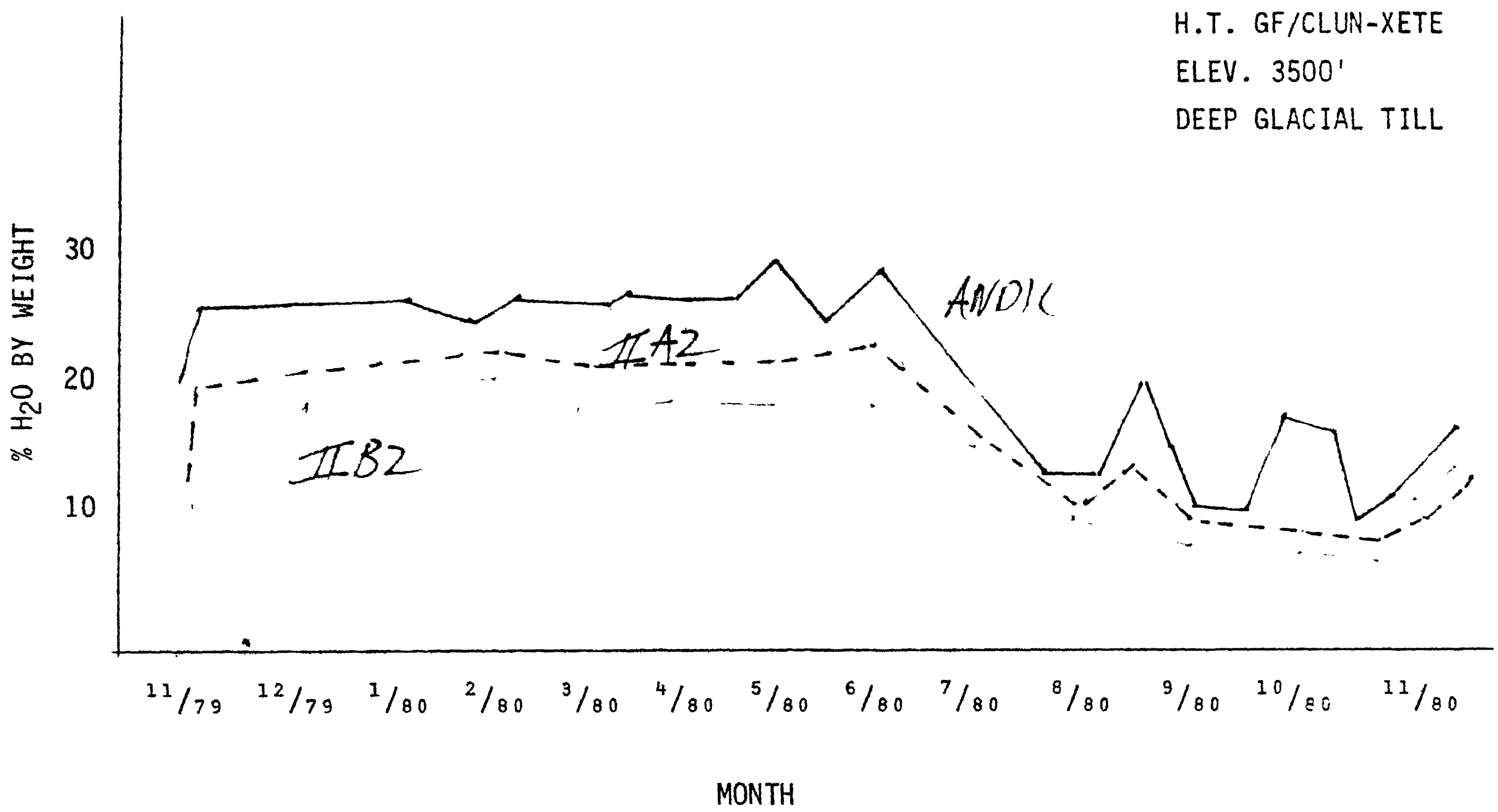
this period, moisture levels in the subsurface horizons remained constant. The entire profile dried out between June and August as evaporative demand exceeded soil recharge. Heavy rains in August and again in September temporarily recharged the andic and IIA2 horizons, but during the ensuing dry period, soil water potential declined to -15 bars.

Although the fluctuations illustrated in Figure 5 are based on a single year's sampling at one site only, these are probably representative of yearly soil moisture trends on similar soil type-habitat types in the Swan Valley. Briefly, the results indicate that soils are at or near field capacity during the period between late fall and late spring. During the summer dry period, soil moisture drops to levels that are limiting to seedling growth (Dykestra, 1974, Lopushinsky and Klock, 1974). The greatest water losses are from the surface horizon.

FIGURE 5

SOIL MOISTURE READINGS FROM

11/79 TO 11/80



CHAPTER II

MANAGEMENT OBJECTIVE

The stand will be managed in the most economically efficient manner for timber production. Implementation of this objective must operate within the framework imposed by the following constraints.

1) The stand will be harvested at the culmination of the soil expectation value.
2) The minimum merchantable tree is at least 9 inches dbh and contains a sixteen foot log to an 8 inch diameter inside bark top.
3) Any commercial entry must remove at least 3000 board feet per acre in trees 12 inches dbh and larger.
4) The site must be regenerated to at least 300 uniformly distributed larch seedlings per acre within five years of final harvest.
5) Harvesting activities will be scheduled to keep soil compaction to a minimum.

CHAPTER III

DEVELOPMENT AND PRESENTATION OF ALTERNATIVES

Gains From Stand Density Regulation

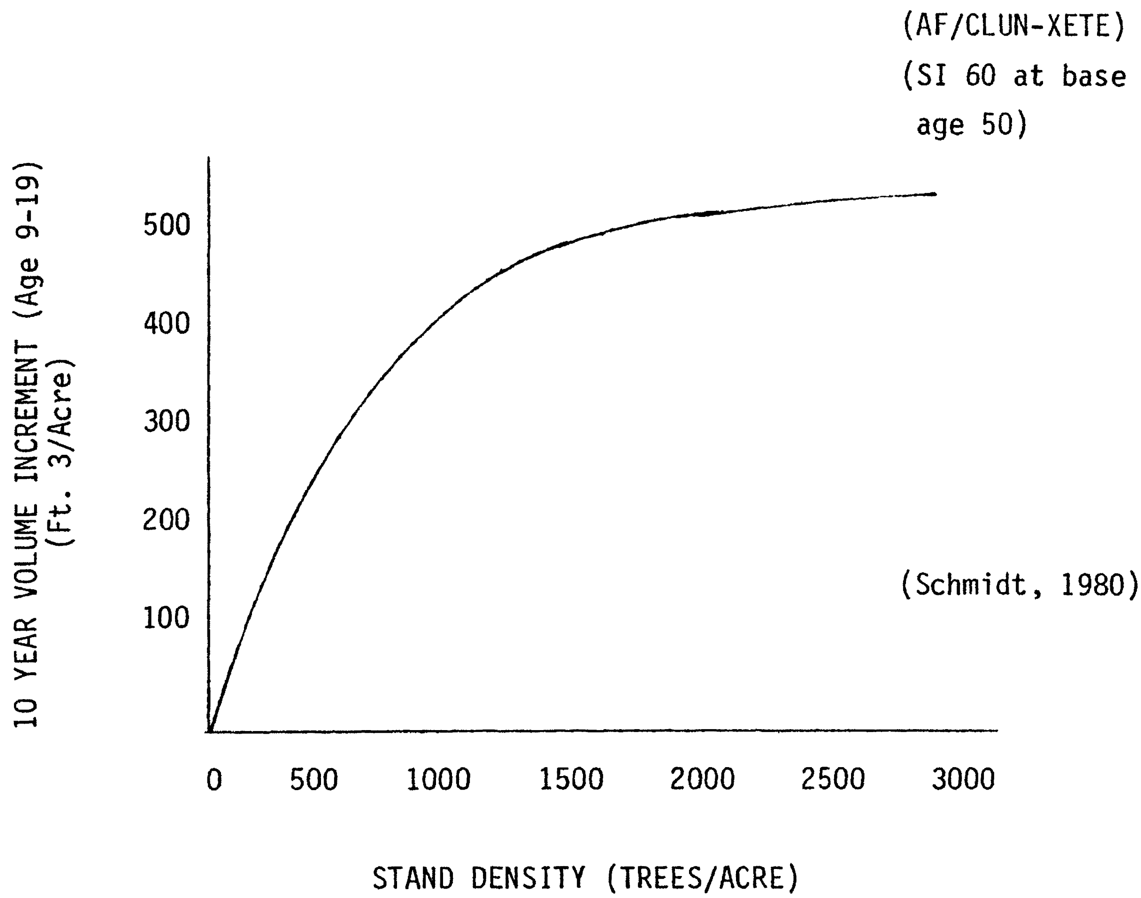
The question posed is how should this stand be managed to achieve maximum value production while complying with the constraints. More specifically, what combination of release cutting and thinning, if any, will yield the greatest return on the investment? Managed stand yield tables are presently unavailable and normal yield tables (Schmidt et al., 1976) are of little use in forcasting future yields under any regime except one in which "normal" stocking is maintained. Properly designed growth and yield studies in larch stands have been undertaken only recently. Consequently, published results describing the effect of stand density regulation on both tree and stand attributes are based on relatively short response periods. The best information available is from two ongoing levels-of-growing stock studies (Schmidt, 1980, Seidal, 1977) but in both, results are from response periods of only 10 years. Despite the lack of long-term results, some general conclusions about the effect of stand density regulation on both tree and stand attributes may be summarized from the literature.

Results reported by Schmidt (1980) from plots thinned to seven spacings ranging from 200 to 2720 trees per acre indicate that sapling stands are capable of a rapid transfer of the growth potential at the site from many trees per acre to a few. Ten year diameter increment of the largest 200 trees per acre increased from a mean of 1.9" at a stocking level of 2720 trees per acre to a mean of nearly 3" at a stocking level of 360 trees per acre. Height increment, less sensitive to stand density, was reduced only at the most dense stocking levels.

In sapling stands ten to twenty years old, release to wide spacings concentrates the growth potential of the site to a relatively few individuals, but at the expense of total volume production. Schmidt (1980) reports that total periodic cubic-foot volume increment declines sharply in stands carrying less than 1000 stems per acre (Figure 6). Yet stocking levels above 1000 trees per acre produce little additional increment in stands between one and four inches dbh. Periodic cubic volume increment at 1000 stems per acre amounts to 86% of that at 2000 trees per acre and 85% of that produced at 3000 trees per acre. Roughly the same amount of wood is produced over a broad range of stand densities but the portion potentially merchantable decreases with increasing density. As indicated in Figure 6, the threshold of full site utilization in ten to twenty year old larch sapling stands is between 1000 and 1500 trees per acre. This interval is the minimum stocking level required for maximization of total cubic-foot volume production in sapling stands.

Response to stand density regulation in pole stands closely parallel those observed in sapling stands. Results from a levels-of-growing stock study established in 1966 (Seidal, 1977) in a 33 year old pole stand thinned to 5 densities ranging from 96 to 745 trees per acre indicate that diameter increment decreases with increasing stand density while per volume cubic volume increment increases.

FIGURE 6



TEN YEAR TOTAL VOLUME

INCREMENT AT AGE 19

IN LARCH STANDS THINNED

TO EIGHT STOCKING LEVELS

AT AGE 9

Vigorous pole stands are capable of a rapid redistribution of the growth potential of the site following stocking reduction. Seidal reports periodic annual diameter increment on the lowest density is almost four times as great as that measured on the highest density plot. For the range of densities tested, height increment remains unaffected by stocking reduction.

Total yield declines with increased spacing while the portion potentially merchantable increases. Ten-year cubic-foot volume increment at 96 trees per acre amounts to only one-half of that produced at 746 trees per acre. Yet the two-fold increase in total production is distributed among 8 times as many stems. Many of these will never reach merchantable size. In contrast, board-foot volume increment culminates at the widest spacing. This response reflects more rapid diameter growth moving trees into merchantable size classes.

Response to release or thinning may be delayed if competition prior to treatment has significantly reduced the crown ratios of the competing stems. Work by Roe and Schmidt (1965) indicates that the response of the residuals is governed not only by the amount of increased growing space but also by the stand vigor prior to treatment.

To summarize, close spacings yield the greatest total volume production. Wide spacings stimulate diameter increment and shorten the rotation length. Gains in individual tree production are offset by a delay in full site occupancy reducing total volume production. Merchantable volume production may either increase or decrease with increased growing space depending upon the merchantability standard.

Results reported for western larch are in general agreement with findings from spacing studies of several other western conifers. Barrett (1970) reports the effects of varying stand densities on diameter increment and both total cubic-foot and board-foot volume production in a 45 year old ponderosa pine (Pinus ponderosa Laus. var. ponderosa) stand. Total cubic-foot volume varies little over a wide range of initial densities; production at 140 trees per acre is the same as that at 460 trees per acre. In contrast, board-foot volume production, strongly related to diameter increment, culminates at 140 trees per acre. Dahm's (1971) report of 10 year results from a spacing trial in a 22 year old lodgepole pine (Pinus contorta Dougl.) stand in central Oregon agrees with Schmidt's (1980) results. Individual tree growth rates increase within limits as growing space is increased but with an accompanying loss in total volume increment.

Alternatives

The brief review of the literature demonstrates the considerable effects that the type and timing of intermediate treatments have on the size, quality, and timing of merchantable products. Current market conditions favor a regime which maximizes individual tree volume increment. Stumpage value per unit volume of wood increases with increasing tree size. The value increase is a result of both a decrease in logging costs and an increase in product values. Jackson and McQuillan (1980) demonstrates the price-size relationship in a function developed to estimate stumpage values on the Lolo National Forest. The trend in value differences between large and small trees is likely to continue. Forcasters

(Adams and Haynes, 1980) predict that the projected increase in real value of stumpage will exceed the projected increase in the real costs of production by 40 percent. Yet will the value gain from increased product size offset the value loss from an accompanying reduction in total board-foot volume production and to a greater extent, in total cubic foot volume production? Is the trade-off in terms of value between product size and total production measured in board-feet even significant?

To illustrate the potential trade-offs associated with the selection of a regime maximizing value production, the relationship between stand density and total volume growth should be examined further. In sapling stands, (Figure 6) total volume increment increases with increasing stand density up to a maximum that remains roughly the same across a wide range of stand densities. A threshold beyond which there is little increase in production marks the point of full site utilization. The relationship between total volume increment and stand density in western larch sapling stands conforms with the hypothesis (Mar: Moller, 1954) that total volume growth varies little over a wide range of densities.

Results from Schmidt (1980) indicate that in sapling stands in which the majority of trees are between 1 and 3 inches in diameter, full site utilization is achieved at approximately 1500 trees per acre. The initiation of competition, resulting in a reduction in diameter increment, occurs at stocking levels between 700 and 900 trees per acre. Between the onset of competition and the point of full occupancy, total production increases as diameter increment declines. Therefore if the intent is near maximum rates of diameter growth, stocking in sapling stands should not exceed 700 to 900 trees per acre. If, on the other hand, the intent is to maximize total volume production, a sapling stand should carry at least 1500 trees per acre. Finally, if board-foot volume production is the goal, stocking should be maintained above the level permitting maximum diameter growth rates but below the one maximizing stand cubic-foot volume production. The exact level depends upon the merchantability standards.

If the form of the curve describing the relationship between total volume production and density in sapling stands remains the same for all stages of stand development (Figure 7), then regimes maximizing diameter increment by maintaining stocking at level A do so at some sacrifice to stand volume production. If the goal is stand volume production, then stocking should be maintained at or near level B, the minimum stocking required for full site utilization. The values of levels of A and B in pole and sawtimber size stands are presently unknown.

If the assumption is made that competition between trees begins when adjacent crowns just touch, stocking level A can be roughly approximated from an equation predicting crown area as a function of mean stand diameter. Table 6 displays estimates of stocking at crown closure for a range of average stand diameters. These estimates, generated by equations developed by Wycoff and Stage (1981) assume square spacing and uniform diameter growth rates.

Following are six alternatives representing three different strategies for maximizing value production.

Alternative #1: Achieving and maintaining near maximum growth rates for a portion of the rotation will yield the highest value returns.

TABLE 6

Average Stand Diameter (inches)	Stocking at Density Level A (trees per acre)
6.0	530
7.2	382
8.7	270
10.0	198
11.3	162
12.5	137
13.6	118
14.6	105
15.7	92

CCF_t = .00724 $DBH^{1.8182}$ for DBH $<$ 10"

CCF_t = .02 + .0148 BDH + .00338 DBH^2 for DBH $\geq$ 10"

DBH = average stand diameter

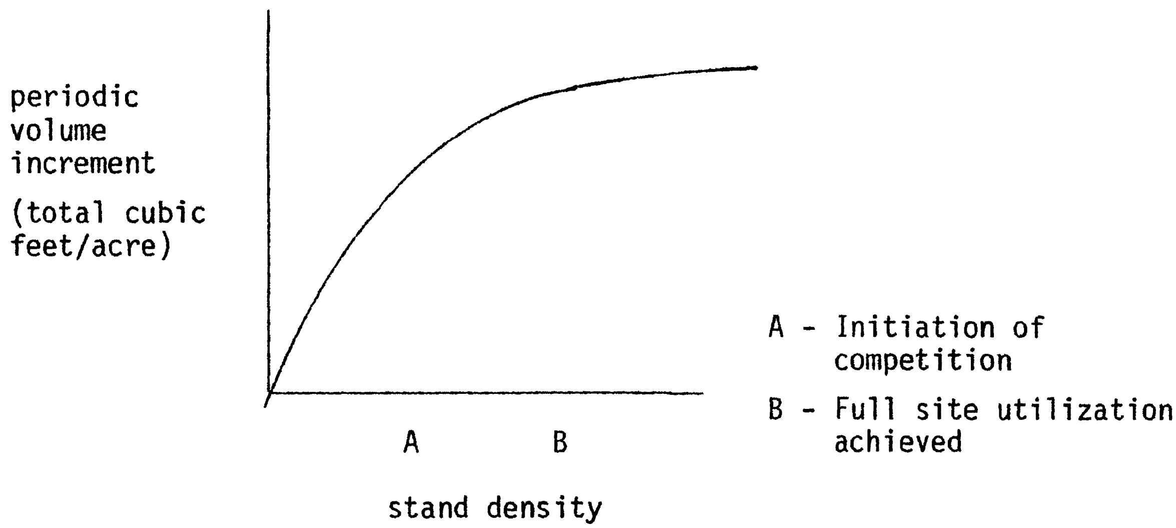
CCF_t = crown area expressed as a percent of an acre

ESTIMATION OF STOCKING

LEVEL A

Source: Wycoff and Stage, 1981

FIGURE 7



Clean to 300 stems/acre in 1982. Harvest at the culmination of the soil expectation value (S.E.V.).

Alternative #1A: A single commercial thinning in addition to the scheduled cleaning will increase the S.E.V. by salvaging potential mortality and redistribute the growth potential of the site on to merchantable trees.

Clean to 300 stems/acre in 1982. Reduce stand density to a crown competition factor of 80 at the earliest practicable time by commercial thinning. Harvest at culmination of S.E.V.

Alternative #2: Greater value production can be gained from earlier occupation of available growing space. A closer spacing after cleaning will allow the residuals to occupy and utilize the growing space more quickly.

Clean to 500 trees/acre in 1982. Harvest at culmination of the S.E.V.

Alternative #2A: Schedule a commercial thinning in addition to the proposed cleaning.

Clean to 600 trees/acre in 1982. Commercially thin at earliest practicable time. Harvest at culmination of the S.E.V.

Alternative #3: The four alternatives proposed so far utilize only a portion of the available growing space. Maximization of stand volume production will yield a greater return. Stand volume growth should be concentrated on the minimum number of trees required for full site utilization.

Do nothing in 1982. Harvest at the culmination of the S.E.V.

Alternative #3A: A commercial thinning will significantly increase the stand yield by salvaging potential mortality.

Do nothing in 1982. Commerically thin at earliest practicable time. Reduce the stand density to a crown competition factor of 100. Harvest at culmination of S.E.V.

Regeneration System

Western larch stands of natural origin are typically even-aged or uneven-aged in structure. Almost always, natural stand establishment has followed wildfire. Uneven-aged stands, not to be confused with all aged stands, consist of two or more distinctly even-aged classes of intermingling trees markedly different in age.

Why is the age class distribution in western larch stands so predictable? Western larch, an early seral species, is the most highly intolerant conifer in the northern Rockies. Well adapted for a fire successional role, the species produces large seed crops (Shearer, 1980) of small, wind disseminated seeds (Shearer, 1959) that germinate best on bare mineral soil (Roe, 1955). Highly intolerant of shade, larch achieves the most rapid juvenile growth in full sun in the absence of competing vegetation (Schmidt, 1969).

Both clearcut and seed-tree regeneration systems mimic the patterns of natural stand establishment but the latter, insuring more uniform seed dispersal, increases the probability of successful natural regeneration. A two cut seed-tree system, consisting of an initial heavy regeneration cut followed in ten years by the seed-tree removal should produce sufficient seed to regenerate the stand. If eight to ten uniformly distributed seed-trees per acre are left after the regeneration cutting, the chances are good that the stand will be regenerated to at least 300 uniformly distributed larch seedlings per acre.

Economic Analysis

The economic analysis uses the soil expectation value as a measure of the relative efficiencies of the alternatives over the longterm. The soil expectation value is the present value computed from receiving an infinite series of present net worth payments. The present net worth is the present value of all discounted costs and benefits. From an investment standpoint, the soil expectation value is a legitimate measure of profitability because it is influenced by the opportunity cost of capital as well as the costs incurred and revenues received.

All management costs were estimated from empirical models developed by Merzinich (1979) from Lolo National Forest cost data. Stumpage values were predicted from a model consisting of size, market, and method of logging variables developed by Merzenich (1981) from data obtained from 39 timber sales on the Flathead National Forest. Stumpage estimates were then adjusted to reflect both anticipated increases in real value and increased milling efficiency over time. All costs and revenues were expressed in 1980 dollars to eliminate the confounding effect of inflation on investment analysis. A discount rate of 4% was selected as the alternate rate of return.

Selection Procedure

Potential production was simulated for each of the alternative silvicultural strategies. Projected yields were then evaluated by investment analysis to determine their relative rankings in order of profitability. Finally the best financial strategy was selected as the preferred alternative.

The growth prognosis model (Stage, 1973), the best projection system available, was selected for yield forcasting. Developed originally to update existing stand inventories in north Idaho and western Montana, the model relies on a single tree distance-independent modeling procedure (Munro, 1973) in which the individual tree is the fundamental modeling unit. Trees are grown as a function of easily measured tree and stand attributes as well as several site parameters. Stand characteristics are then calculated by summing updated tree statistics. The model output, consisting of both tree and stand statistics, permits the analyst to evaluate the effects of selected silvicultural strategies on individual tree attributes.

As of yet, the model does not accurately project growth trends for small trees less than one inch dbh (Al McQuillan - personal communication). To overcome this major limitation, I elected to remove all trees falling into this category from the stand inventory prior to the initial projections.

The Selected Alternative

Value estimates for each of the alternatives examined are presented in Table 7. Alternative 2A outperforms the five others. Following closely is alternative 1A. In both of these alternatives, the soil expectation value culminates just ten years after thinning (Table 9).

The prediction that value production culminates almost immediately after a heavy thinning from above is a direct result of the substantial growth response predicted by the model immediately following thinning. In the simulation of the outcome of alternative 2A, the model predicts a basal area per acre increase of 21 percent from 2030 at the time of thinning, to 2040, the year that the soil expectation value culminates. When one considers that prior to thinning the residuals occupied the mid to lower portion of the stand basal area distribution, the model output appears improbable.

Actual growth responses from test stands heavily thinned from above to a stocking level close to that proposed in alternative 2A are significantly less. Stand basal area increased by just 10% in the 10 years

TABLE 7

MAXIMUM SOIL EXPECTATION VALUE

($/acre)

	No Thinning	Thinning
Release to 300 t./a.	$298.38 @ 55 yrs.	$341.00 @ 65 yrs.
Release to 600 t./a.	$318.00 @ 65 yrs.	$357.00 @ 75 yrs.
No release	$205.50 @ 75 yrs.	$237.00 @ 95 yrs.

TABLE 8

MAXIMUM AVERAGE RATE OF

VOLUME PRODUCTION

(board-ft./acre/yr.)

	No Thinning	Thinning
Release to 300 t./a.	253.7 @ 105 yrs.	238 @ 125 yrs.
Release to 600 t./a.	282.3 @ 115 yrs.	277 @ 105 yrs.
No release	272 @ 115 yrs.	286 @ 125 yrs.

Minimum merchantable tree 9" dbh to 8" top.

TABLE 9

SUMMARY OF ALTERNATIVES

Alt. #1	1982 - Clean stand to 300 t./a.
	2020 - Harvest.
Alt. #1A	1982 - Clean stand to 300 t./a.
	2020 - Commercial thin.
	2030 - Harvest.
Alt. #2	1981 - Clean stand to 600 t./a.
	2030 - Harvest.
Alt. #2A	1982 - Clean stand to 600 t./a.
	2030 - Commercial thin.
	2040 - Harvest.
Alt. #3	1982 - No release.
	2040 - Harvest.
Alt. #3A	1982 - No release.
	2040 - Commercial thin.
	2060 - Harvest.

following high thinning in a 55 year old larch stand growing on a high quality site (site index 83 for base age 50), (Seidal, 1980). If the effect of site is adjusted for, the discrepency between the predicted and the actual is even greater.

Evidently, the diameter increment equation in the prognosis model overpredicts basal area increment following heavy thinning from above. A tree's capacity to respond to increased growing space created by thinning is dependent in part on the size of its assimilating crown surface area (Hatch et. al., 1975). A rough approximation of crown surface area is the live crown ratio, an important variable in the diameter increment equation. Crown ratios predicted by the model just before thinning range between 45 and 55 percent of total height for trees occupying the lower one-half of the stand basal area distribution. In actual stands, the crown ratios of trees in the lower canopy are considerably less. Bias in the crown ratio prediction equation may have contributed to the improbably high stand basal-area growth following the simulated thinning.

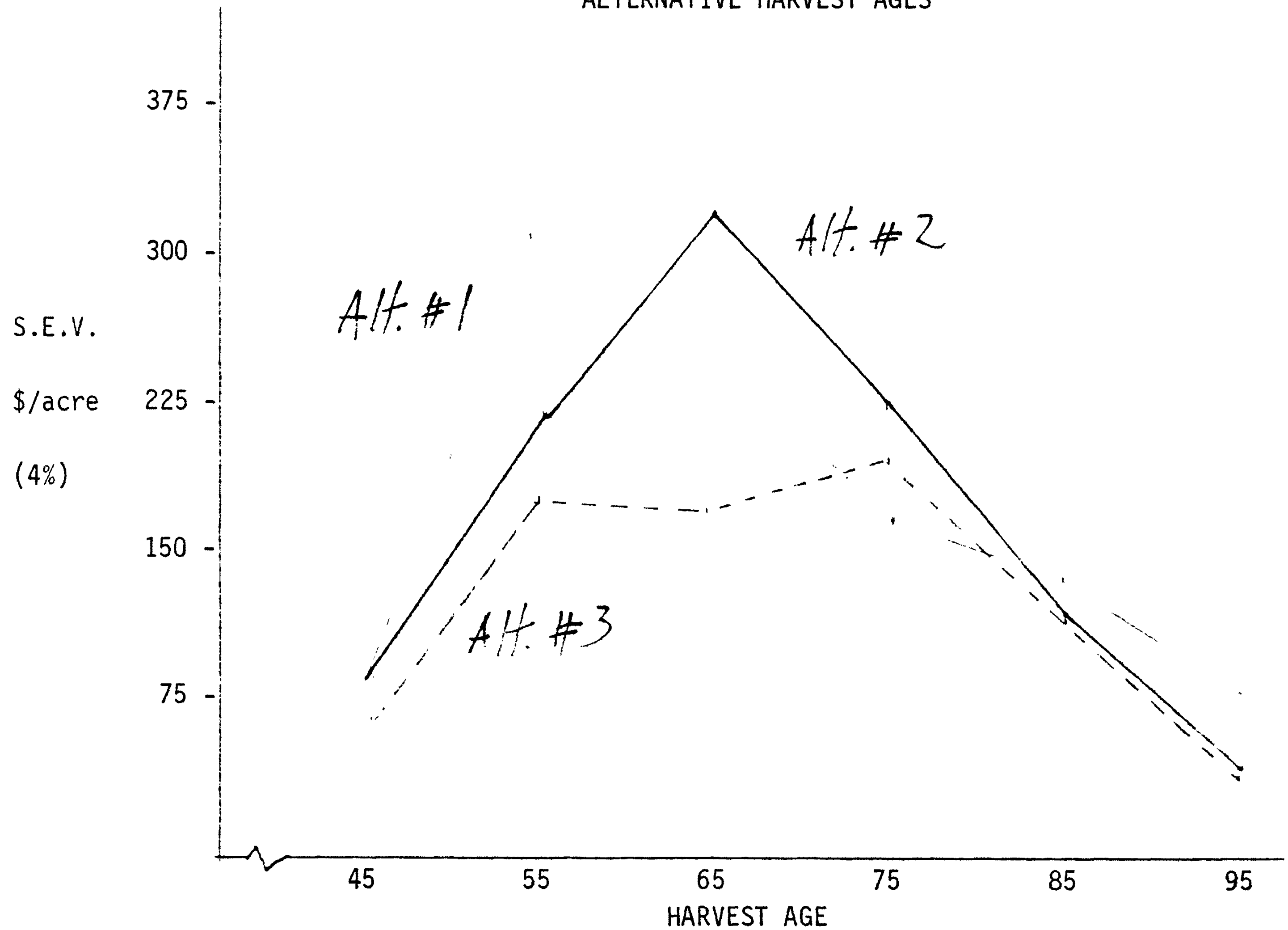
The cursory examination of model output versus real data has revealed that the simulated differs markedly from the actual. Consequently, value estimates for the regimes which include a commercial thinning are highly questionable and will be disregarded.

Of the three remaining options, alternative 2 outperforms both alternatives 1 and 3 (Figure 8). The two alternatives that include early stocking control are more profitable than the no-release option. Board-foot volume production is maximized by alternative 2 (Table 8). Alternative 3, lowest in value production, outperforms alternative 1 in

FIGURE 8

SOIL EXPECTATION VALUES UNDER

ALTERNATIVE HARVEST AGES



board-foot volume production. When the criteria is value production, the ranking reverses. This reversal demonstrates that value production is influenced as much by both the opportunity cost of money and quality premiums as by physical yield.

Alternative 2 is the selected option. Alternative 1, although nearly as profitable, allows far less flexibility in stand management after the initial, drastic cleaning.

CHAPTER IV

GUIDELINES FOR MINIMIZING SOIL COMPACTION

Soil compaction is the reduction in soil macropore space brought about by downward pressure applied by logging equipment during harvesting activities. Some degree of compaction is an expected consequence of harvesting operations involving extensive use of machinery. Yet even moderate increases in soil density may effect changes in soil physical properties that are inhibitive to optimal seedling growth. Accompanying any reduction in soil macropore space is an increase in bulk density as well as a reduction in the rate of water movement into and through the soil. On cutover land following tractor logging, Steinbrenner and Gessel (1955) reported a 2.4% increase in bulk density, a 35% loss in permeability, and a 10% reduction in soil macropore space. These changes adversely affect the seedling environment by restricting root penetration as well as reducing soil aeration and soil water holding capacity.

Reduction in seedling growth resulting from soil compaction during logging has been documented by a number of investigators. Hatchell and others (1979) examined the effects of soil compaction on seedling height growth in a cutover site regenerated naturally to loblolly pine (*Pinus taeda* L.). After three growing seasons, seedling height growth on both temporary and permanent skid trails was significantly less than that observed on undisturbed soil. Youngberg (1959) measured growth and survival two years after planting 2-0 Douglas-fir (*Pseudotsuga menziesii*

(Mirb.) Franco) seedlings on sites representing various degrees of soil compaction. The average bulk densities ranged from .93 grams/cm^3 in undisturbed soils to 1.03 and 1.65 grams/cm^3 on berms and skid trails respectively. After two years, survival was adequate at all locations while seedling heights averaged 17.3, 13.6, and 10.0 cm on undisturbed areas, berms, and skid trails respectively. Froehlich (1976) measured growth of planted ponderosa pine (Pinus ponderosa Laus.) seventeen years after tractor logging on a sandy loam soil. He detected significant reduction in stem volume associated with minor increases in bulk density. Stem volume decreased by 20% at a soil density that exceeded .84 grams/cm^3, the bulk density in undisturbed soil, by only 12%.

The results of potting experiments demonstrate the inhabitory effect of high soil densities on root growth. Root penetration of Douglas-fir seedlings in sandy loams was restricted altogether in pots compacted to 1.59 grams/cm^3. For western hemlock (Tsuga heterophylla Ruf. Sarg.), the upper limit of penetration was at 1.45 grams/cm^3 (Minore and others, 1961). Heilman (1981), reporting a higher threshold for Douglas-fir, estimated an upper limit of root penetration at 1.8 grams/cm^3. Reduction in root growth from compaction occurs well before the threshold of bulk density is reached. Foil and Ralston (1967) found that root weight and length both decreased linearly with increased levels of compaction at bulk densities above .9 grams/cm^3. Heilman reported that root penetration of 35 to 40 day old Douglas-fir seedlings declined with increasing bulk density between 1.37 and 1.77 grams/cm^3, the range of densities tested.

Repeated passes by logging equipment quickly compacts soils to bulk densities inhibiting seedling growth. Steinbrenner (1955) measured increases in bulk density in a clay loam from .91 to 1.04 grams/cm^3 after 6 passes. Bates (1981) quantified the effect of repeated passes by both track machines and rubber-tired skidders on physical properties of a soil formed in volcanic ash over quartizite till. The trails were carried out at two soil moisture levels. In soils near field capacity, both machines significantly compacted the surface horizon after 4 passes. Bulk density was increased from .76 grams/cm^3 in the control to .91 and 1.12 for the skidder and track machine, respectively. Compaction rates were less severe on drier soils. After 4 passes by the skidder, bulk density in the surface horizon was not significantly different from that in undisturbed soil. The same number of passes by the track machine increased bulk density from .76 to .95 grams/cm^3. No increase in density in subsurface horizons was detected at either moisture level. Other studies have detected compaction in the surface hirizons after as few as two passes by heavy euqipment. (Froehlich, 1976, Mae, 1971). Bate's failure to detect compaction after one or two passes may be due in part to the large experimental error within the treatments.

During a tractor logging operation, damage to the logged area may be extensive. Dyrness (1965) estimates that up to two-thirds of the ground area is disturded and 25% severly compacted during tractor logging. In western Montana, soil recovery to precompacted condition is a slow process. Tackle (1962) found no improvement in infiltration rate from the first to the fifth year after logging in a heavily compacted silty clay loam. Kuennen and others (1979) report the persistence of the compacted condition in areas logged 25 years previously.

Some compaction during logging is inevitable, but damage to soil can be minimized if harvesting activities are scheduled when the soil is dry. If scheduling activities to coincide with summer dry periods is not feasible, several other alternatives exist. Following are three alternatives which allow the sale forester some latitude in scheduling logging.

1) Confine logging to July through September when the soil dries out to -15 bars.
2) Log during January and February when the ground is frozen.
3) If the stand is logged when soils are most susceptible to compaction, restrict as much as possible the equipment traffic to a network of permanent skid roads. Accept at least a 25% increase in bulk density in soils beneath these skid roads.

Without site preparation, the probability of successfully regenerating the stand to larch is slim (Shearer, 1979). The optimal condition for seedling growth and survival is moist mineral soil exposed to full sun. This condition can be achieved by either mechanical scarification or broadcast burning. Use of mechanical scarification to achieve the silvicultural objective risks soil compaction as well as displacement of the surface horizon. Broadcast burning has the capability of meeting the regeneration requirements of larch with only a minimal amount of soil disturbance. Work by Shearer (1976) demonstrates that a balance can be achieved between meeting the silvicultural objective and protecting the soil by use of broadcast burning. Shearer found that soil temperatures during burns in which duff thickness was reduced by 75% remained far below levels required to do permanent demage to soil physical properties.

Peak temperatures of 196 and 124 degrees F. measured at one and three inches beneath the soil surface were far below levels required to induce water repellency (Debano and others, 1976) or cause irreversible demage to the clay complex (Ralston and Hatchell, 1971) yet not enough to kill root systems of potentially competing vegetation (Hare, 1960). The literature demonstrates broadcast burning can effectively expose mineral soil with no risk of compaction and only minimal risk of damage to soil physical properties.

Prescription

The stand will be cleaned to 600 trees per acre in 1982. A regeneration cut, the first of a two cut seed-tree harvest system, will be made in 2030. In 2031, the site will be broadcast burned prior seed dispersal. The seed trees will be removed in 2040.

Possibility of a Regeneration Failure

Regeneration failure is a very real possibility even on a relatively moist subalpine fir-clintonia habitat type in the Swan Valley. Natural regeneration is dependent upon a number of factors interacting to produce a favorable seedling environment during the critical period of seedling germination and establishment. An adequate amount of seed must be disseminated onto mineral soil when temperature and moisture conditions are favorable.

Any one of the number of variables essential to seedling establishment may be unfavorable at the time of regeneration. Broadcast burning is not entirely predictable (Beaufait et al., 1977). Larch produces good seed crops infrequently. Shearer (1959) estimates good seed crops occur in only one out of five years. Most land managers do not have the luxury of timing broadcast burning to coincide with good seed crops. Broadcast burning only temporarily suppresses competing vegetation. If regeneration is not prompt, a rapidly developing ground cover of competing vegetation may severely restrict seedling establishment. Pinegrass and blue huckleberry, both present in the prefire community, resprout vigorously following fire (Miller, 1977). Pinegrass, adapted to withstand plant moisture stresses which are lethal to seedlings, effectively depletes the rooting zone of soil moisture (Clark and McClean, 1965).

As potentially detrimental to seedling establishment as the emergence of competing vegetation is prolonged exposure of mineral soil to rainsplash. Rainsplash breaks down soil structure to produce a hard, impervious soil surface. If the stand has not been regenerated within ten years of the regeneration cut, the site should be rescarified and planted.

CHAPTER V

IMPACT ASSESSMENT

The Effect of Harvesting on the Forest Microenvironment

Removal of essentially all the tree canopy during the regeneration cut will drastically increase the radiation load reaching the soil surface and significantly reduce transpiration loss. These changes will in turn influence both temperature and moisture levels at, and immediately below, the ground surface. In addition, harvesting will permit increased air movement near the ground.

The increase in soil water content following harvesting will be most evident during the several years immediately following harvesting. Differences between the pre and post logged stand will diminish as a rapidly developing herb and shrub community occupies the site. Newman and Schmidt (1980) monitored soil water status during the three year period following harvesting to evaluate the effects of four different regeneration systems on soil water content. In August of the second year following clearcutting, the volume of soil water in the clearcut exceeded that measured in the adjacent uncut stand by 18%. Differences in soil water content, diminishing during the third and fourth years following harvesting, averaged 11% over the entire study period. As the rapidly recovering herb and shrub component used more water, the magnitude of the differences declined. This trend will likely continue as ground vegetation expands to fully occupy the site. In a study of plant succession following clearcutting and fire in the northern Rockies, Stickney (1980) reported that herb and shrub stages reached full development between 4 and 6, and 6 and 9 years respectively after clearcutting on an Abies lasiocarpa/Clintonia habitat type.

The gain in soil water following clearcutting on mesic sites is only temporary. The rapidly expanding cover of ground vegetation eventually utilizes most of the surplus created by canopy removal.

A far more permanent and potentially hazardous consequence of canopy removal is the sharp increase in incoming solar radiation. Hungerford (1980) monitored changes in the forest microenvironment brought about by clearcutting a gently west to northwest slope in an Abies lasiocarpa/Vaccinium caespitosum habitat type. The mean daily maximum radiation load received at the ground surface of a 15 acre clearcut exceeded by 80% the level recorded beneath the canopy of an adjacent uncut stand. Shearer (1976) has recorded daytime temperature maximums in excess of 125° F at the soil surface on north facing clearcuts. Temperatures in this range are approaching levels lethal to plant tissue. Accompanying large increases in daytime maximums are decreases in nighttime minimums. At Hungerford's study site, the number of frost free days during the 1978 growing season varied from 20 in the clearcut to 112 in the uncut stand. The severity of the temperature change reported by Hungerford is probably as much the result of differences in topographic position as increased rates of nighttime reradiation.

Potentially more hazardous to seedling survival than lethal temperatures is the concomitant increase in transpirational demand immediately above the ground. Temperature, moisture, and wind act in concert to influence the absolute humidity deficit.

The Effect of the Seed-Type System on Pollen Dissemination and Seed Production

Critics of the seed-tree system maintain that reduction of the seed-producing population to a few stems per acre is a disgenic practice that promotes inbreeding. In larch, male and female flowers, not segrated by crown position, develop together on the same branch. Will the removal of all but 8 to 10 seed producing trees per acre greatly reduce the proportion of seed produced from outcrosses? Blake (silviculture lecture, 1980) refutes charges that the seed-tree system is disgenic by pointing out that seedlings from outcrosses will easily outcompete poorly adapted albinos.

The Effects of Harvesting and Burning on Nutrient Cycling

Timber harvesting and broadcast burning temporarily disrupt nutrient cycling by removing merchantable biomass and drastically increasing rates of decomposition. Lossess incurred by removal of merchantable wood should be relatively minor. Only a small fraction of the site's nutrient capital is tied up in the main stem wood (Cole and others, 1967). Precipitation inputs alone during the following rotation are sufficient to replace losses from biomass removal by conventional harvesting (Stark, 1979).

Broadcasting burning is potentially a far greater drain on the nutrient capital. Burning oxidizes organic matter, bringing about its rapid mineralization into a soluble form. Debyle and Packer (1972) observed accelerated rates of losses from the O horizon during the two years immediately following broadcast burning. Fire volatilized one-third of the total nitrogen. Leaching and overland flow significantly reduced concentrations of phosphorous, magnesium, and potassium in the ash-duff layer. A portion of these were leached into mineral soil, increasing both the pH and the percentage of exchangeable bases. In the third and fourth years following fire, nutrient losses subsided as the rapidly recovering herbaceous vegetation re-established nutrient cycling.

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