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Environment, Vegetation, and Regeneration After Timber Harvest in the Hungry-Pickett Area of Southwest Oregon

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Abstract

Environmental factors were related to forest regeneration on clearcut and partially cut areas managed by the Bureau of Land Management in the Hungry-Pickett area northwest of Grants Pass, Oregon. The multiple regression equations developed for this study can be used to compare the relative difficulty of regenerating forested sites within the study area. The equations show that difficulty of regenerating clearcuttings increases with increasing solar radiation, temperature, rock cover, and depth of the soil A horizon. Difficulty of regenerating partial cuts increases with surface gravel cover and is related to slope, aspect, and vegetation.

Keywords: Regeneration (natural), logging (-regeneration, environmental effects, southwest Oregon.

Introduction

Forest management problems probably are more intricate and varied in southwest Oregon than in any other part of the Pacific Northwest (Hayes 1959). Climate ranges from cool and moist near the coast to hot and dry in the interior valleys, where unshaded soil temperatures may reach 175° (79°C) on west aspects (Hallin 1968). Much of the area (the Klamath Mountain complex) is "a genuine geologic nightmare" (McKee 1972); and this confusing geology is associated with extremely varied soils.

Vegetation in southwest Oregon has elements of the California, north coast, and eastern Oregon floras; but many species are indigenous (Franklin and Dyrness 1973). Brush competition is often severe where adequate moisture is available. Grasses rapidly exhaust soil mositure on many south-facing slopes (Preest 1975).

The environments of southwest Oregon are not all severe, but they are diverse and difficult to identify. Selecting a successful regeneration regime is also difficult, and the selection often must be based on subjective observations. Unfortunately, those observations may not be effective in predicting the relative difficulty of obtaining adequate post-harvest regeneration on a given site. More objective methods are needed to help identify sites that require extra effort or specialized regeneration techniques.

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The moisture and temperature characteristics of sites in southwest Oregon have been identified and correlated with vegetation in several previous studies (Waring 1969, Minore 1972, Minore et al. 1982). Environmental factors have also been correlated with forest regeneration (Carkin and Minore 1974; Minore et al. 1977, 1982; Minore and Carkin 1978) . All of these studies involve relatively small portions of southwest Oregon, however; and none are applicable outside the areas in which they were developed. This is proper, for a large and diverse region like southwest Oregon is best studied by stratifying it into smaller, more homogenous units. This study of the Hungry-Pickett area constitutes one more piece of information about the complex southwest Oregon mosaic.

The Hungry-Pickett area is northwest of Grants Pass in the mixed-conifer and mixed-evergreen forest types described by Franklin and Dyrness (1973). Within the 120-square-mile study area elevations range from 1,000 to 4,000 ft (300 to 1 200 m). Steep slopes are common. Soils vary from shallow, stoney profiles to deep and well developed silty clay loams. Annual precipitation tends to increase from east to west, ranging from about 30 to 80 in (75 to 200 cm). Air temperatures monitored at 25 locations in 1979 ranged from a low of 12° F (-11° C) in January to a high of 121° F (49° C) in July.

We studied the Hungry-Pickett area to derive relationships between environmental factors and post-harvest forest regeneration in clearcut and partial cut areas. These relationships were developed on Bureau of Land Management land, but they should be useful throughout the study area. Our objective was to compare forested sites in terms of relative difficulty of regeneration.

Methods

Clearcuts

From about 70 potential sample areas, 50 were selected to include as many different combinations of aspect and elevation as possible and provide a good geographic distribution (fig. 1). All were 3 to 20 years old and had a nearby, uncut stand of similar slope, aspect, soils, and elevation to represent pre-harvest vegetation and environment.[1] We established a grid of 30 subplots spaced 33 ft (10 m) apart on a relatively uniform area[2] in each sample unit. Each grid was located away from road fills and adjacent stands of timber. The subplots were systematically located and equally spaced. Each consisted of two concentric circles with areas of 1/250 and 1/60 acre (0.0016 and 0.0067 ha).

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[1] An uncut or lightly partial cut stand with differences no greater than 30 percent slope, 35° azimuth, and 200-foot elevation from the clearcut unit.

[2] Uniform slope and aspect for this study were defined as being within a range of 30 percent slope and 35° azimuth.

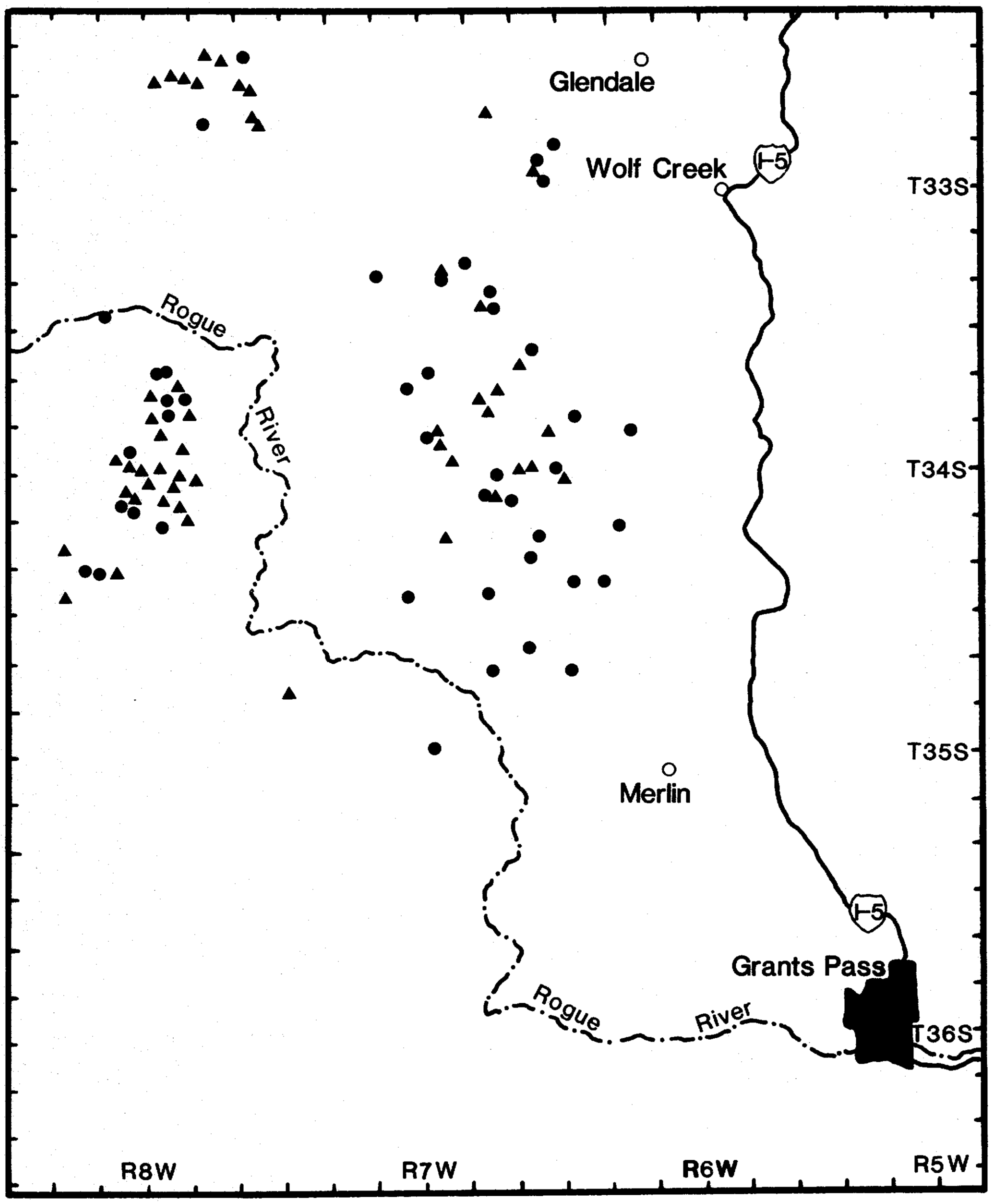

Figure 1. — Sample plot locations in the Hungry-Pickett study area. Clearcuts are indicated by triangles; partial cuts by circles.

On the 1/250-acre (0.016-ha) subplots, conifer seedlings were counted and recorded as established post-harvest,[3] unestablished, or pre-harvest. Established post-harvest seedlings were tallied by species. Cover estimates of grass, forbs, slash, exposed rocks, and surface gravel were recorded; and the dominant grass and forb species were also identified and tallied on the 1/250-acre subplots. Depth of duff was measured to the nearest 0.2 in (0.5 cm). Percent shrub and tree cover and the dominant species of each were estimated on the larger 1/60-acre (0.0067-ha) subplots.

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[3] *Pseudotsuga* and *Abies* seedlings were considered established if they had branched before 1979. Establishment of other conifers was determined by their size and vigor.

Information on slope and aspect was also collected at each subplot. Average plot-grid elevation was determined with an altimeter calibrated daily against known bench marks.

We dug a 20-in (50-cm) soil pit at four well-distributed points in each grid, measured the depth of the A horizon, and estimated percent of coarse fragment content of both the A horizon and the entire 20-in (50-cm) profile. Total soil depth was determined by extending one of the subplot soil pits or by digging in an adjacent road cut down to the C horizon or to 50 in (127 cm). We collected a soil sample at 10 in (25 cm) in each pit, then combined equal volumes of the four samples to obtain a composite sample for the grid. These composite samples were air-dried indoors, then tested by a modified hydrometer technique to estimate silt + clay content. Each composite soil sample was also analyzed for cation exchange capacity, pH, Ca, K, P, No_3, NH_4, Mg, and Fe.

The subplot data for each sample grid were averaged to obtain plot parameters. We used the tables of Frank and Lee (1966) to generate a radiation index for each plot (table 1). The optimum aspect for regeneration was computed by using a procedure similar to that described by Stage (1976). We used the optimum aspect in conjunction with an aspect transformation equation published by Beers et al. (1966) to obtain an aspect code for each plot. The aspect code was used as an independent variable in multiple regression analyses.

Plants found in the uncut stands were identified. Regeneration indicator species were selected and weighted as described by Minore and Carkin (1978), and a clearcut stocking index (CCSI) was calculated for each plot (table 2). Similarly, temperature and moisture indices were also determined for each sample plot. Although vegetative indices do not give precise estimates of environmental variables on a particular site, they do provide a means of gauging the relative differences between sites. Multiple regression was used to correlate these indices and the quantitative environmental variables to stocking percent and number of seedlings per acre.

Table 1 — Radiation indices for 42° N. latitude (from Frank and Lee 1966)

Slope percent	N	S	NNE NNW	SSE SSW	NE NW	SE SW	ENE WNW	ESE WSW	E W
0	.4704	.4704	.4704	.4704	.4704	.4704	.4704	.4704	.4704
10	.4329	.5039	.4359	.5014	.4442	.4942	.4562	.4833	.4700
20	.3930	.5323	.3994	.5278	.4168	.5148	.4416	.4944	.4689
30	.3524	.5553	.3625	.5492	.3898	.5314	.4271	.5032	.4670
40	.3133	.5728	.3270	.5656	.3640	.5441	.4133	.5096	.4644
50	.2786	.5854	.2943	.5773	.3403	.5531	.4005	.5136	.4611
60	.2496	.5935	.2662	.5849	.3191	.5588	.3887	.5156	.4573
70	.2246	.5981	.2424	.5891	.3006	.5617	.3781	.5158	.4530
80	.2030	.5998	.2219	.5906	.2847	.5624	.3685	.5146	.4484
90	.1839	.5993	.2042	.5901	.2710	.5615	.3599	.5124	.4436
100	.1677	.5972	.1887	.5880	.2593	.5593	.3520	.5094	.4388

Table 2 — Indicator species and values to be used in estimating relative regeneration difficulty after clearcutting. A clear-cut stocking index (CCSI) may be obtained by averaging the values of all species present in a given stand. High index values indicate better regeneration (less regeneration difficulty) than low values.

Species	Indicator value
Achlys triphylla	14
Trientalis latifolia	14
Vancouveria hexandra	14
Berberis nervosa	13
Vaccinium ovatum	11
Galium aparine	11
Polystichum munitum	11
Viola sempervirens	11
Libocedrus decurrens	3
Sanicula graveolens	3
Pinus ponderosa	2
Nemophila parviflora	1

Partial Cuts

We sampled 42 partial cut stands (fig. 1) by using the same selection criteria and subplot design used with the clearcuts. All partial cuts which were at least 3 years old were sampled. Similar measurements were also made of environmental factors and regeneration. The only major deviation from our clearcut data collection procedure was the identification of vegetation within the cutting unit instead of in an adjacent uncut stand. For each 1/250-acre (0.0016-ha) subplot, we recorded the cover of herbaceous plants by species and estimated total grass and forb cover percentages. Shrub and tree cover were recorded on a larger 1/60-acre (0.0067-ha) concentric subplot.

At each subplot, we measured residual overstory basal area with a 20-factor prism and estimated stump basal area. Two methods were employed to measure overstory canopy density: we averaged four spherical densiometer readings (one taken in each cardinal direction) and estimated the percent of canopy cover directly above the center of the subplot by sighting through a tube formed by a 10¾ oz. soup can.

At each subplot we also recorded the species, diameter, age, and condition of the nearest live conifer at least 4.5 ft (1.37 m) tall. Breast height age of these trees was estimated by using an increment borer or by counting the branch whorls on saplings. Growth rings were examined to determine the effect of release on individual trees.

We assumed that most plant species in partially cut stands were the same as those present before logging. Using these species, we applied the same methods used with the clearcuts to derive a partial cut stocking index (PCSI, table 3), a moisture index, and a temprature index for each sample stand. These indices and the other quantitative variables were analysed by stepwise multiple regression to obtain an equation for natural regeneration in the sampled partial cuts.

Table 3 — Indicator species and values to be used in estimating relative regeneration difficulty after partial cutting. A partial cut stocking index (PCSI) may be obtained by averaging the values of all species present in a given stand. High index values indicate better regeneration (less regeneration difficulty) than low values.

Species	Indicator value
Xerophyllum tenax	13
Arctostaphylos viscida	12
Lathyrus nevadensis	12
Phlox spp.	12
Pyrola dentata	12
Sanicula graveolens	12
Pinus ponderosa	11
Arctostaphylos patula	11
Melica harfordii	11
Chimaphila menziesii	11
Pyrola picta	11
Rubus leucodermis	3
Rubus parviflorus	3
Deschampsia elongata	3
Hypericum perforatum	3
Quercus kelloggii	2
Aster radulinus	2
Polystichum munitum	2
Symphoricarpos albus	1

Temperature

We established 25 temperature stations (10 recording thermographs and 15 maximum/minimum thermometers) in undisturbed stands throughout the study area. These stands were chosen to sample the range of aspect and elevation present in the Hungry-Pickett area and to obtain an equitable geographic distribution. Only areas with relatively uniform slope and aspect were used. Ridgetops, road cuts, and drainages were avoided.

Air temperature was measured under a shelter at 8 inches (20 cm) above the soil surface at each temperature station. The stations were monitored and calibrated monthly from November 1978 to September 1979 except when prohibited by winter snow accumulations.

A 1/5-acre (0.08-ha) vegetation plot was established at each temperature station in the spring of 1979. All plant species that appeared between April and August were identified and recorded by abundance. Applying a modified version of the procedure described by Warner and Harper (1972), we used maximum temperatures recorded during the growing season and vegetation data to derive indicator species (table 4) and develop temperature indices for our clearcut and partial cut sample areas.

Table 4 — Indicator species and values to be used in estimating relative temperature conditions in undisturbed stands. A temperature index may be obtained by averaging the values of all species present in a given stand. High values indicate warm temperatures. Low values indicate cool temperatures.

Species	Indicator value
Quercus kelloggii	13
Rhus diversiloba	12
Elymus glaucus	12
Arbutus menziesii	11
Ceanothus integerrimus	11
Apocynum androsaemifolium	11
Asarum hartwegii	11
Habenaria spp.	11
Carex spp.	10
Cynoglossum grande	10
Epilobium minutum	10
Madia spp.	10
Achlys triphylla	2
Disporum hookeri	2
Polystichum munitum	2
Chimaphila umbellata	1

Moisture

We established 57 moisture stress plots in undisturbed stands throughout the range of slopes, aspects, and elevations occuring within the study area. Sites that might exhibit unusual soil moisture conditions (e.g., areas near road cuts or fills, draws, creek bottoms, and ridge tops) were avoided. Plant species were identified, and a vegetation list was compiled for each of these plots.

Waring and Cleary's (1967) technique was used to measure nocturnal plant moisture stress with a pressure bomb. On each plot, at least two Douglas-fir saplings between 5 and 10 ft (1.5 and 3 m) tall were sampled during the third week of August 1979. We derived a set of moisture indicator species from these moisture and species data. Here again, a modified version of the procedure described by Warner and Harper (1972) was utilized.

Results

Clearcuts

The clearcut samples ranged in elevation from 1,200 to 3,950 ft (366 to 1 204 m). All aspects were represented, and slopes ranged from 22 to 77 percent. Post-harvest regeneration ranged from 3- to 100-percent stocking. Less than half of the plots were 60 percent stocked, however; and many of the clearcut environments were dominated by seral vegetation.

Several types of seral vegetation occupied the clearcuts in 1979. Tanoak (*Lithocarpus densiflorus*) and whipple-vine (*Whipplea modesta*) appeared as dominant or codominant species on 72 and 76 percent of the sample plots, respectively. Where whipple-vine was absent, beargrass (*Xerophyllum tenax*) and bracken fern (*Pteridium aquilinum*) usually were dominant. Madrone (*Arbutus menziesii*) was prominent on only 12 percent of the sample units, and it was never dominant at elevations above 3,000 ft (914 m). Instead, salal (*Gaultheria shallon*) and varnish-leaf ceanothus (*Ceanothus velutinus*) tended to be dominant above 2,300 ft (701 m).

Variation in dominant seral vegetation was not associated with variation in regeneration on the clearcuts, with two exceptions. Clearcut areas dominated by poison oak (*Rhus diversiloba*) or manzanita (*Arctostaphylos* ssp.) tended to be poorly stocked.

The moisture index, considered separately, was not significantly correlated with post-harvest regeneration or with aspect. Dry and moist sites were found on all aspects. All of the moist sites were at elevations above 2,500 ft (762 m), however; and all of the dry sites were below 3,100 ft (955 m).

Several field observations were confirmed by simple correlations. For example, content of surface gravel and coarse soil fragments tended to increase with increasing slope, and temperature indices decreased with elevation.

Vegetation, slope, and aspect were well correlated with regeneration stocking. Considered separately, the clearcut stocking indices (CCSI's) derived from indicator plants listed in table 2 accounted for 34 percent of the variation in relative clearcut stocking.

Slope and aspect, expressed as radiation indices (table 1), provided a significant indication of regeneration difficulty on the clearcut areas. When regeneration, slope, and aspect are combined in a mathematical model similar to the one described by Stage (1976), the trends can be expressed as a series of curves (fig. 2). These curves indicate that steep slopes on south-southwest aspects tended to have the poorest clearcut regeneration.

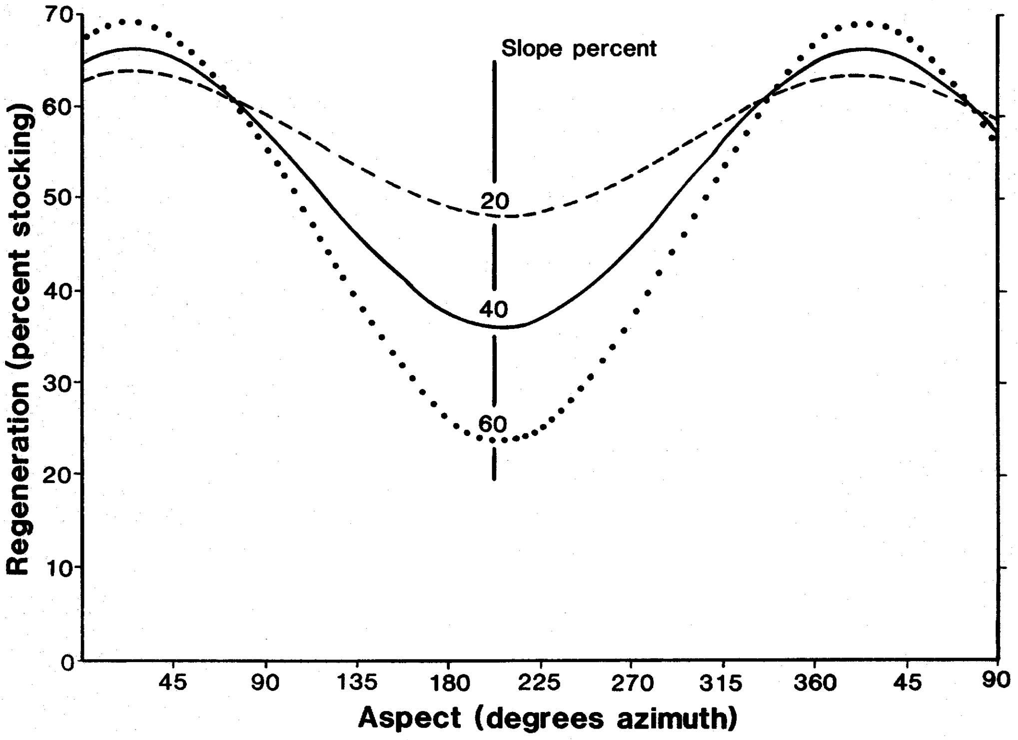

Figure 2. — Post-harvest regeneration trends of clearcuts with different slopes and aspects. Percent stocking = 60.7102 + 0.3412 (slope)(cos. aspect) + 0.1622 (slope) (sin. aspect) - 0.2433 (slope). $r^2 = .27$.

We used stepwise multiple regression analyses to derive mathematical models for estimating relative regeneration difficulty in terms of past regeneration success. The best multiple regression equation in which all coefficients were significant accounted for 57 percent of the total variation:

Relative clearcut stocking percent = 69.633572 - 103.54307 (radiation index)
- 1.879096 (temperature index)
- 0.706681 (depth A horizon in cm)
- 1.147246 (percent rock cover)
+ 5.173157 (clearcut stocking index)
$R^2 = .575$
$S_{y \cdot x} = 18.67$
$n = 49.$

This equation is not suitable for the precise prediction of absolute stocking levels, but it should be useful in comparing the relative regeneration difficulty of sites to be clearcut. The user should calculate relative clearcut stocking percents for the areas to be compared, then use those percents to assess relative regeneration difficulty.

Partial Cuts

We used only post-harvest natural regeneration in our partial cut analyses. The partially cut stands ranged in elevation from 1,100 to 3,800 ft (335 to 1 158 m). Aspects on 17 ranged from 90° to 180°, and 13 had aspects between 270° and 360°. The remaining 12 sample stands were on aspects of 0° to 90° (7 stands) and 180° to 270° (5 stands). Stocking ranged from 0 to 90 percent.

Age structure of the residual overstory varied with the stand sampled; but more than half of the partial cuts (24 of the 42 stands sampled) had two or three distinct age classes. These age classes were about 10 to 20, 140, 230 to 250, or 340 years old. Ten of the sample stands were even aged, with 50 to 100 years being the most common age class. Well balanced uneven aged overstories corresponding to the classic "inverted J" distribution were present in seven sample stands, and one was all aged with conifers ranging from seedlings to 700-year-old trees.

Most of the partial cutting probably was not designed for release purposes, but more than half (59 percent) of the residual trees responded with accelerated radial growth. The percentage of sample trees released varied erratically among sample stands, however, ranging from 8 to 100 percent. Radial growth increased up to more than a millimeter per year in some trees. It was not well correlated with stand age, diameter, or environment but tended to be greatest soon after partial cutting and then tapered off a few years later. This post-harvest increase in radial growth appeared to be sustained longer in grand fir than in Douglas-fir.

A mathematical model described by Stage (1976) relating slope and aspect to natural regeneration (fig. 3) accounted for 24 percent of the variation in stocking. It showed that partial cuts with the best natural regeneration tended to occur on gentle slopes with south-southeast or northwest aspects. When we used this technique to examine the relationship of residual stand basal area and aspect to stocking (fig. 4), the best natural regeneration occurred on south-southeast aspects under residual stands with high basal areas.

Several other partial cut environmental variables showed significant simple correlations ($p < .01$) with regeneration. Both slope/aspect index (table 5) and sugar pine basal area increased with increases in natural regeneration stocking percent. Moisture, depth of the A horizon, and percent of coarse fragment increased with elevation. Temperature indices decreased with decreasing elevation and with increasing pre-harvest basal area.

When dominant species were used as classification criteria for plant communities in the partial cuts, natural regeneration tended to be worst in the *Pseudotsuga/Ceanothus cuneatus* and *Pseudotsuga/Corylus-Holodiscus* communities. It was best where *Pseudotsuga/Lithocarpus/Whipplea* occurred.

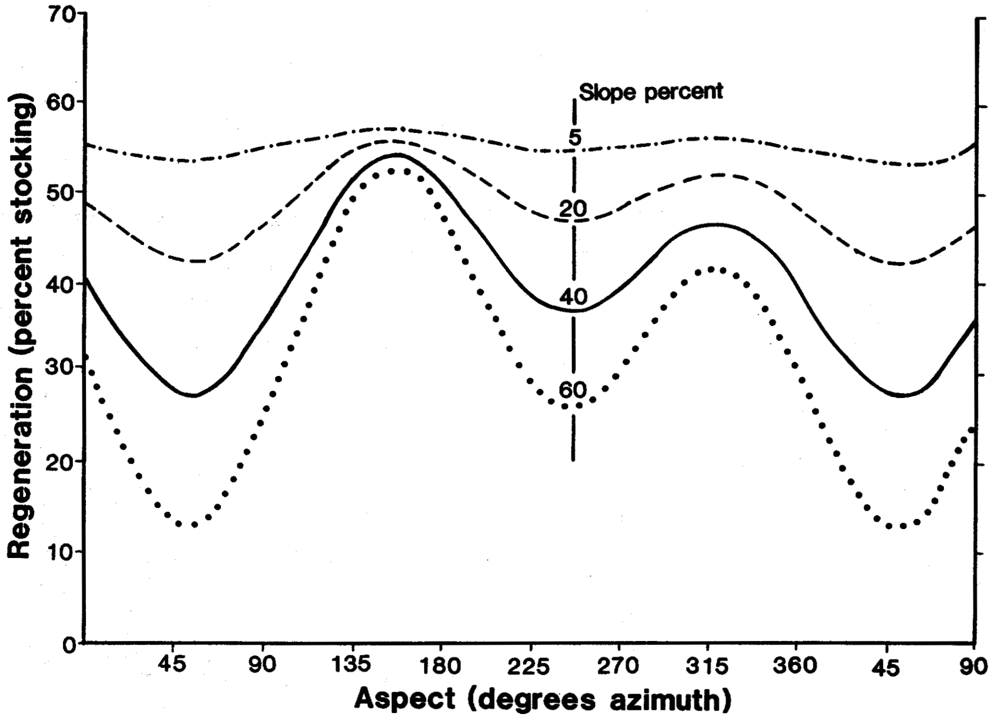

Figure 3. — Post-harvest regeneration trends of partial cuts with different slopes and aspects. Percent stocking = 57.5185 - 0.1374 (slope)(cos. aspect) - 0.0515 (slope)(sin. aspect) + 0.0963 (slope)(cos. [2•aspect]) - 0.1991 (slope)(sin. [2•aspect]) - 0.4025 (slope). $r^2 = .24$.

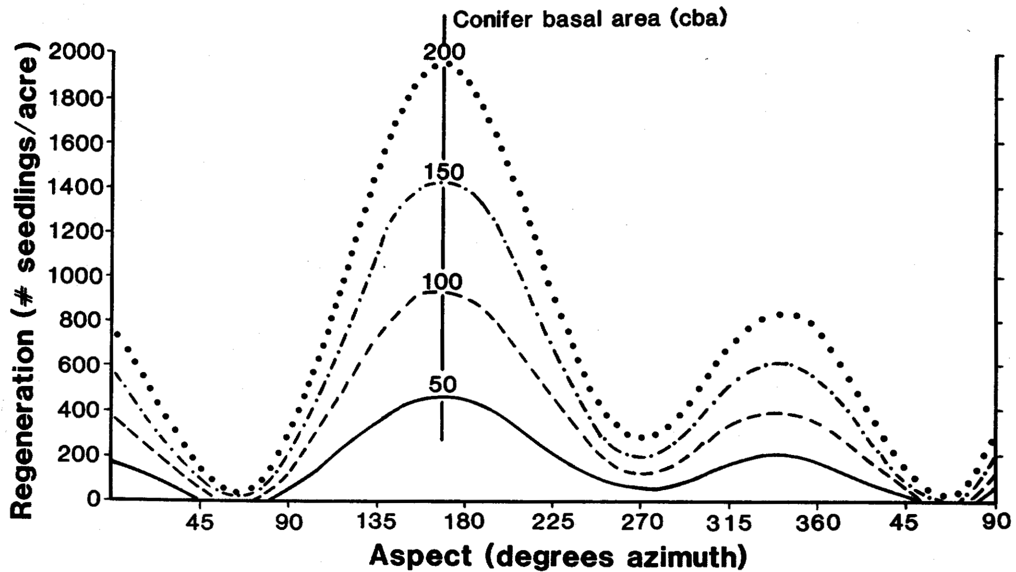

Figure 4. — Post-harvest regeneration trends of partial cuts with different aspects and conifer basal areas. Number of seedlings per acre = -2.1754 - 0.3444 (cba)(cos. aspect) + 0.3140 (cba)(cos. [2•aspect]) - 0.1721 (cba)(sin.[2•aspect]) + 0.4944 (cba). $r^2 = .504$.

Table 5 — Indices used in relating partial cut regeneration to slope and aspect[1]

Aspect azimuth (degrees)	Slope percent									
	0	10	20	30	40	50	60	70	80	90
0	58	53	49	44	40	36	31	27	23	18
10	58	52	47	42	37	32	27	21	16	11
20	58	52	46	40	34	28	22	16	10	4
30	58	50	44	38	31	24	18	11	4	0
40	58	50	43	36	29	22	14	7	0	0
50	58	50	43	35	28	20	13	5	0	0
60	58	50	43	35	28	21	13	6	0	0
70	58	50	43	36	29	22	15	8	1	0
80	58	51	45	38	32	25	19	13	6	0
90	58	52	46	41	35	30	24	19	13	8
100	58	53	48	44	39	35	30	26	21	17
110	58	54	51	47	43	40	36	33	29	26
120	58	55	52	50	47	45	42	40	37	35
130	58	56	54	52	51	49	47	46	44	42
140	58	56	55	54	53	52	51	50	50	48
150	58	57	56	55	54	54	53	52	51	51
160	58	57	56	55	54	54	53	52	51	51
170	58	56	55	54	53	52	51	50	49	48
180	58	56	54	53	51	50	48	47	45	44
190	58	55	53	51	49	46	44	42	40	37
200	58	55	52	49	46	43	40	37	34	31
210	58	54	50	46	43	39	35	31	28	24
220	58	53	49	44	40	36	31	27	22	18
230	58	53	48	43	38	33	28	23	19	14
240	58	52	47	42	37	32	27	22	17	11
250	58	52	47	42	37	32	27	22	16	11
260	58	53	48	43	38	33	28	23	18	13
270	58	53	48	44	39	35	30	26	21	17
280	58	53	49	45	41	37	33	29	25	21
290	58	54	50	47	43	40	36	33	29	26
300	58	54	51	48	45	42	39	36	33	30
310	58	55	52	49	47	44	41	38	36	33
320	58	55	52	50	47	45	42	39	37	34
330	58	55	52	49	47	44	41	39	36	33
340	58	54	51	48	45	42	39	36	33	30
350	58	54	50	47	43	39	36	32	29	25

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[1] These slope/aspect indices were calculated by using the procedure described by Stage (1976).

When considered alone, partial cut stocking indices (PCSI's) derived from the indicator species listed in table 3 accounted for 46 percent of the variation in stocking. This PCSI can be used individually to estimate the relative difficulty of obtaining natural regeneration in Hungry-Pickett partial cuts. Using the partial cut stocking index in conjunction with additional variables, however, provides a more accurate estimate of relative regeneration difficulty. The best multiple regression equation in which all coefficients were significant accounted for 53 percent of the variation in stocking:

$$\begin{aligned}\text{Relative partial cut stocking percent} = {} & -8.414803 + 6.118036\,(\text{partial cut stocking index}) \\ & +0.369486\,(\text{slope/aspect index}) \\ & -0.204111\,(\text{percent of surface gravel cover})\end{aligned}$$

$$R^2 = 0.524$$

$$S_{y \cdot x} = 15.52$$

$$n = 42.$$

Like the equation previously given for clearcuts, this multiple regression equation should be used to assess relative regeneration difficulty, not absolute stocking levels.

Discussion

Adequate regeneration is not easily attained in the Hungry-Pickett area. Only 38 percent of the clearcut sample plots and 21 percent of the partial cut sample plots had stocking of 60 percent or greater (using 1/250-acre (0.0016-ha) subplots and post-harvest seedlings as the stocking criteria). Since these data are based on stands cut before 1976, they do not reflect current silvicultural procedures. They do, however, emphasize the relative regeneration difficulties encountered.

Clearcut harvesting resulted in the best regeneration on north, northeast, northwest, and east aspects with slopes greater than 20 percent. Post-harvest natural regeneration was best after partial cutting on south, southeast, and southwest aspects. Aspect was not critical where slopes were less than 20 percent.

Preharvest regeneration was ignored in our analysis, but it constitutes an additional source of regeneration that should be evaluated on each site. Regeneration damage caused by overstory removal should also be evaluated. We were unable to do so in this study.

Regression data are not suitable for determining cause and effect, and we cannot use our equations to explain the low level of regeneration observed. The study was not designed to determine which environmental factors are most responsible; subjective field observations, however, indicate that vegetative competition was one of the most important problems in the Hungry-Pickett area.

This study included many environmental variables that influence post-harvest regeneration, but several important silvicultural variables could not be measured or evaluated. Site preparation, planting techniques, and condition of the planting stock were all important factors influencing clearcut regeneration. Consequently these variables constitute unmeasured sources of error in our correlations of regeneration and the environment. The partial cut correlations were less affected by these unmeasured variables than clearcut correlations; unlike the clearcuts, the partial cuts were not planted.

We assumed that the effects of environmental factors were not masked by past site preparation or planting treatments, and that regeneration differences related to environmental factors, though somewhat attenuated, were still evident among the plots sampled. When the harsh environment in the Hungry-Pickett area and the poor regeneration frequently recorded in the study plots are considered, this seems to be a valid assumption.

Our results reflect practices in effect 3 to 20 years before the beginning of this study. Increased efforts to improve planting stock or regeneration techniques may result in stocking levels higher than those resulting from our mathematical models, but the relative differences in regeneration difficulty among areas sampled should not change with improvements in reforestation technology. Sites with low relative predicted stocking should be more difficult to regenerate than those with high relative predicted stocking. The mathematical models presented here are not intended to serve as precise, absolute predictors of future stocking levels. Their purpose is to indicate where special techniques and additional effort will be required to obtain adequate regeneration.

The quality of planting stock has improved and more intensive regeneration methods are available; but money, workforce, or management limitations may negate many of these technological gains. Such limitations may enhance the value of this study. By using the equations to predict the relative difficulty of regeneration, reforestation efforts could be given priority.

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Appendix I
List of Pertinent Clearcut Data, by Location

Location (T.R.S.)	Stocking	Elevation	Aspect azimuth	Slope	Clearcut stocking index	Temperature index	Radiation index	Rock	Depth A	Estimated[1] relative stocking
	Percent	Feet	Degrees	Percent				Percent	Centimeters	Percent
35-7-7	63	1400	8	79	10.8	8.5	.2118	1	14	76
34-7-23	27	2600	111	76	5.6	7.9	.5097	2	17	17
33-7-13	20	2400	253	63	8.0	7.9	.4741	19	5	22
34-6-19	77	2100	30	71	11.3	7.4	.2605	2	16	74
34-7-27	47	2550	82	52	12.8	7.6	.4390	1	18	62
33-8-12	47	3750	112	51	13.5	4.7	.5110	20	5	51
34-7-11	63	1300	51	60	12.8	7.1	.3389	1	14	76
34-8-33	27	2400	74	77	10.1	6.8	.3936	22	14	33
34-8-23	50	3000	61	43	13.2	3.6	.3940	2	22	72
34-8-15	47	2550	133	57	11.2	5.8	.5510	4	28	35
34-8-15	73	3100	55	53	13.0	4.8	.3633	1	16	78
34-8-15	73	3050	154	74	11.0	5.0	.5834	3	2	52
34-8-21	47	3950	119	45	13.2	1.8	.5219	8	16	60
34-8-21	57	3800	266	39	8.7	6.0	.4733	5	11	41
34-8-16	30	3700	265	28	8.0	1.0	.4589	1	8	55
33-7-11	80	1850	173	31	12.6	7.3	.5530	3	4	58
33-7-35	7	1700	192	22	5.0	9.4	.5330	0	12	14
34-8-22	97	2850	51	59	10.3	6.5	.3388	2	18	61
34-8-22	3	3050	172	35	8.5	6.8	.5611	2	8	35
34-8-22	37	2550	155	61	11.5	5.8	.5804	2	12	47
34-7-11	13	2450	307	56	9.6	5.8	.3523	5	34	42
34-7-11	53	2050	34	76	12.5	6.5	.2661	4	22	74
33-8-12	53	3500	21	59	13.5	6.3	.2712	15	7	77
33-8-1	50	3800	321	54	12.6	4.3	.3198	37	27	32
34-8-22	87	3500	326	47	12.6	3.6	.3293	11	30	60
34-8-22	27	3150	146	68	9.3	6.5	.5731	2	18	31
34-8-15	37	3450	197	43	12.7	4.0	.5679	1	4	65
34-8-10	17	2800	220	45	9.7	6.8	.5510	0	28	30
34-8-10	40	2700	212	32	7.5	6.5	.5430	0	17	28
33-8-1	47	3100	332	68	11.5	7.0	.2639	25	13	51
33-8-2	77	2700	37	38	11.9	8.4	.3592	1	10	70
34-7-1	50	1200	256	29	7.5	11.3	.4896	1	12	27
33-8-2	47	2600	277	63	12.7	9.3	.4336	1	12	63
34-8-32	47	2150	346	70	11.0	7.0	.2389	5	17	71
34-8-29	23	2950	163	57	2.6	--	.5838	34	13	--
34-7-15	83	2600	19	73	11.1	7.6	.2370	5	22	67
34-7-15	20	2750	43	67	9.6	7.1	.3031	19	22	37
34-7-13	47	2700	24	66	12.8	6.5	.2602	19	19	61
33-8-3	97	3300	73	60	11.4	4.0	.4076	4	18	62
33-8-3	43	3300	288	65	10.1	7.4	.3974	11	11	46
33-7-27	100	1350	7	65	13.2	7.4	.2445	1	14	88
34-7-13	90	2000	353	67	12.6	7.6	.2419	0	21	81
34-7-13	13	2400	268	70	7.0	7.0	.4581	13	33	7
33-8-2	97	2700	344	74	12.6	1.8	.2296	13	18	80
33-8-2	93	2650	23	67	13.0	4.0	.2553	4	26	80
34-7-15	60	2300	78	69	9.9	6.0	.4137	8	23	41
34-8-11	10	2850	165	67	11.0	5.0	.5883	1	20	41
34-8-10	70	2050	75	45	11.4	1.8	.4247	1	7	75
34-8-16	33	3000	305	62	10.4	5.6	.3486	24	23	33
34-8-15	83	3000	312	51	11.4	4.0	.3484	3	11	74
34-8-16	30	3700	265	28	8.0	1.0	.4589	1	8	55

[1] Calculated from: Relative stocking percent = 69.633572 - 103.54307 (radiation index) - 1.879096 (temperature index) - 0.706681 (depth A horizon) - 1.147246 (percent rock cover) + 5.173157 (clearcut stocking index).

Appendix II

List of Pertinent Partial Cut Data, by Location

Location (T.R.S.)	Stocking	Elevation	Aspect azimuth	Slope	Partial cut stocking index	Slope aspect index	Surface gravel cover	Estimated[1] relative stocking
	Percent	Feet	Degrees	Percent			Percent	Percent
37-7-11	67	1100	130	27	7.2	52.96	11	57
35-7-15	53	2450	107	10	11.5	53.74	13	84
34-8-27	90	3400	134	17	11.8	54.65	11	86
34-8-10	27	2900	268	24	5.8	46.51	14	47
35-6-7	30	1450	348	24	3.4	49.03	17	34
35-7-1	53	1600	320	73	6.1	38.48	25	48
34-6-31	60	1600	174	46	8.2	51.70	20	65
34-6-31	40	1750	152	47	5.6	53.85	10	48
34-8-10	83	3100	252	30	9.6	42.29	36	77
34-8-10	50	2900	271	28	9.6	45.05	37	74
34-7-13	70	2800	167	58	7.3	51.88	40	64
34-6-7	23	1900	104	40	4.7	41.16	36	43
34-6-29	27	1700	60	48	5.9	22.17	20	40
34-6-17	13	1900	69	35	5.0	32.85	15	37
34-7-25	30	1500	37	54	3.5	19.36	18	24
34-7-23	20	2400	214	65	5.2	31.26	44	44
34-7-23	37	2600	230	61	7.2	27.87	34	53
34-7-33	70	2100	305	47	6.8	44.10	36	57
34-7-25	37	2100	288	66	6.6	33.82	76	60
33-7-29	20	2000	64	46	3.7	24.15	21	27
34-7-23	30	2900	320	59	5.5	42.13	53	52
33-7-35	30	2000	7	40	5.9	37.66	22	46
33-7-35	23	1950	118	36	4.9	47.85	41	48
33-7-27	27	1900	135	37	5.9	52.47	26	52
34-7-15	63	2450	294	65	5.6	36.10	18	43
34-7-1	17	1200	341	49	3.5	42.13	50	39
34-7-3	40	1400	50	21	5.0	41.93	14	40
34-7-9	7	1800	230	66	3.7	25.44	72	38
34-8-33	23	3600	91	44	6.7	33.74	39	53
34-8-32	0	3500	290	56	6.9	37.98	42	56
34-8-3	40	2600	241	37	8.2	38.61	13	59
34-8-3	43	2550	114	43	9.0	44.32	22	68
34-7-35	47	2000	91	55	5.9	27.79	40	46
34-8-21	67	2800	138	36	8.8	53.20	49	75
34-8-21	90	3800	123	37	9.1	49.25	20	70
34-8-16	40	3600	285	33	6.9	45.16	52	61
33-8-11	47	2600	119	52	8.8	44.04	30	68
33-7-13	53	2100	171	60	7.7	50.76	33	64
33-7-13	20	2200	38	65	5.5	11.31	46	39
33-7-13	43	3000	352	58	6.9	35.46	54	58
33-8-1	30	2150	293	61	8.5	37.13	72	72
33-7-27	20	1400	139	44	5.2	52.45	33	50

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[1] Calculated from: Relative stocking percent = -8.414803 + 6.118036 (partial cut stocking index) + 0.369486 (slope/aspect index) - 0.204111 (percent surface gravel cover).

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