

Tree and Understory Responses to Variable-Density Thinning in Western Washington

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ABSTRACT

The Olympic Habitat Development Study was initiated in 1994 to evaluate whether active management in 35- to 70-year-old stands could accelerate development of stand structures and plant and animal communities associated with late-successional forests. The study used a variable-density thinning prescription as the main tool to alter stand structure; the prescription entailed creating gaps and retaining uncut areas, and thinning the remaining forest matrix. We assessed tree damage (primarily windthrow) following thinning, 5-year tree growth, and 3-year vegetation development in control and thinned plots. Windthrow damage was minor in most plots, occurring primarily in stands with high height-to-diameter ratios and located in vulnerable topographic positions. Tree growth responded positively to thinning. In addition, tree growth differed spatially—trees near gaps or along skid trails had better-than-average growth whereas trees near uncut patches had poorer-than-average growth. Understory vegetation responded to thinning with increased percentage of cover and number of herbaceous species in thinned areas and in created gaps. Percentage of cover of mosses and liverworts was greatest in undisturbed areas. Early results indicate that the thinning is operationally feasible and demonstrate that the variable-density thinning increases spatial heterogeneity within the stands.

KEYWORDS: Tree growth, windthrow, implementation, new techniques.

BACKGROUND

The Olympic Habitat Development Study was initiated in 1994 to evaluate whether variable-density thinning and management of coarse woody debris could accelerate development of stand structures and plant and animal communities commonly associated with late-successional (or old-growth) forests. The study is a joint venture of the Olympic National Forest and the Pacific Northwest Research Station (Silviculture and Forest Models team, Resource Management and Productivity Program). Planning for the study also involved participants from the University of Washington, the Washington Department of Natural Resources, the U.S. Fish and Wildlife Service, and the Washington Department of Fish and Wildlife. Plot sizes were selected to be large enough to assess population responses of small mammals. In addition, the treatments manipulating coarse woody

debris were designed specifically to enhance wildlife habitat. Pretreatment surveys of forest-floor small mammals and arboreal rodents were conducted on all plots (Carey and Harrington 2001). Post-treatment surveys of small mammals and arboreal rodents were collected in 2004 in a subset of the plots but that data, and aspects of the study related to coarse woody debris, are not included in this report.

Variable-density thinning is a relatively recent term for thinning in a nonuniform manner, typically with wildlife or biodiversity along with traditional economic objectives. Despite much discussion about the potential of this approach, as well as the implementation of many projects involving variable-density thinning in the western United States and Canada in the last 10 years, little information is available to managers on stand responses. This report provides early findings on treatment implementation, logging damage and

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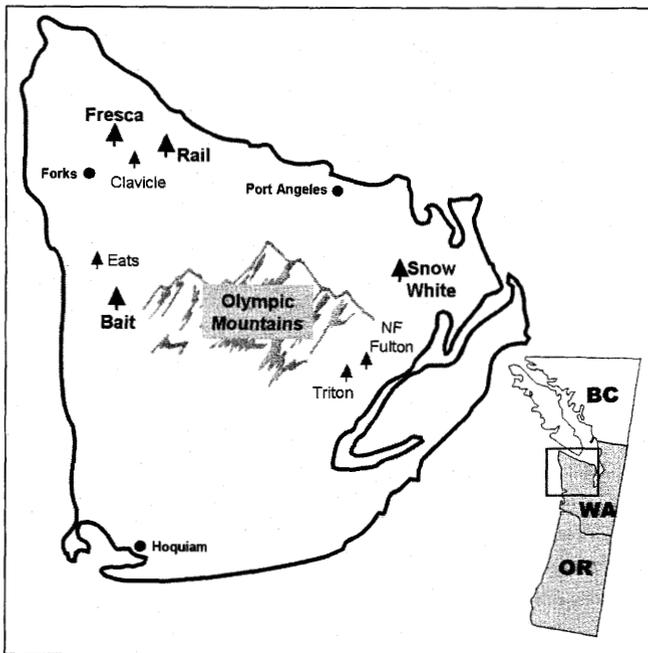


Figure 1—The eight blocks of the Olympic Habitat Development Study (tree symbols) and towns (filled circles) in western Washington. The four locations for which information is presented in this report are represented by the larger symbols.

windthrow following variable-density thinning, tree growth in relation to different components of the thinning, and understory responses.

METHODS

Study Areas

Eight blocks, 50 to 70 ha in size, were selected in 35- to 70-year-old conifer stands on the Olympic National Forest in western Washington (fig. 1). Four or five, 6.5- to 9-ha plots were located in each block such that the plots were similar in forest condition and were buffered to avoid major changes in forest cover adjacent to their boundaries. This report covers responses for four blocks that were treated between 1997 and 2000.

The four blocks differed physiographically from broad flat river valleys at low elevations (150 to 300 m) to steep (>50 percent slope) side hills at higher elevations (580 m) (table 1). Soils were generally silty or sandy loams. Mean annual precipitation ranges from 145 to about 320 cm, with wet winters and dry summers.

Table 1—Site and stand characteristics for the first four blocks thinned in the Olympic Habitat Development Study^a

| Block | Elevation | Annual precipitation ^b | Primary tree species | Stocking | Basal area |
|------------|-----------|-----------------------------------|-------------------------------|---------------------|--------------------------------------|
| | <i>m</i> | <i>cm</i> | | <i>Trees per ha</i> | <i>m².ha⁻¹</i> |
| Bait | 190-335 | 317.5 | Western hemlock, Douglas-fir | 1095 | 63 |
| Fresca | 150 | 265 | Western hemlock, Sitka spruce | 585 | 63 |
| Rail | 275 | 239 | Douglas-fir, Western hemlock | 360 | 46 |
| Snow White | 430-580 | 145-195 | Douglas-fir | 709 | 45 |

^a Stand characteristics based on pretreatment surveys.

^b Annual precipitation estimates based on the parameter-elevation regressions on independent slopes model (PRISM) (U.S. Department of Agriculture Natural Resources Conservation Service et al. 1999).

The blocks differed in initial stand density and basal area (table 1). Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) were present on all plot although they were not necessarily the major species; Sitka spruce (*Picea sitchensis* (Bong.) Carr.), western redcedar (*Thuja plicata* Donn ex D. Don), Pacific silver fir (*Abies amabilis* Dougl. ex Forbes), red alder (*Alnus rubra* Bong.), and big-leaf maple (*Acer macrophyllum* Pursh) were locally common but generally present as minor species or only present at a few plots. Two blocks (Snow White and Bait) had been planted with Douglas-fir, but both also had substantial amounts of naturally regenerated western hemlock. One of the blocks (Bait) had been precommercially thinned, which reduced species diversity and stocking, but the stands still had fairly high stocking levels when the study began. Two other blocks (Snow White and Rail) had been commercially thinned prior to the implementation of the study, but because the thinning at Snow White occurred a fairly long time ago (in the early 1970s), and the sanitation thinning at Rail (in 1986) removed relatively little basal area, these past activities were mostly evident only by the presence of old skid trails.

Treatments

The variable-density thinning prescription designed for this study called for a series of skips (untreated patches that were “skipped over” during the thinning operation) and gaps (stand openings) to be embedded within a thinned matrix (fig. 2). We call this prescription “thinning with skips and gaps.” The skips were about 0.1 to 0.3 ha and covered 10 percent of the plot area. Skips were located to preserve as many large-diameter snags as possible with the proviso that a maximum of one skip was retained in each quarter of the plot (about one per 2.0 ha). Equipment entry was not allowed in the skips, and gaps were placed at least 20 m from the skips, thus maintaining the skips as areas within the stand with minimal disturbance. Gaps were openings 0.04 to 0.05 ha and covered 15 percent of the plot area; existing gaps associated with pockets of root rot or with past thinning operations were included in the 15 percent. All merchantable stems (> 20 cm diameter at breast height (d.b.h.)) were removed from gaps with the exception of species of low local abundance (e.g., hardwoods, western redcedar, and Pacific silver fir). The matrix, covering the remaining 75 percent of the treatment area, was thinned by removing 25 percent of the stand basal area, primarily from the lower crown classes.

Each block consisted of one uncut control plot and three or four plots that received the same variable-density thinning prescription but differed in the degree of clumping of

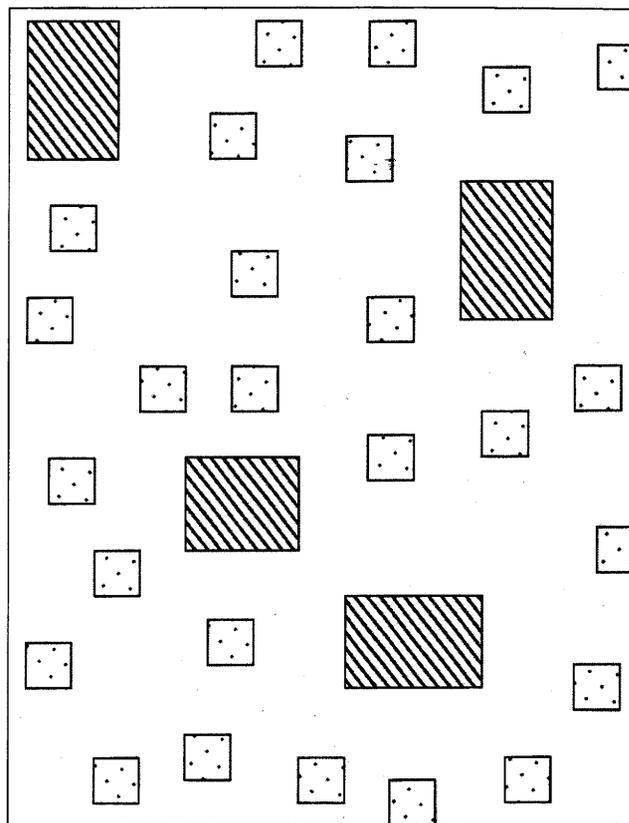


Figure 2—Example of distribution of unthinned skips (dotted areas) and gaps (diagonal lines) at one of the variably thinned plots in the Olympic Habitat Development Study.

residual logs and slash (see Reutebuch et al. 2002 for details). Skips, gaps, and trees to be cut were predesignated, subsequently evaluated, and, if necessary, corrected for adherence to the research prescription. Each block was part of a separate timber sale with additional volume from other stands outside the study plots included in most of the sales. No special restrictions (other than no-equipment entry within skips) were added to the contracts. To facilitate timely implementation of the study, the contracts generally had a 2-year life; however, depressed timber markets and changes in environmental regulations, caused thinning to be considerably delayed. The first two blocks (Fresca and Rail) were thinned in 1997, and the second two blocks (Bait and Snow White) were thinned in 1999 and 2000. By 2004, six of the eight study blocks had been thinned.

Tree and Other Plant Measurements

Eighteen plots were surveyed for logging and wind damage three winters after thinning was completed (most windthrow in this area occurs during winter when soils are saturated and windspeeds are high). Damaged trees were coded as to type of damage and measured for diameter; these

data along with tree position were then entered into a geographic information system. Damage levels were assessed in relation to species, topographic position, and location in relation to components of the thinning treatments. Damage was also related to pretreatment stand information including basal area and heights of dominant trees. Five-year tree growth was assessed on 1.44-ha stem-mapped plots. Growth plots were positioned to include two gaps and all, or portions of, two skips. Plots were measured during the dormant season immediately after completion of the thinning, and at Fresca and Rail, were measured again 5 years later. All trees taller than 1.3 m were initially measured and their location mapped. Due to large numbers of ingrowth trees in some areas, a separate subsample of regeneration and ingrowth was initiated at the 5-year remeasurement. The 5-year remeasurement data for the two stem-mapped plots were used to summarize tree growth for the entire stem-mapped plot, by species, by treatment components within the stem-mapped plot (i.e., skips versus thinned areas), and in relation to distance from skid trails and internal edges created by the treatments. The 5-year remeasurement of the stem-mapped plots at Bait and Snow White is scheduled for winter 2004/2005. Data from the 5-year regeneration and ingrowth subsampling are available from all four areas.

Pretreatment vegetation surveys included four types of subplots to accommodate different size categories of vegetation including herbaceous plants, shrubs, seedlings, saplings, overstory trees, mosses, and lichens. Transects 10 m long were used to record larger understory vegetation including ferns and nontrailing woody shrubs. Three 0.1-m² plots were placed along each transect to assess percentage of cover of smaller plants, mosses, and other features. Circular plots (5.64- and 2.0-m radius) were used to sample overstory and understory trees as well as lichens. In total, 39 transects and 78, 0.1-m² plots were sampled within each plot. Additional vegetation sampling was conducted within the stem-mapped plot at each site and purposefully placed in areas that would be exposed to different treatments.

Post-treatment assessments concentrated on control plots and the thinned plots containing the stem-mapped areas. Although fewer total plots were sampled post-treatment, sampling intensity was increased to capture the anticipated differentiation of the understory. In addition, sampling methods were simplified by eliminating measurements along transects and including all understory components within the 5.64-m fixed-radius plot. The plot size for cover assessments for the smaller plants, mosses, and ground features was increased to 0.4 m². Vegetation data were summarized for the control plot and separately for the three

subtreatment components of the thinned plots (skips, thinned matrix, and gaps).

RESULTS AND DISCUSSION

Implementation of Variable-Density Thinning

The experimental prescription was implemented with only minor problems. Variable-density thinning increased the variability in volume removed per cruise plot and thus necessitated an increase in the number of cruise plots per unit area. Stratified sampling partially compensated for this, but more resources for timber cruising were still needed to meet the accuracy standard for lump-sum sales.

Some loggers were initially ill-informed of contract requirements and expressed concern about restrictions associated with the research function or the different type of prescription. They quickly realized, however, that the prescription was not difficult to implement. In some areas, more trees adjacent to the skid trails were removed than anticipated (as approved by the timber sale administrator to facilitate operations). In other areas, some marked trees were left uncut owing to poor markets, but overall, the prescription was implemented as designed.

In a uniform thinning operation, it can be difficult to fell trees in dense stands; however, the presence of gaps in the variable-density thinning facilitated the felling of trees in the gaps and in the thinned matrix. Because the thinning in the matrix area was a light, low thinning, most of the larger trees felled were in gaps or removed as part of skid trail installation. On blocks where ground-based equipment was used, gaps did receive more equipment traffic than the thinned matrix because of greater volume removal. In addition, owing to the relative contribution of gaps to the overall volume removed, skid trails were generally routed through or along the edges of the gaps. Gaps were also frequently used as temporary log decking areas.

No equipment was allowed in the skips which in some cases forced operators to make sharp turns or reverse logging equipment when reaching the skip boundary. Rutting caused by the turning of equipment was generally shallow, becoming inconspicuous within a few years following thinning.

Damage Associated With Thinning

Logging damage was generally low (table 2). Activities were halted when soils became too wet to continue without risking major rutting and compaction, or where specific equipment or practices were resulting in damage to residual trees or soil. The usual branch breakage and occasional stem

Table 2—Logging damage in stem-mapped plots at four blocks of the Olympic Habitat Development Study

| Block | Any Damage | Severely damaged ^a |
|------------|----------------------------|-------------------------------|
| | <i>Percentage of trees</i> | |
| Bait | 0.3 | 0.0 |
| Fresca | 4.2 | .2 |
| Rail | 4.3 | .1 |
| Snow White | 4.5 | 1.6 |

^a Severely damaged trees were those with very poor growth potential or substantially reduced economic value.

scarring associated with timber falling and extraction were observed, but few trees were affected overall. Removal of bark on the lower bole and exposure or damage to shallow roots were the most common forms of damage observed. Small trees and shrubs were often pushed over by equipment; a timber sale administrator referred to trees less than 15 cm as “like air” to the loggers, implying that they did not see them or were not concerned about running over them. Thus, in some areas with substantial advanced regeneration, many small stems were destroyed in the harvest operation. This was expected and may have been desirable in areas that had prolific advanced regeneration of western hemlock prior to thinning (see below for information on tree regeneration). Falling branches from overstory trees also damaged some residual understory and midstory trees, resulting in top or branch breakage or stem scarring. Large shrubs were also commonly knocked over; some were killed, whereas others resprouted.

Overall, logging damage to the residual timber and soils was low. Some additional restrictions are advisable, however, if understory and midstory trees or large shrubs are desired to meet specific objectives. For example, Wender et al. (2004) suggested that some large shrubs be protected if fruit production is critical.

Wind Damage

Wind-related damage differed substantially from plot to plot across blocks (fig. 3). In terms of total number of wind-damaged stems per hectare, only 1 of the 14 thinned plots had moderate to heavy damage (>50 trees damaged per hectare), 2 of the thinned plots had minor to moderate damage (20 to 25 trees per

hectare), and damage at the other 11 thinned plots and the 4 control plots was very minor (fewer than 5 trees per hectare). Only two plots (one at Bait and one at Fresca) had more than 10 trees per hectare greater than 20 cm in diameter damaged by wind following thinning. Damage was observed to individual trees as well as groups of trees. Damage was occasionally clumped as one tree would fall into a second or third tree and a whole group would come down. Some smaller trees were bowed over and some trees snapped off; however, the majority of wind-related damage was windthrow where all or a portion of the root system was pulled out of the ground.

Stand height-to-diameter ratio (H:D) (as estimated from trees measured to calculate site index prior to thinning) appeared to play a role in predisposing stands to wind damage (table 3). Stands with higher H:D values experienced the most damage. The timing of the thinning in relation to major windstorms also appeared to affect severity of damage. One plot at Bait had very little wind damage even though it had the same H:D ratio (80) and was in a very similar topographic position as the two plots in the block that had the most damage. The plot with little damage was thinned several months after the other plots in the block, thereby avoiding a major windstorm that occurred while the other plots were being thinned. The greatest wind damage generally occurred along skid trails and adjacent to gaps located on ridgetops (Bait) or on a small hill where wind funneled down a river corridor (Fresca). Most wind-damaged trees were western hemlock, but because we did not

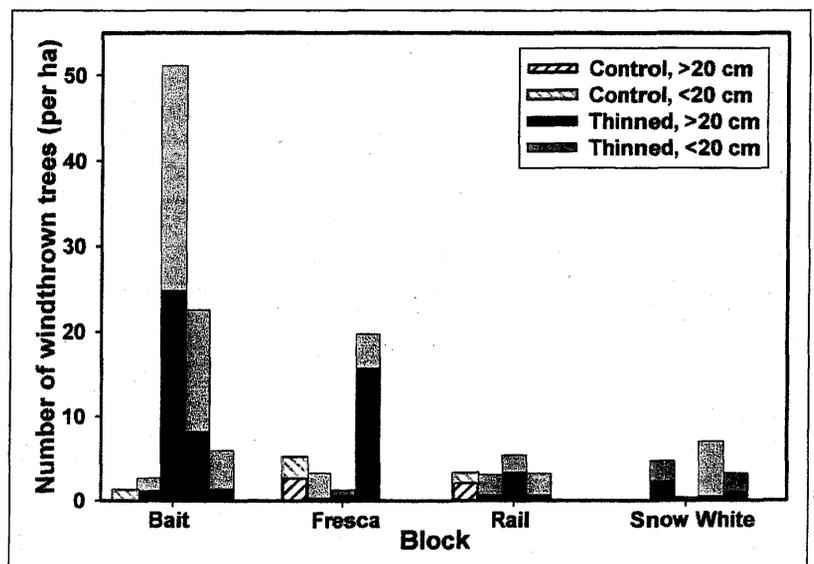


Figure 3—Number of windthrown stems per hectare less than or greater than 20 cm for 4 control plots and 14 variably thinned plots in the Olympic Habitat Development Study. There was 1 control plot and 3 or 4 thinned plots at each block. At Snow White, no windthrow occurred in the control plot.

Table 3—Percentage of thinned plots by level of wind damage and height-to-diameter ratio^a

| Height-to-diameter-ratio | Level of wind damage ^b | |
|--------------------------|--|------------------|
| | >5 trees per ha | >20 trees per ha |
| | <i>Percentage of plots with damage</i> | |
| <65 | 0 | 0 |
| 65-75 | 17 | 0 |
| >75 | 100 | 67 |

^a Based on trees used to calculate site index prior to thinning.

^b Based on 14 thinned plots assessed 3 years after variable-density thinning.

have detailed information on species occurrence by diameter class on each plot, it was not possible to say whether hemlock was more susceptible or simply more prevalent.

Windthrow can be an undesirable side effect of thinning, especially during the first 3 to 5 years following treatment (Cremer et al. 1982). This study did not include uniformly thinned stands so we cannot test differences in windthrow between uniform and nonuniform thinning treatments—but it does not appear that the variable-density thinning prescription, by itself, resulted in greater risk of wind damage. Rather, the factors that commonly predispose thinned stands to windthrow, such as high H:D ratio and topographic position, were involved. Results suggest that if variable-density thinning is to be imposed on high-risk stands in the future, windthrow could be minimized by locating gaps, skid trails, and landings on ridgetop positions where feasible. If that is not possible, gaps could be eliminated or made smaller during the first entry. Earlier thinning entries would also reduce risk by lowering H:D ratios; thus, managers may wish to prioritize stands for earlier thinning if they are in high-risk topographic positions or have high stem densities likely to result in high H:D ratios. Although we were somewhat disappointed at the level of windthrow in the 3 stands that lost more than 10 trees per hectare, even these stands at present retain adequate stocking to meet the original management objectives. In addition, the greater loading of coarse woody debris and increased spatial variability of tree distribution resulting from windthrow are both characteristics consistent with the overall management objectives for this prescription.

Tree Growth

Tree growth in the two stem-mapped plots with 5-year post-treatment data responded positively to the variable-density thinning with increased diameter growth. Although this may seem like an obvious conclusion, we were not sure if these older stands (60+ years old) would respond to

a light thinning in such a short period. In the Fresca block, tree growth also differed by spatial position—trees near gaps or along skid trails had better growth than those farther away, whereas trees near skips had poorer growth than those farther away (fig. 4). These spatial-position effects were not significant at Rail (fig. 4). Fresca had no previous thinning history; however, Rail had received a light thinning 11 years earlier; the recency of the earlier thinning at Rail may have reduced the treatment response. Certainly the general patterns of growth response at Rail between trees greater than or less than 10 m from a gap or skip are consistent with those observed at Fresca.

Where information is lacking concerning the effects of variable-density thinning on tree and stand growth, one option for managers is to estimate the proportion of stand area in each treatment category, predict the growth for that category, and sum the growth for the whole area. This approach assumes there are no effects associated with internal edges created by the thinning treatment. Based on the responses observed at Fresca, we predicted the estimation errors in basal area growth that might occur under three scenarios of patch sizes and relative stand proportions in skips or gaps. Given a scenario of 15 percent of the stand in 0.05-ha gaps and 10 percent of the stand in 0.5 ha skips, basal area growth within the thinned matrix would be underestimated by 13 percent. In a second scenario, if 25 percent of the stand was in 0.05-ha gaps and no skips were present, growth in the thinned matrix would be underestimated by 20 percent. In a third scenario of no gaps and 25 percent of the stand in 0.25-ha skips, growth in the thinned matrix would be overestimated by 5 percent. Thus, the magnitude of the over- or under-estimation of stand growth will depend on the spatial extent and distribution of the various thinning components.

Understory Vegetation

Understory vegetation increased in coverage in almost all treatments and subtreatments; that is, it increased in all four blocks where vegetation was measured from year 0 to 3, and again in the two blocks where vegetation was measured from year 3 to 7. The control plot at Bait was the only plot where coverage declined from year 0 to year 3. Although differences in sample size, protocols, and personnel may have increased variability in the vegetation data, we suspect that the main reason for the general increases in coverage were overstory crown damage associated with several widespread winter storms in western Washington. These storms would have broken branches and tops, thus, resulting in greater light reaching the understory. Four winter storms were recorded in 1996; this was prior to the implementation of any of the thinnings but would have affected understory

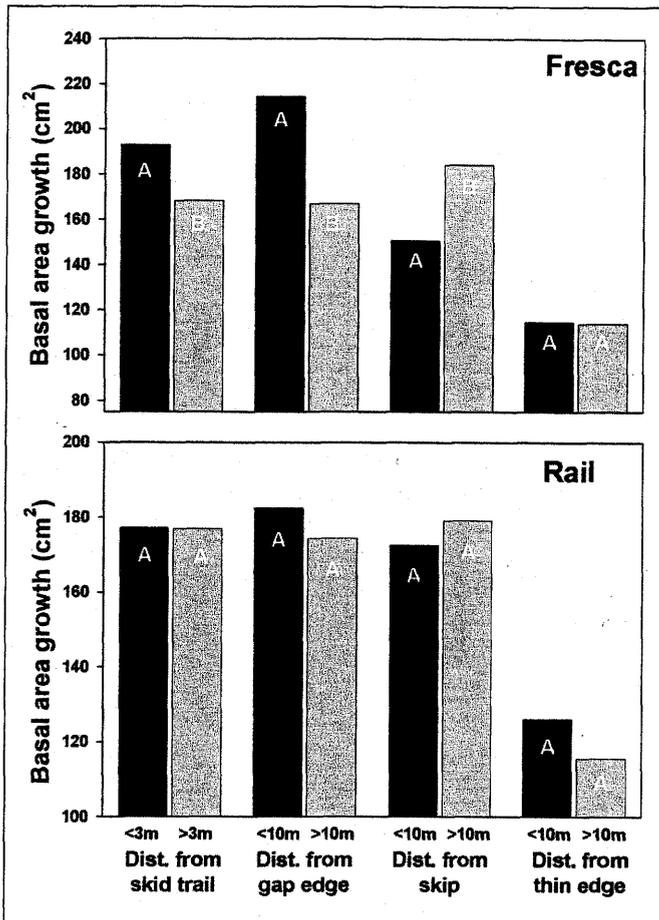


Figure 4—Mean basal area growth per tree by category indicating if trees were within 3 m of a skid trail, or within 10 m of a gap, an unthinned skip, or the thinned matrix. Paired bars with the same letters did not differ at $p = 0.05$.

response in the 1997 to 2000 time period (year 0 to year 3 for Fresca and Rail). Three other major snow and ice storms (in winter and spring 2002 and Jan 2004) could also have affected results between years 3 and 7 at Fresca and Rail.

In addition to the apparently weather-associated increases in understory coverage, the thinning also increased light to the understory and further enhanced understory development in the thinned matrix and the gaps (fig. 5). In the future, we would expect additional increases in the coverage of some species, especially in the gaps; however, if there is an extended period without major storms, crown closure will cause a reduction in percent coverage of some shade-intolerant species.

The pattern of the number of herbaceous species present was similar to the percentage of coverage. That is, there was a general overall increase from year 0 to 3 and again from year 3 to 7, and the greatest increase in number of

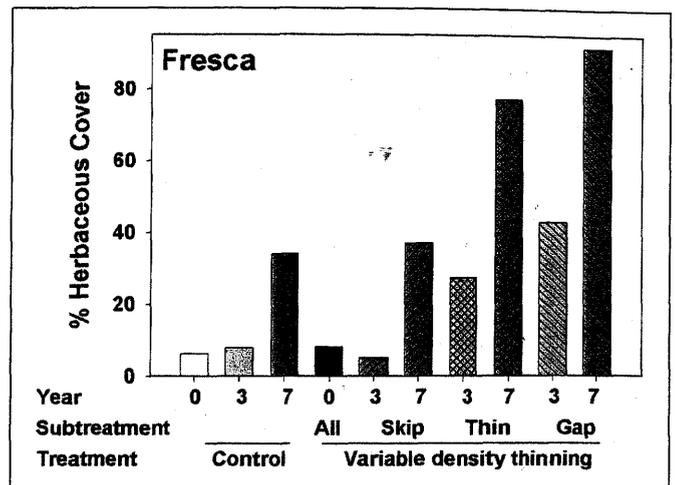


Figure 5—Percentage of cover of herbaceous species prior to thinning and 3 and 7 years after thinning by treatment and subtreatment at Fresca.

species occurred within the more disturbed areas of the thinned plot. For example, the number of herbaceous species within the control plot at Fresca went from 12 to 14 within the first 7 years, whereas the number of species in the gaps of the variable-density thinning increased from 11 to 27 within the same period.

Introduced species were present at all sites and were more prevalent in the thinned and gap subtreatments than in the skips or control plots (fig. 6). All of the introduced species are herbaceous except one, *Rubus laciniatus*, which is a shrub.

The response in the percent coverage of shrubs has been slower than that of herbaceous species and more variable over the four sites assessed. Stands with more initial shrub cover retained higher cover despite whatever damage was sustained in the winter storms or during the logging process, and coverage is generally increasing over time.

Percentage of cover of mosses and liverworts (fig. 7) was least at the one block measured on the east side of the peninsula (Snow White), possibly because this block receives significantly less annual precipitation than the other three blocks (table 1). Coverage of mosses and liverworts was greatest at all blocks in the undisturbed areas (control plots and skips).

Spatial distribution of herbaceous and shrub coverage differs in both control and variably thinned plots, but the rate of differentiation is greater in the thinned plots than in the control plot (fig. 8). The differentiation in the control plots reflects the changes in canopy cover (presumably due,

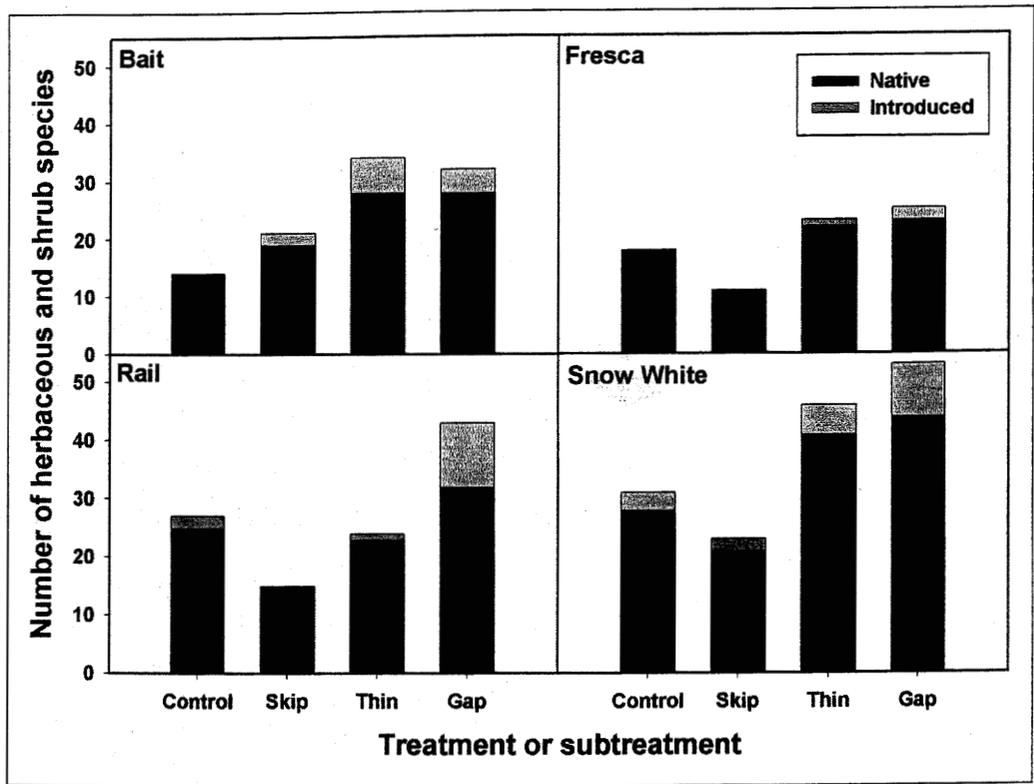


Figure 6—Number of native and introduced herbaceous and shrub species on control (unthinned) and variably thinned (skip, gap and thinned matrix) plots 3 years after thinning. The total number of species is divided into native and introduced species.

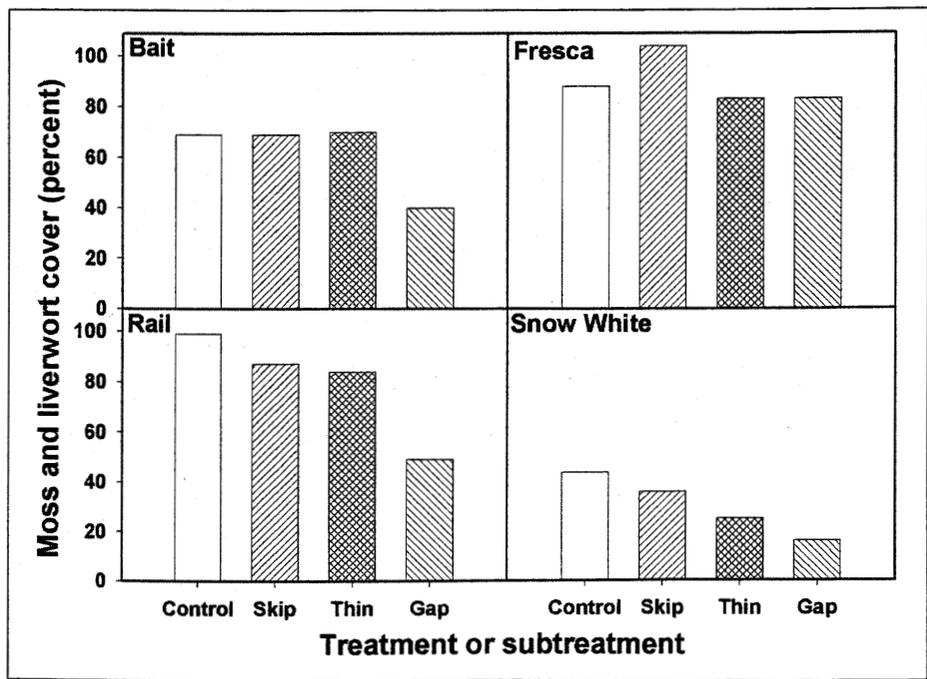


Figure 7—Percentage of cover of moss and liverworts 3 years after thinning by treatment and subtreatment at four blocks of the Olympic Habitat Development Study.

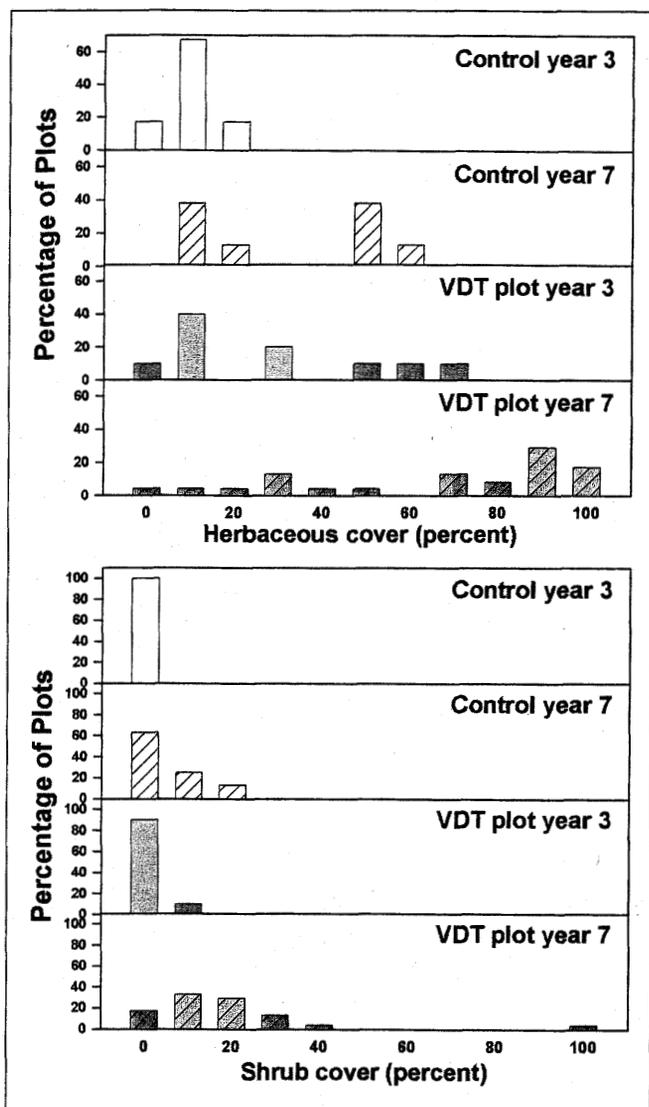


Figure 8—Change in distribution of herbaceous and shrub species cover on a control plot and variably thinned plot 3 to 7 years after treatment at Fresca.

in part, to crown damage associated with winter storms as discussed above) whereas the differentiation in the thinned plots reflects the much greater treatment-imposed variability in overstory cover.

Numbers of seedlings and saplings taller than 25 cm did not follow consistent patterns across the components of thinning at the four blocks (table 4). This may be due to natural variation or may reflect different stand histories at the four blocks. Stand densities at Bait and Fresca were high prior to thinning; thus, it makes sense that the most regeneration occurred in either gaps or the thinned matrix.

The 1986 thinning at Rail (11 years prior to the variable-density thinning) resulted in substantial development of hemlock seedlings throughout the area. Thus, the numbers for the skips at Rail represent 16 years of development of regeneration rather than 5. The variable-density thinning at Rail destroyed much of this advanced regeneration on a portion of the plot as seen by the much lower numbers for the gaps and thinned matrix. Snow White had been thinned between 1971 and 1973, and regeneration that developed following the earlier thinning had already grown into the understory and midstory strata and may have effectively precluded development of additional regeneration. Most regeneration on all four sites was western hemlock, but Douglas-fir, western redcedar, Sitka spruce, and cascara buckthorn (*Rhamnus purshiana* DC.) were also present.

MANAGEMENT IMPLICATIONS

There are many possible patterns and approaches to variable-density thinning prescriptions. The appropriate approach for use in a particular situation will depend on stand characteristics, landscape conditions, and management objectives. Thinning with skips and gaps is more complicated than some other prescriptions because there are three stand components to monitor. This type of prescription, which includes the maximum range of stand density from openings to unthinned patches, will likely result in greater heterogeneity than prescriptions that simply vary thinning intensity. No research is yet available to demonstrate whether the additional complexity is warranted for specific stand types or management objectives. We do know, however, that the prescription was easy for loggers to implement, and it did protect snags and other resources in the skips.

Early results from this study demonstrate that the variable-density thinning is increasing spatial heterogeneity in stand density and tree growth as well as heterogeneity in understory vegetation within the stands. Measurements from additional blocks as they develop following treatment, and long-term measurements on all blocks will help determine how universal the treatment responses are and how long they last. In addition, as a major rationale for the study was to examine treatment effects on wildlife habitat, future surveys should assess wildlife response. (In 2004, 8 of the original 36 plots were surveyed for the small mammals for the first time since treatment implementation.)

Future entries into these stands could remove additional overstory trees or possibly thin the developing understory. Possible future treatments might include rethinning the

Table 4—Density of regeneration taller than 25 cm at four blocks 5 years following variable-density thinning

| Block | Skip | Thin | Gap | Treatment mean |
|------------|-------------------------------|--------|--------|----------------|
| | <i>Number of trees per ha</i> | | | |
| Bait | 3,272 | 12,544 | 10,469 | 9,524 |
| Fresca | 9,903 | 1,924 | 17,118 | 7,357 |
| Rail | 149,353 | 73,021 | 60,243 | 90,623 |
| Snow White | 4,679 | 4,297 | 1,981 | 3,897 |

matrix; increasing gap size (for a subset of gaps); releasing (thinning around) individual overstory, midstory, or under-story trees; and augmenting snags and large down wood. Managers should continue to try new methods, as it is unlikely a “one-size-fits all” variable-density thinning prescription will meet all objectives.

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