# Short-term Responses of Overstory and Understory Vegetation to Thinning Treatments: A Tale of Two Studies

**Klaus J. Puettmann, Erich K. Dodson, Adrian Ares, and Carrie A. Berger**

## Abstract

The Density Management Study and Young Stand Thinning and Diversity Study were initiated to investigate whether alternative thinning treatments can accelerate the development of forests toward late-successional structures. An overview of overstory and understory vegetation responses indicates that the magnitude and direction of thinning effects initially varied among structural stand components. Average crown length, diameter growth, and seedling and sapling density increased rapidly after thinning. However, diameter growth of the largest trees was less responsive to thinning, at least in the short term. Overall shrub cover was initially reduced by thinning, which was likely a consequence of harvesting damage. Thinning tended to increase overall species diversity by benefitting early-successional species, and had little influence on late-successional species diversity. This trend appeared to reverse itself quickly, as early-seral vegetation declined within a decade. It appears that silvicultural treatments may best target specific stand structural components, e.g., large trees, crown length, or an understory shrub layer, rather than attempting to achieve all late-successional structural elements simultaneously. Increasing variability at smaller and larger spatial scales may be an option to achieve multiple management goals.

**Keywords:** Thinning, late-successional habitat, Douglas-fir, overstory, understory vegetation, regeneration.

## Introduction

The dispute about management of federal forest land resulted in the Northwest Forest Plan in 1994, which emphasized development of late-successional habitats in a context of sustainable wood production. Concurrently, new research indicated that many old-growth stands in western Oregon had originated at densities that were substantially lower than densities found in current Douglas-fir (*Pseudotsuga menziesii*) plantations (Tappeiner et al. 1997). The effect of thinning on tree growth and timber production had been well researched (e.g., Marshall and Curtis 2002). Lacking, however, was information on the potential for thinning (or uneven-age management) to balance wood production with ecological concerns, such as wildlife habitat and biodiversity. Of specific interest to federal foresters were forest structures associated with late-successional habitat features (Bauhus et al. 2009), such as large trees, a layered canopy, advanced regeneration, and well-developed

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understory layers (Old Growth Definition Task Group 1986). As a consequence, several studies were initiated in the western portion of the Pacific Northwest region to investigate whether thinning young, even-aged stands dominated by Douglas-fir can accelerate the development of late-successional forest structures (Poage and Anderson 2007). We present results from the first decade of two Large-scale Management Studies (Monserud 2002): 1) the Density Management Study (DMS); and 2) the Young Stand Thinning and Diversity Study (YSTDS), which were established in the Coast Range and western Cascades of Oregon.

The main objective of this paper is to present a brief overview of findings regarding the vegetation response to various thinning treatments applied in the two studies. Specifically, we present responses of overstory trees, including tree and stand growth patterns, tree mortality, and overstory canopy closure. Understory responses include seedling and sapling densities, as well as cover and composition of understory vegetation, separated by life-form (tall shrubs, low shrubs, herbs, and bryophytes) and origin (exotic species). We present up-to-date findings from the two studies, including previously unpublished results. Findings already published are highlighted by referring to the appropriate publications, where detailed findings, methods, and discussions can be found.

## Methods

### Study Sites and Treatments

To represent the variety of conditions in the Bureau of Land Management (BLM) ownership in Oregon, the DMS includes study sites in the Coast Range and western Cascades of Oregon. Study details are described in Cissel et al. (2006). Seven 40- to 60-year-old stands (between 100 and 150 ha in size) that had never been commercially thinned were selected, and each stand received one complete set of treatments. Treatment units ranged from 15 to 40 ha and included an unthinned control treatment (approximately 600 trees per hectare [tph]), a high-density retention (around 300 tph), a moderate-density retention (200 tph) and a variable retention which included areas with 100, 200, and 300 tph. For interpretation of average treatment conditions, it is important to note that 4 to 18 percent of the unit in all thinning treatments was reserved in circular leave islands (0.1-, 0.2-, and 0.4-ha). In addition, 4 to 18 percent of the moderate- and variable-density treatments were cut as circular gap openings (0.1-, 0.2-, and 0.4-ha). Units with 100 tph and the gap openings were planted with a mix of conifer species. Thinning was implemented between 1997 and 2000, and data described in this report were taken 6 and 11 years after the thinning operation. More detailed results from these studies can be found in Fahey and Puettmann (2007, 2008), Wilson and Puettmann (2007), Kuehne and Puettmann (2008), Ares et al. (2009, 2010), Wilson et al. (2009), Dodson et al. (2012), and Berger et al. (2012).

The YSTDS is located on the McKenzie and Middle Fork Ranger Districts of the Willamette National Forest on the western slopes of the Oregon Cascade Range. Four stands between the ages of 35 and 50 years that were dominated by even-aged Douglas-fir were selected. Each stand received a set of thinning treatments, which included an unthinned control (C; approximately 700 tph), a heavy thin (HT; 125 tph), a light thin (LT; 250 tph), and an additional light thin, in which 20 percent of the unit was cut in circular 0.2-ha gaps (LG). The heavy thin and the gaps in the light thin with gaps were planted with a mix of conifer species. The thinning was implemented between 1994 and 1997 (mostly 1995 and 1996) and the data described in this report are from measurements 1, 3, 5, and 10 years after thinning. More detail about the study establishment can be found in Manning and Friesen (in prep.[1]). Detailed results from this study are provided by Berger and Puettmann (2007), Davis et al. (2007), Kuehne and Puettmann (2008), and

Davis and Puettmann (2009).

Both studies generally used a thinning from below, but hardwoods and other minority species were maintained wherever possible. Conditions such as slope and aspect varied widely among the study sites and treatment units, and also within the treatment units. This resulted in large within-treatment variation in tree densities and other conditions (Cissel et al. 2006). The studies were implemented using operational timber sales, and variation in terrain and logging operators led to the use of both cable and ground-based harvest systems within several individual treatments. This increased the variability within individual treatment blocks compared to the homogeneity that can be achieved in small experimental units. However, this also means that the study includes many issues associated with operational treatments and results do not have to be scaled up, as is commonly done with small experimental plots.

### Measurements and Analysis

The DMS sampling protocol is presented in Cissel et al. (2006). The sampling design for over-and understory vegetation of the YSTDS is presented in Davis et al. (2007) and Davis and Puettmann (2009). For the presentation below, mean values of each treatment unit in the YSTDS were calculated by averaging the plot means, with the exception of the treatment units that included gaps. A weighted average of sub-treatment (gap, edge, interior forest) means was used to calculate these treatment unit means. Weights for each sub-treatment were based on the proportion of areas in each sub-treatment to total treatment units (Davis et al. 2007).

The statistical analysis of the YSTDS data presented below used ANOVAs with a randomized complete block model in conjunction with the Tukey-Kramer adjustment for all multiple comparisons (PROC GLM). Data aggregated to the treatment unit level (n = 16 treatment units) were approximately normal; therefore, no transformations were performed. Significance level in the analysis and figures below indicate $P \leq 0.05$. Analysis procedures for the DMS varied, but are described in detail in the publications.

[1]Manning, T.; Friesen, C., eds. [n.d.] The Young Stand Thinning and Diversity Study establishment report and study plan. Manuscript in preparation.

## Results and Discussion

### Overstory Responses

Stand growth patterns showed inconsistent responses. Overall, basal area after thinning was reduced in both studies. Basal area growth for the measurement interval from 5 to 10 years after thinning in the YSTDS averaged 86, 73, and 88 percent of control for the Heavy, Light, and Light with Gap treatments, respectively (table 1). Note, that these values were not significantly different from each other, and the low basal area growth in the Light treatment is mainly due to a single site (Mill Creek). In the DMS study, basal area growth 6 to 11 years after thinning was not significantly different from the controls (Dodson et al. 2012). Such discrepancies may be due to a combination of variability in age, site quality, and associated ability of trees to respond to canopy openings. Douglas-fir can maintain stand growth under a relatively wide density range (Marshall and Curtis 2002), and little impact would be expected in the lower-intensity thinnings. Apparently, such effects in conjunction with site variability did not allow detection of statistically significant differences.

Diameter growth showed a consistent response in both studies. Average diameter growth of trees increased after thinning (table 2, also Dodson et al. 2012). This is due to a combination of the removal of slower-growing trees by thinning from below (i.e., the chainsaw effect), as well as improved growing conditions for residual trees. A more detailed analysis suggested that smaller trees especially benefitted from thinning by increasing their growth rate. The largest trees were growing faster prior to thinning and did not experience as large an increase in growth rates as smaller trees

**Table 1**—Mean basal area ($m^2 \cdot ha^{-1}$) for all trees ≥8 cm dbh in post-treatment years 1, 3, 5, and 10. Data are from the Young Stand Thinning and Diversity Study.

| | | Mean basal area for all trees ≥8 cm dbh ($m^2 \cdot ha^{-1}$) | | | |
|---|---|---|---|---|---|
| **Block** | **Treatment** | 1997 | 1999 | 2001 | 2006 |
| Cougar Reservoir (CR) | Control | 39.8 | 45.0 | 47.2 | 51.4 |
| | Heavy thin | 13.2 | 15.7 | 17.5 | 22.3 |
| | Light thin | 24.6 | 27.6 | 29.6 | 35.6 |
| | Light thin with gaps | 17.6 | 20.5 | 22.9 | 27.3 |
| Mill Creek (MC) | Control | 46.7 | 50.3 | 52.5 | 56.3 |
| | Heavy thin | 21.1 | 23.2 | 24.9 | 25.0 |
| | Light thin | 31.5 | 33.7 | 35.6 | 35.3 |
| | Light thin with gaps | 27.0 | 29.7 | 29.4 | 30.0 |
| Christy Flats (CF) | Control | 53.2 | 55.1 | 56.4 | 61.6 |
| | Heavy thin | 14.4 | 15.4 | 16.8 | 20.7 |
| | Light thin | 20.8 | 21.9 | 23.5 | 27.8 |
| | Light thin with gaps | 19.1 | 20.2 | 21.9 | 25.6 |
| Sidewalk Creek (SC) | Control | 38.7 | 39.7 | 41.0 | 41.5 |
| | Heavy thin | 11.8 | 13.3 | 14.6 | 17.6 |
| | Light thin | 20.4 | 22.0 | 23.4 | 25.4 |
| | Light thin with gaps | 15.4 | 16.8 | 18.0 | 19.4 |

**Table 2**—Mean dbh (cm) for all trees ≥8 cm dbh in post-treatment years 1, 3, 5, and 10. Data are from the Young Stand Thinning and Diversity Study.

| | | Mean dbh for all trees ≥8 cm dbh (cm) | | | |
|---|---|---|---|---|---|
| **Block** | **Treatment** | 1997 | 1999 | 2001 | 2006 |
| Cougar Reservoir (CR) | Control | 24.3 | 25.8 | 26.8 | 28.5 |
| | Heavy thin | 31.1 | 31.6 | 32.5 | 33.1 |
| | Light thin | 29.0 | 30.7 | 31.8 | 33.7 |
| | Light thin with gaps | 29.8 | 31.3 | 32.2 | 31.9 |
| Mill Creek (MC) | Control | 26.8 | 28.7 | 29.9 | 31.4 |
| | Heavy thin | 26.9 | 27.8 | 28.5 | 30.3 |
| | Light thin | 27.8 | 28.9 | 29.6 | 30.9 |
| | Light thin with gaps | 26.9 | 27.5 | 27.9 | 28.4 |
| Christy Flats (CF) | Control | 25.5 | 27.2 | 29.1 | 30.3 |
| | Heavy thin | 35.2 | 36.6 | 38.7 | 40.6 |
| | Light thin | 32.8 | 34.6 | 37.0 | 41.1 |
| | Light thin with gaps | 32.6 | 35.2 | 37.2 | 39.9 |
| Sidewalk Creek (SC) | Control | 22.5 | 23.2 | 24.0 | 25.0 |
| | Heavy thin | 26.6 | 25.6 | 24.5 | 22.8 |
| | Light thin | 28.4 | 29.4 | 30.5 | 31.8 |
| | Light thin with gaps | 26.9 | 26.7 | 26.9 | 26.9 |

(Davis et al. 2007; Dodson et al. 2012). Quite likely, the largest trees did not experience a major improvement in growing conditions as part of the standard thinning operation. However, the more open growing conditions resulting after thinning will likely mean that growth rates of larger trees can be maintained longer than under unthinned conditions (Latham and Tappeiner 2002). As an indication of this trend, the largest trees responded with increased growth under very heavy thinnings (Davis et al. 2007) and when adjacent trees were removed as part of gap creation (Dodson et al. 2012).

In general, mortality rates were higher in the control treatments than in the thinning treatments (tables 3 and 4, Dodson et al. 2012). Most tree mortality in the controls was in the smaller diameter classes, suggesting competition-related mortality as the major factor. On the other hand, mortality rates in the thinned units were minor and did not show a size-related pattern (table 4), indicating that most trees were able to withstand the exposed conditions created by thinning. These results also imply that most snags in unthinned conditions are in smaller size classes, limiting their wildlife value. Even recruitment of small snags was reduced by thinning; thus current snag densities and expected mortality may not be sufficient to reach snag levels similar to those found in old-growth stands (Ares et al. 2012). Active snag creation may be necessary to achieve specific habitat goals, especially if these goals include larger snags (Dodson et al. 2012).

Overstory cover is an important measure of wildlife habitat, but for practical purposes overstory closure is often used as an indicator of canopy density (Jennings et al. 1999), as was done in the YTSDS (no overstory closure data were available for the DMS). Typical overstory canopy closure under unthinned control conditions in the YSTDS was around 80 percent (table 5, fig. 1). As expected, thinning reduced overstory closure to around 30, 50, and 42 percent of the controls in the Heavy, Light,

**Table 3**—Mean trees per hectare for all trees ≥8 cm dbh in post-treatment years 1, 3, 5, and 10. Data are from the Young Stand Thinning and Diversity Study.

| | | Mean trees per hectare, all trees ≥8 cm dbh (tph) | | | |
|---|---|---|---|---|---|
| **Block** | **Treatment** | 1997 | 1999 | 2001 | 2006 |
| Cougar Reservoir (CR) | Control | 753 | 741 | 723 | 697 |
| | Heavy thin | 151 | 165 | 172 | 199 |
| | Light thin | 312 | 312 | 309 | 327 |
| | Light thin with gaps | 221 | 229 | 237 | 266 |
| Mill Creek (MC) | Control | 655 | 614 | 594 | 589 |
| | Heavy thin | 283 | 290 | 292 | 304 |
| | Light thin | 415 | 408 | 408 | 425 |
| | Light thin with gaps | 346 | 357 | 327 | 378 |
| Christy Flats (CF) | Control | 869 | 791 | 717 | 724 |
| | Heavy thin | 133 | 131 | 129 | 139 |
| | Light thin | 207 | 198 | 188 | 185 |
| | Light thin with gaps | 1498 | 184 | 178 | 180 |
| Sidewalk Creek (SC) | Control | 792 | 771 | 747 | 733 |
| | Heavy thin | 165 | 191 | 216 | 288 |
| | Light thin | 277 | 279 | 276 | 290 |
| | Light thin with gaps | 225 | 241 | 244 | 267 |

**Table 4**—Conifer and hardwood (≥5 cm dbh) percent mortality by block and treatment. Data were collected in 2006, ten years post-treatment and are from the Young Stand Thinning and Diversity Study.

| | | Mortality of trees ≥5 cm dbh (percent) | |
|---|---|---|---|
| **Block** | **Treatment** | Conifers | Hardwoods |
| Cougar Reservoir (CR) | Control | 4.0 | 10.6 |
| | Heavy thin | 0.3 | 0.0 |
| | Light thin | 1.1 | 0.0 |
| | Light thin with gaps | 1.6 | 1.1 |
| Mill Creek (MC) | Control | 2.2 | 4.0 |
| | Heavy thin | 1.3 | 4.8 |
| | Light thin | 0.5 | 0.9 |
| | Light thin with gaps | 1.3 | 0.4 |
| Christy Flats (CF) | Control | 4.5 | 33.3 |
| | Heavy thin | 0.9 | 0.0 |
| | Light thin | 1.5 | 3.0 |
| | Light thin with gaps | 0.0 | 4.8 |
| Sidewalk Creek (SC) | Control | 1.4 | 2.5 |
| | Heavy thin | 0.0 | 0.0 |
| | Light thin | 0.9 | 0.0 |
| | Light thin with gaps | 0.4 | 0.5 |

**Table 5**—Mean percent overstory cover in post-treatment years 1, 3, 5, and 10. Data are from the Young Stand Thinning and Diversity Study.

| | | Overstory cover (percent) | | | |
|---|---|---|---|---|---|
| **Block** | **Treatment** | 1997 | 1999 | 2001 | 2006 |
| Cougar Reservoir (CR) | Control | 82 | 83 | 89 | 85 |
| | Heavy thin | 25 | 37 | 37 | 51 |
| | Light thin | 50 | 62 | 72 | 73 |
| | Light thin with gaps | 40 | 47 | 55 | 60 |
| Mill Creek (MC) | Control | 82 | 76 | 76 | 85 |
| | Heavy thin | 46 | 54 | 60 | 62 |
| | Light thin | 62 | 68 | 75 | 77 |
| | Light thin with gaps | 50 | 57 | 62 | 71 |
| Christy Flats (CF) | Control | 79 | 79 | 71 | 80 |
| | Heavy thin | 17 | 22 | 27 | 30 |
| | Light thin | 37 | 44 | 46 | 56 |
| | Light thin with gaps | 36 | 44 | 45 | 54 |
| Sidewalk Creek (SC) | Control | 70 | 77 | 73 | 76 |
| | Heavy thin | 31 | 27 | 36 | 46 |
| | Light thin | 53 | 58 | 63 | 62 |
| | Light thin with gaps | 42 | 46 | 49 | 54 |

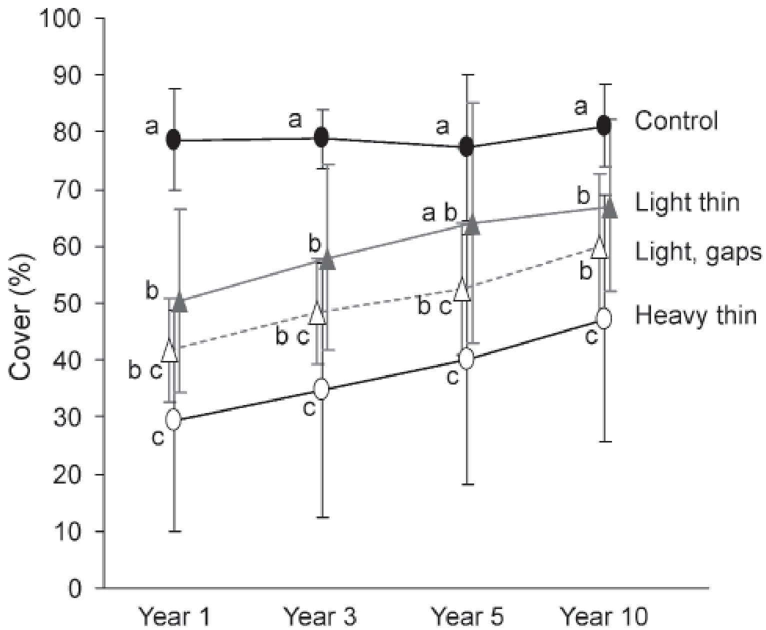



**Figure 1**—Overstory cover (percent) by year (includes 95 percent confidence intervals). Letters indicate significant differences among treatments (treatments with the same letter do not differ at P ≤ 0.05 level).

and Light with Gap treatments, respectively. However, the overstory recovery was quite rapid in the first decade, with average canopy closure increasing from 1 to 2 percent per year (fig. 2), a value similar to other studies in the region (e.g., Chan et al. 2006). Similarly, crown lift stopped fairly quickly after thinning (Chan et al. 2006; Davis et al. 2007). Even though overstory closure is still significantly lower 10 years after thinning, the trends suggest that long-term maintenance of open canopy conditions will require repeated thinning operations.

## Tree Regeneration

Partial harvests, such as thinning, provide opportunity for establishment of a new cohort of trees through increased vigor, and thus seed production by residual trees (Reukema 1961), exposure of mineral soil that provides seed beds, and resource availability for seedlings (Nyland 2002). Generally, natural regeneration was significantly more abundant after thinning than in control treatments in both studies (fig. 3, Kuehne and Puettmann 2008; Ares et al. 2010; Dodson et al. 2012). Seedling establishment likely increased due to a combination of seedbed preparation through harvesting disturbances and increased resource availability as a result of the removal of overstory trees and damaged understory vegetation. However, short-term effects on tree regeneration did not differ among thinning treatments (Kuehne and Puettmann 2008), but the variability within treatments and among replications of treatments was high.

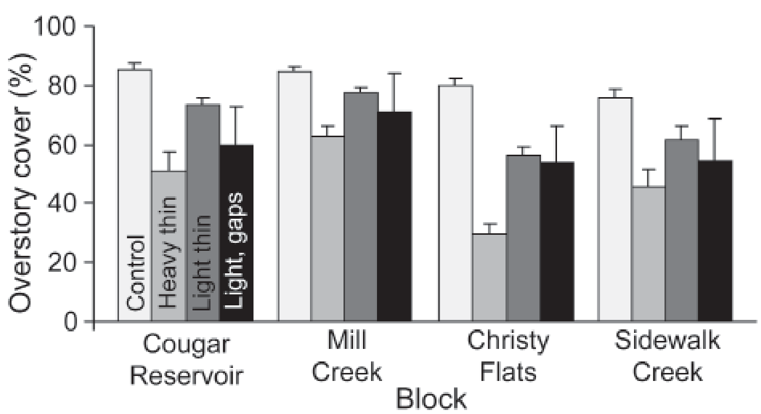



**Figure 2**—Ten-year post-treatment mean percent overstory cover by block (includes standard error bars).

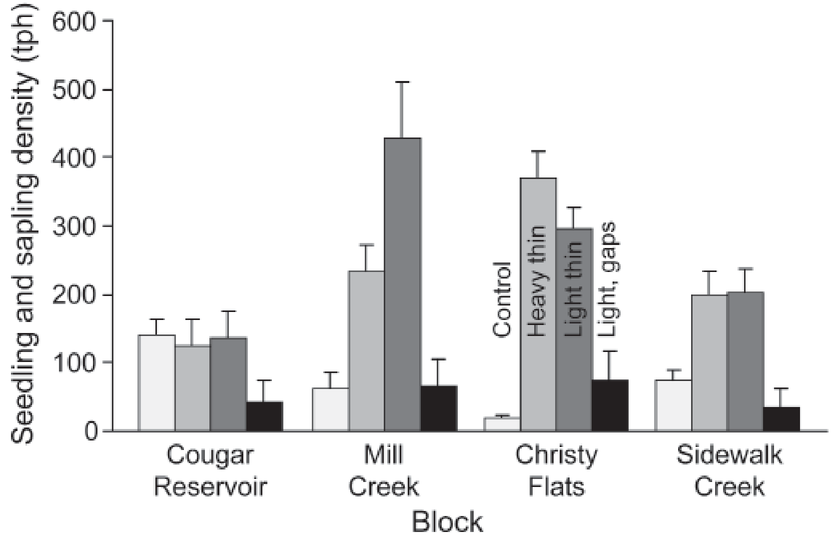



**Figure 3**—Ten-year post-treatment mean seedling and sampling density (tph) by block (includes standard error bars).

In some plots, the regeneration density was sufficiently high to initiate a discussion about future pre-commercial thinning (Cissel et al. 2006).

Saplings also showed higher densities in thinned units than in controls 11 years following thinning (fig. 3, Dodson et al. 2012). They likely were established prior to implementation of thinning treatments, and interpretation of these numbers needs to consider that at least some saplings were damaged during the harvesting operation (Dodson et al. in prep.[2]). Since saplings were not influenced by thinning impacts on seedbed conditions, the growing environment in thinned units appears more conducive than in unthinned controls. This has also been shown by greater growth of some species under less dense conditions (Shatford et al. 2009). The patterns in in-growth also suggest that differences in overstory density among thinning treatments will be reflected in the diameter distributions in the long run, with higher seedling and sapling densities in the more intensive thinning treatments (Dodson et al. 2012; Dodson et al. in prep.[2]).

The dominant species on the study sites (usually Douglas-fir, and in some cases Western Hemlock, *Tsuga heterophylla*) were also dominant in the seedling and sapling pool. Species richness of seedlings was higher in thinned units, and the spatial patterns suggest that the presence of "minority" species in the overstory is also reflected in the seedling pool (Kuehne and Puettmann 2008). Differential growing patterns, especially in response to competition from overstory trees, suggest that the density of light-demanding species such as Douglas-fir may decline over time (Shatford et al. 2009) unless repeated overstory thinning maintains open growing conditions. Thinning operations also damage regeneration, which can become problematic when the density of regenerating seedlings is low, e.g., in understory plantings (Newton and Cole 2006). However, five years after a second thinning, density values of natural tree regeneration were similar to units that had not been thinned a second time (Berger et al. 2012). In terms of seedling densities, the damage due to the harvesting operation during this treatment was apparently balanced out by new recruitment.

## Understory Vegetation

Responses to thinning varied among understory life-forms. Tall shrubs showed a large decline right after thinning in the YSTDS to less than half of cover values found in control

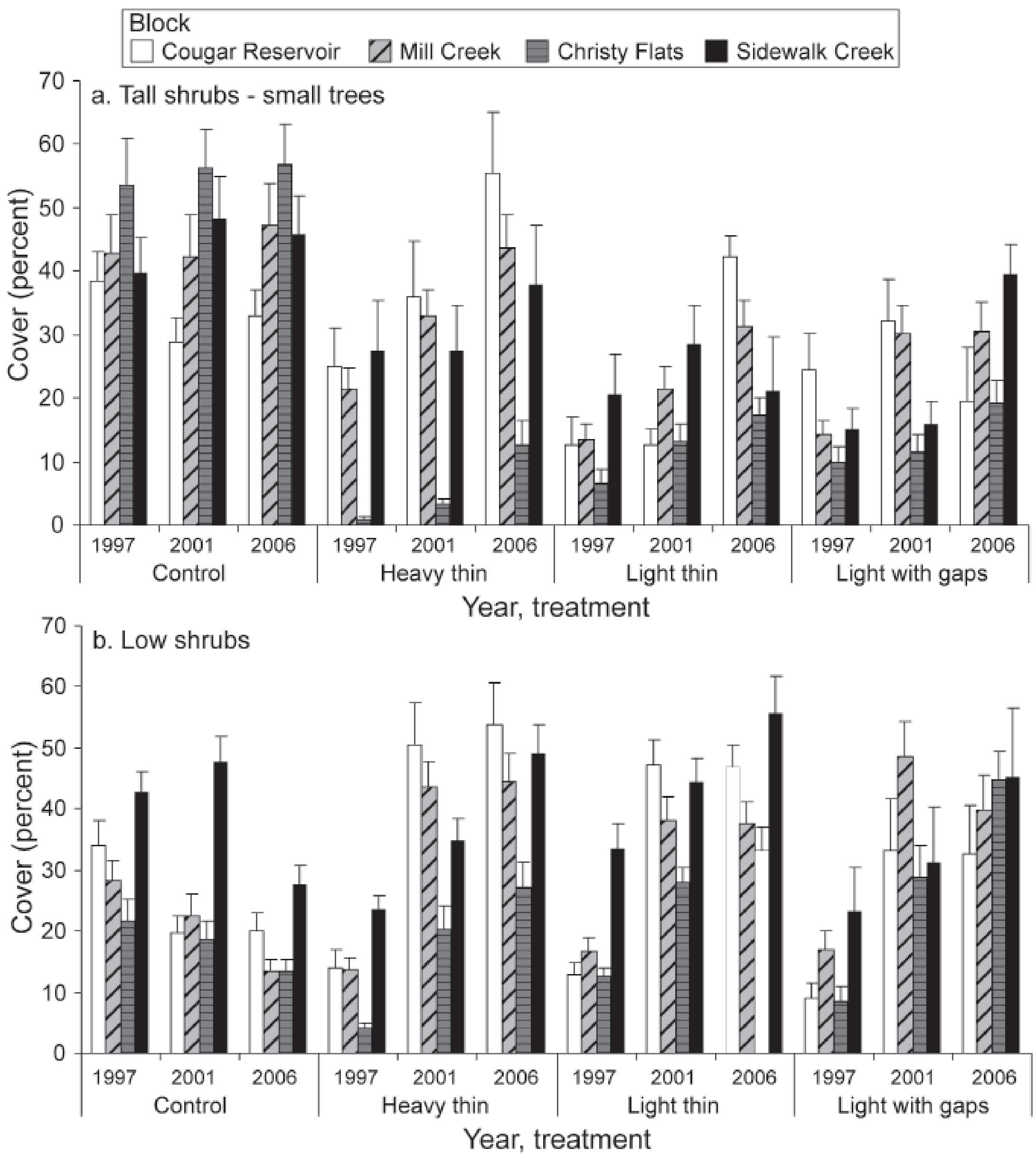
[2]Dodson, E.K.; Ares, A.; Burton, J.; Puettmann, K.J. [n.d.] Natural regeneration after thinning Douglas-fir stands in western Oregon. Manuscript in preparation for the Canadian Journal of Forest Research.

units (figs. 4a and 4b, table 6a and 6b). Since we do not have any evidence to suggest a bias in pre-thinning conditions, it appears that the harvesting operation led to physical damage of shrubs (Davis and Puettmann 2009; Dodson and Puettmann, unpublished data). Tall shrub cover was not significantly different on thinned units after a decade, suggesting that some recovery occurred. However, values remained lower than on control units.

A meta-analysis of five thinning studies in the region suggests that thinning does not consistently reduce shrub cover (Wilson et al. 2009). Instead, thinning reduced shrub cover only when shrub cover is initially high (>30 percent cover), with little effect in stands not dominated by shrubs, suggesting that mechanical damage occurs during the harvesting operations.

In contrast to shrubs, cover of herbaceous vegetation did not experience a post-harvest decline (Wilson et al. 2009, fig. 4c, table 6c). Instead, herbaceous cover increased quickly

**Figure 4**—Mean percent cover for a) tall shrubs/small trees, b) low shrubs, c) herbs, and d) bryophytes in post-treatment years 1, 5, and 10.



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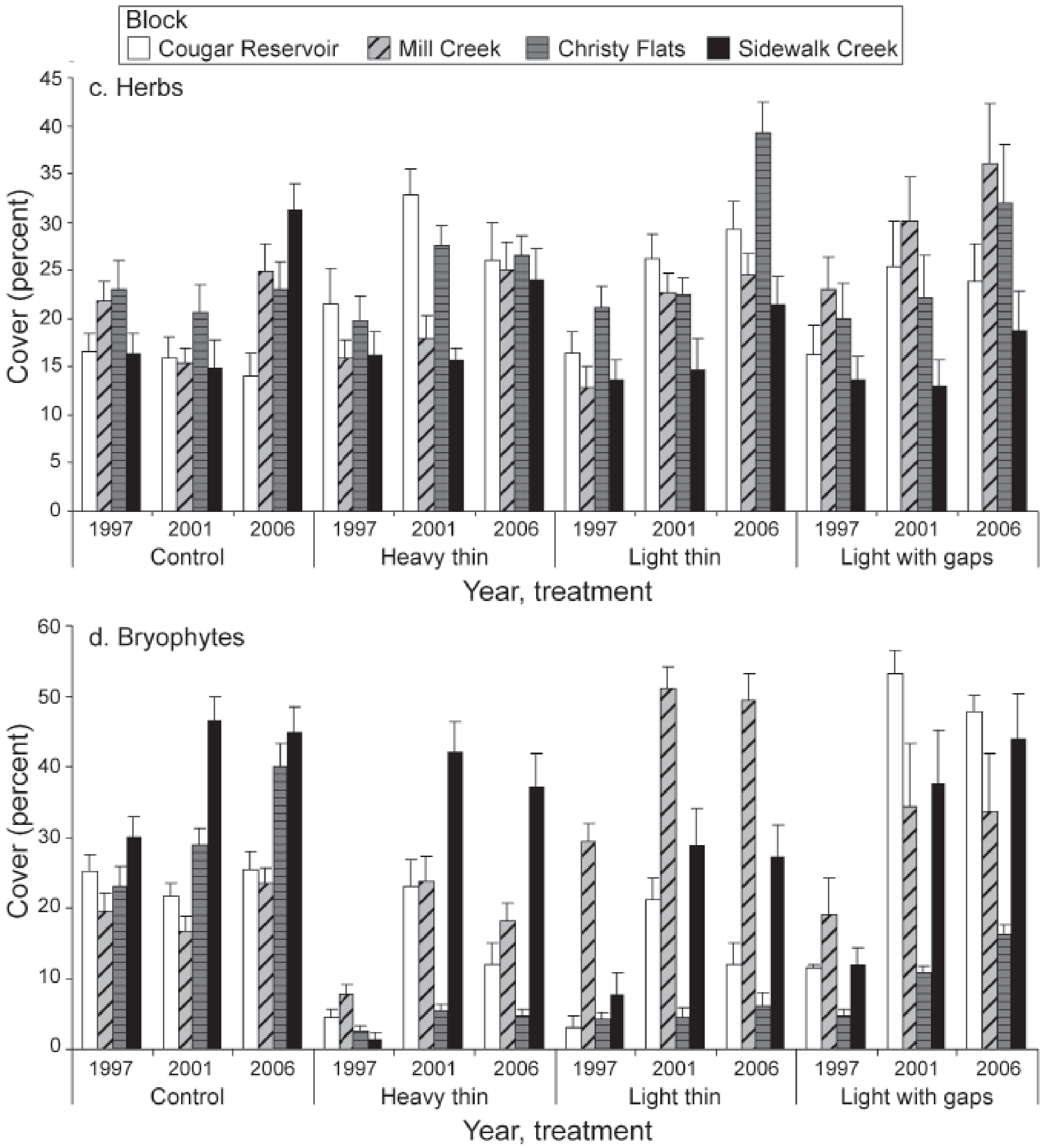


after thinning, apparently benefiting from reduced competition (Ares et al. 2009). Further increases of herbaceous cover may be limited due to increased competition, as shrubs and trees respond to thinnings. Similar to herbs, bryophyte ground cover showed an initial increase, likely covering ground that was exposed during the harvesting operation (Davis and Puettmann 2009, fig. 4d, table 6d). Over time, ground cover of bryophytes increased slightly in the YSTDS, but differences among treatments were not statistically significant. Bryophyte cover in the DMS study was significantly lower in the heavily thinned treatments than controls a decade after thinning (Ares et al. 2010).

A decade after thinning, other categories of ground cover, such as bare soil, stumps, rocks, or logs, typically covered less than 5 percent of the area in the DMS. Treatment patterns were hard to detect, but duff layers still appear to be lower in thinned units than in controls (Ares et al. 2009). The absolute cover value of litter was higher in controls, with cover in thinned units being approximately two-thirds of control value

**Table 6**—Mean percent cover for a) tall shrubs/small trees, b) low shrubs, c) herbs, and d) bryophytes in post-treatment years 1, 3, 5, and 10. Data are from the Young Stand Thinning and Diversity Study.

| ***a. Tall Shrubs/Low Trees*** | | **Tall shrub/small tree understory cover (percent)** | | | | |
|---|---|---|---|---|---|---|
| **Block** | **Treatment** | 1997 | 1999 | 2001 | 2006 | Trend |
| Cougar Reservoir (CR) | Control | 38.4 | 35.2 | 28.7 | 32.9 | ↓↑ |
| | Heavy thin | 25.0 | 36.2 | 36.1 | 55.5 | ↑ |
| | Light thin | 12.8 | 16.2 | 12.7 | 19.6 | ↑ |
| | Light thin with gaps | 24.3 | 31.0 | 32.0 | 42.3 | ↑ |
| Mill Creek (MC) | Control | 42.8 | 44.9 | 42.2 | 47.3 | ↑ |
| | Heavy thin | 21.3 | 32.2 | 33.0 | 43.7 | ↑ |
| | Light thin | 13.4 | 20.8 | 21.4 | 30.4 | ↑ |
| | Light thin with gaps | 14.2 | 22.5 | 30.1 | 31.3 | ↑ |
| Christy Flats (CF) | Control | 53.5 | 54.6 | 56.2 | 56.9 | ↑ |
| | Heavy thin | 0.9 | 2.9 | 3.3 | 12.7 | ↑ |
| | Light thin | 6.5 | 12.4 | 13.2 | 19.1 | ↑ |
| | Light thin with gaps | 9.9 | 11.7 | 11.6 | 17.2 | ↑ |
| Sidewalk Creek (SC) | Control | 39.8 | 46.0 | 48.4 | 45.8 | ↑ |
| | Heavy thin | 27.4 | 36.3 | 27.4 | 37.9 | ↑ |
| | Light thin | 20.6 | 31.3 | 28.6 | 39.4 | ↑ |
| | Light thin with gaps | 15.0 | 16.2 | 16.0 | 21.2 | ↑ |

| ***b. Low Shrubs*** | | **Low shrub understory cover (percent)** | | | | |
|---|---|---|---|---|---|---|
| **Block** | **Treatment** | 1997 | 1999 | 2001 | 2006 | Trend |
| Cougar Reservoir (CR) | Control | 34.1 | 29.5 | 19.6 | 20.1 | ↓ |
| | Heavy thin | 13.9 | 36.5 | 50.6 | 53.8 | ↑ |
| | Light thin | 9.0 | 22.5 | 33.4 | 32.8 | ↑ |
| | Light thin with gaps | 13.0 | 28.9 | 47.2 | 46.8 | ↑ |
| Mill Creek (MC) | Control | 28.4 | 23.1 | 22.6 | 13.5 | ↓ |
| | Heavy thin | 13.8 | 37.0 | 43.7 | 44.6 | ↑ |
| | Light thin | 16.9 | 30.6 | 48.5 | 39.9 | ↑ |
| | Light thin with gaps | 16.8 | 25.3 | 38.0 | 37.6 | ↑ |
| Christy Flats (CF) | Control | 21.7 | 16.1 | 18.8 | 13.4 | ↓ |
| | Heavy thin | 4.1 | 10.3 | 20.2 | 27.1 | ↑ |
| | Light thin | 8.4 | 18.5 | 28.9 | 44.8 | ↑ |
| | Light thin with gaps | 12.7 | 30.1 | 27.9 | 33.2 | ↑ |
| Sidewalk Creek (SC) | Control | 42.7 | 35.7 | 47.8 | 27.6 | ↓ |
| | Heavy thin | 23.6 | 34.1 | 34.8 | 49.0 | ↑ |
| | Light thin | 23.3 | 33.1 | 31.2 | 45.4 | ↑ |
| | Light thin with gaps | 33.6 | 39.8 | 44.6 | 55.7 | ↑ |

**Table 6, continued**—Mean percent cover for a) tall shrubs/small trees, b) low shrubs, c) herbs, and d) bryophytes in post-treatment years 1, 3, 5, and 10.

| ***c. Herbs*** | | **Herbaceous understory cover (percent)** | | | | |
|---|---|---|---|---|---|---|
| **Block** | **Treatment** | 1997 | 1999 | 2001 | 2006 | Trend |
| Cougar Reservoir (CR) | Control | 16.5 | 16.9 | 15.8 | 14.1 | ↓ |
| | Heavy thin | 21.5 | 30.2 | 32.8 | 26.0 | ? |
| | Light thin | 16.5 | 21.9 | 26.2 | 29.2 | ↑ |
| | Light thin with gaps | 16.2 | 22.0 | 25.4 | 23.8 | ↑ |
| Mill Creek (MC) | Control | 21.8 | 19.2 | 15.5 | 24.8 | ↓↑ |
| | Heavy thin | 16.0 | 19.1 | 17.9 | 25.0 | ↑ |
| | Light thin | 12.9 | 20.1 | 22.7 | 24.6 | ↑ |
| | Light thin with gaps | 23.0 | 25.3 | 30.1 | 36.0 | ↑ |
| Christy Flats (CF) | Control | 23.1 | 18.1 | 20.6 | 23.0 | ↑ |
| | Heavy thin | 19.7 | 24.5 | 27.6 | 26.5 | ↑ |
| | Light thin | 21.1 | 20.9 | 22.5 | 39.3 | ↑ |
| | Light thin with gaps | 20.0 | 29.3 | 22.2 | 32.0 | ? |
| Sidewalk Creek (SC) | Control | 16.4 | 11.7 | 14.9 | 31.2 | ↓↑ |
| | Heavy thin | 16.2 | 20.5 | 15.7 | 24.0 | ↑ |
| | Light thin | 13.7 | 15.7 | 14.8 | 21.4 | ↑ |
| | Light thin with gaps | 13.7 | 16.6 | 13.1 | 18.7 | ? |

| ***d. Bryophytes*** | | **Bryophyte understory cover (percent)** | | | | |
|---|---|---|---|---|---|---|
| **Block** | **Treatment** | 1997 | 1999 | 2001 | 2006 | Trend |
| Cougar Reservoir (CR) | Control | 25.1 | 21.5 | 21.8 | 25.4 | ↓↑ |
| | Heavy thin | 4.5 | 5.8 | 23.1 | 12.1 | ↑↓ |
| | Light thin | 11.5 | 27.3 | 53.1 | 47.9 | ↑ |
| | Light thin with gaps | 3.0 | 5.0 | 21.1 | 12.0 | ↑↓ |
| Mill Creek (MC) | Control | 19.5 | 16.7 | 16.8 | 23.5 | ↓↑ |
| | Heavy thin | 7.8 | 11.7 | 23.7 | 18.1 | ↑ |
| | Light thin | 19.0 | 20.8 | 34.4 | 33.6 | ↑ |
| | Light thin with gaps | 29.5 | 24.6 | 51.0 | 49.3 | ↑ |
| Christy Flats (CF) | Control | 23.0 | 24.9 | 28.9 | 39.9 | ↑ |
| | Heavy thin | 2.5 | 2.3 | 5.3 | 4.7 | ↑ |
| | Light thin | 4.8 | 5.8 | 10.8 | 16.3 | ↑ |
| | Light thin with gaps | 4.4 | 6.6 | 4.5 | 6.1 | ? |
| Sidewalk Creek (SC) | Control | 30.2 | 36.3 | 46.5 | 44.9 | ↑ |
| | Heavy thin | 1.4 | 21.9 | 42.2 | 37.3 | ↑ |
| | Light thin | 12.0 | 25.3 | 37.7 | 43.9 | ↑ |
| | Light thin with gaps | 7.7 | 26.6 | 29.0 | 27.3 | ↑ |

(Ares et al. 2009).

Vegetation composition showed a consistent trend toward higher species richness, which was mainly attributable to increases in early-seral species after thinning (Davis et al. 2007; Ares et al. 2009, 2010). The combination of ground disturbance and increased resource availability likely allowed establishment of these species, especially in harvested gaps (Fahey and Puettmann 2007, 2008). Species richness of mid- to late-seral species did not appear to be reduced. Notable exceptions include the reduction of obligate mycotrophs, plants in symbiotic relationships with fungi (Davis et al. 2007). This may be related to lower numbers and production of selected mushrooms after thinning (Pilz et al. 2006). Exotic species increased slightly after thinning operations, but absolute cover values typically remained under 2 percent (Davis and Puettmann 2009; Ares et al. 2009). One exception was a single treatment unit at a single site that had a nearby seed source of Scotch Broom (*Cytisus scoparius*), where cover values of exotic species increased to over 3 percent. However, it appears that within a decade the cover values of exotic species are declining, suggesting that most of these species are not invasive and expanding. In the long run, one would expect that the transitory increase in resources would be declining, but still be reflected in species composition for an extended time period, even after the overstory closure has reached high levels (Lindh and Muir 2004).

## Conclusion

The short-term responses to thinning in the two studies show that questions regarding the efficacy of thinning for accelerating late-successional development do not have a simple answer. Instead, different measures of late-successional habitat appear to respond in different ways and at different time scales. For example, rapid increases in crown length and tree growth suggest that thinning is accelerating some features of late-successional structure. In contrast, late-successional attributes such as tall shrub cover and cover of late-seral species were not accelerated by thinning. Instead, they showed the opposite trends toward open and early-successional conditions, at least in the short term. Few responses varied significantly among alternative thinning treatments, suggesting that in the short term the thinning activity itself is more important than the actual choice of residual densities, or that the range of thinning treatments in these two experiments was too narrow. However, in the long run, one would expect that growth of overstory trees, tree regeneration, as well as species composition of understory vegetation, would reflect the different thinning intensities, including gap creation.

While long-term data are not available, the short-term trends in overstory development suggest that in thinned units most responses are transitory: they may be still detectable after canopy closure, but development trends will have slowed down. To maintain the benefits of an accelerated development of late-successional characteristics in thinned stands likely requires multiple entries (Del Rio and Berg 1979). Alternatively, very heavy thinning and gaps may provide sufficient conditions to accelerate late-successional habitat with a single entry. Including a variety of treatments in thinning operations, especially gaps and leave island treatments, also provides opportunities to increase the small-scale spatial variability within stands, a major characteristic of old-growth stands (Franklin and Van Pelt 2004).

The differential responses to thinning of various aspects of forest structure in these two studies suggest that managers should assess which specific structural attributes and processes are critical. Because all attributes cannot be achieved simultaneously, setting priorities is important. Alternatively, managing for heterogeneity can be used to emphasize different attributes at different spatial scales within and among stands. Tying silvicultural treatments and stand development into a multi-scale landscape plan will facilitate achievement of multiple management goals (Wilson and Puettmann 2007).

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