Thinning Effects on Tree Mortality and Snag Recruitment in Western Oregon

Erich K. Dodson, Klaus J. Puettmann, and Adrian Ares

Abstract

Tree mortality shapes forest structural development and the resulting dead wood provides habitat for many species. However, the effects of thinning on mortality and large snag recruitment have been variable and remain poorly understood. We examined thinning effects on tree mortality at eleven Density Management Study (DMS) sites in western Oregon. Thinning reduced mortality rates for small trees, especially Douglas-fir (*Pseudotsuga menziesii*), but had little influence on mortality of large trees (≥50 cm dbh). Gaps created by harvest did not result in increased mortality during the sampling period (6 to 11 years following gap creation). Few large snags (≥50 cm dbh) were produced regardless of treatment. Thinning likely reduced ongoing suppression mortality of small trees, but in the short-term did little to provide the large snags that are characteristic of late-successional forests. Large snags may be created in subsequent planned thinning entries, but low mortality after the first thinning implementation suggests that active creation of large snags may be necessary to accelerate their development.

Keywords: Coarse woody debris, Douglas-fir, multi-cohort management, variable-density thinning, wildlife habitat.

Introduction

Tree mortality is an important ecosystem process (Franklin et al. 1987). It shapes community composition and forest structure, with direct implications for snags and down wood, which provide habitat for many species (Hayes and Cross 1987; Berg et al. 1994). Intensive management has resulted in young, homogeneous stands in the Pacific Northwest, with higher tree densities than found in many old-growth stands (Tappeiner et al. 1997). Consequently, these young stands lack many habitat features of late-successional forests, including large snags and large-diameter down wood (Spies et al. 1988; Hayes et al. 1997). Thinning has been widely proposed as a means to accelerate the development of late-successional structure (Muir et al. 2002; Bauhus et al. 2009), but its effects on mortality and snag recruitment are still not well understood. For example, thinning has been found to reduce (Williamson 1982; Marquis and Ernst 1991; Davis et al. 2007) or increase (Walter and McGuire 2004; Maguire et al. 2006) mortality rates. Thinning from below can remove small, stressed trees that are at high risk for mortality and leave a residual stand of large, vigorous trees with low mortality rates (Powers et al. 2010). Thinning also increases the resources available to smaller, residual trees, thus reducing suppression mortality (Williamson 1982; Marquis and Ernst 1991). In contrast, thinning can increase physical damage to residual

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trees due to wind, snow, and ice (Harrington and Reukema 1983; Franklin et al. 1997), with especially strong effects for trees along harvest edges (Chen et al. 1992; Zeng et al. 2004). We examined data from 11 Density Management Study (DMS) sites in western Oregon with a variety of site histories and conditions (Cissel et al. 2006) to better understand the effects of alternative thinning treatments on tree mortality.

Large snags (≥50 cm dbh [diameter at breast height]) are common in late-successional forests of the Pacific Northwest (Spies et al. 1988; North et al. 2004; Ares et al. 2012; Lutz et al. 2012), provide habitat for numerous species (Schreiber and de Calesta 1992; Barbour et al. 1997; Marcot et al. 2002), and may be critical for some species (Mannan et al 1980). Young stands may have an abundance of small snags (Carey and Johnson 1995; Van Pelt and Nadkarni 2004). However, without management intervention, more than 250 years may be required for large snag formation in natural stands (Van Pelt and Nadkarni 2004; Gerzon et al. 2011). A better understanding of large snag recruitment in thinned and unthinned forests is needed to guide management actions that seek to accelerate the development of late-successional forest characteristics.

We examined rates of mortality with and without thinning, with an emphasis on understanding effects of thinning on developing late-successional stand structure, using two components of the DMS study: initial thin (seven sites) and rethin (four sites). We use a combination of previously reported mortality results (Dodson et al. 2012) and new data analyses to address the effects of thinning on mortality. Specific research questions included:

1. Does thinning affect mortality rates of residual overstory trees?
2. Are large snags being created, and is this process affected by thinning?
3. Does gap creation during harvest alter mortality rates of nearby trees?

Methods

Study Sites

The DMS initial and rethin studies (Cissel et al. 2006) were each established on land managed by the Bureau of Land Management in western Oregon. Sites were selected to be relatively homogeneous and were generally dominated by Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). Common conifer species included Douglas-fir, Western Hemlock (*Tsuga heterophylla* (Raf.)) and Western Redcedar (*Thuja plicata* Donn ex D. Don). Common hardwoods included Big-leaf Maple (*Acer macrophyllum* Pursh), Red Alder (*Alnus rubra* Bong), California Hazel (*Corylus cornuta* Marsh), Pacific Madrone (*Arbutus menziesii* Pursh, *Frangula purshiana* (DC.) Cooper) and Golden Chinkapin (*Chrysolepis chrysophylla* (Douglas ex Hook.) Hjelmqvist). The initial thin sites were at least 80 ha in size and ranged from about 40 to 60 years old at the time of thinning. Rethin sites were are least 16 ha in size, ranged from 50 to 80 years old and had been thinned 25 to 30 years prior to study initiation to a density of ≥250 trees per hectare (tph). Detailed site characteristics are provided in Cissel et al. (2006) and details of tree species composition are given in tables 1 and 2.

Treatments

Initial thin treatments were implemented in a randomized-block design with one replication of four thinning treatments (including controls) applied at each of seven sites for a total of 28 treatment units. Individual treatment units ranged from 14–58 ha. Control stands were unthinned and had an average density of 565 tph. The high-density (HD) treatment was thinned to a residual stand density of 300 tph with 3 to 13 percent of the total stand retained in non-thinned circular reserves. In the moderate-density (MD) treatment, stand density was reduced to 200 tph. Additionally, 4 to 18 percent of the stand was cut in circular gap openings and 4 to 13 percent of the stand was left in unthinned circular leave islands. The variable-density (VD) treatment was designed to create the maximum spatial

Table 1—Total number of trees and number of trees dying over the period 6 to 11 years following thinning for each species or species group and treatment in the initial thinning study.

	Hardwood		**Douglas-fir**		**Western Hemlock**	
Treatment	Trees sampled	Mortality (5 years)	Trees sampled	Mortality (5 years)	Trees sampled	Mortality (5 years)
Control	266	36	3716	516	1686	142
High density	528	82	3260	195	1022	100
Moderate density	607	92	2463	189	1027	93
Variable density	475	55	2203	114	840	44

Table 2—Total number of sampled trees and the number of sampled trees that died from 1 to 11 years following thinning for each species or species group in each treatment for the rethin study.

	Cedar[1]		**Hardwood**		**Douglas-fir**		**Western Hemlock**	
Treatment	Trees sampled	Mortality (10 years)	Trees sampled	Mortality (10 years)	Trees sampled	Mortality (10 years)	Trees sampled	Mortality (10 years)
Once-thinned	262	26	104	15	1038	104	161	11
Rethinned	168	13	170	25	615	43	191	10

[1]Includes Western Redcedar (*Thuja plicata*) and Incense Cedar (*Calocedrus decurrens*).

variability and complexity within the stand. This treatment included both the high (300 tph) and moderate-density retention (200 tph) treatments each applied over 25 to 30 percent of the stand and an additional 8 to 16 percent of the stands were thinned to a residual density of 100 tph. Finally, 4 to 18 percent of the stand was assigned to leave islands and gap openings, respectively. Gaps and leave islands in all treatments were a mixture of 0.1-, 0.2- and 0.4-ha circular areas. Thinning was completed between 1997 and 2000. All thinning was "from below" focusing on taking out the smaller trees. Less-abundant species (typically all species other than Douglas-fir), especially hardwoods, were preferentially reserved. Details of treatment implementation at individual sites are presented in Cissel et al. (2006).

The rethin study included stands that had previously been thinned in a clumpy distribution 25–30 years before study initiation. It included just two treatments, a control (270 to 580 tph) that was not thinned again, and a second thinning to a residual tree density between 80 and 150 tph (Cissel et al. 2006; Berger et al. 2012). No gaps or leave islands were included in the rethin study.

Sampling

In the initial thin study, 77 permanent 0.1-ha circular plots were established at each of the seven sites to measure overstory trees. Plot locations were randomly selected across the entire treatment unit including gaps and leave islands, with 21 plots in each of the thinned treatment units and 14 plots in each control treatment unit at each site. All trees ≥5 cm dbh were tagged, identified to species, measured for dbh, and recorded as live or dead. Clumped hardwood trees were measured as separate trees provided their dbh was ≥5 cm. Data were collected in the summer 6 years after thinning (2003–2005) and 11 years after thinning (2008–2010), with sample years varying among sites.

Plots in the rethinning study were non-randomly established in areas where residual tree density was within 20 percent of target density and distributed to maximize coverage of the treatment unit. Spacing between plots varied among sites to establish a total of 20–25 plots per site. All overstory trees (>5 cm dbh) were tagged, identified to species, measured for dbh, and recorded as live or dead. Data were collected for each site 1, 6, and 11 years after thinning.

Statistical analyses

We selected a significance level $\alpha = 0.05$ prior to statistical analysis. All analyses were performed in SAS (SAS Institute, Cary, NC, v. 9.3). We report results from a previous study (Dodson et al. 2012) that examined the average annual mortality rate in the initial thinning study for the five-year sampling period as the number of trees that died between the first and second measurements divided by the total number of trees present at the first measurement for each treatment unit (n = 28 treatment units). For this study, average annual mortality rates were compared among treatments using a mixed model with thinning treatment as a fixed effect and site as a random effect. Post-hoc tests were conducted between each combination of individual treatments with a Tukey correction for multiple comparisons (Dodson et al. 2012). Residuals were inspected to ensure that assumptions of normality, equal variance, and independence were not violated.

Mortality for the rethin study was evaluated over a ten-year period, from 1 to 11 years following rethinning, with a mixed-model logistic regression. The analyses focused on Douglas-fir because this species was well-represented at all sites, spanned a range of initial sizes, and comprised the majority of trees (table 2). Individual trees that were alive in the first sample, one year after thinning, were assigned a "yes" or "no" based on whether they were also alive 11 years after thinning. The probability of mortality was modeled as a function of initial tree size, with treatment included as a categorical fixed effect. Site, treatment unit within site, and plot within treatment unit were included in the model as random effects to account for the nested structure of the sampling design. Model fit was evaluated visually by overlaying mortality rates for 10-cm dbh classes with predicted values. The Kenward-Roger method was used to calculate the denominator degrees of freedom due to the unbalanced sampling design.

We compared mortality rates among plots of different treatment "strata" (gaps, leave islands, and thinned areas) to examine whether small-scale treatment effects had an impact on mortality rates. Only the initial thinning treatment included gap creation, and only the MD and VD included all three strata; therefore, the analyses used only plots from these treatments. A total of 286 plots were included in this analysis, of which 71 plots included at least a portion of a gap and 32 plots included at least a portion of a leave island. Plots that included any portion of a gap or leave island were included in these strata, respectively. Gap plots included some residual trees (plots were not entirely in the gap) which were used to calculate rates of mortality. The remaining plots were considered as the "thinned" stratum for the analysis. The average annual mortality over five years (from 6 to 11 years following treatment) was calculated for each plot as described above for the initial thin study. A mixed model with stratum as a fixed factor and site as a random factor was used to analyze the effects of strata on mortality rates. A random effect was also included for treatment unit to account for nesting of plots within treatments units at a site. Post-hoc tests were conducted between the three strata with a Tukey correction for multiple comparisons. Residuals were inspected to ensure that assumptions of normality, equal variance and independence were not violated. The Kenward-Roger method was used to calculate the denominator degrees of freedom due to the unbalanced sampling design.

Results and Discussion

Douglas-fir was the dominant tree species in most stands (tables 1 and 2) and the vast majority of the large trees were Douglas-fir (Dodson et al. 2012). Douglas-fir also comprised the majority of the mortality in both the initial and rethin studies (tables 1 and 2). Douglas-fir is less shade-tolerant than the other conifer species on these

Table 3—Type III tests of fixed effects for the mixed model logistic regression for individual tree mortality in the re-thin study.

Effect	Numerator DF	Denominator DF	F-value	*P*
Treatment	1	6	9.9	0.018
dbh	1	1649	94.7	<0.001
dbh · treatment	1	103	15.3	<0.001

sites (Minore 1979; Shatford et al. 2009). This lower shade-tolerance many have contributed to higher rates of mortality for small Douglas-fir relative to other species (Dodson et al. 2012).

Thinning significantly affected mortality in both the initial thinning (Dodson et al. 2012) and rethin studies (table 3). In the initial thinning study, the VD treatment had significantly lower mortality than the control (fig. 1; Dodson et al. 2012). The HD and MD were intermediate and not significantly different from any other treatment (fig. 1; Dodson et al. 2012). In the rethin study, thinning effects varied significantly with initial tree size (table 3). Thinning reduced the probability of mortality for small Douglas-fir, but had little effect on mortality of larger trees (≥50 cm dbh; fig. 2). A similar effect was observed in the initial thinning study (Dodson et al. 2012). The decreased average annual mortality rate after thinning from below in these two component studies (Dodson et al. 2012; fig. 2) is similar to patterns observed in other Douglas-fir forests (Davis et al. 2007) and other forest types (Marguis and Ernst 1991; Powers et al. 2010). However, thinning from above can result in the opposite pattern (Marguis and Ernst 1991; Powers et al. 2010), which may contribute to some of the variability reported by previous studies.

Small trees had higher mortality rates than large trees in both the initial and rethin studies. This pattern is consistent with ongoing suppression mortality, which is common in young forests (Carey and Johnson 1995; Van Pelt and Nadkarni 2004). More than 80 percent of the trees that died across all sites and treatments in the initial thinning study were relatively small (≤35 cm dbh). In contrast, large trees (≥50 cm

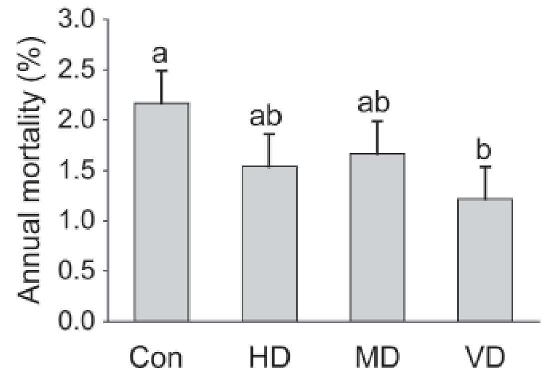

Figure 1—Annual mortality rates of all species combined in the initial thin study for each treatment for the period from 6 to 11 years following thinning. Different letters represent statistically significant differences in Tukey-HSD pair-wise comparisons. Con = Control, HD = High-density, MD = Moderate-density, VD = Variable-density.

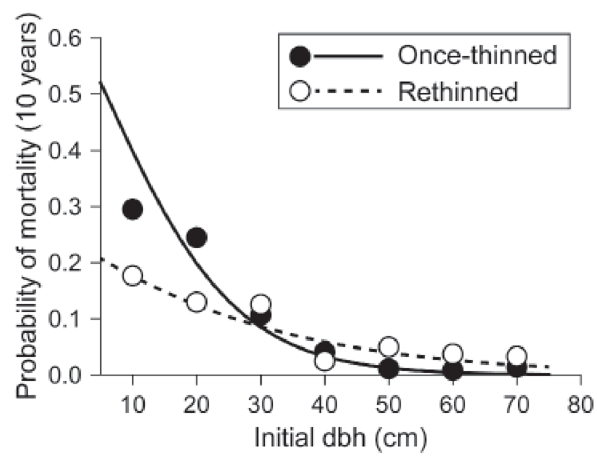

Figure 2—Probability of mortality as a function of initial tree size for a 10-year period after thinning in the once-thinned and twice-thinned units of the rethin study for Douglas-fir. Lines are predicted values from mixed-model logistic regression. Scatterplot points are mortality rates calculated from the data with trees divided into 10-cm size classes. Open circles are rethinned values, closed circles are once-thinned values.

dbh) had much lower mortality rates in both the initial thin study (Dodson et al. 2012) and rethin studies (fig. 2). For example, just one large snag per 10 ha was formed on average each year across all treatments in the initial thinning study, despite an average of about 75 large live trees per ha. These low rates of large-tree death suggest that few large snags form under current conditions, regardless of thinning treatments. This suggests that current management practices are not sufficient for the accelerated development of large snags in young forests in the short term; and indeed active creation of large snags may be implemented as part of the DMS study plan if this pattern continues over subsequent thinning entries (Cissel et al. 2006).

Average annual mortality rates varied significantly among strata (F = 3.0, P = 0.05). However, gap formation appeared to have little effect on mortality during our study period (6 to 11 years following gap creation). Average annual mortality rates on plots with gaps, which included both portions of gaps and neighboring forest interior, was 1.4 percent. This was intermediate between thinned plots (1.2 percent annual mortality) and leave island plots (1.9 percent annual mortality) and not significantly different than either (fig. 3). However, mortality rates were significantly lower on thinned plots than plots in leave islands (P = 0.046), consistent with the overall effect of thinning reducing mortality. Additionally, trees located directly on gap edges (Dodson et al. 2012) had an annual mortality rate of just under 2 percent from 6–11 years following thinning, or nearly equivalent to the rate observed in the control and leave islands. However, previous studies have reported increased mortality along clear-cut edges (Chen et al. 1992; Zeng et al. 2004) suggesting that gap size may be an important consideration. Furthermore, mortality due to physical agents such as wind is often episodic (Lutz and Halpern 2006) or may occur soon after thinning operations are completed (Chan et al. 2006), which may not have been captured in this study. Thinning effects on mortality likely also depend on the timing of thinning relative to stochastic events such as wind and ice storms. For example, if a severe storm immediately follows thinning, thinning may increase mortality, but if no such storm happens thinning may decrease mortality. The lack of an obvious increase in mortality with gap formation across the seven sites in this study, which have a variety of site histories and site conditions and were thinned in different years (Cissel et al. 2006) suggests that thinning treatments including gap creation can often be done without large increases in mortality (Roberts et al. 2007).

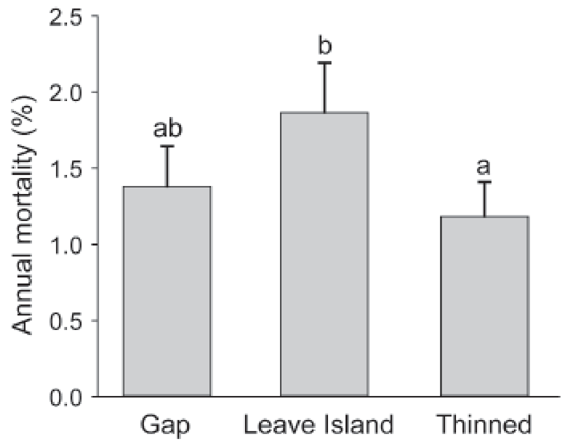

Figure 3—Annual mortality rates for all species combined from 6 to 11 years following thinning in the three different plot types in the MD and VD treatments. Different letters represent significant differences in Tukey HSD pair-wise comparisons. "Gap" plots included both portions of gaps and neighboring forest.

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