Understory Tree Development with Repeated Stand Density Treatments in Coastal Douglas-Fir Forests of Oregon

Jeffrey P.A. Shatford, John D. Bailey, and John C. Tappeiner

ABSTRACT

We studied the potential for stand density management treatments to increase growth rates of advanced regeneration in the understory of 50- to 70-year-old Douglas-fir (*Pseudotsuga menziesii*) forests. Study sites in Oregon included a mesic coastal site, a moderate coast range site, and a drier coast range foothills site. Commercial thinning treatments in 1974–1984 led to the establishment of Douglas-fir and western hemlock (*Tsuga heterophylla*) in the understory and, in 1997, parts of these same stands were thinned for a second time to release this advanced regeneration and promote two-story structure. Both species responded positively where overstory was reduced to 30–40 m^2/ha, but western hemlock saplings grew 30–80% more rapidly than Douglas-fir. Average annual height growth of all western hemlock saplings that were more than 1.0 m tall in 1999 was 23–30 cm/year in twice-thinned stands but only 13 cm/year in denser, once-thinned stands. About one-half of all western hemlock saplings doubled or tripled their height in 4 years after a second overstory treatment; the largest 10% of these saplings grew 74–93 cm/year and now represents midstory structure. The response of Douglas-fir saplings to a partial overstory removal was limited. Repeated density management treatments in these Douglas-fir forests can accelerate growth of understory saplings, resulting in the development of two or more canopy layers over time; however, repeated and/or heavy thinning will be required for Douglas-fir sapling growth. Furthermore, because of western hemlock's potential for rapid height growth, some reduction of hemlock sapling density may be needed to maintain vigorous Douglas-fir.

Keywords: second growth, seedling, sapling, thinning, gap, old-growth

Stand density decreases as young conifer forests mature, whether because of self-thinning or precommercial and commercial thinning, leading to an increase in the abundance of understory vegetation (Oliver and Larson 1996, Bailey and Tappeiner 1998). A cohort of young seedlings and saplings often is included in this developing understory, most of which die before forming a second canopy layer or reaching the overstory. The growth and survival of this cohort of advanced regeneration is dependent on the interplay of their tolerance to understory conditions, especially light and soil water availability, as regulated by the density and continuity of the overstory and its rate of development.

Currently, many parts of western Oregon are dominated by Douglas-fir (*Pseudotsuga menziesii*) plantations as a result of intense forest management over the last 60 years. Dense stands of Douglas-fir (often more than 500 trees/ha) grow rapidly and respond well to thinning (Marshall and Curtis 2002); many of these will be managed as even-aged Douglas-fir stands on short rotations. However, on many such hectares of public and private lands, goals include (1) promoting mixed species, two-story or uneven-aged stand structure; (2) providing old-growth forest characteristics; and (3) on some sites, growing stands more resistant to diseases such as Swiss needle cast (*Phaeocryptopus gäumannii*). Commercial thinning is used in Douglas-fir stands (often at the age of 30–40 years) to provide initial timber yields and improve the long-term timber value of a stand (Curtis et al. 1998, Tappeiner et al. 2007) and can be used to promote understory development (Bailey and Tappeiner 1998). In coastal forests, rarely has the release of advanced regeneration been of interest except in shelterwood harvests or where uneven-aged management is being considered (Miller and Emmingham 2001).

Recent studies have shown that conifer regeneration is common in heavily thinned stands (Deal and Farr 1994, Deal and Tappeiner 2002). Deisenhofer (2000) and Miller and Emmingham (2001) reported high densities of Douglas-fir and some western hemlock (*Tsuga heterophylla*) saplings under uneven-aged management practices. Increased light, soil water, and seed production (Reukema 1979), along with soil scarification from thinning, provides microsites for seedling establishment. If properly managed, these seedlings/saplings have the potential to provide a midstory in young stands, a characteristic of developing old-growth stands. However, with height growth rates of 10 cm/year or less in a forest understory (Bailey and Tappeiner 1998), trees likely remain stunted or die.

Previous studies (Helms and Sandiford 1985, Tesch et al. 1993) have shown that Douglas-fir and true fir (*Abies* spp.) advanced regeneration responds favorably to complete overstory removal. Western hemlock, in particular, can be an important understory tree species contributing to structural character of older stands given its shade tolerance and ability to respond well to release (Oliver and

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Table 1. Stand history and condition for once-thinned and twice-thinned treatment units at three study sites in western Oregon (overstory density [±SE] and basal area [±SE], and understory regeneration density for stands in 2003).

Site	Elevation (m)	SI50[a] (m)	Stand age in 1997 (yr)	Year of 1st thinning	Once-thinned density (trees/ha)	Twice thinned density (trees/ha)	Once-thinned basal area (m^2/ha)	Twice-thinned basal area (m^2/ha)	Regeneration density (stems/ha)
Blue Ridge	353	39	51	1984	311 (22)	208 (22)	56.8 (2.3)	37.9 (2.8)	1,449
Sand Creek	525	39	71	1974	259 (20)	163 (27)	64.9 (1.3)	33.0 (2.8)	2,198
Little Wolf	568	31	61	1982	361 (37)	198 (27)	41.9 (3.0)	30.1 (1.9)	2,553

[a] SI50 mean height (m) of dominant trees at the age of 50 yr.

Larson 1996). Brandeis et al. (2001) found that the survival and growth of underplanted conifers—western redcedar (*Thuja plicata*), grand fir (*Abies grandis*), Douglas-fir, and western hemlock—in the understory were inversely related to overstory tree and understory shrub density. Chan et al. (2006) report poor survival of underplanted Douglas-fir and western hemlock in unthinned stands and an increase in sapling growth associated with thinning intensity. There is little information on the growth release of advanced natural regeneration of Douglas-fir and western hemlock after partial removal of the overstory. Such information is needed to evaluate the possibility of using a two-story or uneven-aged silvicultural system with these species.

Our objective was to determine the effect of a second partial overstory removal (at the age of 60–70 years) on the growth rate of advanced Douglas-fir and western hemlock regeneration. Our study sites had been commercially thinned 20–30 years before our research (Bailey 1996). After the first thinning, understory seedlings were established, mostly Douglas-fir and western hemlock. We predicted that a second thinning (hereafter, twice thinned) would lead to an increased growth rate for understory trees compared with areas that were not thinned again (once thinned). This provided a unique opportunity to assess this two-story silvicultural approach.

Study Area and Methods

The growth response of western hemlock and Douglas-fir saplings was studied at three sites administered by the Bureau of Land Management in the Oregon Coast Range including Blue Ridge (latitude 43.274; longitude −124.082), Little Wolf (latitude 43.417; longitude −123.630), and Sand Creek (latitude 44.832; longitude −123.597; Table 1). These sites are within the Western Hemlock Zone where hemlock is the climax species (Franklin and Dyrness 1973). Average monthly precipitation ranged from 20 (Little Wolf) to 50 cm (Blue Ridge) in winter months (Sand Creek being intermediate), to less than 2 cm in summer months. Average daily temperatures were 5°C in winter and 28°C in summer at Little Wolf and Sand Creek and from 5°C (winter) to 16°C (summer) at Blue Ridge (1962–1999 averages, Oregon Climate Service). Study sites were paired with closest climate stations, i.e., North Bend for Blue Ridge (distance, 18 km), Valsetz for Sand Creek (distance, 4 km), and Drain for Little Wolf (distance, 37 km). The moderating coastal influence on temperature and humidity was most evident at Blue Ridge. In contrast, Little Wolf was warmer, drier, and showed greater variation in annual temperature and precipitation.

Douglas-fir was the primary overstory tree species at each site, having regenerated naturally after clearcut logging between 1920 and 1940. When the resulting stands were 40–50 years old, they were commercially thinned from below, removing 30–55% of their standing volume (Bailey 1996). The first stand entry took place between 1974 and 1984. By 1997, the density of advanced regeneration at each site ranged from 1,449–2,553 stems/ha (Table 1). At this time, half of each site, randomly assigned, was thinned from below to a density of 163–208 overstory trees/ha with the goal of releasing overstory and understory tree growth. We refer to these portions of the stands as "twice thinned" and those treated only at the age of 40–50 years as "once thinned." In this fashion, advanced regeneration that established after the first thinning was monitored with and without a subsequent overstory thinning treatment.

In 1997, before the second thinning, stands varied in the composition and abundance of advanced conifer regeneration and shrubs (Bailey and Tappeiner 1998, Bailey et al. 1998). For example, advanced regeneration at Sand Creek included both western hemlock and Douglas-fir saplings and associated understory species: red huckleberry (*Vaccinium parviflora),* salal (*Gaultheria shallon*), and salmonberry (*Rubus spectabilis*). Blue Ridge was almost exclusively western hemlock saplings with abundant understory shrubs, especially red huckleberry, salmonberry, and pacific rhododendron (*Rhododendron macrophyllum*). Little Wolf was almost entirely Douglas-fir regeneration along with a shrub community of oceanspray (*Holodiscus discolor*), hazelnut (*Corylus cornuta*), and salal. In 1997, before the second thinning, we tallied all advanced regeneration that was more than 15 cm tall. Estimated understory sapling density at that time ranged from 1,449 to 2,553 stems/ha (Table 1).

Three randomly established 50 × 15 m transects were assigned in each treatment area (6 transects/site). In 1998, we measured and tagged approximately 100 saplings in each transect. This resulted in an average of 248 tagged saplings per treatment unit in the 1st year of the study. Of the large number of saplings present, few showed obvious damage by logging. For all tagged trees, we measured initial basal diameter (15 cm aboveground to nearest millimeter), dbh (where possible to nearest millimeter), total height (to nearest centimeter), and height to live crown (to nearest centimeter). In 2002, we returned to each transect and remeasured basal diameter, dbh, and height after four growing seasons (only three at Blue Ridge). This included all tagged trees that were readily relocated in a single sweep of each transect by three people walking side by side. Western redcedar and grand fir were included in the initial sample but were too infrequent to be analyzed. Douglas-fir and western hemlock were insufficient in number at Blue Ridge and Little Wolf, respectively, to be considered further. Given these limitations, an average of 104 seedlings per treatment unit was used in the final analysis. We annualized growth to correct for minor differences among sites in the time between the first and last measurements. The sampling unit was the treatment unit at each site.

Analysis

Initial sapling height and diameter relationships were assessed using linear regression to describe the growth form of advanced regeneration 14–24 years after the commercial thinning of the stands. Absolute sapling growth is reported and compared among saplings in different size classes, less than 1.5 m and more than

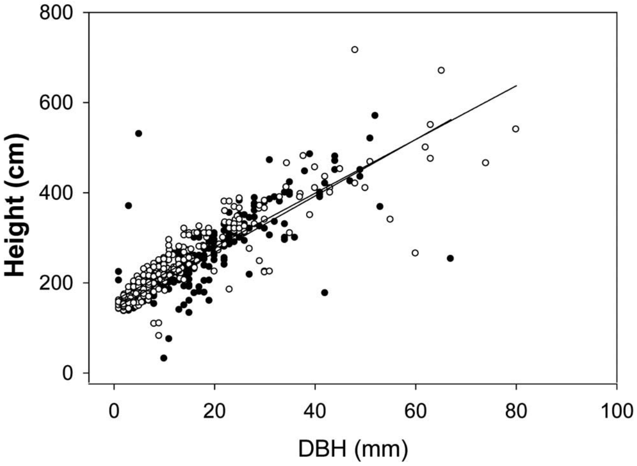

Figure 1. The relationship between understory western hemlock open circles (n = 418) and Douglas-fir closed circles (n = 242) sapling dbh and their total height at sites in the Oregon Coast Range. Both conifer species occurred at Sand Creek, and Douglas-fir occurred at Little Wolf and western hemlock occurred at Blue Ridge. Douglas-fir equation height = intercept 132.873 + 7.26921 × (dbh) R^2 = 0.900; hemlock equation height = intercept 180.879 + 6.64194 × (dbh) R^2 = 0.895.

1.5 m, as well as for the largest 10% of the population (those most likely to contribute to the future stand).

Analysis of covariance was used to model annual height and basal diameter growth as a function of treatment using initial sapling size (total height) as a covariate. This approach acknowledged that treatment effects may vary with initial sapling size. Separate analysis of covariance models was used for each site to estimate regression parameters and compare mean annual height growth and diameter growth between treatments (Littell et al. 2002). The analysis was conducted in Proc Mixed (SAS 9.1; SAS Institute, Inc., Cary, NC), which allowed for nonhomogeneous variance among treatment groups. The regression models took the form

$$\text{annual growth} = \beta^0 + \beta^1 \times \text{initial size},$$

where annual growth was height or diameter growth, and initial size was total height in 1998. Variation in sampling growth associated with initial size (pretreatment height) was controlled for, providing better estimates and improved statistical power (Littell et al. 2002). A comparison of regression slopes among treatment groups (once-thinned versus twice-thinned) was used to determine whether the effect of treatments was consistent across the range of initial sapling heights. Models were used to compute height and basal diameter growth for trees in different height classes. We report analysis of covariance results for height growth only (type III sums of squares) and tested for homogeneity of variance using Levene's test (SAS 9.1). Hemlock data analyses were based on 477 saplings, 291 at Blue Ridge and 186 from Sand Creek; Douglas-fir analyses were based on 359 saplings, 157 at Little Wolf and 202 at Sand Creek.

Results

Western Hemlock

Western hemlock saplings, which averaged 1.7 m in height in 1998 (range, 0.1–5.4 m) in both stands, grew to 2.9 m (range, 0.40–9.5 m) on average by 2002. Initial sapling height was strongly associated with dbh ($P < 0.001$; $R^2 = 0.895$; Figure 1). Overall annual height growth was similar at both sites; Blue Ridge height growth averaged 30.2 cm/year (±10.3 standard error [SE]; $n = 2$) and Sand Creek growth averaged 34.7 cm/year (±14.2 SE; $n = 2$). However, hemlock saplings in twice-thinned treatments grew more in height and dbh than once-thinned treatments (Table 2). Overall height growth averaged 20.2 cm/year (±0.3 SE; $n = 2$) in the once-thinned treatment and 43.7 cm/year (±4.2 SE; $n = 2$) in twice-thinned stands. As a result of the second treatment, a near doubling in absolute height growth was common for all size classes and at both study sites (Table 2). Although the tallest 10% of the individuals in the stands tended to respond better than smaller size classes, this was particularly true at Sand Creek (Table 2).

Initial height was a strong predictor of subsequent growth and warranted the use of analysis of covariance. At Blue Ridge, a significant interaction between the treatment and initial height was apparent (Table 3). At this site, the growth response was linear for both treatment groups (Figure 2). There was a significant and positive effect of thinning on western hemlock height growth; however, the magnitude (slope) of the relationship between size and response was greater for saplings in the twice-thinned treatment compared with the once-thinned unit (Figure 2). At Sand Creek, the influence of initial size was consistent across the range of the sample (e.g., equal regression slopes). There was a significant positive effect of the second thinning on western hemlock sapling growth (Table 3). Repeated thinning of the stands had a significant influence on the variation in growth response (homogeneity of variance test). Western hemlock saplings within the twice-thinned units at both sites exhibited greater variance in growth rates than those in once-thinned stands ($P < 0.001$).

Douglas-Fir

Average height of Douglas-fir seedlings and saplings in 1998 was only 1.5 m (range, 0.15–5.20 m); they grew to 2.1 m on average in 4 years (range, 0.19–7.0 m) with a slight increase in size range. Sapling height was strongly associated with dbh ($P < 0.001$; $R^2 = 0.90$; Figure 1). Differences in absolute growth in height and diameter between treatments appeared to be inconsistent among size classes (Table 2). For example, annual Douglas-fir height growth rate was estimated as 1.6 times (less than 1.5 m class) for twice-thinned stands compared with once-thinned stands at Sand Creek. Height growth in a larger size class (e.g., more than 1.5 m) was only 1.4 times greater for twice-thinned stands compared with once-thinned stands at this same site. The fastest growing 10% of these saplings grew two to three times faster than the population mean as a whole (Table 2). Comparisons between treatments at Little Wolf suggest that saplings grew only moderately well regardless of treatment (Table 2).

Initial height was a strong and consistent predictor of subsequent sapling growth at both sites ($P < 0.001$) and across both treatment types (equal slopes, Figure 3). At Sand Creek, thinning treatment led to a significant and positive difference in annual growth for Douglas-fir (Table 2 and Figure 3). Thinning increased the variance in tree growth ($P < 0.05$) as evident in the spread of data points around the regression lines in Figure 3.

Species Comparison

Live crown ratio for western hemlock average 0.80 (±0.01, 95% confidence interval) compared with 0.59 (±0.01) for Douglas-fir.

Table 2. Annual height and diameter growth (±SE) of western hemlock and Douglas-fir advanced regeneration in once- and twice-thinned stands in western Oregon.

Site	Saplings <1.5 m		Saplings >1.5 m		Tallest 10% of saplings	
	Thinned once	Thinned twice	Thinned once	Thinned twice	Thinned once	Thinned twice
Western hemlock						
Height growth (cm/yr)						
BR	16.4 (1.1) $n = 36$	33.9 (1.5) 111	21.5 (1.0) 77	51.5 (2.0) 67	29.3 (2.2) 11	53.8 (2.7) 18
SC	14.5 (1.1) $n = 45$	39.9 (3.1) 40	28.9 (2.5) 32	54.2 (2.9) 69	39.7 (4.2) 12	68.0 (12.4) 9
Diameter growth (mm/yr)						
BR	1.4 (0.2)	2.3 (0.1)	2.2 (0.2)	5.0 (0.2)	3.5 (0.5)	5.5 (0.4)
SC	1.3 (0.1)	3.9 (0.4)	4.2 (0.4)	7.8 (0.5)	5.1 (0.5)	11.6 (1.8)
Douglas-fir						
Height growth (cm/yr)						
SC	7.5 (1.0) $n = 72$	13.5 (1.4) 41	17.7 (1.5) 53	26.1 (2.3) 36	23.7 (3.0) 13	25.5 (6.5) 8
LW	10.6 (1.0) $n = 49$	10.2 (1.0) 48	26.6 (2.4) 21	27.1 (2.1) 39	31.4 (3.3) 7	28.5 (4.2) 8
Diameter growth (mm/yr)						
SC	0.9 (0.1)	1.7 (0.2)	2.2 (0.2)	3.8 (0.4)	2.6 (0.4)	3.4 (0.8)
LW	1.0 (0.1)	1.6 (0.2)	2.2 (0.2)	3.6 (0.3)	1.8 (0.3)	4.8 (0.9)

BR, Blue Ridge; LW, Little Wolf; SC, Sand Creek.

Table 3. Effect of thinning treatment and initial height on annual height growth for western hemlock and Douglas-fir at sites in western Oregon (analysis of covariance).

	F-value	*P*
Western hemlock		
Blue Ridge		
Treatment	8.73	0.0034
Height1998	76.54	<0.0001
Treat × height	16.68	<0.0001
Sand Creek		
Treatment	24.04	<0.0001
Height1998	62.14	<0.0001
Treat × height	0.25	0.618
Douglas-fir		
Little Wolf		
Treatment	0.78	0.3798
Height1998	140.39	<0.0001
Treat × height	1.01	0.3164
Sand Creek		
Treatment	7.27	0.0076
Height1998	66.36	<0.0001
Treat × height	0.08	0.7831

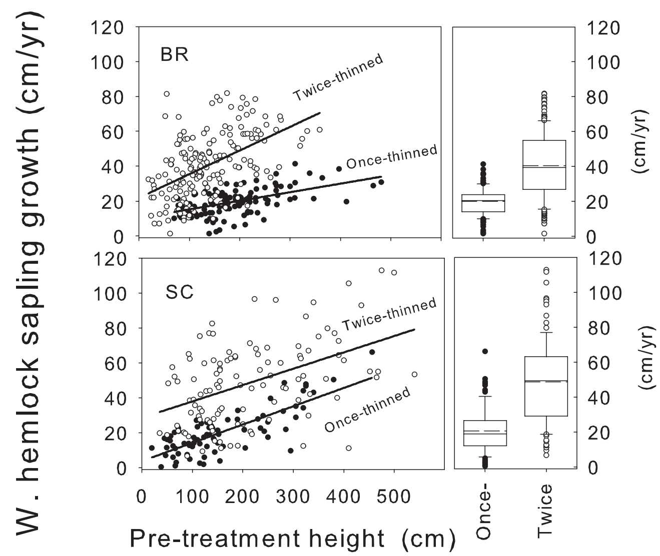

Figure 2. The relationship between western hemlock annual height growth (cm/year) and initial height (cm) for once- and twice-thinned treatments at sites in the Oregon Coast Range.

Height/diameter ratio also was higher for western hemlock compared with Douglas-fir, 1.06 (±0.02, 95% confidence interval) versus 0.93 (±0.02). At Sand Creek, where the two species can be found in the same treatment units and stand, western hemlock saplings grew consistently faster than Douglas-fir saplings (Table 2). Height and diameter growth rates of western hemlock saplings averaged 30–80% greater than those of Douglas-fir saplings depending on initial size, and diameter growth was more than double for the largest individuals of both species. After a second treatment, western hemlock growth was consistently twice that of Douglas-fir for both measures and all sizes (Table 2).

More than 30% of the western hemlock saplings doubled or tripled their height after 3 to 4 years in twice-thinned stands at both Sand Creek and Blue Ridge sites (Figure 4). Only a small percentage (approximately 10%) of Douglas-fir saplings doubled or tripled their height over this same time period. The response from Douglas-fir to the stand reduction in 1997 was most apparent in the resulting shift in size class distribution resulting from the second thinning (Figure 4).

Discussion

Stand density reduction has been shown to be an effective tool for stimulating the initiation and early growth of natural regeneration in Douglas-fir forests in the Pacific Northwest. Other studies have documented similar increases in understory tree density and diameter growth (e.g., Deal and Farr 1994 and Deal and Tappeiner 2002) and, specifically, with understory hemlock and Douglas-fir saplings after a single commercial thinning (Bailey and Tappeiner 1998, Deisenhofer 2000, Miller and Emmingham 2001, Chan et al. 2006). Where initial commercial thinning can result in sapling densities averaging 1,433 trees/ha (range, 141–6,714 trees/ha; Bailey 1996), the current study documented that such regeneration can persist for decades and continue to grow reasonably well after repeated thinning. Heavy thinning and earlier entries into a stand are consistently important for releasing advanced regeneration, establishing larger quantities of new regeneration, and perpetuating these in the understory environment.

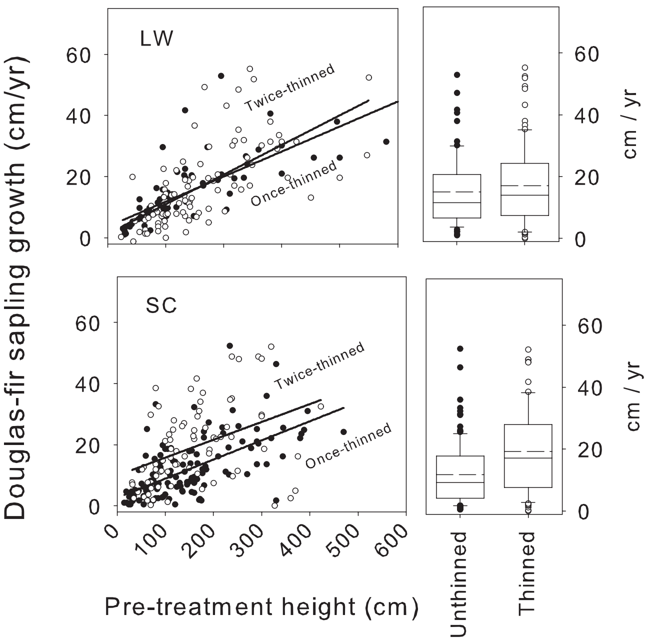

Figure 3. The relationship between Douglas-fir annual height growth (cm/year) and initial height (cm) for once- and twice-thinned treatments at sites in the Oregon Coast Range.

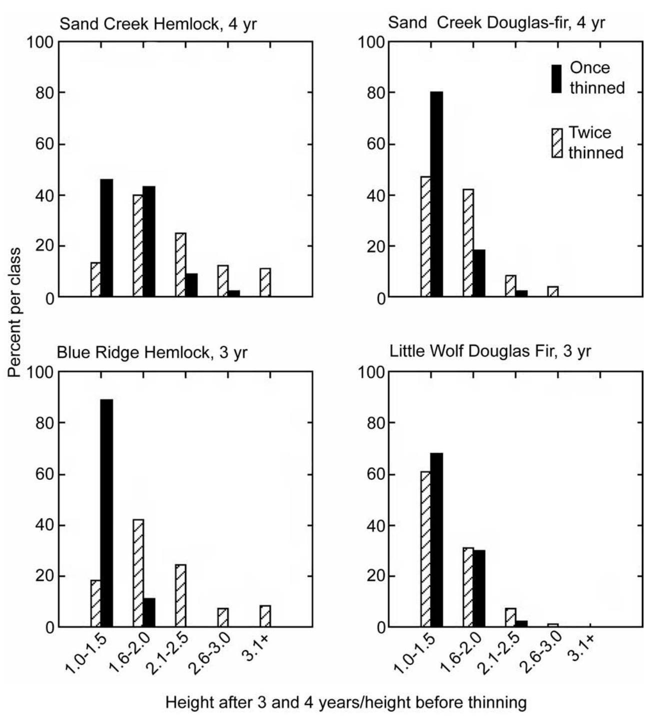

Figure 4. Frequency distribution (%) of various sapling height growth classes (height at end of study/height at start of study) under different stand density treatments for western hemlock (left column) and Douglas-fir (right column) at sites in the Oregon Coast Range.

The reduced density of the twice-thinned stands typically leads to increased light and water availability (Lindh et al. 2003) and changes in temperature and wind velocity within the stand. The response of overstory trees to density reduction typically includes live crown expansion, increased foliage density (and foliage longevity), and more efficient photosynthetic rates (Tappeiner et al. 2007). Live crown area expands because more space is available for lateral branches and more water is available to support photosynthesis. The growth response of the saplings we observed suggests understory trees in thinned stands share at least some of the same benefits as the overstory trees. Thinned stands with approximately 100 trees/ha are likely to have more than 15% of available sunlight reaching the forest floor, whereas unthinned stands may have as little as 5% (J. Bailey, unpublished data, 1996). The removal of individual trees during the second thinning would not likely influence the understory in a homogeneous fashion. Rather, resources would be rather patchy in their distribution and we suspect this patchiness increased the variance in growth rates for saplings in the twice-thinned stands.

Western hemlock and Douglas-fir seedlings and saplings both responded to partial overstory removal with increased height and diameter growth rates. However, western hemlock with greater live crown ratio and greater shade tolerance (Minore 1979) consistently outperformed Douglas-fir. The vigor and photosynthetic capacity of Douglas-fir in the understory (Drever and Lertzman 2003) was likely much less than that of western hemlock. Hemlock height growth rates in this study (approximately 30 cm/year for 3-m individuals, once thinned) were consistent with Deal and Farr (1994) at 30–50 cm/year, depending on thinning intensity. Such growth rates are substantially lower than maximum growth rates of young trees in open conditions, such as those after complete overstory removals (Omule 1987). For example, open grown western hemlock in British Columbia sustained a periodic annual height growth of 0.55–0.73 m between the ages of 8 and 26 years (Omule and Krumlik 1987) while open grown Douglas-fir grew 50–90 cm/year on sites in Washington (Flewelling et al. 2001). In the current study, Douglas-fir only attained 10–30 cm/year of height growth after repeated stand entry. Where both species grew together in the understory (Sand Creek), western hemlock grew faster than Douglas-fir in both the once-thinned (259 overstory trees/ha) and the twice-thinned stand (163 trees/ha). Deisenhoffer (2000) also found that 8 years after thinning, the rate of height growth for western hemlock saplings 1–4 m tall was nearly twice that of Douglas-fir, both species with similar growth rates to our study.

Implications for Management

Consideration for the current developmental stage, site characteristics, and vegetation structure will aid in evaluating the responses of advanced regeneration to single or multiple density reductions (Tappeiner et al. 2007). Two-story management dictates sufficient densities (at least 100 stems/ha) of fast-growing seedlings and saplings to develop the second lower canopy. Along with consideration to density, attention to composition, distribution, and vigor of saplings before thinning is warranted. If sapling composition or density is insufficient, additional ingrowth can be expected to occur after thinning. Alternatively, treeplanting may be used effectively to meet target composition, densities, and distribution (Chan et al. 2006). Where understory regeneration has been profuse, some level of density reduction of the understory saplings may be warranted. Meeting the long-term objective may require heavy overstory thinning to provide adequate growth rates of the understory saplings (i.e., 30 cm/year height growth). Multiple-story management objectives dictate the need for additional heavy entries that perpetuate sapling growth and initiate new seedling cohorts without excessive tree shock (Harrington and Reukema 1983) or mechanical damage.

Some guidelines for two-story management can be developed from historic stand conditions (Stewart 1988). Reconstruction studies suggest that current late-successional forests in this part of the Northwest actually initiated from low density stands (Poage and Tappeiner 2002). They found that old-growth stands contained an average of only 50–73 saplings/ha (0.5–1.0 cm in diameter at a height of 1.4 m) and 36–80 understory trees/ha (20–50 cm in diameter). In total, this is only about 5–15% of the understory regeneration densities observed at our study sites. However, dense patches of western hemlock regeneration in old-growth stands likely started at nearly the same densities as areas in our study.

Rapid height growth after treatment is necessary for only a proportion of the largest saplings in these understories. The fact that a high proportion (more than 50%) of the larger western hemlock doubled or tripled their heights suggests that they will become a major part of the midstory. Eventually, larger ones likely will overtop and further suppress smaller saplings. The fact that the largest Douglas-fir (about 10% of the sample) more than doubled their height in a few years after a second treatment suggests that these saplings also have the potential for becoming part of a second canopy layer, particularly near small gaps. However, precommercial thinning of hemlock in the understory may be needed to assist smaller Douglas-fir, depending on spatial proximity to hemlock and the continuity of overstory trees. The creation of larger gaps within a stand also may be a reasonable means of sustaining the growth of at least part of the understory Douglas-fir cohort. Saplings likely will reach overstory stature only where natural gaps occur from wind, root disease, or where previous thinning leaves areas of uneven spacing (a possible management objective) and/or are followed by additional treatment. Such management can emulate natural gap dynamics as these stands mature.

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