Height:Diameter Ratios and Stability Relationships for Four Northern Rocky Mountain Tree Species

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ABSTRACT: *Ratios of tree height to diameter have been used to predict susceptibility to storm damage for many years. In this study, individual trees damaged by recent snow and wind events in western Montana were sampled in 1997 and 1998 to determine their height:diameter ratios in comparison to nearby undamaged trees. Four species were sampled: ponderosa pine* (Pinus ponderosa), *western larch* (Larix occidentalis), *interior Douglas-fir* (Pseudotsuga menziesii *var.* glauca), *and lodgepole pine* (Pinus contorta *var.* latifolia). *Ratios of 80:1 (both measures in equal units) provided a stability threshold for all four species. Trees with higher ratios were more prone to damage than trees with lower ratios. Height:diameter ratios from trees grown in spacing trials were used to examine spacings that avoided development of unstable trees. Wide spacings or early thinnings provide the best means of avoiding major losses to snow and wind damage. The growth and yield model Prognosis was unable to predict height:diameter ratios for developing stands. West. J. Appl. For. 16(2):87–94.*

Key Words: Height:diameter ratio, tree stability, thinning, stand density, western Montana.

In the northern Rocky Mountains, snows can be heavy from October to June, and winds can strike with force at any time of the year. Recent events, particularly a late spring snow in 1995 and record snowfalls during the 1996–1997 winter, have shown that these natural disturbances can be devastating to the region's forests. By understanding the degree to which trees, or stands of trees, are susceptible to snow- or wind-related damage, forest managers can better design prescriptions that will improve tree and stand stability.

European foresters have used height:diameter ratios as a gauge for susceptibility to snow and wind damage for many years (Cremer et al. 1982, Nykänen et al. 1997). Relationships between height:diameter ratios and incidence of damage have been very strong (Brunig 1974, Faber 1975). Conifer trees in northern Europe have shown increased probability of damage with increases in height:diameter ratios (Lohmander and Helles 1987, Nykänen et al. 1997). Cremer et al. (1982) found no damage at height:diameter ratios below 74 (when measured in identical units) and almost complete damage at ratios above 90 for radiata pine (*Pinus radiata*) in New Zealand.

With the exception of very high and very low stocking levels, the height growth of dominant trees is usually not affected by density (Lanner 1985). Subordinate members of the canopy, however, do experience height growth repression (Oliver and Larson 1996) as competition increases with age and stocking. This competition reduces diameter growth more severely than height growth, leading to "spindly" trees with high height:diameter ratios (Cremer et al. 1982).

Previous spacing trials have reported greater incidence of snow and wind damage with increasing stand density (Reukema 1970, 1979; Cremer et al. 1982; Oliver 1997). In a study of pole-sized ponderosa pine (*Pinus ponderosa*) in California, Powers and Oliver (1970) showed that snow related damage increases with higher stand densities. Schantz-Hansen (1939), and Godman and Olmstead (1962) also documented this relationship for other conifers.

Variations in height:diameter ratios are largely a result of spacing. Spacing trials document height and diameter dynamics for differing stand densities for a variety of western conifer species (Seidel 1987, 1989; Cochran and Barrett 1995, 1998, 1999; Cochran and Seidel 1999; Oliver 1997; Cochran and Dahms 1998). All studies show that as intertree spacing increases, height:diameter ratios decrease. The additional growing space provided through wider initial spacing or thinning allows residual trees to maintain rapid diameter growth, thus reducing their susceptibility to snow damage (Cremer et. al. 1982).

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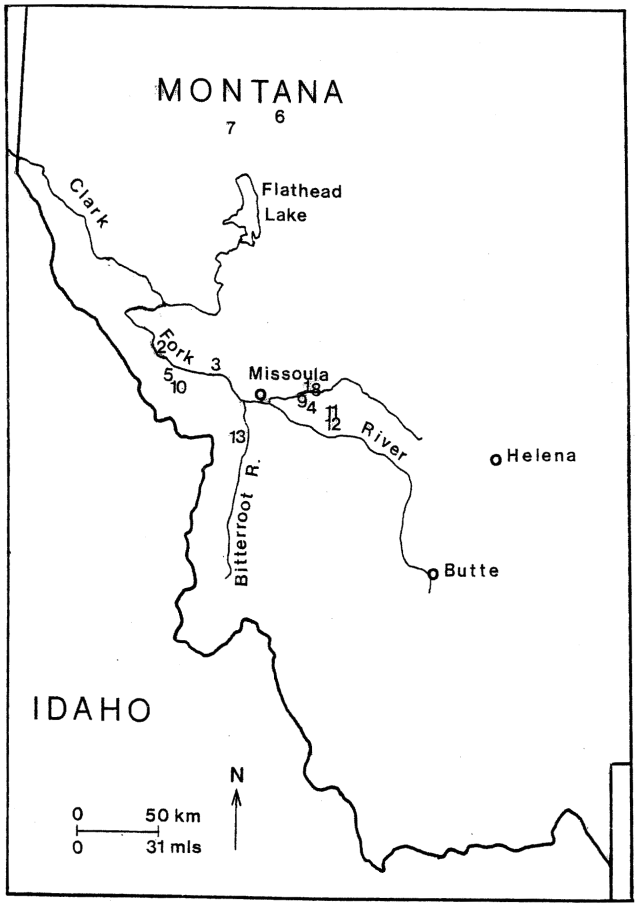

Figure 1. Location of sample stands in western Montana. Numbers denote sites as indicated in Table 1.

Little is known about height:diameter ratios and susceptibility to snow and wind damage of northern Rocky Mountain tree species. This study investigated damage susceptibility thresholds for ponderosa pine, western larch (*Larix occidentalis*), interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca*), and lodgepole pine (*Pinus contorta* var. *latifolia*). We approached this by measuring characteristics of damaged and undamaged trees at 13 sites in western Montana. Average height:diameter trends from regional spacing trials and growth and yield model projections were used to assess tree stability with different spacing regimes.

Methods

Sites were chosen based on habitat type, site index, density, stand structure, topography, species present, and extent of existing damage from recent snow and wind events (Figure 1, Table 1). Each site was classified by habitat type according to Pfister et al. (1977) and assigned a structural classification according to O'Hara et al. (1996). Each site was evaluated in terms of aspect, slope location, and average percent slope. Some repetition was used in site variables and topographic features among species, but intraspecific repetition was minimized. All sampling took place in 1997–1998 or 1 yr after most damage occurred.

Sites that exhibited characteristics of rare natural disasters were excluded. An example of such an event was a catastrophic windthrow, in which exceptionally strong winds cause extensive damage to a large area. These events may supersede attempts to accurately predict tree stability by skewing height:diameter ratios of damaged trees. Endemic windthrow occurs more regularly and at smaller scales. It usually occurs as a result of numerous low-velocity windstorms, affecting individual stems or small groups of trees. Unlike catastrophic windthrow, endemic windthrow hazard can be effectively reduced with sound management practices (Stathers et al. 1994).

Five dominant trees from each site were measured for total height with a clinometer and aged at breast height. Milner's (1992) site index curves for western Montana were used to establish site index based on dominant tree measurements. As with other site variables, preference was given to sites exhibiting different densities and site indices.

Damaged trees displayed obvious stem bending or breakage. Those trees whose average bend was less than 15° from vertical were not included. Such a slight bend may be the result of growing conditions and not necessarily caused by stem bending under snow or wind pressure. Uprooted trees were not included, because this type of damage is often a

Table 1. Site characteristics for sampled stands in western Montana. Site numbers refer to locations in Figure 1.

Site no.	Species*	Site location	Habitat type†	Basal area (ft^2/ac)	Site index (ft at 50 yr)	Aspect	Slope (%)	Slope location	Structural stage
1	PP	Lubrecht Exp. Forest	PSME/SYAL/SYAL	171	59	229°	12	Mid-upper	Closed stem exclusion
2	PP	Lozeau	PSME/ARUV	199	48	117°	0	Lower	Closed stem exclusion
3	PP	Six Mile	PSME/CAGE	60	54	130°	3	Mid-lower	Understory reinitiation
4	WL	Garnet Range	PSME/LIBO/SYAL	116	57	6°	8	Mid-upper	Young multi-strata
5	WL	Sunrise Creek	PSME/PHMA/PHMA	184	63	352°	15	Upper	Open stem exclusion
6	WL	Coram Exp. Forest	ABLA/CLUN/CLUN	103	68	313°	9	Mid	Closed stem exclusion
7	WL	Miller Creek Demon. Forest	ABLA/CLUN/ XETE	98	75	24°	14	Mid-upper	Closed stem exclusion
8	DF	Lubrecht Exp. Forest	PSME/SYAL/SYAL	133	62	229°	12	Mid-upper	Closed stem exclusion
9	DF	Garnet Range	PSME/LIBO/SYAL	94	71	12°	8	Mid-upper	Young multi-strata
10	DF	Sunrise Creek	PSME/PHMA/PHMA	85	55	345°	24	Upper	Closed stem exclusion
11	LPP	Elk Creek	PSME/SYAL/SYAL	143	66	124°	16	Mid-upper	Closed stem exclusion
12	LPP	Cap Wallace Gulch	PSME/LIBO/CARU	193	58	63°	7	Mid-lower	Closed stem exclusion
13	LPP	McClain Creek	ABLA/LIBO/XETE	112	52	104°	24	Mid	Closed stem exclusion

* PP = ponderosa pine; WL = western larch; DF = Douglas-fir; LPP = lodgepole pine.

† PSME = *Pseudotsuga menziesii*; ABLA = *Abies lasiocarpa*; SYAL = *Symphoricarpos albus*; ARUV = *Arctostaphylos uva-ursi*; CAGE = *Carex geyeri*; LIBO = *Linnaea borealis*; PHMA = *Physocarpus malvaceus*; CLUN = *Clintonia uniflora*; XETE = *Xerophyllum tenax*; CARU = *Calamagrostis rubescens*.

result of circumstances unconnected to height:diameter ratios and tree stability. Uprooted trees can be classified as either root breaks (rotational falls) or tree throws (hinge falls) (Stathers et al. 1994). In both cases, damage is primarily a result of root and/or soil condition. Stem break, however, is a result of structural weakness in the stem and can be associated with height:diameter ratios (Stathers et al. 1994).

Trees exhibiting recent damage were selected as sample trees. Diameter (dbh) of damaged trees was measured prior to felling. Total tree length (height) and length of live crown were measured after each damaged tree was felled (only damaged trees were felled to obtain accurate height measurements). Live crown length was considered to be the distance between the lowest living branch and the top of the tree. Epicormic branches were excluded from the crown length measurement when the distance below the main crown to the epicormic branch exceeded 10% of total tree height.

The nearest undamaged tree of the same species to each damaged tree was selected for measurement. Trees with crooked stems were not considered to be undamaged, since past snowfall or wind could have altered their form. Dbh was measured for each undamaged tree. Total tree height and live crown length were measured using a clinometer. To obtain an estimate of stand density, basal area was estimated with a 10-factor prism at every fifth undamaged tree measured and an average basal area per acre calculated.

A total of 660 trees in 13 stands were sampled. Number of trees (damaged and undamaged) sampled ranged from 20 to 80/stand depending on amount of damage present in the stand. Height:diameter ratios were expressed in identical units and always used diameter at breast height.

The *Prognosis* or *Forest Vegetation Simulator* model (version 6) was used to simulate stand growth at various spacings for each species (Wykoff et al. 1982). Identical keyword files were used for all species, with the exception of species planted and thinning preference (see Wonn 1998 for details). Trees were planted at 1 ft heights and grown for 100 yr. A thinning from below was implemented in the model with species preference codes to attain desired stocking of particular species. Average heights and diameters were then calculated from a list of tree attributes, and a stand average height:diameter ratio was derived.

Difference of means t-tests were conducted for damaged and undamaged trees of each species. Comparative data were used so that larger undamaged trees were not included in the testing. Any undamaged tree with a diameter greater than the largest damaged tree was omitted. Difference of means t-tests were also conducted on crown ratio data of damaged and undamaged trees to determine if live crown ratio was a good predictor of tree stability. Undamaged trees with a dbh greater than the largest damaged tree were omitted from these tests to minimize the bias of undamaged trees having much larger diameters.

Results

Trees from different sites followed similar trends in height and diameter distributions, so were combined by species for all analyses. Ratios of total tree height to diameter at breast height for damaged trees were significantly higher than for undamaged trees for all species at a significance level of 0.05 (P-value < 0.001).

Figure 2 shows height and diameter for damaged and undamaged trees from all four species. A threshold ratio of approximately 80:1 (ft:ft) exists from all four species above which trees become more susceptible to damage by wind or

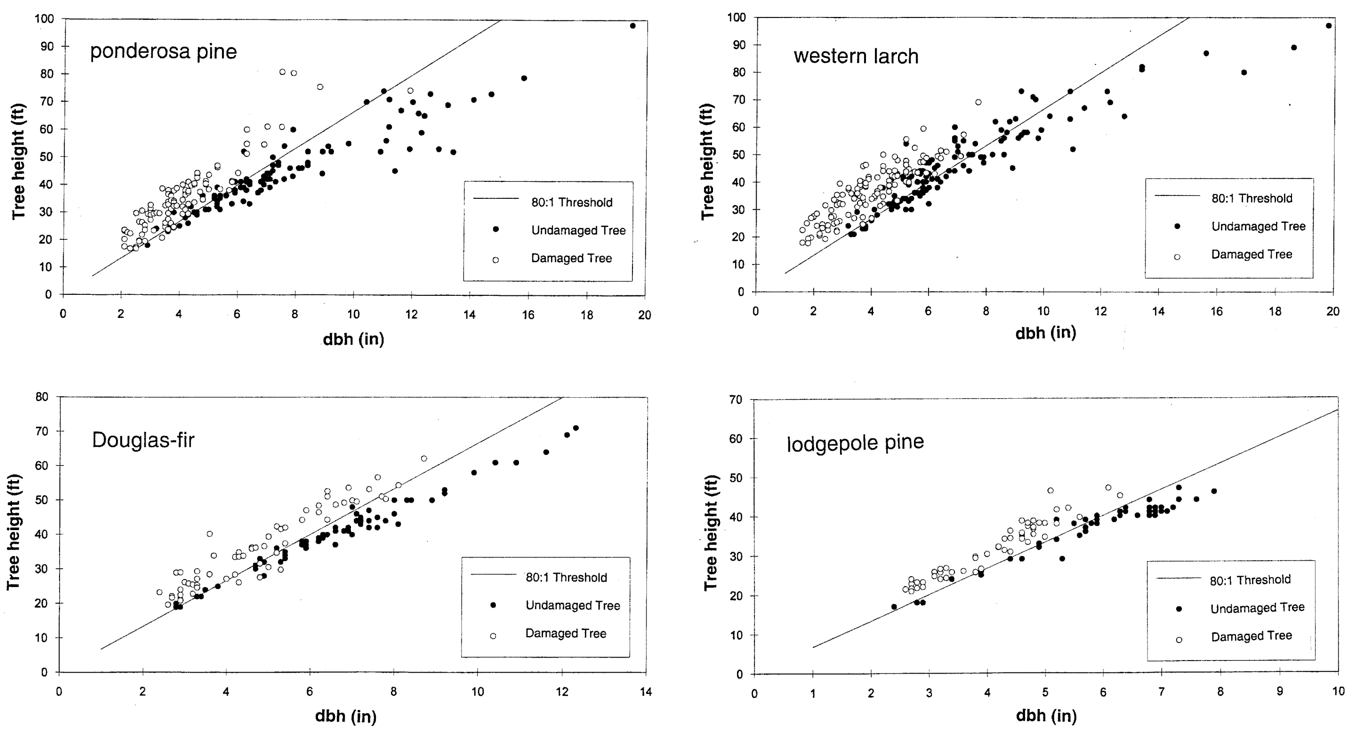

Figure 2. Height and diameter of damaged and undamaged ponderosa pine, western larch, Douglas-fir, and lodgepole pine. Data within a species were combined from all study sites. The threshold ratio is height and dbh in equal units.

Table 2. Percent damaged and undamaged trees with height:diameter ratios greater than 80:1.

Species	Damaged	Undamaged
	(%)	
Ponderosa pine	95.0	22.0
Western larch	99.2	45.8
Douglas-fir	88.3	11.1
Lodgepole pine	100	22.0

snow. The percentage of damaged trees exceeding this threshold greatly exceeded the percent of undamaged trees above this point (Table 2). In addition, trees from intermediate or suppressed canopy classes had greater height:diameter ratios than those from more dominant crown classes (Table 3).

Lodgepole pine was the only species that showed significant differences ($\alpha = 0.05$) in crown ratios between damaged and undamaged trees ($0.002 < P$-value < 0.005). The other three species showed no significant difference between damaged and undamaged trees (P-value > 0.10).

Height:diameter ratios predicted with *Prognosis* for ponderosa pine are shown in Figure 3. The model predicts wider spacings will have higher height:diameter ratios than narrower spacings. Ratios also appear to decline with age for some spacings.

Average height:diameter ratios are plotted in Figures 4–8 for a selection of regional spacing and growing stock level trials for interior species. Most of these spacing trials show relatively constant or slightly increasing average height:diameter ratios over time for unthinned stands (Figures 4 and 5). In the ponderosa pine spacing study in northern Washington, all spacing treatments had increasing height:diameter ratios. The control was generally decreasing. Likewise, the lodgepole pine spacing study in northeast Oregon showed an increasing height:diameter ratio in the narrowest spacing by stand age 31 (Figure 5). Average ratios for the 200 largest crop trees/ac for western larch are shown in Figure 6. These ratios are all increasing after stand age 20.

Height:diameter ratios for two growing stock level studies are shown in Figures 7 and 8. In contrast to the spacing studies, the height:diameter ratios in these studies had flat to decreasing trends with repeated thinnings to constant residual stocking levels thus indicating the potential for thinning to improve stability.

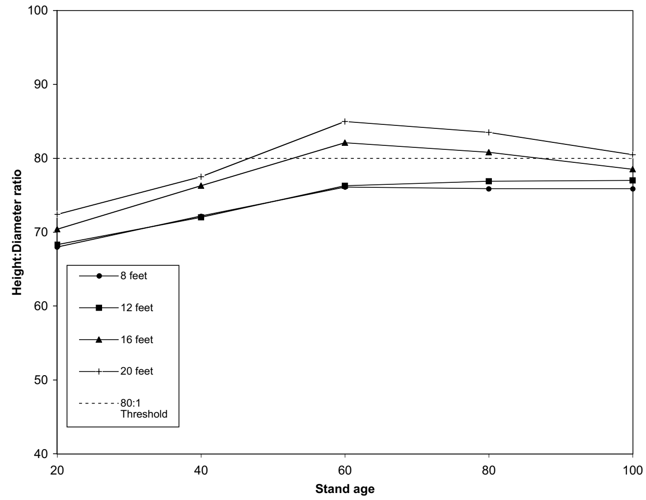

Figure 3. Average height:diameter trends for ponderosa pine in the Lolo National Forest of western Montana (data from *PROGNOSIS*). Legend shows average spacing between trees.

Discussion

Tree stability for ponderosa pine, western larch, Douglas-fir, and lodgepole pine becomes jeopardized when height:diameter ratios exceed a threshold level of 80:1. Below this threshold, trees are relatively stable and resistant to snow and wind damage. While this trend is relatively consistent among species, some variation does exist within species. For example, some damaged trees are found below this threshold, and undamaged trees are found above the threshold for nearly all species. However, despite the exceptions, the 80:1 ratio appears to provide a useful threshold that can be used to predict damage.

Western larch is the most variable of the four species, probably because of its deciduous nature. The lack of needles in the winter makes western larch less susceptible to the same snow and wind forces that damage evergreen species. Western larch typically receives heaviest snow damage during late spring when trees have a partial to full complement of needles (Schmidt and Schmidt 1979). Because of warmer temperatures at this time of year, these snows are often “wet” snows, which increase weight and stress on the larch (Schmidt and Schmidt 1979). These

Table 3. Average height:diameter ratio by crown class and species for each study site. Numbers in parentheses denote sample size.

Site	Species	Dominant	Codominant	Intermediate	Suppressed	Sample ave.
		(height: diameter ratios)				
Lubrecht	PP	63.8 (2)	59.3 (9)	77.8 (35)	93.5 (34)	82.1 (80)
Lozeau	PP	—	79.7 (16)	94.7 (51)	105.7 (13)	93.5 (80)
Six Mile	PP	68.2 (11)	91.2 (10)	99.4 (7)	105.1 (12)	90.5 (40)
Garnet Range	WL	57.7 (3)	79.3 (13)	90.9 (19)	113.1 (45)	100.2 (80)
Sunrise Creek	WL	69.7 (2)	69.9 (6)	103.8 (28)	135.3 (4)	100.1 (40)
Coram	WL	—	88.6 (10)	101.6 (57)	111.7 (13)	101.6 (80)
Miller Creek	WL	74.7 (4)	81.8 (9)	89.7 (21)	89.7 (6)	86.4 (40)
Lubrecht	DF	68.9 (2)	78.7 (16)	84.6 (16)	91.2 (6)	82.4 (40)
Garnet Range	DF	66.7 (2)	79.4 (10)	82.9 (18)	92.3 (10)	83.6 (40)
Sunrise Creek	DF	70.4 (3)	71.7 (10)	82.9 (13)	90.8 (14)	81.9 (40)
Elk Creek	LPP	77.3 (1)	77.6 (14)	88.1 (15)	91.7 (10)	85.1 (40)
Cap Wallace	LPP	73.9 (4)	79.4 (7)	82.8 (18)	96.3 (11)	85.0 (40)
McClain Cr.	LPP	69.9 (1)	79.4 (3)	85.5 (11)	88.8 (5)	84.6 (20)

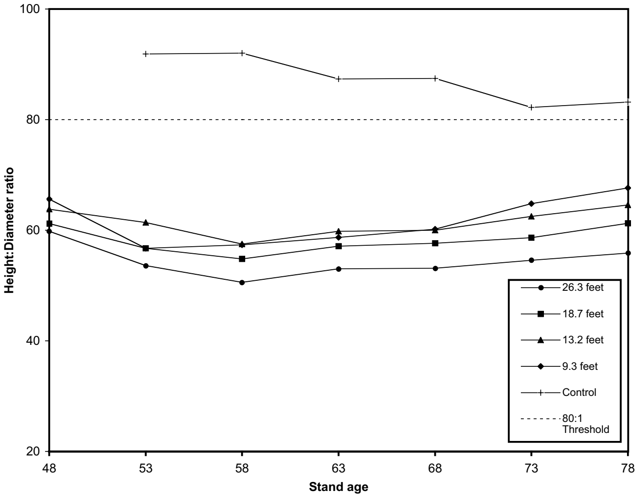

Figure 4. Average height:diameter trends for ponderosa pine spacing trial data in Methow Valley of northern Washington (data from Cochran and Barrett 1998). Legend shows average spacing between trees. Control plots averaged 3.3, 4.3, and 5.3 ft spacings.

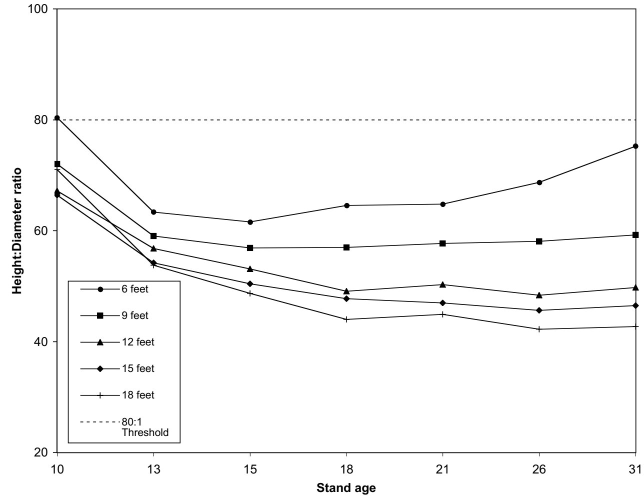

Figure 5. Average height:diameter trends for lodgepole pine spacing trial data in northeast Oregon. Numbers denote average spacing between trees (data from Cochran and Dahms 1998). Legend shows average spacing between trees. Note stand age axis is categorical, not linear.

"wet" snows may not occur on an annual cycle, allowing larch to exceed the height:diameter threshold level and remain standing for several years. The extremely high height:diameter ratios recorded for many damaged western larch and the relatively high percentage of undamaged western larch above the threshold may be attributable to this fact (Figure 2).

Ponderosa pine, Douglas-fir, and lodgepole pine show less variability with relation to the 80:1 threshold (Figure 2). The probability of damage to these species apparently increases once the threshold has been exceeded. As with other evergreen trees, the majority of damage probably comes from midwinter snows that accumulate in the crown or endemic wind events that lead to stem breakage. The poor potential for differentiation and dense nature of many lodgepole pine stands may make this species prone to high height:diameter ratios (O'Hara and Oliver 1999). All damaged lodgepole pine had height:diameter ratios exceeding 80:1 (Table 2, Figure 2).

In an attempt to maintain canopy position and better compete for light resources, intermediate and suppressed trees have less diameter growth for a given unit of height growth than more dominant trees. This leads to "spindly" trees that are unstable and susceptible to damage by snow and wind (Table 3). Figure 2 shows that as undamaged tree diameter increases, height:diameter ratios tend to decrease. The flattening of the undamaged tree curve as diameter increases is a result of stand differentiation and mortality of lower crown class trees. A tree with a dominant or codominant canopy position is able to allocate more resources to diameter increment relative to height increment and therefore has a higher height:diameter ratio.

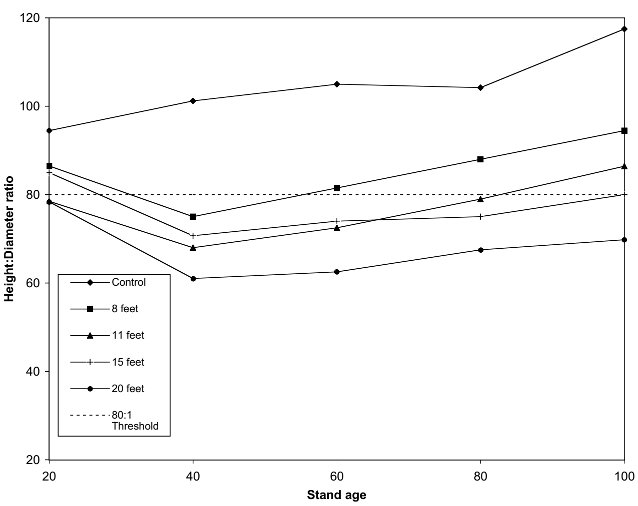

Figure 6. Average height:diameter trends for western larch crop trees in a spacing trial replication at Coram Experimental Forest (Coram 1). Crop trees are defined as largest 200/ac (data from Schmidt 1998). Legend shows average spacings between all trees.

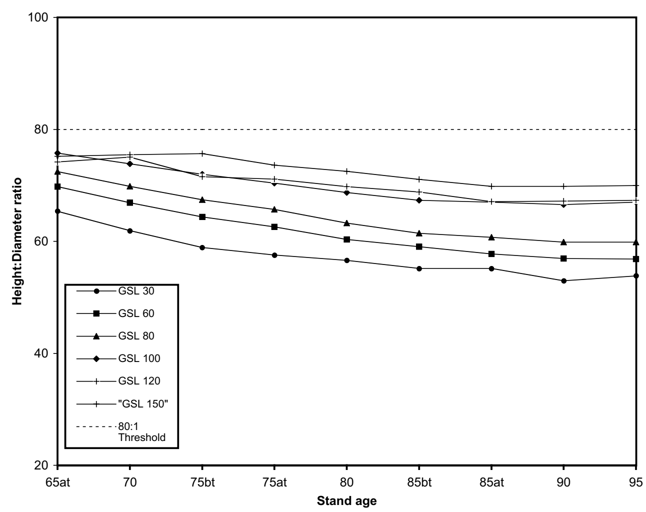

Figure 7. Average height:diameter trends for ponderosa pine trees in a growing stock level (GSL) in central Oregon. Stands were periodically thinned to growing stock levels that were defined as the residual basal area present after thinning treatments (data from Cochran and Barrett 1999). Note stand age axis is categorical, not linear, and letters "bt" and "at" designate height:diameter ratios before thinning and after thinning.

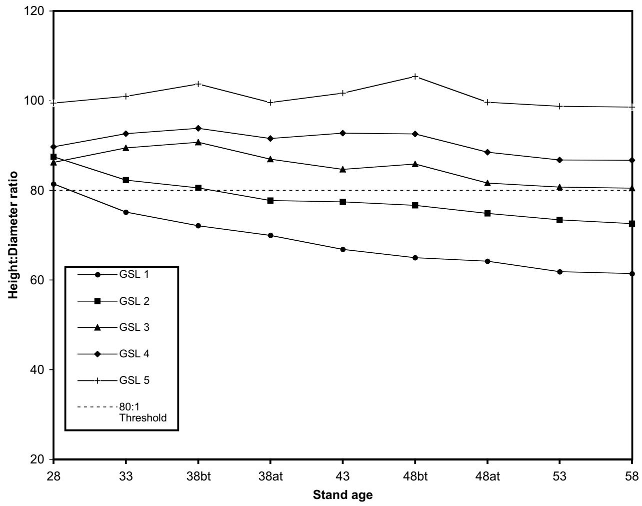

Figure 8. Average height:diameter trends for western larch trees in a growing stock level (GSL) study in the Blue Mountains of Oregon. Stands were periodically thinned to growing stock levels that were defined as 5,000, 10,000, 15,000, 20,000, and 25,000 ft of bole area/ac for GSLs 1 through 5 (data from Cochran and Seidel 1999). Note stand age axis is categorical, not linear, and letters "bt" and "at" designate height:diameter ratios before thinning and after thinning.

During stand development, a number of processes are occurring that affect height:diameter ratios. First is the trend of decreasing height:diameter ratio with increasing dominance in a stand (Table 3). As stands differentiate, lower crown classes have smaller heights and disproportionately smaller diameters. Second, all spacings, including the widest, are probably increasing in height:diameter ratio during stand development in fully stocked stands. This is evident in Figure 6, where only the 200 largest trees/ac are shown. Third, self-thinning removes primarily lower crown classes from the stand. This process removes trees with high height:diameter ratios and has the effect of lowering the average ratios for the stand even though all individual tree height:diameter ratios may be increasing with time. The net effect of these three processes is that stand averages—such as those shown in Figures 4, 5, 7, and 8—poorly reflect the dynamics of this measure of tree stability.

Live crown ratio was not a good predictor of tree stability. The lack of significant difference between crown ratios of damaged and undamaged trees suggests that larger or smaller crown ratios did not predispose a tree to damage by wind or snow. As tree size increases, and relative canopy position becomes more favorable, crowns expand to occupy growing space. Snow accumulation may occur primarily in the upper crowns of these conifers, and longer crowns may not lead to greater snow accumulation or snow damage. Crown length may be an important variable in areas receiving less snow damage and where wind damage is the predominant factor affecting tree stability.

Prognosis poorly represented height:diameter trends at different spacings. For higher density stands, the model predicts lower height:diameter ratios. Figure 3 shows this trend for ponderosa pine. Western larch, Douglas-fir, and lodgepole pine projections with *Prognosis* followed similar trends. This is counter to spacing/growing stock trial data, in which increasing density corresponds to increases in height:diameter ratio (Figures 4-8). The internal height-increment model in *Prognosis* causes the discrepancy. *Prognosis* predicts height growth with an independent small-tree model, as well as an independent large-tree model. The small-tree model predicts height growth with explicit site and stand density variables, without a diameter-increment term (Wykoff et al. 1982). *Prognosis* simulations to reflect height:diameter trends performed as expected early in stand development. However, as the transition is made to the large-tree model, diameter becomes more of a driving force in height-increment prediction (Wykoff et al. 1982). As density decreases, average tree diameter increases. This corresponds to a disproportionate increase in height growth at wider spacings. This increased height growth relative to diameter at lower densities leads to higher height:diameter ratios as density decreases. Although growth modifiers for large-tree height increment (HTGMULT) can be used to better simulate height:diameter trends, the lack of supporting data from spacing trials makes input multipliers difficult to determine.

Management Recommendations

To maintain stand stability in ponderosa pine, western larch, Douglas-fir, or lodgepole pine in the northern Rocky Mountains and similar forest types elsewhere, height:diameter ratios should be kept below an 80:1 threshold. Height:diameter ratio is primarily a function of spacing, allowing for the control of stand stability through density management. To effectively maintain height:diameter ratios below threshold levels throughout stand development, wide spacings should be encouraged early during stand development. Thinnings done early in the development of a stand will benefit residual trees more than thinnings done late (Schmidt and Seidel 1988). The short response time associated with a young thinned stand will enable residual trees to quickly utilize growing space and increase diameter increment relative to height. Thinning to reduce density prior to, or at the time of, stand differentiation will be most effective in development of a stable stand. However, stands with a range of stocking levels can be thinned to reduce or maintain stable height:diameter ratios as shown in the two growing stock level studies (Figures 7 and 8). Older stands with borderline height:diameter ratios should receive a series of low intensity thinnings. Such a regime will allow residual trees to respond to available growing space while not jeopardizing stand stability.

If done improperly, thinning can significantly increase wind damage, particularly in dense, even-aged stands (Stathers et al. 1994). For several years after thinning, trees may be more susceptible to snow and wind damage, particularly if height:diameter ratios are high. Caution should be used when thinning stands at high risk for damage, such as stands adjacent to openings, stands with prevalent root rot, pure stands, stands at higher elevations, or stands with one uniform canopy layer (Stathers et al. 1994). Leaving trees with height:diameter ratios below 80:1 should ensure that extensive damage does not take place following a thinning operation. Furthermore, thinnings done at intervals (e.g., every 10 yr) are not as effective in reducing height:diameter ratios as heavy thinnings done early during stand development because trees are less able to recover lost diameter increment.

Intermediate and suppressed crown classes generally have the highest height:diameter ratios (Table 3). In stands with significant differentiation, stand average height:diameter ratio may not be a useful tool for predicting stand level damage. Dominant and codominant trees may be stable even though average stand ratios are high. Caution must be used when assessing stand-level risk to snow and wind damage under high levels of stand differentiation.

Thinning stands from above will exacerbate stability problems by removing trees with lower height:diameter ratios. Low thinnings will have the opposite effect on the average stand ratio and will also encourage greater diameter growth in residual trees resulting in lower ratios in these trees. Measuring height:diameter ratios of trees can allow managers to identify practical stand structural targets and design thinning treatments that remove unstable trees and make thinning feasible.

Spacing trial data provide average height:diameter trends over time and identifies spacings prone to snow and wind damage. For ponderosa pine in eastern Washington (Cochran and Barrett 1998), stands at spacings greater than 10 ft maintained average ratios less than 80:1 (Figure 4). These average stand data do not show within-stand variation. Results from this study (Table 3) indicate a stand-average height:diameter ratio near 80:1 implies many trees are exceeding this threshold. This would be particularly true in stands with high levels of differentiation. The ponderosa pine data from Cochran and Barrett (1998) also indicate stagnation at narrower spacings because average height of controls was only half the average height of the widest spacing at age 82. The western larch spacing trials in western Montana maintained average ratios of less than 80:1 at spacings of 15 ft or more through age 35 (Schmidt 1998). In eastern Oregon, western larch stands thinned to spacings greater than 17 ft produced trees with stable ratios through age 53 (Seidel 1987). The western larch in western Montana were initially thinned at age 9, while the western larch in eastern Oregon were initially thinned at age 33 implying timing of thinnings is critical.

These spacing trials also demonstrate that average height:diameter ratios increase over time for a given spacing, and land managers need to anticipate stability thresholds in designing density management regimes. Recommendations for spacing based on stable height:diameter ratios depend on good spacing trial data. Unfortunately, such data do not exist for some species in the interior west, and other data have limitations. Foremost among these is that the published spacing trial data only show *average* patterns, not the differentiation into different tree sizes and different height:diameter ratios. For example, the ponderosa pine spacing trial data in Figure 8 show no stability problems in stands through age 85 for any spacings. Because the range of height:diameter ratios cannot be determined from these published data, only estimates can be made as to appropriate spacings. Western larch stability seems to be encouraged with spacings greater than 17 ft established early in stand development. Other species in the northern Rocky Mountains would also benefit from wide spacings established early, although specific spacings are difficult to recommend at this time. Long-term spacing trial data will make it possible to determine more precise spacings to encourage stand stability. Until such data become available, forest managers should monitor height:diameter ratios and design prescriptions (e.g., thinnings) when necessary to keep ratios below 80:1.

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