Effects of a Western Spruce Budworm Outbreak on Private Lands in Eastern Oregon, 1980–1994

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ABSTRACT

Forest Inventory and Analysis data from three inventory periods were used to examine the effects of a western spruce budworm outbreak on private lands in eastern Oregon. Growth was negatively related to defoliation with differences between crown ratio and species. The mortality and salvage harvesting caused changes in stand structure on private lands. Although many stands showed a decrease in basal area, there was no detectable decrease in host species as a percentage of basal area. The combined effect of mortality, harvest, and loss in predicted growth may be as much as 30% of the initial standing volume.

Keywords: forest inventory, defoliation, growth effects, stand structure, eastern Oregon

Western spruce budworm (WSB; *Choristoneura occidentalis*) is the most widespread forest defoliator in North America (Swetnam and Lynch 1993). Spatial and temporal patterns of outbreaks vary widely. Typical outbreaks last 10–15 years and affect millions of acres of forest (Dolph 1980, Swetnam et al. 1995, Sheehan 1996). Fire exclusion has been practiced in North America for a 100 years and is hypothesized as contributing to the size and intensity of recent WSB outbreaks. Fire exclusion promotes the survival and abundance of WSB hosts in midelevation forests (Weaver 1959, McCune 1983, Anderson et al. 1987, Wickman 1992, Hadley and Veblen 1993, Agee 1993, Camp 1999). Common WSB host species in western North America are Douglas-fir (*Pseudotsuga menziesii*), grand fir (*Abies grandis*), white fir (*Abies concolor*), Engelmann spruce (*Picea engelmannii*), subalpine fir (*Abies lasiocarpa*), Pacific silver fir (*Abies amabilis*), and western larch (*Larix occidentalis*; Furniss and Carolin [1977]). However, for many western forests, these host species occur along with nonhost and resistant species. In addition to the influence of fire exclusion, the selective harvest of nonhost and resistant trees, such as ponderosa pine (*Pinus ponderosa*) and western larch, respectively, may also have contributed to a higher proportion of WSB hosts in midelevation stands (Wickman 1992).

WSB is endemic to eastern Oregon, and outbreaks have been documented as occurring every 21–53 years (Dolph 1980, Swetnam et al. 1995). Several published studies report the effects of WSB defoliation in Oregon forests. Two studies examined the impact of WSB defoliation on pole size and larger trees from a number of sites in northeast Oregon (Williams 1966, Carolin and Coulter 1972). In these studies, grand fir was defoliated more than Douglas-fir. A study by Powell (1994) examined 130 inventory plots on the Malhuer National Forest in 1989, very near the end of the most recent WSB outbreak. Only plots with at least a 50% stocking of WSB host species were chosen for evaluation. Estimates of defoliation, topkill, and tree mortality were analyzed by various tree and site characteristics. Powell's report is the only extensive examination of WSB impact in forest stands during the 1980–1994 outbreaks. The response of radial growth in WSB hosts to WSB defoliation was examined by Mason et al. (1997) and Torgersen et al. (1995). An important finding in Mason's study was that the maximum cumulative effect on increment growth in lower bole lags WSB defoliation by 3 years. Wickman et al. (1992) also looked at growth response to thinning and fertilization in budworm-infested stands. Youngblood and Wickman (2002) examined the contribution to dead wood loading caused by defoliation and subsequent mortality at two sites in northeastern Oregon.

The five types of tree damage associated with WSB defoliation are growth loss, topkill, deformity, reduced seed production, and mortality (Fellin and Dewey 1982). Growth loss, topkill, and mortality are related to the duration of the outbreak and associated droughts (Alfaro et al. 1982, Ferrell and Scharpf 1982). Much of the mortality and topkill in larger trees during a WSB outbreak is caused by bark beetle attacks (Johnson and Denton 1975, McGregor et al. 1983, Powell 1994). WSB defoliation increases mortality in understory trees, predisposes larger trees to bark beetle attack, and reduces the amount of canopy foliage (Williams 1966, Carolin and Coulter 1972, Hadley and Veblen 1993).

An aspect of WSB outbreaks that is rarely discussed in the literature is the salvage of dead and damaged trees by private landowners and the effects it may have on stand composition. Often, these salvage operations are not limited to damaged host trees, but include the largest trees in the stand regardless of species (Lettman 1995). This leads to the question, Are WSB outbreaks and subsequent salvage harvest(s) reversing the direction of succession and moving stands to an earlier serial condition?

Our research looks at regional impacts of a WSB outbreak on forest ecosystem processes of development, growth, and mortality on private timberlands, defined as nonreserved forested lands capable of producing 20 ft^3 or more per acre per year at a culmination of mean annual increment. The outbreak studied was the largest WSB attack on record in Oregon and occurred between 1980 and 1994;

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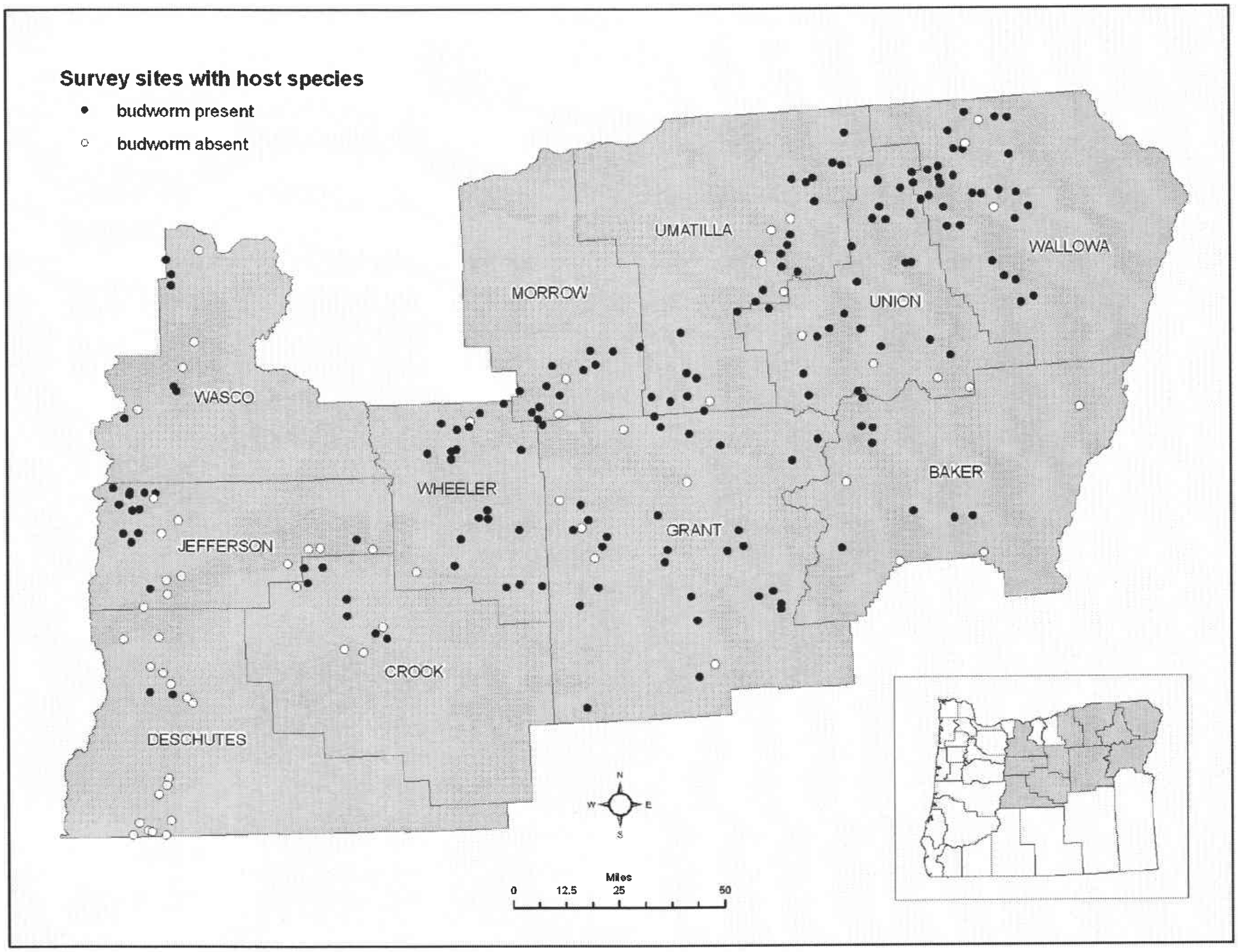

Figure 1. Eastern Oregon with affected counties and plots with and without spruce budworm.

over 6.3 million ac of forestland had visible defoliation (Sheehan 1996). The 1980–1994 WSB outbreak in eastern Oregon had many of the conditions for tree damage: many years of defoliation, an associated period of drought, and increasing bark beetle activity.

Our research objectives were to (1) assess the impact of WSB on growth and mortality, (2) to test the interaction of stand composition with WSB occurrence and level of damage, and (3) to examine the hypothesis that WSB can reverse successional processes in stands where the climax species was not a host species on private timberlands.

Methodology

We used the data from the Forest Inventory and Analysis (FIA) program of the Pacific Northwest Research Station, which provides a unique regional picture of WSB impacts on private timberlands. The FIA conducted surveys on private timberland in eastern Oregon in 1977, 1987, 1992, and 1998. The FIA sampling design enables estimates of area and tree attributes for private timberland in eastern Oregon by using a double sample for stratification (Cochran 1977). The inventory consists of aerial interpreted points on a 0.85-mi grid used for creating strata and ground plots systematically located on a 3.4-mi grid. This study combines the data from 1987, 1992, and 1998 inventories. Although each inventory had a slightly different plot design, in each case the old plot was remeasured before establishing the new plot over the same location (US Forest Service 1987, 1992, 1998).

The study area encompasses 11 counties (Baker, Crook, Deschutes, Grant, Jefferson, Morrow, Umatilla, Union, Wallowa, Wasco, and Wheeler) and 19 million ac of eastern Oregon (Figure 1). Using 1992 inventory estimates, this area contains about 1.8 million ac of private timberland, with ponderosa pine dominant on about 41% of the area, Douglas-fir dominant on about 29%, grand or white fir dominant on about 15%, and other species dominant elsewhere.

At each ground plot, a cluster of five variable-radius plots was established to measure trees greater than 5-in. dbh. Trees less than 5-in. dbh were measured on a smaller fixed-radius plot within the larger plot. In each of the inventories a set of tree attributes such as but not limited to diameter, height, compacted crown ratio (Monleon et al. 2004), and evidence of insects were measured or evaluated. As a special addition in the 1992 data, for trees greater than 1-in. dbh with WSB damage, data were collected on both topkill and defoliation. Evidence of WSB effect on individual trees was indicated by a damage code for seedlings and by a topkill or defoliation percentage for trees larger than 1-in. dbh. For trees less than 5-in. dbh, the entire crown was evaluated as a whole and classified into one of four defoliation classes (none, 1–25%, 26–75%, and more than 75%). For trees greater than 5-in. dbh, the crown was evaluated in three segments (lower, middle, and upper third) for three foliage classes (current, 1 year old, and 2 years old). For each of these nine divisions, binoculars were used to estimate defoliation as one of six classes (none, 1–25%, 26–50%, 51–75%, 76–99%, and no foliage remaining). For analysis purposes, defoliation on the larger trees was grouped into the same classes used for the smaller trees. For trees greater than 5-in. dbh, total tree defoliation was computed by averaging across the segments of the crown and across foliage age classes using the midpoints of the percentage intervals recorded, with the 26–75% and the greater than 75% classes considered moderate and heavily defoliated, respectively.

In 1992, the amount of topkill on host species was recorded in three percentage classes (none, 1–10%, and more than 10%) for trees less than 5-in. dbh and 10 classes (none, 1–10%, 11–20%, 21–30%, 31–40%, 41–50%, 51–60%, 61–70%, 71–80%, and more than 80%) for trees greater than 5-in. dbh. For analysis purposes, classes were aggregated for the larger trees into the same three classes used for the smaller trees.

Mortality was estimated for two periods. Because of the widespread harvesting after 1992, we felt that using 1987–1992 as the comparison period with 1977–1987 would give a more accurate comparison of mortality levels than using the 1987–1998 period. All mortality estimates are lower than what actually happened, because trees that died in the period and were harvested before the remeasurement would not be counted as mortality.

The average basal area increment (ABAI) between 1987 and 1998 was affected by multiple variables. A generalized least squares regression model was fit with tree and site parameters to prediction ABAI. The model fit with previous dbh, defoliation code, crown ratio class, productivity class, and total basal area explains a significant amount of variability in ABAI. We examined the tree level parameters of defoliation, crown class, and species for differences in ABAI. To compute growth lost to defoliation over the period, ABAI was projected for the 1987 trees assuming the growth rate for healthy trees. An adjustment factor was calculated for ABAI in each of two crown ratio classes (1–49% and 50–100%). The factor was the ratio of the weighted ABAI over the three defoliation classes, all species combined, compared with the ABAI of the nondefoliated trees.

Projected "healthy" 1998 diameters were computed for the trees found to have defoliation in 1992 by multiplying the annual diameter increment by the adjustment factor. Projected "healthy" 1998 volume was estimated using the 1998 height and projected dbh; the differences between the projected "healthy" volume and the actual volume were expanded to a population level and compared.

Many of the comparisons in the following text refer to stocking of WSB host species. We used relative stocking, which indicates an individual tree's contribution to stand occupancy (Curtis 1970, 1971). Stocking is commonly referred to as the percentage of a normally stocked stand that an individual tree represents and is computed as a function of diameter, species, social position, and stage of development. Here, we use a cumulative stocking value for WSB species as an indicator of how much of the stand is composed of WSB host species. We used a product-moment correlation (r) to compare stocking of host species and the number of trees affected.

Results and Discussion

Area

The 1987 inventory had an estimated 1.08 million ac with evidence of WSB damage in the 11-county area in eastern Oregon. In 1992, we examined 252 private timberland plots of which 199 (79%) had WSB host species, and of those, 188 had evidence of WSB damage, representing 1.3 million ac. For plots that had WSB host species present, 66% had greater than 50% of the relative stocking in WSB host species. By 1998, 74% of the plots had WSB host species and the WSB damage incidence had dropped to zero; of the plots with WSB host species, 61% had greater than 50% relative stocking of WSB host species.

Stand Occupancy and WSB Effects

Stocking of host species in 1987 and the number of trees affected in 1992 were positively correlated ($r = 0.67$). The level of severity of the attack as measured by the percentage of trees moderately or heavily defoliated did not appear to be directly correlated ($r = 0.21$) to the number of host trees on the plot. There is, however, some evidence that higher stocking of host species leads to higher levels of defoliation (Figure 2); a significance probability of 0.09 was found when comparing the mean level of host species heavily or moderately defoliated for plots above and below 50% stocking of host species. Similar results were found by Needham and Kershaw (1999) and by van Raalte (1972). A significant difference ($\alpha = 0.05$) also can be found for the proportion of plots with no trees heavily or moderately defoliated when comparing the below and above 50% stocked, 0.55 versus 0.33, respectively.

Nearly all sampled trees greater than 1-in. dbh showed some evidence of WSB damage, and only 55% of the sampled seedlings showed damage. Using the 1992 inventory data we estimated 288 million trees on private land showed some evidence of WSB damage.

Topkill

More than 80% of all host species had no topkill registered. The percentage of trees with topkill was relatively small, the worst case being the white/grand fir group having 32%. However, only 6.3% of the white/grand fir group had greater than 10% topkill (Table 1). The topkill information is not differentiated by cause; some topkill on host and other species could have been caused by other agents.

Defoliation

Defoliation occurred on more than 94% of the plots containing WSB host species. The majority of trees showed less than 25% defoliation. Subalpine fir, Pacific silver fir (in the extreme western portion of our study area), and Engelmann spruce showed the least amount of damage (Table 2). Douglas-fir, grand fir, and white fir showed the greatest number of trees with severe defoliation. We found no plot parameters, such as aspect, slope, elevation, or climax tree species that were related to the number of trees severely defoliated other than the number of host trees available.

Harvest

The WSB outbreak lasted until 1994, and associated salvage harvesting probably continued a few years longer. The *Oregon Forest Harvest Reports* (Oregon Department of Forestry [ODF] 2006) exhibits an average annual harvest increase of 26% on private timberlands between 1992 and 1997, over the 42-year average from 1962

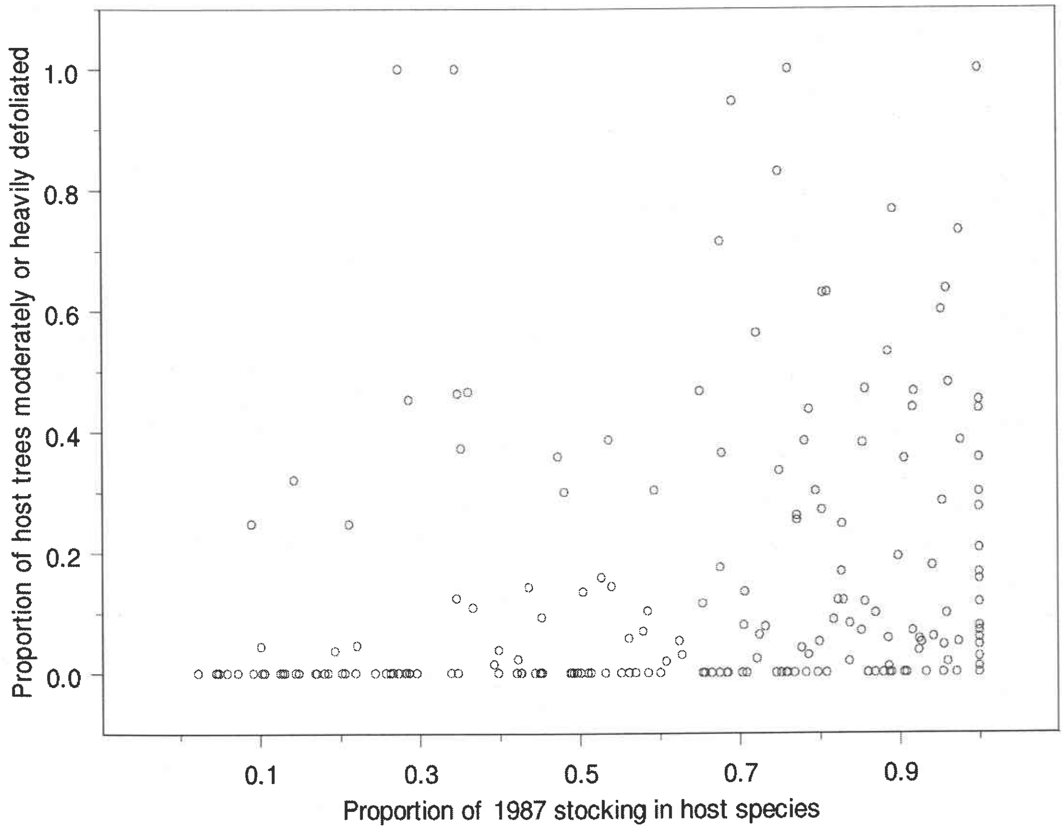

Figure 2. Proportion of 1987 relative stocking in host species versus the proportion of host trees that were heavily or moderately defoliated in 1992.

Table 1. Percentage of trees more than 1-in. dbh by species group, dbh class, and topkill class, for private timberland in 11 counties in eastern Oregon, 1992.

	Topkill class					
	No topkill		1–10%		>10%	
	<5 in.	≥5 in.	<5 in.	≥5 in.	<5 in.	≥5 in.
Douglas-fir	80.4	80.7	18.7	18.1	0.7	1.1
White/grand fir	74.4	67.9	22.2	25.7	3.3	6.3
Subalpine/ Pacific silver fir	96.0	87.4	4.0	10.7	0	1.8
Engelmann spruce	80.4	89.5	18.7	9.9	0.7	0.8

to 2003. National forest lands show a 55% decrease over the same period. To provide the best comparison of timber harvest levels from FIA data, we used the 1987–1998 period for comparison against the 1977–1987 period. Of the 252 plots that were remeasured in 1992, over 45% had evidence of harvesting between 1987 and 1992. Azuma et al. (2004) reported on the periodic removals between 1988 and 1998 when private lands showed more harvest and mortality than growth. Figure 3 shows the disproportionate increase in harvest of WSB host species in comparison with nonhost species. All WSB host species groups show more than a doubling in the estimated number of harvested trees, whereas the nonhost group of ponderosa and lodgepole pine showed only a 32% increase. The estimated harvest volume between 1987 and 1998 was about 190 million ft^3 for WSB species alone.

Across all remeasured plots there was a decrease in average live tree basal area per acre, all species, indicating high levels of harvest and mortality. Plots where more than 25% of the trees were highly defoliated had significantly ($\alpha = 0.05$) less mean basal area than plots where less than 25% of the trees were highly defoliated (60 ft^2 ac^{-1} versus 246 ft^2 ac^{-1}). This difference in basal area decline and the disproportionate increase in harvesting is evidence that WSB host species were being logged as they were defoliated or died.

Mortality

The 1992 estimates show more than twice the number of dead trees for WSB host species in about one-half as many years as the first period (Figure 4). The differences are greatest in the grand/white fir and Douglas-fir species groups.

Changes in Stand Composition

The stocking of WSB host species was unchanged from 1992 to 1998 and averaged 59%. Although the mean basal area per acre declined between 1987 and 1998, the mean percentage of basal area in WSB host species dropped only slightly, from 62 to 56%. We did not see a significant shift in species owing to the WSB outbreak and subsequent salvage logging in either stocking or basal area values. For only plots that were classed as having a nonhost climax species, the basal area decline was still marginal, 37–34% between 1987 and 1998. We infer from these data that either fire or active management that selects for nonhost species would be needed to transition stands to an earlier successional stage. We speculate that the lack of change in either stocking or basal area of host species is caused by regeneration and ingrowth on our plots.

Table 2. Percentage of trees greater than 1-in. dbh by species group, defoliation class, and dbh class for private timberland in 11 counties in eastern Oregon, 1992.

	Defoliation class							
	None		1–25%		26–75%		75+ %	
	<5 in.	≥5 in.	<5 in.	≥5 in.	<5 in.	≥5 in.	<5 in.	≥5 in.
Douglas-fir	59.2	0	23.2	48.8	10.2	44.6	7.1	6.4
White/grand fir	50.4	0	28.6	40.3	13.7	44.4	7.2	15.1
Subalpine/Pacific silver fir	75.0	0	25.0	84.0	0	15.9	0	0
Engelmann spruce	31.4	0	37.1	79.6	31.4	20.3	0	0

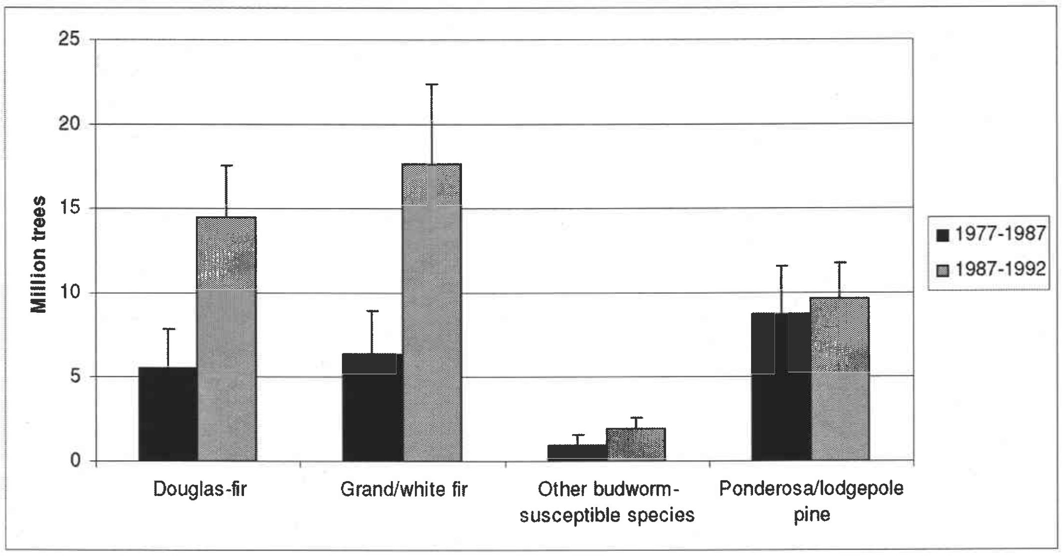

Figure 3. Estimated number of harvested trees between the periods of 1977–1987 and 1987–1998 for private timberland in an 11-county area in eastern Oregon.

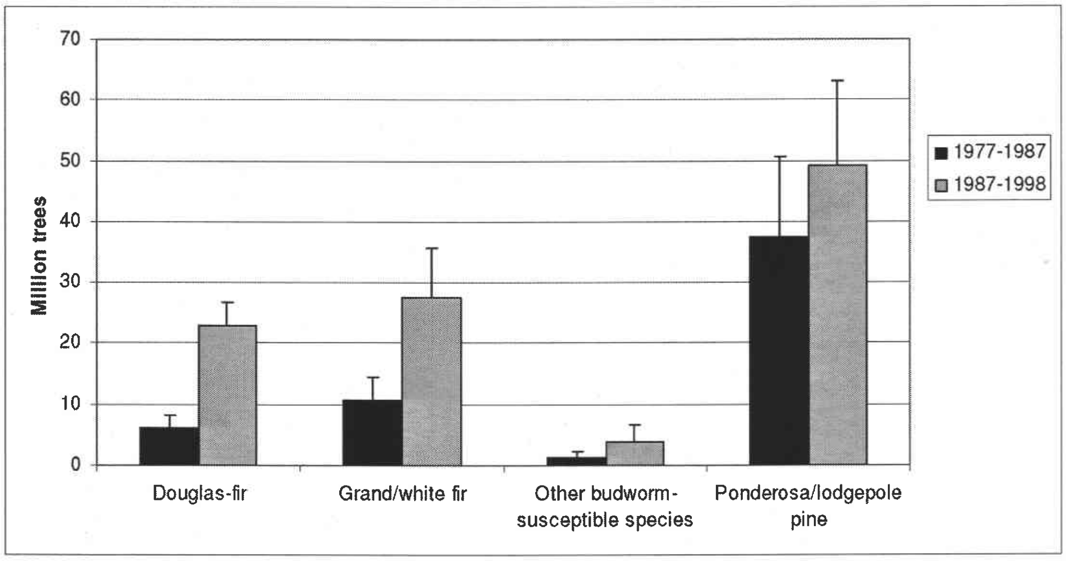

Figure 4. Estimated number of trees that died on private timberland in an 11-county area of eastern Oregon for 1977–1987 and 1987–1992.

Growth Effects

The differences in ABAI across the tree level parameters of species, crown ratio, and defoliation groupings are displayed in Table 3. The subalpine fir/Pacific silver fir group has a slower basal area growth than grand/white fir, Douglas-fir, and Englemann spruce. The crown ratio of a tree also has a major effect on the amount of basal area increment. Trees with less than 50% live crown ratio displayed a larger growth reduction (43%) from a 25% defoliation

Table 3. Average annual basal area increment (1987–1998), standard error, and (sample size) for budworm-susceptible species on private timberland for 11 counties in eastern Oregon, by crown ratio and defoliation class.

Crown ratio (%)	Defoliation class (%)	Englemann spruce	Douglas-fir	Subalpine/Pacific sliver fir	Grand/white fir	All species
1–49	None	3.26	2.88	0.96	2.61	2.73
		0.84 (11)	0.38 (58)	0.36 (6)	0.56 (29)	0.28 (104)
	1–25	2.05	2.18	0.48	0.70	1.54
		0.36 (15)	0.21 (134)	0.11 (21)	0.17 (83)	0.14 (253)
	26–75	2.47	1.82	0.54	0.72	1.42
		0.99 (3)	0.15 (148)	0.32 (2)	0.14 (89)	0.11 (242)
	75+	—	0.94	—	1.93	1.45
		— (0)	0.15 (35)	— (0)	0.25 (14)	0.13 (49)
Total		2.56	2.02	0.58	0.97	1.63
		0.38 (29)	0.12 (375)	0.11 (29)	0.12 (215)	0.08 (648)
50+	None	5.17	4.60	1.05	4.26	4.14
		1.50 (9)	0.43 (73)	0.27 (15)	0.73 (34)	0.33 (131)
	1–25	3.91	3.82	0.83	3.13	3.49
		0.67 (22)	0.27 (145)	0.27 (9)	0.32 (94)	0.19 (270)
	26–75	1.08	2.74	2.45	3.23	2.87
		0.48 (5)	0.20 (121)	— (1)	0.30 (76)	0.16 (203)
	75+	—	0.94	—	1.92	1.45
		— (0)	0.36 (15)	— (0)	0.67 (16)	0.39 (31)
Total		3.83	3.49	1.03	3.25	3.33
		0.58 (36)	0.16 (354)	0.20 (25)	0.21 (220)	0.12 (635)

rate compared with trees with greater than 50% crown ratio having a 15% reduction in ABAI across all species.

Volume Effects

We modeled the "healthy" 1998 dbh by using the individual tree annual diameter increment between 1987 and 1998 and a factor that adjusts for crown class and presence of defoliation. Basal area growth does vary with tree size, stand conditions, and climate, and this could affect the accuracy of predictions. Using the measured 1998 height and modeled dbh, we estimated the volume of the trees assuming no defoliation for over 2,000 trees from the 1987 inventory that were remeasured in 1998. Projected "healthy" and measured volume across all 11 counties differed by 249 (standard error, 41) million ft^3 or about 10% of the 1987 standing volume for all species.

Conclusions

The FIA data covering the 1980–1994 WSB outbreak provide the best-known comprehensive view of forest conditions and WSB impacts on private timberlands in eastern Oregon. Of the WSB hosts found on private timberlands, Douglas-fir and white/grand fir are the most numerous and economically important. Among the results of this study are several facts that may help in the management of stands containing WSB hosts between outbreaks. As other studies have shown, the white/grand fir group was found to be the most susceptible to mortality, topkill, and radial growth loss from defoliation. Second, it appears that trees with less than 50% crown ratio have greater radial growth loss with minor amounts of defoliation when compared with trees with larger crown ratios (43% versus 16%). The grand-fir/white fir species group shows the greatest basal area increment loss in the lower crown ratio class. Third, data from defoliated stands indicate that tree damage from WSB defoliation tends to be more severe when host trees represent more than 50% of the stand: this conclusion agrees with recommendations from Carlson et al. (1983).

A comparison of the 1987, 1992, and 1998 inventories shows an increased level of harvest and mortality of WSB host species. There was a decrease in the average amount of basal area on the remeasured plots; however, the percentage of WSB host species did not decline. The speculation that the WSB outbreak in the late 1980s and early 1990s may have reset the ecological clock to an earlier successional stage by reducing the amount of WSB host species was not borne out by our data. The high level of harvest on these lands that included harvest of nonhost species suggests that private lands were not being managed for nonhost species and that these lands will remain at risk to future outbreaks.

The WSB outbreak of the late 1980s coupled with the slowdown of harvest on national forests and a corresponding increase of harvest on private lands had a significant impact on private forest resources in eastern Oregon. In 1987, WSB host species included 1.9 million ft^3 in volume or 58% of the standing volume in the 11-county area. The estimated mortality volume (and standard error) from 1987 to 1992 was 145 (26) million ft^3 and harvest was 190 (30) million ft^3. Together, the harvest and mortality account for about 18% of the 1987 standing volume for WSB host species. Including the estimated growth, loss from defoliation of 249 (41) million ft^3 brings the effect to around 30% of the 1987 standing volume. Growing stock losses during the WSB outbreak continue to affect harvest levels on private lands more than 10 years after the outbreak.

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