The Effects of a Western Spruce Budworm Outbreak on the Dead Wood Component in Relation to Ownership in Forests of Eastern Oregon

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ABSTRACT

Forest Inventory and Analysis data were used to investigate the effects of a severe western spruce budworm outbreak on the dead wood component of forests in 11 counties of eastern Oregon for two time periods. The ownership and the level of damage (as assessed by aerial surveys) affected the resulting down woody material and standing dead trees. The pattern of coarse woody debris with respect to ownership and management intensity remained consistent into the next 10-year period. Harvesting tended to lower the amount of coarse woody debris on private forests. Federally managed forests had more standing dead trees than private lands, with more in the reserved than nonreserved areas. There was a reduction in the number of standing dead trees between the two periods.

Keywords: forest inventory, western spruce budworm, dead wood, coarse woody debris, aerial damage surveys

Western spruce budworm (*Choristoneura occidentalis*) (WSB) is one of the more common defoliators in North America (Anderson et al. 1987, Swetnam and Lynch 1993). The WSB is endemic to western forests that contain the primary hosts (Douglas-fir [*Pseudotsuga menziesii*] and true fir [*Abies*] species) and is normally present at levels at which defoliation is not readily detectable. Populations have been shown to reach epidemic levels every 21 to 53 years in eastern Oregon based on historical and dendrochronological evidence (Dolph 1980, Swetnam et al. 1995). Outbreaks typically last between 10 and 15 years, with the severity of effects differing widely in spatial and temporal scales. Budworm defoliation typically results in radial growth loss, top kill, and (where severe defoliation occurs for 4 or more consecutive years) tree mortality. The outbreak in eastern Oregon from 1980 to 1994 encompassing more than 2.4 million ha and is well documented in the literature (Powell 1994, Sheehan 1996, Mason et al. 1997, Azuma and Overhulser 2008). The increased mortality due to this outbreak, minus removal by harvesting or fires, should be manifested in the numbers of standing dead trees and amount of coarse woody debris (CWD).

Although WSB has been shown to be of less importance as a mortality agent than root disease and dwarf mistletoe across the Pacific Northwest Region (Steed and Wagner 2002), in the 11-county study area, there was a marked increase in mortality in budworm host tree species during the period of the late 1980s and early 1990s in eastern Oregon (Azuma and Overhulser 2008). Hummel and Agee (2003) also found increases in dead wood from a WSB outbreak in the eastern Washington Cascades. The effects on CWD from an insect outbreak are not immediate, like those from windstorms, fire, or logging, although there may be some-short term inputs. The majority of the influence will be seen over time as standing dead trees fall, although at any one site the input could be episodic with extreme weather or fire. The contribution to CWD from large-scale insect outbreaks probably provides a stable environment for wildlife species dependent on standing dead trees and CWD because of gradual recruitment of dead trees (Youngblood and Wickman 2002).

It has been well noted that standing dead trees and CWD have an important function in the ecosystem (Harmon et al. 1986), from supporting populations of insects that feed insectivores to providing habitat for mammals and birds (Maser et al. 1979, Buskirk et al. 1989, Bull et al. 1997, Laudenslayer 2002).

The down wood stores carbon and adds nutrients as it decays but at the same time adds to fuel accumulation in the forest ecosystem. Management for timber has been shown to affect the distribution and amount of CWD (Spies et al. 1988, Duvall and Grigal 1999). Management in the form of salvage harvesting and slash burning should reduce the amount of standing dead trees and CWD.

Differing ownership objectives play a key role in how forests are managed. The US Forest Service (FS) manages roughly 70% of the productive forestland (forestland capable of producing 1.39 m^3/ha per year of wood at culmination of mean annual increment) in the 11-county study region. Management in the form of timber harvest changed in the early 1990s, with the FS reducing volumes harvested by more than 60% from 1990 to 1994 and private lands showing a slight increase (Azuma et al. 2004). However, the management effects on FS lands from the previous decades could still be present during the inventory period. Under a less aggressive management regime, as used by the FS in the early 1990s, the increased mortality may result in an increase in the amount of dead wood in the forest. A comparison between reserved (no harvest allowed) and nonreserved (harvest allowed) lands is included to illustrate the level of

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This article uses metric units; the applicable conversion factors are: centimeters (cm): 1 cm = 0.39 in.; meters (m): 1 m = 3.3 ft; square meters (m^2): 1 m^2 = 10.8 ft^2; hectares (ha): 1 ha = 2.47 ac.

management on federal lands in relation to standing dead trees and CWD. Federal reserved lands such as wilderness areas do not have removals other than by fire, leaving dead material to accumulate.

The timber production from private lands increased in eastern Oregon in conjunction with the spruce budworm outbreak in the late 1980s and early 1990s. On private lands, mortality is often captured by salvage harvesting, so an increase in budworm-caused mortality may not show an increase in standing dead trees and CWD. Often, these salvage operations are not limited to damaged host trees but include the largest trees in the stand regardless of species (Lettman 1995). Almost 50% of the privately owned timberland plots sampled by the FS Forest Inventory and Analysis (FIA) program in the late 1980s and early 1990s had evidence of harvest. Many of the plots that did not show recent harvest, would have been managed in the previous 20 years, and represent an interesting comparison for both standing dead trees and CWD. Historical treatments on private lands have included selection harvest of larger trees, often followed by postharvest slash burning.

This research was designed to examine the effects of ownership, FS versus private, and its related management regimes and the level of impact from WSB on the dead wood component of the forest. It is hypothesized that increased harvest rates would be manifested in stands heavily affected by WSB by showing less dead wood in privately owned stands managed for timber production compared with the less actively managed FS stands and private stands that did not have recent harvest.

Methods

The study area includes all forested lands in 11 counties in eastern Oregon (Baker, Crook, Deschutes, Grant, Jefferson, Morrow, Umatilla, Union, Wallowa, Wasco, and Wheeler) and contains roughly 2.6 million ha of productive forestland. This area is represented by approximately 3,700 forested inventory plots from the 1990s, with most plots located in the Blue Mountains and some in the eastern Cascades, and represents the majority of the area in which the WSB outbreak occurred. The study used data from forest inventory plots located on a systematic grid across all forested lands in the 11 counties, including data from the FIA program of the Pacific Northwest Research Station, collected in 1998, and data from the National Forest Current Vegetation System (Max et al. 1996), collected from 1993 to1996. Data are also included from a second period, FIA's annual inventory system, collected between 2001 and 2007.

Private forest lands in eastern Oregon tend to be lower in elevation than FS lands. The private plots in this study were roughly 335 m lower in elevation, on average, than FS plots. The lower elevation is reflected in the stand composition containing a greater amount of the nonhost species, such as ponderosa (*Pinus ponderosa*) and lodgepole pine (*Pinus contorta*). The mean basal area per acre of budworm host species (Douglas-fir, grand fir [*Abies grandis*], white fir [*Abies concolor*], Pacific silver fir [*Abies amabilis*], subalpine fir [*Abies lasiocarpa*], Engelmann spruce [*Picea engelmannii*], and western larch [*Larix occidentalis*]) is 46% greater on FS lands in comparison with private lands. For comparison purposes, only stands that had some budworm host species present on them in the 1990s were used in the analysis, yielding roughly 1,900 plots. The mean percentage of basal area of host species on selected plots is not statistically different between private and FS lands, at 60% and 58%.

Data collected on plots include but are not limited to individual live-tree parameters (such as diameter, height, and species), standing dead trees, CWD, and plot-level attributes (such as evidence of harvest, reserved status, and dominant cover type). CWD material was sampled using line-intersect sampling, as outlined by Woodall and Monleon (2008). In the first period, standing dead trees were sampled on variable-radius plots for nonfederal and fixed-radius plots for federal lands. The size limit for CWD is 12.7 cm at intersection diameter, and for standing dead trees it is 12.7 cm dbh with a 1.37 m-minimum height. From 2001 to 2007, standing dead trees and CWD were sampled on a national standard plot design instituted by FIA in 2001 (Bechtold and Patterson 2005). Although the center point of the matched periodic to annual plot is the same, the layout of the subplots within the plots is different. The CWD is sampled on transects, and the locations of those transects changed between the sampling design used in the 1990s and that used in the annual measurement. Per-hectare values for both CWD and standing dead trees were computed and summarized at the plot level and compared across various groupings of plot attributes.

Data from Forest Health Protection's annual aerial detection survey (US Forest Service 2008) were used to classify areas as to the severity and temporal extent of damage by the spruce budworm outbreak of the late 1980s and early 1990s in eastern Oregon. Aerial sketchmaps in the form of GIS layers were intersected with plot locations, and attributes of the four-class defoliation system (Sheehan 1996) were extracted for each plot for the years between 1986 and 1994. The aerial survey was combined between 1986 and 1994 to produce an "effect of outbreak or damage" parameter for individual plots. The aerial survey defoliation data were condensed to a low/medium/high variable for each year, using a numeric value of 1, 2, or 3, and a 0 for plots outside of sketchmap polygons. The individual year's value was squared, the squared values were summed over the 9-year period, and the square roots of these sums were used as an indicator of the amount of damage on a specific plot. The creation of this index is to capture the differences in the severity of the defoliation rating, the assumption being that a defoliation rating of 3 has a much greater effect on a stand than a 1. For analysis purposes, a no-damage, low, medium, or high value was used to describe the severity of the attack associated with the plot, where low, medium, and high are each approximately one-third of the range of the index (0, 0.5–2.9, 3.0–5.9, and 6–10.8, for none, low, medium, and high, respectively).

The CWD volumes per hectare and numbers of standing dead trees per hectare were analyzed with S-PLUS using a multifactor analysis of variance (ANOVA) with the following model form:

$$\begin{aligned}\text{Response} \sim\ & \text{owner} + \text{damage} + \text{management intensity} \\ & + \text{owner} \times \text{damage} + \text{owner} \times \text{management intensity} \\ & + \text{damage} \times \text{management intensity}\ e \\ & + \text{damage} \times \text{management intensity} \times \text{owner}.\end{aligned}$$

I used a logarithmic transformation to stabilize the variance within the model. The factors included were ownership, delineated by FS or not; damage, as a 0, 1, 2, or 3 code; and management intensity, as a binary variable representing recent harvest/no-harvest for non-FS lands or reserved/nonreserved for FS lands. There was no harvest code recorded for plots on federal lands, so reserved/nonreserved is used as a proxy for management intensity. Statistical significance of factors or differences between factor-level means is reported at the 0.05 level.

Table 1. Summaries of analysis of variance testing for effects of ownership, damage, and management intensity on coarse woody debris (CWD) and standing dead trees for 1990s and annual data.[a]

		1990s CWD		1990s standing dead trees		Annual CWD		Annual standing dead trees		Differenced-matched plots CWD		Differenced-matched plots standing dead trees	
	df	MS	*F*	MS	*F*	MS	*F*	MS	*F*	MS	*F*	MS	*F*
Own	1	0.25	0.10	31.3	11.31[b]	28.11	16.05[b]	74.24	22.42[b]	0.00	0.00	0.02	0.17
Dam	3	49.77	20.45[b]	17.8	6.43[b]	7.55	4.31[b]	5.47	1.65	0.03	0.73	0.09	0.89
Int	1	9.99	4.10[b]	125.4	45.26[b]	2.13	1.22	78.0	23.55[b]	0.02	0.67	0.17	1.61
Own × Dam	3	1.26	0.52	4.7	1.72	0.96	0.55	1.74	0.52	0.00	0.07	0.04	0.41
Own × Int	1	16.42	6.74[b]	1.8	0.64	0.78	0.44	0.57	0.17	01	0.33	0.03	0.31
Int × Dam	3	17.88	7.34[b]	1.2	0.42	2.06	1.17	2.63	0.79	0.0	0.07	0.32	3.04[b]
Int × Dam × Own	3	2.09	0.86	7.7	2.79[b]	0.93	0.53	1.54	0.46	0.0	0.13	0.29	2.76[b]
Error[c]	1,912	2.43		2.8		1.75		3.31		0.04		0.10	
FS only													
Dam	3	41.91	16.5[b]	16.37	6.01[b]	4.11	2.31	5.46	1.64				
Int	1	23.36	9.20[b]	79.94	29.33[b]	0.37	0.21	62.39	18.8[b]				
Dam × Int	3	18.92	7.45[b]	4.31	1.58	1.42	0.80	1.29	0.39				
Error	1,704	2.53		2.72		1.77		3.31					
Non-FS:													
Dam	3	8.79	5.59[b]	8.74	2.79[b]	4.53	2.76[b]	0.96	0.29				
Int	1	4.05	2.57[b]	39.58	12.63[b]	2.14	1.31	18.53	5.69[b]				
Dam × Int	3	1.05	0.67	4.60	1.47	1.57	0.96	2.87	0.87				
Error	208	1.57		3.13		1.64		3.29					

[a] df, degrees of freedom; MS, mean square; *F*, computed *F* statistic; Own, owner; Dam, damage; Int, intensity; FS, US Forest Service.
[b] Significant at the 0.05 level.
[c] Error degrees of freedom for annual both owners is 555, FS only is 455, non-FS is 101.

Per-hectare values for plots where the center point had the same location in the 1990s and annual were subtracted from each other, yielding a difference value for CWD or standing dead trees, and were analyzed using the ANOVA model above. Roughly 570 plots from of the 1990s plots were sampled in the annual inventory.

Results

CWD

The ANOVA for amount of CWD present in the 1990s indicates differences between levels of damage and management intensity. A comparison across levels of damage found the no-damage category significantly different from the other levels of damage. Furthermore, comparisons showed differences between the low and high damage levels and between the medium and high damage levels. The ANOVA also showed the interaction terms between owner group and management intensity and between management intensity and damage level to be significant (Table 1). Figure 1 shows the factor-level means and standard errors for the 1990s data.

The 1990s patterns change slightly when using annual data (Figure 1). Roughly 10 years after the initial measurements, the owner group factor becomes significant, and the damage remains significant in the model (Table 1). However, the intensity factor drops out. Both interaction terms are no longer significant, probably because of the reduced sample size for the nonfederal lands (Table 1).

The ANOVA for the difference between per hectare volumes for matched annual and 1990s plots showed no significant factors or interactions terms (Table 1), with an overall mean difference between 1990s and annual CWD being −2.67, with a standard error of 3.1 m^3/ha. A similar ANOVA model using 1990s data on just non-FS lands found both the management intensity and damage factors as being significant (Table 1). The model using the FS data showed the damage and intensity factors and the damage/intensity interaction term as being significant. The ANOVAs for annual data by owner show some change, with the FS model having no factors being significant and the non-FS model having the damage factor being significant.

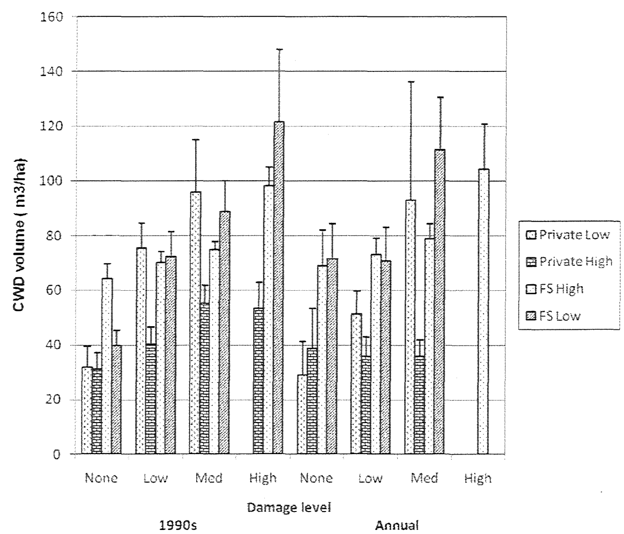

Figure 1. Means and standard errors for volume of CWD by inventory period, damage level, ownership, and management intensity. A total of 1,928 plots were used for the 1990s and 571 for annual data. Missing bars indicate small samples (fewer than five plots).

Standing Dead

The number of standing dead trees for 1990s data differed by ownership, management intensity, and damage levels (Table 1). The three-way interaction term between ownership, intensity, and damage level was also significant within the model. Factor level means and standard errors are displayed in Figure 2. The annual data had only the main factors of management intensity and owner being significant within the model.

The ANOVA model for matched plots showed the damage-intensity and damage-intensity-owner interaction terms as being significant (Table 1). The overall mean difference for matched

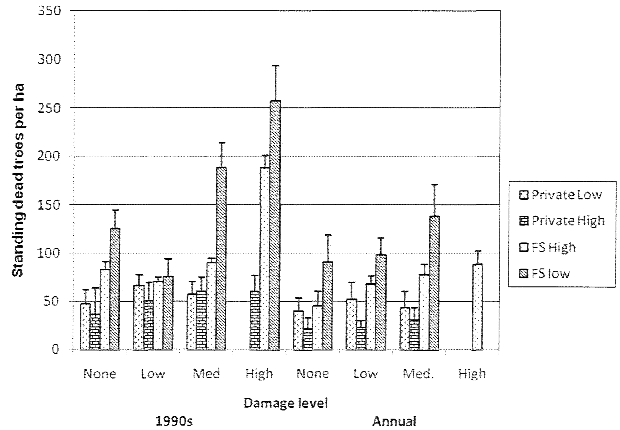

Figure 2. Means and standard errors for standing dead trees on plots by inventory period, damage level, ownership, and management intensity. A total of 1,928 plots were used for the 1990s and 571 for annual data. Missing bars indicate small samples (fewer than five plots).

annual-1990s plots was −14.84, with a standard error of 4.9 trees per hectare. The separate models for the two owner groups showed the same factors to be significant in both time periods; the 1990s had damage and management intensity being significant and only management intensity being significant for the annual data.

Discussion

The WSB outbreak and management regimes of the two owner groups seem to have had a demonstrated effect on the structure of the remaining forests with regard to the 1990s dead wood component. The plots on private lands with no damage as viewed from the aerial surveys seem to have the same amount of CWD regardless of harvest. Plots with damage show a decrease in CWD when there is evidence of recent harvest on private lands. This may be due to the increasing propensity for harvest as the stand has increasing amounts of damage. The FS plots have few differences in accumulated CWD between the lower damage levels; however, the maximum damage level shows an increase. At the time of this study, no data were available for plot-level information on harvesting on FS lands. However, the slowdown in harvesting on FS lands reported by Azuma et al. (2004) is a good indicator of the number of acres covered in treatments in the 1990s in comparison to the 1980s. Another indication of the general lack of recent management disturbance with respect to CWD on FS lands can be seen in the similarities in the means for nonreserved and reserved stands (Figure 1), where the only disturbance on the reserved lands should be from wildfire. A curious exception is in the no-damage class, in which the nonreserved lands seem to have more CWD than the reserved. This may be an indication of management prior to WSB infestation contributing to an increase in CWD. The general lack of management disturbance on FS lands is also reflected in the significance of the model interaction term of ownership-management intensity, because a management effect on CWD can be seen on private lands but not on FS land.

The number of standing dead trees per hectare in the 1990s data differed between federal and private lands and across both the damage and intensity variables. Reserved lands tended to have more dead trees than did the nonreserved lands, and FS lands in general had more than private. Surprisingly little difference was seen between non-FS plots that had some harvesting associated with them as opposed to those without (Figure 2). With the exception of the low damage index, differences are seen between reserved and nonreserved FS land at all levels of damage index, probably because of historic management on the nonreserved lands (Figure 2). The lack of difference at the low index may be an artifact of the index creation in that low/medium/high are artificial divisions created to represent a continuum. The largest differences are in the high/medium damage index groups on FS lands, where the difference in numbers of standing dead trees between reserved and nonreserved lands is almost 2-fold. The historic differences in management are borne out by the significance of the three-way interaction terms in the main model for standing dead trees. The dominance of the management intensity term for the FS indicates that the reserved/nonreserved nature of the plots outweighs the level of damage as noted from aerial surveys.

The significant model components for the annual CWD and standing dead tree data change from the periodic values, with the CWD losing the intensity term and the interaction terms but gaining a significant ownership term. The loss of interactions may be due to a reduction in sample size between the two periods. The addition of the ownership term is probably an indication of the recruitment of CWD in the lack of management in the form of salvage harvesting on the FS lands. There are more changes in the standing dead trees model, reflecting the losses of standing dead, with only the ownership and intensity components being significant, dropping the damage and interaction terms. The damage index seems to be more relevant in a short time period for standing dead trees, showing significance in the 1990s standing dead trees model but then dropping out in the annual model. The annual model for CWD retains the damage while losing the intensity term, but in it, the ownership variable is significant, indicating that a difference in CWD, more on FS lands, can be seen between the owner groups regardless of damage effect.

The models for differences between matched plots show no significant factors for CWD; however, in the standing dead trees model, the three-way interaction term and the two-way term between damage and intensity are significant. The overall mean for the difference in standing dead trees per hectare is significantly different from 0, indicating an overall loss of standing dead trees between the two periods. The losses of standing dead trees are not surprising in a 10-year period given suggested fall rates of between 1.6 and 0.7% per year (Huggard and Kremsater 2007). The longevity of snags is dependent on species, cause of death, and tree size (Morrison and Raphael 1993).

A direct comparison between 1990s and annual data is problematic in that there are different plot designs used for each. Although the center point of the matched periodic to annual plot is the same, both the layout of the subplots within the plots and the tree selection procedures were different, making direct comparisons difficult. The CWD is sampled on transects, and the locations of those transects changed between the sampling design used in the 1990s and that used in the annual measurement. If estimates of direct change in CWD are desired, a different sampling protocol would be needed. Estimates of change would require the same types of components that trees would have, such as pieces lost and gained.

There is some evidence (Donato et al. 2006) that managed stands may produce more down wood because of harvesting activities, but this study shows a general decrease in the amount of CWD on recently harvested stands. This study only accounted for CWD 12.7

cm in diameter and larger; results might differ if smaller diameter CWD was included in the sampling. Current sampling protocol includes smaller diameter pieces.

Conclusions

It appears that epidemic levels of WSB can have an effect of the amount of CWD and standing dead trees and that an index created from aerial survey data can explain some of the differences in the amount of standing dead trees and CWD. Management regimes in the form of harvesting can influence both components of dead wood in forested landscapes. Past treatment history on FS lands seems to have a small influence on the average amount CWD in the absence of WSB damage and a greater influence in the number of standing dead trees, as indicated by the differences between reserved and nonreserved lands. However, the levels of standing dead trees are greater on FS lands than private and greater on reserved than non-reserved, most likely because of management prior to the WSB outbreak. Decreases in numbers of standing dead trees per hectare, mainly in the high damage class, are seen on both federal and private lands over the 10-year period between collection of 1990s and annual data.

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