Western Spruce Budworm and Wildfire: Is There a Connection?

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In the interior Pacific Northwest, extensive defoliation of mixed-conifer forests during outbreaks of western spruce budworm (WSB) may leave the visual impression of a tinderbox with trees primed to burst into flame. But is this the case?

We addressed this question with funding from the USDA/U.S. Department of the Interior Joint Fire Science Program (project 09–1–06–5). Here we summarize our three recent publications exploring the potential relationship between WSB outbreaks and fire. We used a multimethod approach to explore potential disturbance interactions that might cause one disturbance to change the occurrence or severity of the other. We used tree-ring records to see whether WSB and fire are related in time and computer modeling to see how defoliation could affect crown fire behavior.

Study Design

WSB is the most damaging defoliator in western North America. Caterpillars emerge in the early spring and feed on the new foliage of many short-needled conifer species, especially Douglas-fir, grand fir, and white fir. Outbreaks of WSB may last for a decade or more and extend over hundreds of miles. A study of a large outbreak in the 1980s showed that, in most areas, fewer than 25 percent of the canopy trees were killed, but mortality rates may be high for smaller trees (Powell 1994). Widespread synchronous outbreaks have been tied to climate, but previous studies have reported conflicting results regarding the specific climate conditions driving this phenomenon (Flower and others 2014a).

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> Western spruce budworm is the most damaging defoliator in western North America.

Detecting synergisms between disturbances is difficult because both WSB outbreaks and wildland fires occur sporadically over large areas and are strongly modified by forest composition and climate. Efforts by Meigs and others (2015) to map and quantify the spatial overlap of the two kinds of disturbances (fig. 1A) are complicated by the fact that fire is naturally more common in low-elevation ponderosa pine forests, whereas WSB outbreaks occur at higher elevations in mixed-conifer forests. Other studies have found that even when WSB and fire don't occur in a stand at the same time, they can still affect each other (fig 1B). Analyses of late 20th-century outbreaks in British Columbia (Lynch and Moorcroft 2008) and in Oregon and Washington (Preisler and others 2010) found decreased fire risk for 3 to 7 years following a WSB outbreak. However, modern records of disturbance are limited because fire suppression and logging have

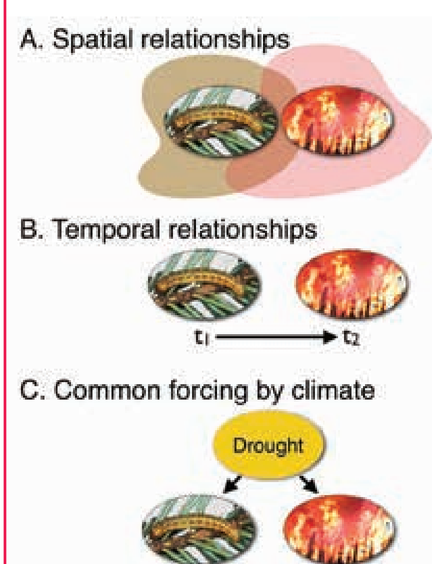

Figure 1—*Western spruce budworm outbreaks and wildfire are disturbances operating across landscapes and through time. You can test their association by examining their spatial overlap (A) or temporal leads and lags (B), but apparent synergisms between the disturbances may be the result of a common climatic forcing (C).*

decreased fire frequency and have led to an increase in the density of conifer species preferred by WSB, thereby intensifying WSB damage (Wickman 1992). Climate can also confuse the relationship between the two disturbance types because it can be difficult to differentiate interactions between fire and WSB from the reactions of each to a common climate driver (fig 1C).

These issues motivated us to isolate the different factors affecting the dynamics of WSB outbreaks. Accordingly, we:

1. Created a multicentury tree-ring record of WSB outbreaks and assessed the climate conditions that caused outbreaks to initiate;
2. Created a multicentury fire history record and compared it to both our WSB record and to climate records; and
3. Used a physics-based fire behavior model to address the effect of defoliation on torching and crowning potential if the two disturbances were to overlap in space and time.

Tree-Ring Records

The tree-ring record gives a detailed annual history of disturbances and their connection to climate over the past few hundred years. Many studies have revealed the strong connection between climate and forest fires by comparing the dates of fire scars preserved in tree rings with independent tree-ring reconstructions of temperature or precipitation (Falk and others 2011). Other studies have reconstructed the occurrence of WSB defoliation by identifying periods of reduced growth in the rings of trees that survived defoliation (Swetnam and others 1995). However, prior to our study, no one has analyzed the temporal relationship (for example, leads or lags) between both fire and WSB records at the same sites. We reconstructed 3 centuries of WSB outbreaks from tree rings at 13 sites along a 249-mile (400-km) transect from eastern Oregon to western Montana, reconstructed fire histories at 10 of those sites, and compared both records with previously published tree-ring reconstructions of moisture availability.

> We concluded that budworm outbreaks had no discernible effect on the probability of fire occurrence and vice versa.

Our tree-ring records revealed several new findings. We detected an average of 12 outbreaks per site, with a trend toward longer and more severe outbreaks in the era of fire exclusion after 1890. Between 1739 and 2000, 17 outbreaks synchronously affected more than half the sites. Both local and regionally synchronous outbreaks tended to occur at the end of multiyear drought periods (Flower and others 2014a). We detected an average of seven fires per site, with fires becoming almost entirely absent after around 1890. We found no association between fire and multiyear trends under previous climate conditions; rather, fires were simply more likely to occur during single dry years (Flower and others 2014b). Thus, while drought affected both WSB outbreaks and fire, it affected them differently.

We used a suite of statistical tests to analyze the synchrony between fire dates and the initiation dates, duration, and intensity of WSB outbreaks (Flower and others 2014b). These tests all revealed that wildland fires had no bearing on the timing of WSB outbreaks (fig. 2). We concluded that WSB outbreaks had no discernible effect on the probability of fire occurrence by changing fuels and that wildland fires had no discernible effect on the likelihood of a WSB outbreak by altering host tree density. Thus, although both types of disturbance may increase in a future of rising drought and climate variability, we found no precedent for their occurrence growing in a synergistic way.

Fire Behavior Modeling

Although WSB outbreaks may not increase the probability of fire occurrence, they can affect how fires burn. To understand how WSB and fire might interact, we examined the effect of WSB on the potential for trees to torch and crown during wildfires. The indirect effects of WSB are likely important, such as the accumulation of coarse wood in the understory over long periods of time, but they are difficult to model due to high spatial variability. So we focused instead on the most direct effect of WSB: reduction of foliage density in the canopy.

The effects of defoliation on fire behavior occur at fine temporal and spatial scales, and traditional operational fire models do not have the parameters to capture the effects at such fine scales. We therefore used a computational fluid dynamics model, the wildland–urban interface fire dynamic simulator (WFDS), to address complex interactions between fire and fuel (Mell and others 2009). The experimental design was straightforward: For a range of defoliation levels of a moderate-sized Douglas-fir tree, what was the effect of WSB defoliation on canopy consumption, given a range of surface fire intensities?

We consistently found that defoliation reduced the vertical and horizontal propagation of fire (Cohn and others 2014). Trees defoliated by less than 30 percent torched after some crown fuels ignited at a threshold level of surface fire intensity, whereas trees defoliated by 50 to 80 percent did not have sufficient canopy fuel to sustain a crown fire. We modeled a wide range of surface fire intensities, including the high intensities predictable from maximum increases in accumulated surface fuels; even at these high intensities, defoliation had the same impact on torching and crowning. Potential variation in branchwood moisture did not have a significant effect on torching in our simulations.

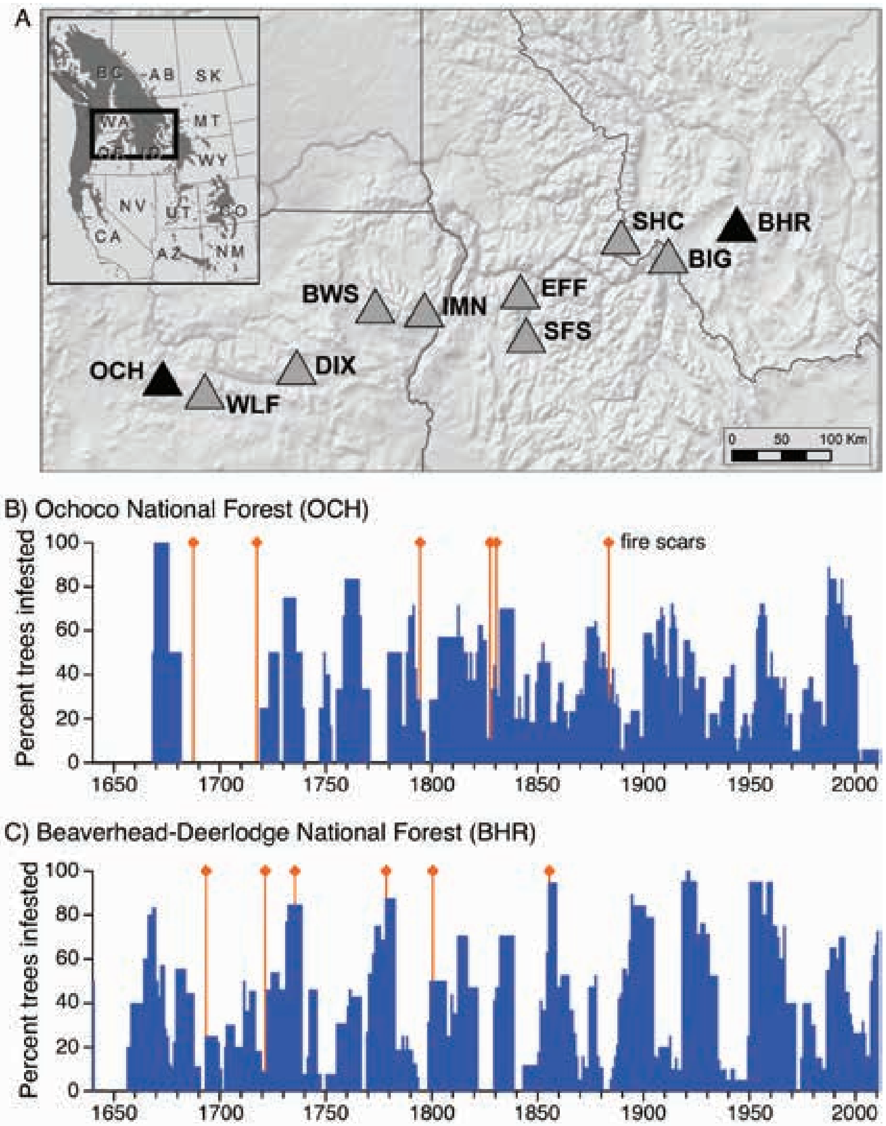

Figure 2—*The map shows the locations of 10 sites with western spruce budworm (WSB) outbreaks (A), including the Ochoco National Forest (OCH) and Beaverhead–Deerlodge National Forest (BHR); the inset map of the Western United States (A, upper left) shows the range of WSB host tree species. The graphs (B and C) show tree-ring reconstructions of WSB outbreaks in relation to wildland fires for two of the sites (OCH and BHR); the percentage of trees with distinct growth reductions due to WSB outbreaks (the blue bars) is superimposed on fire dates detected at the same sites (the red lines). We found no temporal relationship between WSB outbreaks and fire.*

The WFDS model is state-of-the-art in terms of exploring the partial effect of defoliation on crown fire, and it agrees with coarse-scale models used previously. Another study found that defoliated stands had increased surface fuel loads and increased canopy base heights (Hummel and Agee 2003). Using the Fire and Fuels Extension to the Forest Vegetation Simulator, that study predicted small changes to surface fire intensity and critical flame length, with no significant change in torching or crowning potential.

Extrapolating Results: Reduced Tree Mortality

Taken together, the tree-ring and modeling studies suggest a lack of synergism between WSB outbreaks and wildland fires. However, a different kind of synergism may exist: Defoliation might dampen the severity of a subsequent wildfire. To explore this possibility, we used existing empirical equations that show the probability of mortality due to defoliation (fig. 3A) and the probability of mortality due to crown scorch (fig. 3B), combined with the simulated results of canopy consumption at different levels of defoliation (fig. 3C), to extrapolate the summed probability of mortality under a range of surface fire intensities and defoliation levels (fig. 3D). The results suggested a distinct "fireproofing" effect of defoliation: The increased risk of mortality by WSB is more than compensated for by reduced foliage consumption during moderate surface fire intensities. For example, trees with 50-percent defoliation have a distinctly lower probability of mortality when surface fires are less than about 74 kilowatts per square foot (800 kW/m²).

However, we considered only the partial effect of defoliation on fire occurrence; we did not take into account other effects of WSB outbreaks, such as mortality of small trees. Of course, field observations are required to test our prediction. Remotely sensed burn severity maps, in combination with prior surveys of insect effects, could address this issue. One such study of the 2003 B&B Complex Fire in Oregon showed that prior defoliation had a marginal effect on reducing fire severity that was not statistically significant (Crickmore 2011). However, an analysis by Meigs and others (2016) of all post-WSB fires in Washington and Oregon from 1987 to 2011 showed that there is

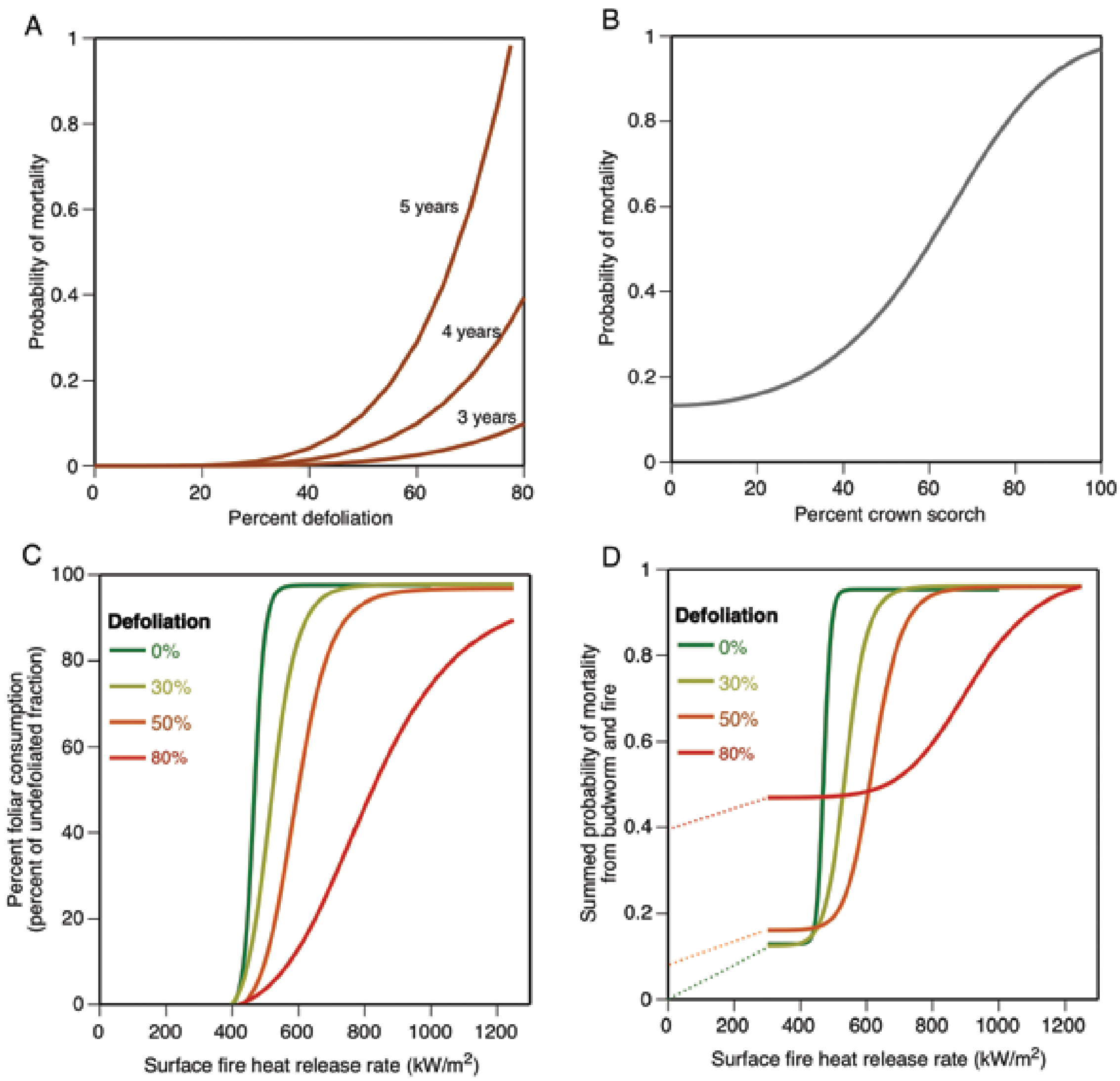

Figure 3—*(A): The probability of mortality as a function of defoliation by western spruce budworm (WSB) sustained over 3 to 5 years (Alfaro and others 1982). (B): The probability of mortality as a function of crown scorch using the equation from Ryan and Amman (1994) for a tree with a diameter of 19 inches (49 cm), a height of 39 feet (12 m), a canopy base height of 6.6 feet (2 m), and a bark thickness of 0.9 inch (2.4 cm). (C): The percentage of live foliage consumed in model runs of the wildland–urban interface fire dynamic simulator for the tree described for (B). The curves are logistic regression lines fit to data in Cohn and others (2014). (D): The summed probability of mortality from WSB and fire, assuming 4 years of defoliation (A) and the crown scorch estimated from (C) entered into the Ryan and Amman (1994) equation (B). Increasing surface fire intensity results in rapid torching (and mortality) of undefoliated trees (green line), but defoliation reduces crown scorch and thus mortality probabilities.*

The results suggested a distinct “fireproofing” effect of budworm defoliation, with reduced foliage consumption during moderate surface fire intensities.

a statistically significant reduction in fire severity that persists for up to 20 years following an outbreak. Thus, the effect of defoliation on crown fire behavior modeled by Cohn and others (2014) appears to be confirmed by the analysis of burn severity data by Meigs and others (2016).

Fireproofing Effect?

It may seem reasonable to assume that extensive defoliation, causing sustained low levels of tree mortality in mature trees, should have a measurable effect on wildfire occurrence. However, fire is a highly variable disturbance in itself, and it is highly sensitive to specific climate and winds during the fire event. The scale of fuel changes wrought by WSB may be too small to affect subsequent fire probability in ecosystems where fire is limited by fuel moisture and ignition sources rather than fuel availability. Our data show that these two disturbance types do not share similar histories, despite a common link to drought events.

Nevertheless, we hypothesize a “fireproofing” effect on host trees from defoliation due to WSB outbreaks. Although such an effect has been detected statistically from recent fire events (Preisler and others 2010; Meigs and others 2016), the inferred processes at play remain to be studied in detail at the site scale. ■

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