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ORIGINAL ARTICLE

Dendroentomological and forest management implications in the Interior Douglas-fir zone of British Columbia, Canada

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Abstract

Douglas-fir (*Pseudotsuga menziesii* var. *glauca* Mirb. Franco) forests in the Interior of British Columbia, Canada, show periodic defoliation due to western spruce budworm (WSB) (*Choristoneura occidentalis* Freeman) outbreaks. Tree defoliation causes a reduction in radial growth and is therefore visible in tree rings. In this paper, we identify WSB defoliation history, and critically examine the potential for using dendrochronological analysis by comparing tree-ring estimates with insect surveys. WSB defoliation history was investigated using cores from Douglas-fir growing in the Lac du Bois region of the Kamloops Forest District. Years with an abrupt decrease in radial growth were considered as negative pointer years that potentially reflected WSB outbreaks. The comparison with ponderosa pine (*Pinus ponderosa* Dougl., ex P. & C. Laws.) (a non-host species) permitted differentiation between growth reductions in Douglas-fir due to climatic effects and those due to defoliation by WSB. The dendrochronological data were matched with information reporting visible damage in Forest Insect Disease Survey (FIDS) and British Columbia Ministry of Forest records. Our objective-based method using ring-width measurements from host and non-host chronologies was compared with qualitative techniques based on the software program OUTBREAK. We were able to distinguish seven distinct outbreak events in 300 years of record.

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Introduction

Knowledge of the disturbance history of interior Douglas-fir forest over broad temporal and spatial scales is essential for understanding forest ecosystems (Pickett and White, 1985). By studying the history of these disturbances, we can identify the trends, variations

and periodicities of events and processes that sustain or change forest ecosystems (Wickman et al., 1994; Swetnam et al., 1999).

Insects are an integral component of forest ecosystems with important roles in forest dynamics (Haack and Byler, 1993) and often interact with other forest disturbances (i.e. pathogens, fire, windthrow). In the Interior Douglas-fir (IDF) (*Pseudotsuga menziesii* var. *glauca* Mirb. Franco) forests of British Columbia, the western spruce budworm (WSB) (*Choristoneura*

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occidentalis Freeman) is a native defoliator whose actions cause either tree mortality or a reduction of growth rates in forests of Douglas-fir, grand fir (*Abies grandis* (Dougl. Ex D. Don, Lindl.), white fir (*A. concolor* Gord. and Glend. Lindl. Ex Hildebr.), subalpine fir (*A. lasiocarpa* Hook., Nutt.) Engelmann spruce (*Picea engelmannii* Parry ex. Engelm.), and western larch (*Larix occidentalis* Nutt.) trees. Although occasional hosts, trees such as ponderosa (*Pinus ponderosa* Dougl., ex P. & C. Laws.) and lodgepole (*Pinus contorta* var. *latifolia* Dougl. Ex Loud.) pine maybe important in various ways to the population ecology of the budworm, they cannot in themselves support a continuing outbreak of the insect.

WSB infestations have been reported since the early 1900s in British Columbia and have caused widespread defoliation that last from a few to ten or more years (Alfaro et al., 1982; Harris et al., 1985). Budworm defoliation severely reduces the radial growth of trees by destroying photosynthetic tissue (Kramer and Kozlowski, 1979); however, the ultimate effect of defoliation is influenced by the species of tree and insect, the frequency and timing of feeding, and physiological condition of the tree (Alfaro and MacLauchlan, 1992; Mason et al., 1997). During successive years of infestation the width of annual rings is reduced, in a cause–effect relationship that usually has a one or more year lag (Fig. 1) (Alfaro and MacLauchlan, 1992). The preferential feeding by budworm on the current year's buds and foliage, reduces or eliminates apical growth during each year of defoliation, this results in defoliated trees taking several years to regain their full foliage and during this period radial growth rates are slow to recover. Extensive defoliation events that continue over a number of years often cause mortality of the upper crown that reduces the height of the trees in the overstorey by one to several internodes (Alfaro and MacLauchlan, 1992).

Climatic variations may also increase or decrease the vulnerability of trees to budworm attack (Larsson, 1989; Ryerson et al., 2003). For example, the density of natural populations of *Choristoneura* ssp. increases during extended periods of warm dry weather (Campbell, 1989). In British Columbia, there has been only limited research undertaken to examine the

effect of climate on WSB infestations in the IDF forests (Shepherd, 1961; Hard et al., 1980; Thomson et al., 1984). However, Thomson (1979) has stressed the significance of climate on establishing a synchrony between larval emergence and bud flush and Swetnam and Lynch (1993) established a positive relationship between spring and early summer precipitation and the occurrence of regional-scale outbreaks in northern New Mexico. Outbreak reconstructions by Ryerson et al. (2003) reported that WSB outbreaks in the mixed conifer forests of south-central Colorado State typically corresponded with times of increased moisture.

The Opax Mountain Case Study

Our goal in this research was to establish the history of WSB outbreaks in representative IDF forests in the Kamloops Forest District. Standardized dendrochronological techniques were used to determine outbreak characteristics, such as timing and frequency as well as evaluate possible relationships between climatic patterns and outbreaks (Fritts, 1976; Wickman et al., 1994; Zhang et al., 1999). Our dendroentomological investigations were completed within the *Opax Mountain Silviculture Systems Research Project* site located northwest of Kamloops (Fig. 2). The site is characterized by mixed stands of Douglas-fir and ponderosa pine at lower to mid elevations (400–1250 m asl) and Douglas-fir and lodgepole pine at high elevations (1130–1460 m asl). Coniferous trees in the IDF respond to environmental disturbances such as climate, insects, and fire, with corresponding changes in their annual growth rings. Consequently, a disturbance record is retained in tree rings that can be examined using dendroecological techniques (Fritts and Swetnam, 1989). Historical disturbance regimes are essential for evaluating whether these IDF forests are presently outside their historical range of variability (Klenner et al., 2001). The information we gathered will be used to strengthen the development of sustainable forest management practices within Interior British Columbia, by providing a long-term perspective on the growth and yield response of these dry Douglas-fir forests to WSB defoliation.

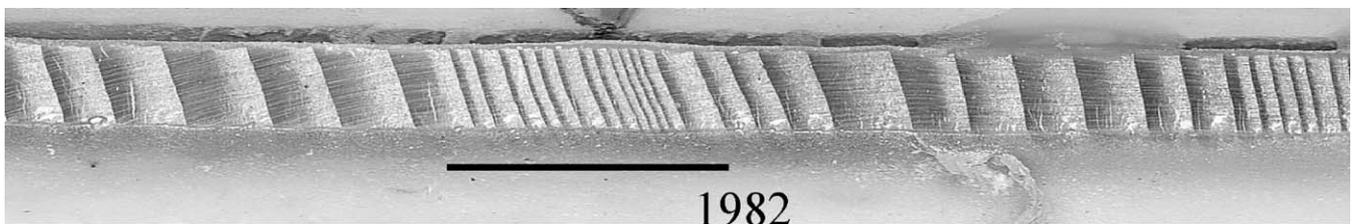


Fig. 1. Increment core from a Douglas-fir tree showing a period of growth reduction due to the western spruce budworm outbreak (1982–1993). Increased growth is also evident following many of the reduced growth periods.

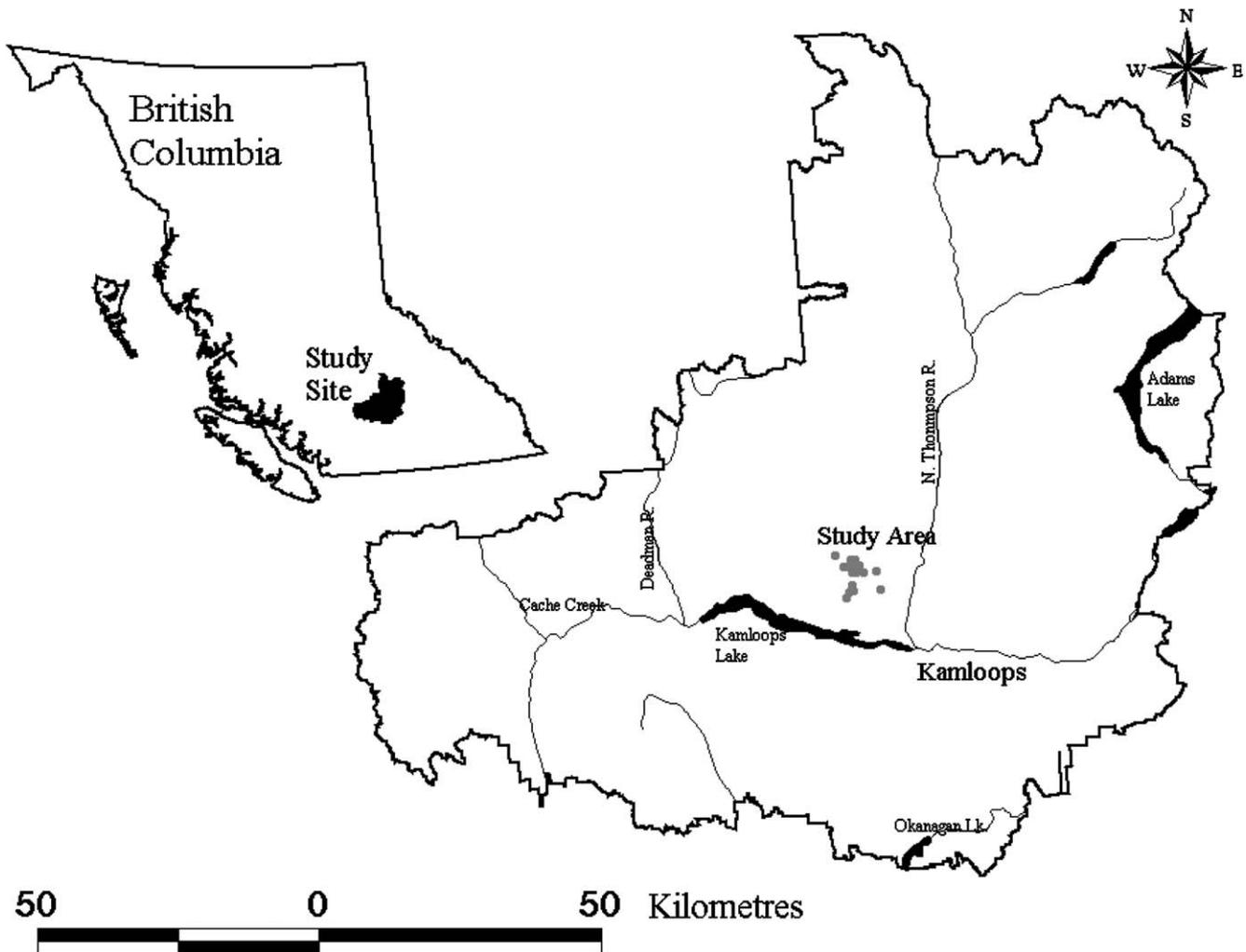


Fig. 2. Map of Kamloops Forest Region, showing locations of Douglas-fir and ponderosa pine stands sampled in this study.

Research methods

Nineteen forest stands were selected in areas of documented historic defoliation events that displayed homogeneity and contained Douglas-fir (host) and ponderosa pine (non-host) trees. At each sample site, individual trees were selected based on DBH (>42 cm), the presence of crown defoliation and cored to the pith. The measured ring sequences were visually crossdated and quality checked using the International Tree-Ring Data Bank (ITRDB) software program COFECHA (Holmes et al., 1986; Holmes, 1994). Samples that did not initially crossdate were corrected or deleted until a significant correlation was obtained for the entire chronology.

All nineteen Douglas-fir chronologies are significantly correlated ($p < 0.05$) with the regional ponderosa pine chronology over the period from 1600 to 2000 AD. It was, therefore, assumed that all of the chronologies

contain the same strong climate signal that Watson and Luckman (2001, 2002) attribute to regional drought conditions. The climatic variation contained in the Douglas-fir index series was removed through the subtraction of the lodgepole pine index series by assigning values to parameters in the software program OUTBREAK Version 6.00P (Holmes and Swetnam, 1996). OUTBREAK automates the “correction” of host tree-ring chronologies (all site standardized ring-width series averaged per site) and applies a set of user-defined criteria to identify the timing (dates) of insect outbreaks and related growth reduction (Swetnam et al., 1995; Speer et al., 2001; Ryerson et al., 2003). The “corrected” indices record radial growth in the host tree species after reduction or elimination of climate signals as indicated by the non-host tree species. The characteristic ring-width pattern (of suppressed growth) associated with WSB defoliation was used to infer past outbreak occurrences throughout individual tree-ring

chronologies (Holmes and Swetnam, 1996). The timing of the infestation periods identified by OUTBREAK was verified by examination of the dated tree-ring specimens in the context of confirmed historical defoliation episodes from Forest Insect and Disease

Survey (FIDS) and British Columbia Ministry of Forests (BCMoF) aerial survey records (Erickson, 1987; Koot and Hodge, 1996; British Columbia Ministry of Forests, 2001). During defoliation episodes the annual ringwidth within Douglas-fir trees was typically reduced during the first year or so of heavy defoliation, and the latewood was very thin or lighter in colour as compared to that formed during years without defoliation (Fig. 1; see Swetnam et al., 1985; Swetnam and Lynch, 1993). Fig. 3 presents a regional outbreak chronology. This chronology highlights years of extreme low growth in the Douglas-fir chronology that are attributed to non-climatic influences. A comparison of this chronology with known WSB outbreak events (1912–2000 AD) indicates that these low growth years do correspond with known outbreaks (Fig. 3). Multiple periods of obvious reduced growth in the Douglas-fir chronology were seen in the 1982 and 1930s, but it appears that minimum radial growth was lowest in 1709 and 1723 suggesting outbreak years. The “corrected” Douglas-fir chronology had some of the longer-term climate trends common to both the Douglas-fir and the ponderosa pine removed. For example, narrow “marker” rings within the regional ponderosa pine and Douglas-fir chronologies pointed to probable drought years in the 1680s were absent in the corrected tree-ring indices (Fig. 3). Although there is

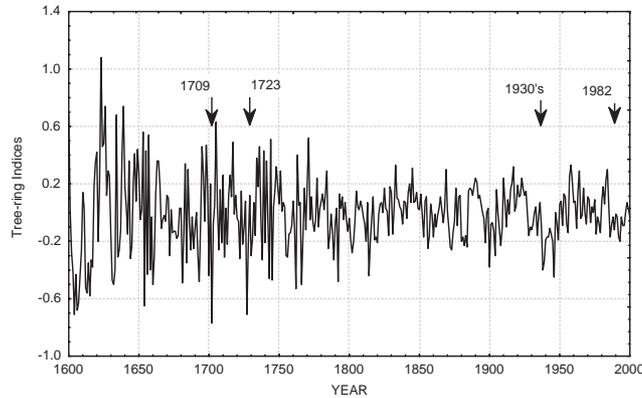


Fig. 3. Outbreak chronology created by subtracting the master Douglas-fir chronology from the master ponderosa pine chronology in order to highlight the differences between the host and non-host species. Multiple periods of obvious reduced growth in the Douglas-fir chronology were seen in 1982 and the 1930s, but minimum radial growth was lowest in 1709 and 1723 suggesting outbreak years.

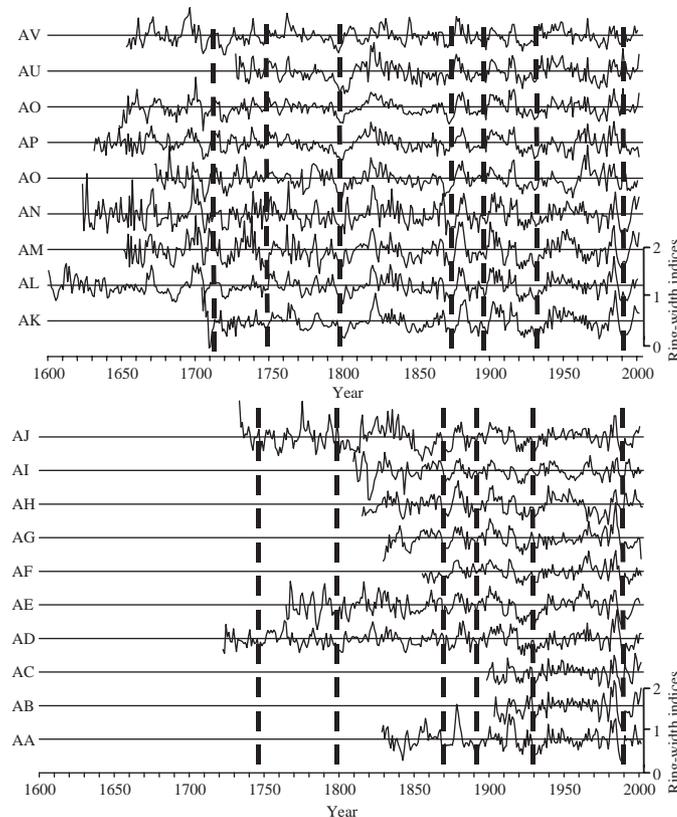


Fig. 4. Periods of reduced growth relative to ponderosa pine, which indicate potential western spruce budworm outbreak timing and duration in interior Douglas-fir forests near Kamloops, British Columbia from 1600 to 2000. The vertical dashed lines indicate years in, which possible defoliation caused significant growth reduction over study area.

considerable variation in the timing and duration of WSB outbreaks in the 19 “corrected” site chronologies outbreaks appear to occur more or less synchronously across the study area (Fig. 4).

Discussion

Our research shows that seven regional WSB outbreaks have occurred over the last 300 years in this portion of the Kamloops Forest Region (Fig. 4). The persistence of mature overstorey trees shows these forests can coexist with budworms for long periods of time. These findings are similar to those reported by previous researchers (Swetnam and Lynch, 1993; Swetnam et al., 1995; Alfaro et al., 2001; Ryerson et al., 2003) and appear to be the case even when WSB populations do not reach the same level of defoliation in all trees (Myers, 1993; Bjørnstad, 2000). It is suspected that forest characteristics, such as the nutritive value of foliage, may be a factor preconditioning WSB populations success and that the regional climate has a synchronizing influence (Royama, 1984; Williams and Liebhold, 1995, 2000; Myers, 1998).

Comparison of tree-ring data from climatically sensitive non-host ponderosa pine and host Douglas-fir are especially useful in studying long-term insect outbreak patterns because they provide replicated observations of past outbreaks in the context of ongoing climatic fluctuations (Swetnam and Lynch, 1993; Ryerson et al., 2003). The historical outbreak record with local climate data suggests that an early spring season characterized by low precipitation during winter months and normal spring air temperatures increase the success of budworm emergence, and potentially reduces the Douglas-fir trees’ ability to defend against WSB foraging (Campbell, 2003). Evidently, spring climate can effect changes in both the host plants and the phytophagous species, which synergistically affect growth and survival of the phytophagous population, for example, dry, early spring climates that promote budworm feeding and reduce disease and snowy, late spring climates suppressing the growth of the insect population (Myers, 1981). This indicates that with higher overwintering survival, increased population growth rates, and a longer growing season, outbreak areas of some species are likely to shift in latitudinal range and may increase in size. Changes in geographical ranges and spatial extent of outbreaks of WSB are likely consequences of climatic change.

Conclusion

Climate and the anthropogenic transformation of forest ecosystems have important extrinsic influences on

insect and host communities. A range of observations across spatial scales, from individual trees to stands, enabled us to identify both unique local-scale (individual site) patterns, and the larger regional-scale patterns in which they were embedded. Overall regional occurrences of outbreaks were still at least partly driven by spring precipitation amounts. At the same time, the temporal-dynamical behaviour of the system also suggests that endogenous factors (perhaps delayed density dependence) may also be at play. Thus, combinations of small and large-scale processes, endogenous and exogenous factors, and chance and necessity interact to produce the forest-budworm dynamic.

In British Columbia the WSB has a long-term coexistence with its primary host tree, Douglas-fir. The strength of tree-ring reconstructions of this historical-regional approach is that observations match the temporal and spatial scales of important processes influencing the ecosystems. The limitations of this approach include an inherently “noisy” signal, and diminishing sample sizes with increasing time before the present that lower the reliability of estimates in earlier periods. These problems prevent precise identification of the specific manner in which climatic variations influence budworm populations. Future research will involve simultaneous observations of insect numbers, defoliation amounts and tree-ring growth parameters to test the fidelity of the host–non-host correction approach in reconstruction of past outbreaks to test the importance of climate variations on WSB and host trees.

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