Forest Ecology and Management 315 (2014) 72–79

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Periodicity of western spruce budworm in Southern British Columbia, Canada

René I. Alfaro [a,*], Jenny Berg [a], Jodi Axelson [b]

[a] Canadian Forest Service, Pacific Forestry Centre, 506 W Burnside Rd, Victoria, BC, Canada
[b] British Columbia Ministry of Forests, Lands and Natural Resource Operations, Cariboo Region, Williams Lake, BC, Canada

ARTICLE INFO

Article history:
Received 6 September 2013
Received in revised form 17 December 2013
Accepted 22 December 2013
Available online 9 January 2014

Keywords:
Choristoneura occidentalis
Choristoneura freemani
Douglas-fir pests
Insect defoliation
Dendrochronology

ABSTRACT

The western spruce budworm (WSB), *Choristoneura occidentalis* Freeman), a defoliator of conifers in western North America, causes severe timber losses to forests. In British Columbia, Canada, where the main species damaged is Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, outbreaks of *C. occidentalis* have been recorded since 1909. However, there is little information on the frequency of outbreaks of this defoliator for previous centuries. This information is needed to establish baselines defining the historic range of variability of this disturbance, to calculate potential depletions in timber supply from defoliation, and to refine forest management plans. Also, precise estimates of budworm recurrence are needed to assess potential ecosystem changes and possible departures from the historic range of this disturbance due to global warming. We used dendrochronology and time series analysis to determine past frequency of spruce budworm outbreaks in southern BC and found that, since the 1500s, outbreaks have been periodic, with a mean return interval of 28 years (95% Confidence Interval 21–35 years). No data was available before the 1500s. We found the number of outbreaks per century, since the 1800s, was fairly constant, with 3–4 outbreaks per century.

1. Introduction

Spruce budworms, *Choristoneura* species (Lepidoptera: Tortricidae), are destructive defoliators of conifers in North America, causing tree mortality, growth loss and lumber defects. In terms of economic damage, the most important members of this genus are the spruce budworm, *Choristoneura fumiferana* Clem., a severe defoliator of the Canadian Boreal forest, and the western spruce budworm (WSB), *Choristoneura occidentalis* Freeman, a defoliator of conifers in western North America. Although *C. occidentalis* has been recently renamed *Choristoneura freemani* Razowski (Razowski, 2008), the new scientific name has not yet been adopted in North America. For this reason, in this paper we continue to use *C. occidentalis*.

In British Columbia (BC), Canada, where the main species damaged is Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, outbreaks of *C. occidentalis* have been recorded since 1909, with the earliest recorded outbreak occurring on south eastern Vancouver Island (Mathers, 1931; Harris et al., 1985), but records for this early outbreak are imprecise. More precise accounts of budworm outbreaks in BC started in the 1950s, when systematic ground surveys and increased use of aerial monitoring was initiated by the Forest Insect and Disease Survey (FIDS) of the Canadian Forest Service. However, with the exception of the work of Campbell et al. (2005, 2006), there is no published information on the frequency of outbreaks of this defoliator before the 1900s in BC. This information is needed to establish baselines defining the historic range of variability of this disturbance for use in forest management planning and to calculate potential depletions in timber supply from WSB outbreaks. Precise estimates of past budworm recurrence are also needed to assess potential ecosystem changes and possible departures from the historic range of this disturbance due to global warming.

The western spruce budworm lays its eggs on the underside of needles in July and August, shortly after the new adult moths have emerged from pupation and mated. Within 10–12 days eggs hatch and the new larvae overwinter without feeding, as second-instar larvae. Feeding begins after the larvae emerge from overwintering in mid to late May. Pollen cones, buds and old needles are mined until new foliage flushes and becomes available for feeding (Nealis, 2012). The larvae go through five instars before they pupate in late June to mid-July, and the one year cycle is completed 12–20 days later, when the new adults emerge (Furniss and Carolyn, 1977, Duncan, 2006). Outbreaks of *C. occidentalis* are economically important in BC; since 1990 and until 2011, defoliation has averaged over 500,000 ha per year (data provided by the Canadian Forest Service and the BC Ministry of Forests, Lands and Natural

* Corresponding author. Tel.: +1 2502982363.
E-mail address: ralfaro@nrcan.gc.ca (R.I. Alfaro).

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http://dx.doi.org/10.1016/j.foreco.2013.12.026

Resource Operations). The expected damage through growth loss and mortality is high enough to prompt the need for annual spray operations, in selected areas, aimed at protecting industry's timber supply (Maclauchlan and Buxton, 2012).

Douglas-fir occurs in a large area of south and central British Columbia identified as the Interior Douglas-fir (IDF) biogeoclimatic (BEC) zone (Krajina, 1965; Murdock et al., 2013). Other tree species susceptible to WSB defoliation in BC include Engelmann spruce, *Picea engelmannii* Parry ex Engelm., and subalpine fir, *Abies lasiocarpa* (Hook.) Nutt (Furniss and Carolyn, 1977).

The cross-section ring width sequence of trees record the variations in growth rates as influenced by the many factors affecting growth at the time of formation of the ring. The study of these variations forms the basis for the science of dendrochronology, which endeavors to reconstruct variation in conditions of growth over time (Speer, 2010). Periods of reduced growth are caused by adverse conditions such as drought or removal of foliage by insects. By removing foliage during the growing season, defoliating insects cause sequences of narrow rings in the years when foliage has been removed (Alfaro et al., 1982). Dendroentomology, a subfield of dendrochronology, documents past occurrence of forest insect outbreaks, and provides an understanding of insect population dynamics, including duration of outbreaks, interval between outbreaks and spread (Speer, 2010). The method relies on comparing the specific tree ring signal left by particular insect disturbance during outbreaks, to rings patterns in undamaged species in the same area. Dendroentomology has been used to explore the temporal periodicity and spatial variation of outbreaks of the two-year cycle budworm, *Choristoneura biennis* Freeman in BC (Zhang and Alfaro, 2002, 2003), the recurrence of western spruce budworm in BC (Campbell et al., 2005, 2006) and in the western United States (Swetnam and Lynch, 1989, 1993; Swetnam et al., 1995; Ryerson et al., 2003). Extensive dendroentomology work has also been completed to reconstruct the history of *C. fumiferana* in the boreal forest of eastern Canada (Blais, 1983; Boulanger et al., 2012; Jardon et al., 2003; Morin et al., 1993; Simard and Payette, 2001) and northern BC (Burleigh et al., 2002). These studies reveal periodicity in the population dynamics of the genus *Choristoneura* (Dutilleul et al., 2003; Jardon et al., 2003; Royama, 1984; Swetnam and Lynch, 1993).

The objective of this study was to use dendrochronology to reconstruct the history of WSB in the south central region of British Columbia and expand on the results of Campbell et al. (2005, 2006) by including additional areas in southern BC. The dendrochronological budworm history compiled by Campbell et al. (2005, 2006) was based on cores collected in a small area (about 15 by 15 km) at Opax Mountain near Kamloops, BC. Here we utilize the Campbell data, along with dendrochronology data from seven additional locations, to prepare a comprehensive history of budworm for Southern BC.

2. Methods

To identify past western spruce budworm outbreaks in southern British Columbia we compared annual growth patterns of trees affected by WSB (host trees) to growth patterns of non-host trees, utilizing the software program OUTBREAK (Holmes and Swetnam, 1996; Swetnam et al., 1995). This procedure removes the influence of factors that are not specific to WSB disturbance, such as ring width variations due to weather and that affect all tree species at a site. Remaining deviations are then assumed to be the result of species-specific activities of WSB (Swetnam and Lynch, 1993; Holmes and Swetnam, 1996; Ryerson et al., 2003). In this case, we used the sympatric species ponderosa pine (Py), (*Pinus ponderosa* Dougl., ex P.& C. Laws), as the non-host species, which has been shown to share the same climate signal as Douglas-fir when growing in similar sites (Fritts, 1974).

2.1. Study area, data collection and chronology development

We obtained increment core data from eight locations in southern British Columbia (Table 1, Fig. 1). For analyses purposes, and based on proximity, these were grouped into five datasets: Railroad Creek, Stein Valley, Okanagan, Kamloops (two locations) and Cache Creek (three locations) (Table 1). All but one site is located in the IDF Biogeoclimatic zone of BC's hot and dry southern Interior Plateau, in subzones ranging from Xeric Hot to Wet Warm or Dry Cool (Meindinger and Pojar, 1991); the remaining site was in the Ponderosa Pine zone (Table 1), which is also xeric and hot. Elevation of sites ranged from 200 to 1310 m. Climate in these zones is characterized by a long growing season with dry summers and frequent moisture deficits (Lloyd et al., 1990).

The increment core data in this study come from different sources (Table 2). During the summer of 2012 the authors collected increment cores from the three Cache Creek sites and from the Railroad Creek site. One core per tree was collected at breast height from Douglas-fir trees, and from any locally available ponderosa pine trees, using a 5 mm Pressler increment borer. Sample sizes (number of trees cored per site) are given in Table 2. All cores were prepared in the lab following standard dendrochronology procedures as outlined by Stokes and Smiley (1996). Samples were scanned and measured using a WinDendro™ system (Regent Instruments Inc.1995), with a measurement precision of 0.01 mm.

Archived tree ring data for Douglas fir and ponderosa pine for the area of interest was also used (Table 2). To be used in the study, archived data needed to be accurately cross dated, i.e., the dates assigned to each ring had been verified and had significant interserial correlation. Significant values of the interserial correlation of the tree ring series in a site indicate the presence of a strong common signal among the samples.

The Kamloops dataset was compiled from two existing sources: (1) Data from the Opax Mountain case study reported by Campbell et al. (2005, 2006), consisting of 630 Douglas-fir and 94 ponderosa pine cross-dated series, was made available to us by André Arsenault, Canadian Forest Service, Cornerbrook, Newfoundland, and (2) the International Tree Ring Data Bank, ITRDB (http://web.utk.edu/~grissino/itrdb.htm), identified in Table 1 as Kamloops ITRDB. The Kamloops ITRDB dataset consisted of 22 Douglas-fir and 20 ponderosa pine cross-dated cores (Fritts, 2013a,b) (Table 2).

The Stein Valley data was also obtained from the ITRDB, and consisted of 15 Douglas-fir and 27 ponderosa pines, all cross-dated (Table 2) (Riccius et al., 2013a,b).

The Okanagan data set was derived from cores collected during the 2008 North American Dendroecological Fieldweek near Peachland, at McCall Lakes, by R. Alfaro and students attending the course (Alfaro et al., unpublished report, 2008). In this case, 64 Douglas-fir and 23 ponderosa pine cores were collected, cross-dated and archived at the Pacific Forestry Centre (Table 2).

Datasets obtained from these sources were reduced to one core per tree (when needed) by selecting the core with the highest interserial correlation, as reported by the authors of the datasets and eliminating, whenever possible, any trees less than 300 years old. The final sample size for each area and tree species is given in Table 2. These datasets were used to develop new Douglas-fir master chronologies for each of the five areas of interest (Table 2). Chronologies for each location were developed using the computer program COFECHA (Holmes, 1983) and standardized using the computer program ARSTAN (Cook and Krusic, 2005) using either a negative exponential curve, linear regression or a horizontal line as appropriate (Cook et al., 1990). Detailed descriptions of COFECHA and ARSTAN can be found in Speer (2010).