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Stand recovery and self-organization following large-scale mountain pine beetle induced canopy mortality in northern forests

Mariano M. Amoroso [a,*], K. David Coates [b,c], Rasmus Astrup [c,d]

[a] Instituto Argentino de Nivología, Glaciología y Ciencias Ambientales, CONICET, Av. Ruiz Leal s/n, Parque Gral. San Martín, C.C. 330, 5500 Mendoza, Argentina
[b] Ministry of Forests, Lands and Natural Resource Operations, Bag 6000, Smithers, British Columbia V0J N20, Canada
[c] Bulkley Valley Research Centre, Box 4274, Smithers, BC V0J 2N0, Canada
[d] Norwegian Institute for Forest and Landscape Høgskoleveien 8, Ås Postboks 115, 1431 Ås, Norway

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ABSTRACT

A mountain pine beetle (MPB) epidemic is currently ravaging large areas of interior British Columbia (BC) with significant implications for ecosystem services including future timber supply and community economic stability. Information is needed on future stand dynamics in areas of impacted forests that are unlikely to be salvaged logged. Of greatest concern are stands dominated by lodgepole pine (>50% timber volume). Predicting how surviving trees in these areas respond and grow and the timing and species composition of natural regeneration ingress is of critical importance for multiple forest values. We undertook a retrospective study in the Flathead Valley of southeastern British Columbia where an intense MPB epidemic peaked in 1979–1980. Our objective was to gain insight into stand recovery and stand self-organization as influenced by species-specific growth responses of different sized secondary structure trees (individual seedling, sapling, sub-canopy and canopy trees surviving the epidemic) and post-beetle regeneration dynamics. MPB mortality rates, the percent of basal area killed by beetles, varied from 42% to 100% with most stands between 60% and 80%. In general, all surviving secondary structure released but the extent of growth release exhibited species variability. Release of surviving canopy lodgepole pine trees was often dramatic and greatest in stands with high total stand MPB mortality rates. Ingress of natural regeneration was slow in the first few years after MPB attack but there was a strong pulse of recruitment 10–20 years post disturbance which then slowed considerably. Nearly 30 years after the MPB attack, the stocking and composition of the understories have changed dramatically. Overall, the occurrence of the MPB epidemic resulted in more structurally and compositionally diverse stands leading to multiple successional pathways different from those of even-age pine dominated stands. The recovery and self-organization of unsalvaged natural stands in the Flathead Valley was a complicated process. It has provided insights for future forest management in areas impacted by the current massive MPB epidemic ongoing for the past decade in western North America.

1. Introduction

The mountain pine beetle (*Dendroctonus ponderosae*) (MPB) is currently in the outbreak phase of an infestation cycle throughout much of its range in British Columbia (BC). The current epidemic, starting in the late 1990s, has now impacted over 18 million hectares of BC forest land in the interior portions of the province (Walton, 2012). The current MPB epidemic is the most significant forest management challenge BC has ever faced and has caused variable levels of damage from near complete mortality in many lodgepole pine (*Pinus contorta* var. *latifolia*)-dominated stands to partial mortality in mixed-species stands. In the central and southern interior regions of BC, the MPB epidemic has impacted just over 10 million hectares of the 22 million hectare provincial operable land base (the total area available for commercial timber harvest in all of BC). The epidemic has killed a cumulative total of 710 million m^3 of pine in the operable land base, or 53% of the merchantable pine volume in the province at the start of the infestation, and is now projected to kill approximately 57% of the pine volume by 2017 (Walton, 2012).

In response to the epidemic an aggressive salvage strategy has been implemented to harvest dead pine while it retains economic value. Targeted stands for salvage were those dominated by pine (>50% by volume). It is estimated about 5 million hectares of the operable land base are pine dominated and just over 1 million hectares were salvage logged and reforested to 2011. Depending on future harvest intensity assumptions, salvage operations may reach 1.7–2.1 million hectares by 2024, at which time the dead

* Corresponding author. Tel.: +54 261 542 4257.
E-mail addresses: mariano.amoroso@gmail.com, mamoroso@mendoza-conicet.gob.ar (M.M. Amoroso).

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pine are no longer expected to have economic value for conventional sawmill products. Clearly, large areas of the operable land base severely impacted by the epidemic will not be logged. Information on the speed, composition and density of post-MPB regeneration combined with data on expected growth rates of trees surviving the epidemic will be of considerable importance for projecting future timber supply in the operable land base and have clear implications for community economic stability in the highly impacted areas of BC. Likewise, understanding stand recovery and self-organization in MPB-impacted forests in both the operable and non-operable land base will be important for predicting their future provision of ecosystems services such as carbon sequestration (Bowler et al., 2012), hydrological recovery (Winkler et al., 2012) and wildlife habitat (Bunnell et al., 2011).

The composition and size structure of trees surviving the epidemic is highly variable with different combinations of species and densities of understory and overstory trees that have been collectively called 'secondary structure' (Coates et al., 2006, 2009; Vyse et al., 2009; Hawkins et al., 2012). In the drier forest types of the central and southern interior, understory and sub-canopy trees that survive the epidemic are often dominated by lodgepole pine. The understory and sub-canopy trees surviving the epidemic in moister forest types or in the more northern regions of the epidemic area are primarily more shade tolerant conifer species than pine. Larger diameter trees that survive the beetle epidemic are typically of non-host species (e.g., interior spruce (*Picea glauca* × *engelmanii*), subalpine fir (*Abies lasiocarpa*), Douglas-fir (*Pseudotsuga menziesii* var. *glauca*), or broadleaf species).

There are two pathways for recovery of MPB attacked stands. First, impacted stands can be salvage logged, usually by clearcutting with retention, followed by planting or natural regeneration. Salvage logging prescriptions follow standard practices with predictable outcomes from a timber supply perspective. Second, and the focus of our analysis, is the recovery of MPB-impacted stands that are not salvaged logged. The timing and abundance of post-beetle natural regeneration and the growth responses of new regeneration and secondary structure in unsalvaged MPB-impacted stands is a much more complicated issue for projection than a salvage logging and planting scenario.

Astrup et al. (2008) found that recruitment of new seedlings in the early years of the current MPB epidemic in central British Columbia was patchy and poorly developed and was substantially lower than the strong pulse of regeneration observed after stand replacement wildfires in these northern forests. Likewise, Axelson et al. (2009) and McIntosh and MacDonald (2013) concluded that natural seedling recruitment following MPB outbreaks is a slow process. Furthermore, the recruitment of new regeneration after MPB-attack is quite variable across biogeoclimatic zones in British Columbia (Hawkes et al., 2004; Hawkins et al., 2012). Overall, the longer-term timing and extent of post-disturbance recruitment from seed is poorly understood in MPB-disturbed forests (Mitchell, 2005).

For the major tree species found within MPB-impacted stands there has been considerable work done on how seedlings and saplings grow as a function of their light environment (Wright et al., 1998; Coates and Burton, 1999), how rapidly growth rates of seedlings and saplings reflect their new light environment following disturbance (Wright et al., 2000), and how sub-canopy and canopy trees grow as a function of their competitive neighbourhoods (Canham et al., 2004; Coates et al., 2009; Coates et al., 2013). These studies all suggest canopy mortality of lodgepole pine will result in improved growing conditions (increased light availability and reduced belowground competition) for surviving secondary structure. Elsewhere, it has been observed that insect epidemics that rapidly kill canopy pine trees create ideal conditions for a rapid and prolonged release response of surviving trees (Baskerville, 1975; Romme et al., 1986; Thompson et al., 2007). The magnitude of the release response can be modified by factors such as tree species, age, size, condition and damage (Messier et al., 1999; Griesbauer and Green, 2006).

Even so, skepticism about the potential of secondary structure to release and grow well and help mitigate expected timber supply shortages and other ecosystems services in MPB-impacted landscapes remains strong. An effective method to acquire growth data for secondary structure after beetle attack is to undertake retrospective studies in areas attacked in the past (Heath and Alfaro, 1990). Our retrospective study examines long term species-specific growth responses of different sized secondary structure trees and post-beetle regeneration dynamics in unsalvaged natural stands after a short but severe MPB epidemic that peaked in 1979–1980 in the Flathead Valley of southeastern BC (Young, 1988). Specifically, we (a) quantify release of surviving seedlings, saplings, sub-canopy and canopy trees of different tree species, and (b) reconstruct understory recruitment dynamics after the epidemic.

2. Methods

2.1. Study area

The study area was located in the Flathead Valley, a term used to identify a large system of drainages in the southeastern corner of BC that eventually join up and flow into Flathead Lake in Montana (Young, 1988). The dominant area of sampling was approximately 60 km southeast of Fernie, BC. The Flathead Valley is in the Dry Cool subzone (MSdk) of the Montane Spruce biogeoclimatic zone, about 1500 m above sea level (Meidinger and Pojar, 1991). The MSdk experiences a continental climate (mean annual temperature of 3–5 °C) with cold, snowy winters (mean coldest month temp of −9.4 °C) and short, warm summers (mean warmest month temp of 15.6 °C) with 151 frost free days per year. Mean annual precipitation is 750 mm (May–September 275 mm) with annual winter snowfall of 342 cm (Lloyd et al., 2006). Lodgepole pine, interior spruce, subalpine fir, Douglas-fir, and western larch (*Larix occidentalis*) are the dominant coniferous tree species.

The Flathead Valley experienced a number of fires in the early 1900s with the largest occurring in 1936 resulting in the establishment of extensive lodgepole pine stands (Young, 1988; Barrett et al., 1991). Since 1945 there have been no significant fires in the Flathead Valley. An intense MPB epidemic started in the Flathead Valley in 1976, peaking in 1979–1980, and then abruptly ended in 1981, likely due to severe winter temperatures (Young, 1988). At the time of the epidemic the forest profile of the Flathead Valley was one dominated by pine forests 40–60 years old, but it also contained pockets of mature pine that had survived the earlier fires (Young, 1988).

2.2. Field sampling

In the fall of 2007, we sampled a total of 22 stands that encompassed a range of surviving secondary structure and pine mortality from the 1976–1981 MPB attack. The boundaries of the epidemic location were well documented and selection of sample stands was based on old maps of the epidemic area. We sampled stands with mesic soil moisture and nutrient conditions that had clear evidence of prior MPB mortality. Stands with evidence of other disturbances or unaccounted mortality were avoided. We specifically sought out stands with variability in surviving secondary structure species composition and MPB mortality rates (expressed as percent total stand mortality or percent pine mortality, Table 1). There was, however, no attempt to place stands into different attack intensity categories. Our objective was to have a balanced sample of stands