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Residual mature trees and secondary stand structure after mountain pine beetle attack in central British Columbia

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ABSTRACT

Lodgepole pine forests in British Columbia (BC) are experiencing the largest mountain pine beetle (MPB) epidemic in recorded history. Now that the peak of the epidemic has passed, information regarding the existing live secondary stand structure (height >4 m but DBH <7.5 cm), regeneration (⩽4 m in height) and residual mature trees (DBH >7.5 cm) in the MPB-attacked stands are needed to assess management options and future timber supply. In total, 459 MPB-attacked pine stands were sampled from eight different age classes (13–250 yr) in three different ecological subzones (dry, mesic, moist) of central BC. Mean MPB attack was greater than 40% when stand age was ⩾20 years. Secondary stand structure and residual mature tree layers offer significant opportunities for mitigating the effects of MPB attack on future commercial wood values and ecological processes. The mean density of secondary stand structure and regeneration varied widely within and among ecological subzones. Depending on stand age, 44–98% of stands still contained sufficient stems after MPB attack to be considered stocked. Species composition varied at the stand level, but most stands had sufficient amounts of BC's preferred commercial species. Due to MPB caused mortality, most of the stands were moving towards a mixed species and uneven aged condition. A SORTIE-ND model projection suggests that stands which had a minimum of 900 stems/ha of secondary structure >4 m in height can reach merchantable volumes within 30 years.

1. Introduction

Lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) forests of British Columbia (BC) are experiencing the largest mountain pine beetle (MPB) (*Dendroctonous ponderosae* Hopkins) epidemic in recorded history. As of 2010, it was estimated that over 17.5 million hectares of lodgepole pine forests across BC were affected to varying degrees by MPB attack (BC Ministry of Forests and Range, 2011). It is projected that at least 59% of the of the total merchantable lodgepole pine volume (age >60 years) in BC will be killed in this epidemic (Walton, 2011). In addition, an estimated 50% of the immature lodgepole pine stands (age <60 years) may also be attacked (Westfall and Ebata, 2008). It is likely that the current epidemic will end only when most of the mature pine has been killed (BC Ministry of Forests and Range, 2006a) along with a portion of the immature pine (Runzer et al., 2008).

Generally, MPB attacks larger diameter (DBH >20 cm) (Amman et al., 1977) and older (ages >60 years) trees (Shore et al., 2006). However, the present MPB outbreak is more widespread and severe than past outbreaks. As a result, MPB also attacked younger stands (even <20 years old) if no mature trees were available to attack (Maclauchlan, 2006; Runzer et al., 2008). However, Shrimpton and Thomson (1985) mentioned that tree age had little predictive value for attack by MPB while Katovich and Lavigne (1986) suggested that phloem width was the best indicator of host susceptibility to MPB attack. Pine trees killed by the MPB emulate a thinning from above (Roe and Amman, 1970) and post attack stand dynamics will be driven by residual mature trees (⩾7.5 cm DBH), secondary stand structure (saplings <7.5 cm DBH and >4 m in height) and regeneration (⩽4 m in height). Almost 200 million m^3 of MPB-attacked timber may remain unsalvaged throughout BC (BC Ministry of Forests, 2004) due to low feasibility for salvage (accessibility, management objectives, lack of milling capacity, economic factors) and ecological concerns. However unsalvaged stands may have higher rates of surface fires due to the high deposition of fuel sources (Page and Jenkins, 2007).

The peak of the MPB epidemic has now passed the central BC interior (Walton et al., 2008) and efforts are required to determine the conditions of attacked stands. Therefore information regarding existing residual mature trees, secondary stand structure and

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regeneration are needed to project stand dynamics and future forest condition. In north central BC, Coates et al. (2006) reported that 20–30% of stands have enough secondary stand structure to contribute to a mid-term timber supply if left unsalvaged and an additional 40–45% of stands have sufficient understory to be considered stocked (stands have a minimum number of healthy stem, according to BC legislation 900 stem/ha if height is >4 m or 700 if height is >6 m for MPB-attacked stand) in a certain height group. Retaining such stands would reduce the rotation age by 10–30 years, compared to starting anew (Coates et al., 2006), help to mitigate the projected mid-term timber supply shortfall (Pousette and Hawkins, 2006; Pousette, 2010) and enhance ecological diversity. Coates et al. (2006) also suggested that only 20–25% of stands needed some form of intervention due to lack of secondary stand structure. Therefore, not all residual stands may need rehabilitation from a timber management or an ecological point of view. In this regard, a post MPB-attacked inventory in Central BC is needed to gain insight about residual mature trees, secondary stand structure and regeneration status. Such information will help to select those stands where immediate management intervention is required to meet timber supply obligations.

Forest dynamics is the change of forest composition and structure over time and understanding these is an important research question for MPB-attacked stands. The ability to accurately model complex forest dynamics and project future growth, yield and structure of stands is critical to sound forest management. Similarly understanding of regeneration patterns and stand dynamics including growth and mortality are vital factors when modeling stand development for management objectives (Coates et al., 2009).

The model SORTIE-ND (http://www.sortie-nd.org/) is an ecological modeling program that has been designed to predict stand dynamics based upon the growth of individual trees in multi-species, complex stands. This model is well suited to predict future growth for MPB-attacked stands in British Columbia (Coates et al., 2003). The model SORTIE-ND uses a combination of empirical and mechanistic sub-models to predict forest dynamics based on field experiments that measure fine-scale and short-term interactions among individual trees (Coates et al., 2010). This model can be adapted to a wide range of specific conditions and has the flexibility to incorporate new research findings model parameter files.

The main objectives of this study were (1) to determine the quality and quantity of residual mature trees and secondary stand structure in MPB-attacked stands, and (2) to predict the future growth and yield of some MPB-attacked stands based on secondary stand structure. The outcomes of the research will help to guide management activities in MPB-killed stands especially for growth and quality of secondary stand structure. Moreover, it also improves harvest scheduling in central BC by identifying which stands are most suitable for retaining or harvesting.

2. Materials and methods

2.1. Site selection

The sample area was located within the Prince George forest district from 53°22′ to 54°55′ N and 120°15′ to 125°04′ W with a total area of about 54,000 km^2 (Fig. 1). The area is in the sub-boreal spruce biogeoclimatic zone with three broad sub-zones dry, mesic and moist all with a cool thermal regime (Meidinger et al., 1991). Most of the sampled stands were lodgepole pine-dominated covering eight different age classes from 13 to 250 years (Table 1). Stands were attacked by MPB within the past 9 years and were 1–9 years post MPB disturbance. The origins of the sampled younger stands ($\leqslant$40 years) were harvest-based plantations whereas the older ones were of natural disturbance origin, primarily fire-based. Before reconnaissance, stands were identified on forest cover maps obtained from aerial photos and satellite images. Generally, 70% of the stands were selected randomly and the remaining 30% were targeted to ensure complete coverage of the study area, ecological zones and different age classes.

2.2. Data collection and sampling protocol

Data were collected from 459 stands across the district in 2005 (dry area) in 2006 (moist area) and in 2007 (mesic area) (Table 1). The initial sampling design was based on protocols and recommendations presented by BC Ministry of Forests (1998), and summarized in Rakochy (2005). Depending on stand area, 4–10 temporary sample plots (TSP) were established along a transect line at 50 m intervals in each stand. Transects commenced 50 m or at least two tree lengths off any given base line (road, timber type or age class change). All TSP plot centers were painted and GPS locations were recorded for future reference. Two different radii, (a) 5.64 m (100 m^2) plots for residual mature trees ($\geqslant$7.5 cm DBH) and (b) 3.99 m (50 m^2) plots for secondary stand structure (height >4 m but DBH <7.5 cm) and regeneration ($\leqslant$4 m in height) were established in each TSP. Inter-plot spacing was increased by increments of 25 m when unrepresentative areas were encountered (swamps, openings, or change in timber type). For each TSP, mean tree age, crown closure [using a densitometer (an instrument used for taking measurements of canopy cover) and hemispheric photos], stand age, site classification (slope, aspect, topographic location), and site index [SI_{50} = is defined as top height at a breast height reference age of 50 years (Nigh, 1999)] were measured. For the mature layer, all trees (DBH $\geqslant$7.5 cm) were numbered with tree marking paint and DBH, MPB attack status (current, older, strip attack, dead), Workers Compensation Board (WCB, now WorkSafe BC) danger tree code, tree health, and crown class were recorded at each TSP. For all secondary stand structure (DBH <7.5 cm) species, height, DBH, and vigor were recorded. Tree health was assessed based on four vigor codes: A = healthy and vigorous trees with no stem defects; B = healthy and vigorous trees with minor stem defects; C = unhealthy trees with major stem defects; and D = moribund trees (expected to die in the next 2–3 years).

2.3. Defined secondary stand structure

In 2008, the BC Ministry of Forests and Range initiated a Forest Planning and Practices Regulation (FPPR) amendment for secondary stand structure which indicated that MPB-killed stands with an ‘‘adequate stocking density’’ will not be harvested and only pine leading (pine-dominant) stands that have inadequate secondary structure will be harvested. According to FPPR amendments the term ‘‘adequate stocking density’’ is defined as a minimum number of certain sized suitable secondary structure trees per hectare that are necessary to produce a merchantable stand volume (150 m^3/ha) by the mid-term. The mid-term timber supply is a term that refers to that portion of the timber inventory that would be available for harvest within the middle of the normal management cycle. However mid-term timber supply for MPB-infested stands are associated with the end of the MPB-damaged pine salvage period. According to ABCFP (2011), the period of mid-term timber supply is normally 30–70 years in the BC interior. Based on growth and yield analysis by BC Ministry of Forests and Range (2008), the minimum stocking level for a MPB-attacked stand is 900 healthy stems/ha of trees >4 m in height or 700 stems/ha with height >6 m with at least 1.6 m separating each tree. During field investigation, the FPPR amendment was modified in two ways: (a) instead of a distance measurement we calculated the health of