How to Conduct Forestry in British Columbia Post Mountain Pine Beetle Epidemic
– A literature review

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Table of Contents

1. Abstract

This article is a general review on the current issue regarding mountain pine beetle epidemic. Considerations include fire and carbon dynamic, stand reconstruction, silviculture potential, and beetle-wood market. Recognizing the problem of the latest mountain pine beetle outbreak and understanding the causes of the current status is needed to mitigate current damage and preparation for future reoccurrence of such epidemic. This article reviews publications on topics around challenges posed by mountain pine beetle situation and potential solutions. Forest carbon storage immediately after mountain pine beetle would have a sharp drop but gradually recover over several decades. Future stand structure varies dramatically due to the vast difference of post-epidemic stand structure and ecological variances. Several silviculture approaches are proposed to construct a more resilient future stand. From an economic perspective, beetle-affected wood will maintain some value shortly after mortality. But the economic viability of beetle-affected wood will decrease over time, and the uncertainty of future fibre supply poses a significant risk of potential market expansion.

Keywords: Mountain pine beetle, lodgepole pine, fire, carbon dynamic, silviculture, forest management, stand recruitment, mountain pine beetle wood

2. Background

Lodgepole pine (*Pinus contorta* Dougl. ex Loud. Var.*latifolia* Engelm.) is a highly adapted species distributed across a wide range of landscapes of British Columbia (BC). It is valuable socially, culturally and economically. First Nations have been utilizing this species in construction, food and medicinal (Coward 1977). Lodgepole pine is also highly commercialized in the Canadian softwood lumber industry. Lodgepole pine-dominated forests constitute about 29% of BC's forest timber harvest landscape (Bell 2010).

Mountain Pine Beetle (*Dendroctonus ponderosae* Hopk. [Coleoptera: Scolytudae]) is a native bark beetle species that primarily infests lodgepole pine forests in North America. During the past century, starting around the end of the 1990s, a record-breaking beetle outbreak hit interior British Columbia and caused catastrophic repercussions.According to the Ministry of Forests, Lands and Natural Resource Operations (MFLNRO), approximately 140 million m3 was observed as red-attack in the year of 2005. 728 million m3 of merchantable pines are likely killed by the year 2014. MFLNRO also projected a 55% (737 million m3) mortality rate of pine volume provincial wide in the year 2017 and an additional 1% increase in the year 2024, which is significantly lower than the previous projection of an 80% mortality rate in the year 2006 (Walton 2016). Though the province could still rely on other forest types to support a healthy forest industry and the repercussion has not been so destructive on a provincial scale, many communities including First Nations in the interior BC would suffer from the loss of available lodgepole pine timber.

Beetle attack consists of three stages: green attack (within one year of attack), red attack (one to three year after death), and grey attack (over three years since death) (Klutsch et al. 2009).

During the red attack, blue stains block the vascular water uptake system. Needles with no water soon lost viability, significantly decreasing photosynthesis. In grey attack stage, needles fall off branches, so the canopy appears to be grey.

Bark beetles have a preference towards large diameter trees due to a positive correlation between tree diameter and phloem thickness (Amman 1969; Shrimpton and Thomson 1985). However, other factors may change this relationship between tree diameter and phloem thickness such as the vitality and the available resources of the tree (Berryman 1982). The growth of lodgepole pine stands peaks around age 40 to 60 which coincide with stand resistant to mountain pine beetle colonization. It is when the stand reaches ages over 80 that they are favored by the mountain pine beetle as their vitalities start to decline (Safranyik et al. 1974; Amman et al. 1977; Smith & Resh 1999).

Two critical aspects are constituting to the unprecedented epidemic. The first is an availability of abundant susceptible host trees and the second is a sustained favorable weather condition over several years (Safranyik 1978).

Mountain pine beetle carries blue stain fungi such as *Ophiostoma clavigerum* and *O. mountium*, and possibly *O. minus* and *O. ips* (Kim et al. 2003; Lee et al. 2003). These fungi weaken trees by interrupting the vascular system for water thus lower wood moisture content (Unger 1993). The surplus volume of this epidemic created within a short period and a higher machine processing energy cost resulted from a lower moisture content causes significant economic loss to the province. The blue stain fungi carried by the beetle also reduces the aesthetic value and limits the profitability of wood products made from beetle wood (Stickney & Doucet 2007).

Before any fire or timber management in North America, the forest age structure dynamic, as well as its susceptibility to beetle, are mostly related to the fire regime which includes both wildfire and active burning by the aboriginal people (Taylor et al. 2006).The natural fire cycle in British Columbia was about 60 years (Smith 1981). British Columbia has been actively suppressing fire for over a century now, and its effort has been proven to be effective by observing the area burnt in pine-dominant forests since 1920 (Taylor & Carroll 2004). Since the large scale pine-harvesting for lumber and pulp production did not occur until the 1960s, the stand-replacing disturbance to British Columbia's pine forests decreased significantly (Taylor et al. 2006).

3. Challenges and Solutions

3.1 Forest carbon and mountain pine beetle

The beetle infested dead or dying trees create a serious problem of carbon emission. Significant amounts of carbon transferred from live pools to dead pools, promoting heterotrophic respiration (Edburg et al. 2011). The forests of British Columbia have shifted from a carbon sink to a carbon source since 2003 (Kurz et al. 2008) (Figure 2). The magnitude of carbon emissions had been increasing for about five years from 2004 to 2009 and gradually declined afterward, but the difference between projected carbon source and modeled carbon sink without beetle still will be sitting at over 10 Mt C per year until the year 2020 (Kurz et al. 2008).

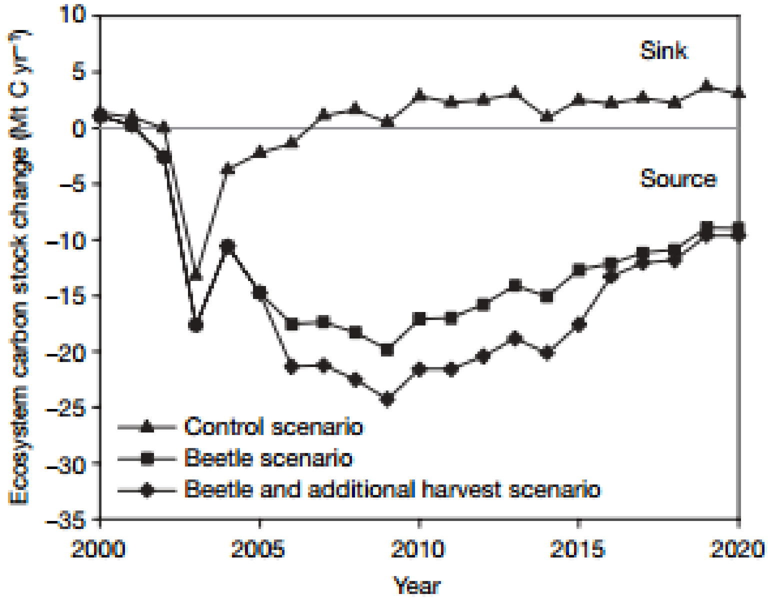

FIGURE 1. TOTAL ECOSYSTEM CARBON STOCK CHANGE FOR THREE SCENARIOS (KURZ ET AL. 2008)

However, the gradual decline in carbon emissions projected is not optimistic. The built up needle layer on the ground has a high surface contact area with soil thus, a high decompose rate which slowed down after five years due to the live canopy loss (Kurz et al. 2008). Decomposition rate for the dead pool that is not in contact with the ground is dramatically slower than those are, and it may take decades for the large standing dead trunks to fall (Hansen 2014). Fuel structure in mountain pine beetle-affected area changes dramatically (Jenkins et al. 2014). Canopy loss indicates more solar input and higher in stand wind speed, which further alters fuel moisture, increase fire hazard (Jenkins et al. 2014). Thus, the dead grey forests now standing are acting like a time bomb that is waiting for a large fire or windthrow to set it off. On the other hand, some studies pointed out that even when the snags finally fall onto the ground, the carbon emission caused by heterotrophic respirations might not be that substantial considering the low autotrophic respirations post-outbreak may cancel their effect (Morehouse et al. 2008).

While the accumulating fuel of the mountain pine beetle-killed trees might create big carbon emission spike with a big fire, the silver lining is that it also set the forest back to a high carbon productivity stage. In a way, the outbreak resets carbon cycle stage of the pine forests and open up more potential for future carbon storage. However, the trend for carbon storage outcome from beetle infestation comparing to an uninfested scenario remains uncertain. Figure 3 simulates aboveground net primary productivity in trees and total system carbon storage in a 300-year period. It indicates that the productivity of carbon after a sharp drop would bounce up and down synchronizing with a hypothetical 50-year beetle outbreak cycle while the total carbon storage in a beetle scenario would take much longer to recover.

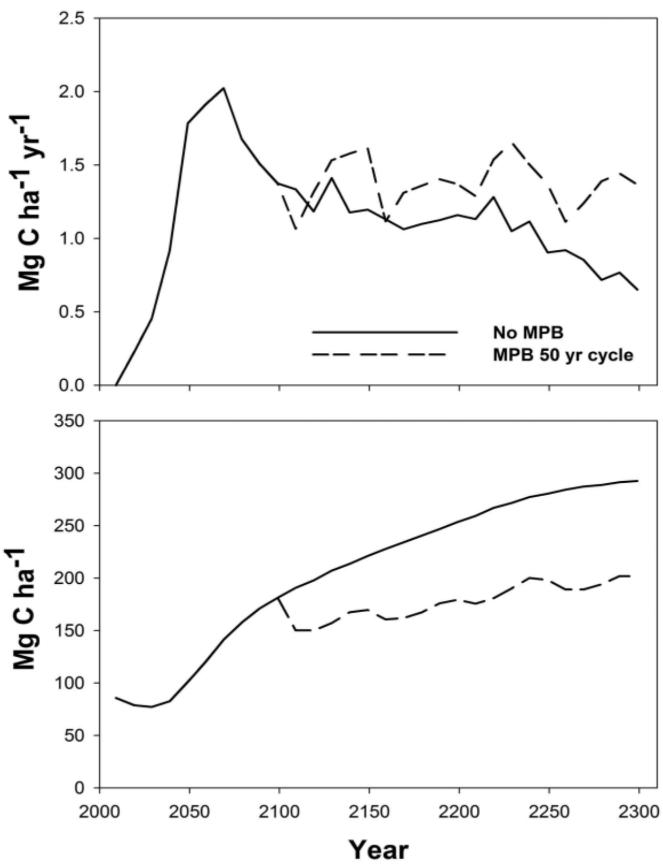

FIGURE 2. ABOVEGROUND NET PRIMARY PRODUCTIVITY IN TREES AND TOTAL SYSTEM CARBON STORAGE (HANSEN 2014).

In various studies conducted in the United States Rocky Mountain areas, both infested stands and uninfested stands exhibited a decline in productivity. In some cases, depending on the post infestation juvenile stem productivity, carbon storage could be matched by previously infested stands after 29-161 years (Pfeifer et al. 2011). One drawback of applying Pfeifer et al.'s study to interior BC is the climate under their study is more favorable for tree growth compared to the cooler temperature in central BC, but the milder winter caused by global climate change may compensate it to a degree. Rehabilitation of mountain pine beetle-killed forest provides a tremendous opportunity to sequester carbon in the next few decades. There are significant additional opportunities to invest in silviculture in BC to sequester carbon, reforest mountain pine beetle areas, and carry out incremental treatments on existing stands. I will discuss future stand recruitment and development in the next few paragraphs.

3.2 Stand Reconstruction

The extreme severity of the current mountain pine beetle epidemic has caused high mortality rate of the dominant large-diameter lodgepole pines in BC, and mountain pine beetle has been attacking greater percentage of younger age class pines in the recent past than historical records (Safranyik et al. 1974; Amman et al. 1977; Shore et al. 2000; Klutsch et al. 2009; Hawkins et al. 2012). Nonetheless, the survival of none-host species, mature trees (over 7.5 cm in diameter at breast height), and secondary structure layers remain high (Coates 2008; Vyse et al. 2009; Coates et al. 2009; Hawkins et al. 2012). Due to the mountain pine beetle's preference for large-diameter trees with thick phloem (Amman 1969; Shrimpton and Thomson 1985), pine trees in the younger age classes often remain vigor and high in stock. In Hawkins et al.'s study (2012), most age classes are well stocked considering all commercially viable species [over 600 stems per hectare per 20 year age span defined by BC Ministry of Forests and Range (2006)], and only the age class of 101-120 has an average stem per hectare number just below 600 at 592.

Stand recruitment post-outbreak displays various possible outcomes related to stand seral stage, canopy structure, sub-canopy composition, secondary disturbance, etc. (Hansen 2014). In varies studies of the stand recruitment post-mountain pine beetle epidemic, stand structure and composition show dramatic variation from each other and difference from the pre-attack circumstances in BC (Axelson et al. 2009; Diskin et al. 2011; Hawkins et al. 2012; Amoroso et al. 2013). The vast difference is to some extent resulted from the geological, biological and climatically variance within the landscape of BC. The stand may shift to a shade-tolerant species domination or grow back into a predominant pine stand (Hansen 2014). Due to a combination of growing space release and growing rate increase, a near fully recovery to a pre-outbreak live basal area and stem density could be achieved naturally in two to three decades (Pelz & Smith 2012).

Fire plays a vital role in the future stand composition as well. Lodgepole pine produces both open cones and serotinous cone, but the percentage of the serotinous cone positively correlated with latitude (Koch 1987). An average of 80% pine trees in the northern limit of lodgepole pine distribution produce serotinous seeds (Shore et al. 2006). The high ratio of serotinous cone habit of lodgepole pine in western Canada results in the requirement of fire to successfully regenerate and dominate the landscape (Agee 1993; Shore et al. 2006). Pine would dominate the landscape again after a fire because of the serotinous seeds are usually heavily stocked during a large-scale disturbance (Hawkes et al. 2004). If a fire does not occur, which is rare in central British Columbia, succession to a shade tolerant species dominant stand may be hastened, subjecting to pre-mountain pine beetle stand composition. Heath and Alfaro (1990) showed that a previous lodgepole pine-Douglas-fir (*Pseudotsuga menziesii*) stand converted to a predominantly Douglas-fir stand after mountain pine beetle infestation. Similar reactions occur in spruce-pine co-dominant stands as well (Alfaro et al. 2004). As a result of the shade from the long standing of infested canopy pines, the natural pine regeneration is limited whereas subalpine fir is more favored in such environment (Astrup et al. 2008). However, a conversion from a lodgepole pine forest to a non-pine forest should have a minor impact on wildlife habitat (Chan-Mcleod & Bunnell 2004). Lodgepole pine provides cover and food sources for many grouse species, and its seeds serve as important food source for many birds and mammals (Zwickel & Bendell 1970; Pendergast & Boag 1971; Lotan & Perry 1983). Nonetheless, these eco-services could also be provided by fir or spruce forests (Chan-Mcleod & Bunnell 2004). Hence, natural rehabilitation should be fine by leaving those unmanaged forests and non-commercially desired lands on their own where pine production is not essential. A shift towards uneven-aged, mixed-species forest structure could also be beneficial considering forest resilience both ecologically and economically (Dhar & Hawkins, 2011; Oliver & Larson 1996)

3.3. Silviculture Potential

The forests infested by the mountain pine beetle in the recent epidemic grew up without any active silviculture measure; most were developed without any management control over species composition, density or growth rate, etc. (Safranyik et al. 1974; Safranyik et al. 1975).

Thus, they naturally had a high variation in susceptibility towards natural disturbances (Whitehead et al. 2004). Mountain pine beetle outbreak is influenced by climate suitability for mountain pine beetle, an abundance of susceptible hosts, and forest management practices (Taylor et al. 2006). Host susceptibility is largely influenced by the stand structure, which includes attributes such as age, contiguity and species composition. Although global climate change is not subject to control, both stand structure and management practices could be influenced by human intervention.

Eaton in 1941 documented the first silvicultural treatment specifically designed for managing mountain pine beetle. It was recognized by Hopping (1951) as only a palliative treatment. And Hopping went on suggested treatments targeting at forest type conversion – converting the forest into a more resilient state by managing stand age, species composition, size distribution, and density (Hopping 1951). Basing on the research of Bartos and Amman (1989), current strategies for reducing the susceptibility of existing mature stands are low thins for regulated spacing to create an optimum microclimate, vitality, and inter-tree spacing. Many cases of success had been documented by Whitehead et al. in 2004. Since then, the most basic principles needed to manage for reducing mountain pine beetle damage had been known, and researchers have been focusing more on developing proactive management systems (Safranyik et al. 1974; Whitehead et al. 2006). Active management could be break into **landscape planning** and **stand management** (Whitehead et al. 2006)

On a landscape level, there are two different approaches to achieving a desired future pine forest age distribution. The first one is a non-timber value oriented; natural 100-year-return fire dominated natural distribution (Taylor & Carroll 2004), while the other one highly managed, providing sustainable yield for of timber with an 80-year rotation. Both actions, fire, and logging, would reduce the amount of susceptible lodgepole pine concentration in the landscape. A general principle to follow is to create a landscape with less old pine, more dispersed spacing, a diversified pine age structure, and species mix that will not favor a major outbreak (Amman and Safranyik 1985; Amman and Schmitz 1988).

For an active management such as the 80-year rotation cut mentioned above, priority should be given to those stands with the most susceptibility and high risks. Access should be built and maintained for low-risk stands because poor accessibility would make any immediate remedy difficult (Whitehead et al. 2006). A simplified model for active landscape management of harvesting is shown below (Figure 3).

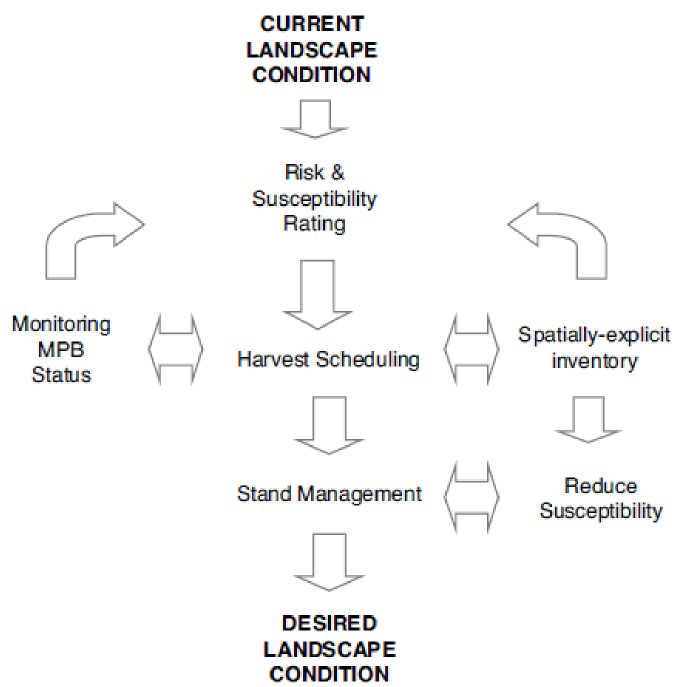

FIGURE 3. LANDSCAPE MANAGEMENT MODEL FOR PIN-DOMINATED STANDS FOR HARVESTING (MPB = MOUNTAIN PINE BEETLE; WHITEHEAD ET AL. 2006)

On a stand level, there are also ways to manage a newly developed stand to prevent potential future outbreaks.

Maintaining stand hygiene and vitality is one of the effective ways to build a resilient stand. At the starting stage, beetles require weakened susceptible trees to build up the population successfully (Coulson 1979; Coulson & Stark 1982). Thinning, or similar density removal practices, could help release competition thus increase the vitality of remaining trees. Remove trees show decay, diseased or damaged during stand tending could reduce the probability of beetle infestation within the stand. Trees with signs of either biotic disturbances or affected by abiotic disturbances should be removed in beetle-favorable weather conditions because stressed trees could increase the outbreak probability (Cole 1989; Cole & McGregor 1985).

Density management could retain tree vigor by release growing space and delay its physiological maturity (Anhold & Long 1996). Such stand would be less susceptible to mountain pine beetle and has the potential to produce specific market desired wood products, increase timber supply, and promote wildlife habitats (Farnden 1996).

Mountain pine beetle requires certain characteristics (mature, weakened large pine trees in high density) to survive its incipient stage. Some practices at a stand level such as converting to favourable species, susceptible tree removal and high thin for beetle proofing could be done to create a healthier and more resilient forest (Whitehead et al. 2004).

Beetle proofing describes a commercial thinning practice, which uniforms the inter-tree spacing and harvests mature trees to a remain of fewer than 600 trees per hectare. This way of thinning significantly decreases the chance of inter-tree infestation by decreasing contact between trees while not compromising other harvesting constraints such as timber supply, visual quality, habitat, etc. (Whitehead et al. 2004). In five cases conducted by Whitehead et al., beetle proofing proved to be working by decreasing the proportions of trees under attack to one-third to one-fourth comparing to untreated stands. While beetle proofing shows effectiveness, it is important to note that it is a proactive measure rather than a treatment to stands already under attack.

3.4. Canadian Wood Industry

Allowable annual cut and mountain pine beetle

In British Columbia, about 95% of the forest land base is publicly owned, so it is the provincial government's decision regarding the amount of timber to be harvest each year. It is not until the 1990s when the decision of allowable annual cut takes inputs from economic analyzes or local people into account (Wagner et al. 2006).

Allowable annual cut (AAC) is a decision by the chief forester of British Columbia, taking into account of all aspects including social, environmental, and economic consideration. In short, AAC is the volume of trees could be harvest annually (MFLNRO 2015). There had been increases in AAC started in 2001 to manage the current mountain pine beetle infested forests. 12 out of 28 beetle-affected management units (timber supply areas and tree farm licenses) had seen substantial (over 100%) increase after the year 2000. AAC for Kamloops TSA increased from 2.7 million cubic meters to 4 million cubic meters in 2004; Quesnel TSA saw a 171% increase from 2.3 million cubic meters to 4 million cubic meters in 2001; Price George TSA had its AAC rose to 12.5 million cubic meters in 2002 from the previous 9.4 cubic meters (MFLNRO 2014). In the fiscal year of 2012-13, 38% of the volume harvested in the interior British Columbia was dead pine. Pine harvest (live and dead) in the same context contribute 59%

of the timber harvested in total (SR44, 2014). Approximately two-third of the harvested pine during 2012 to 2014 was dead while MFLNRO estimated that about 50% of the pine on the landscape is dead, which indicates a harvesting focus on the dead pine in the recent past (MFLNRO 2014; Walton 2013).

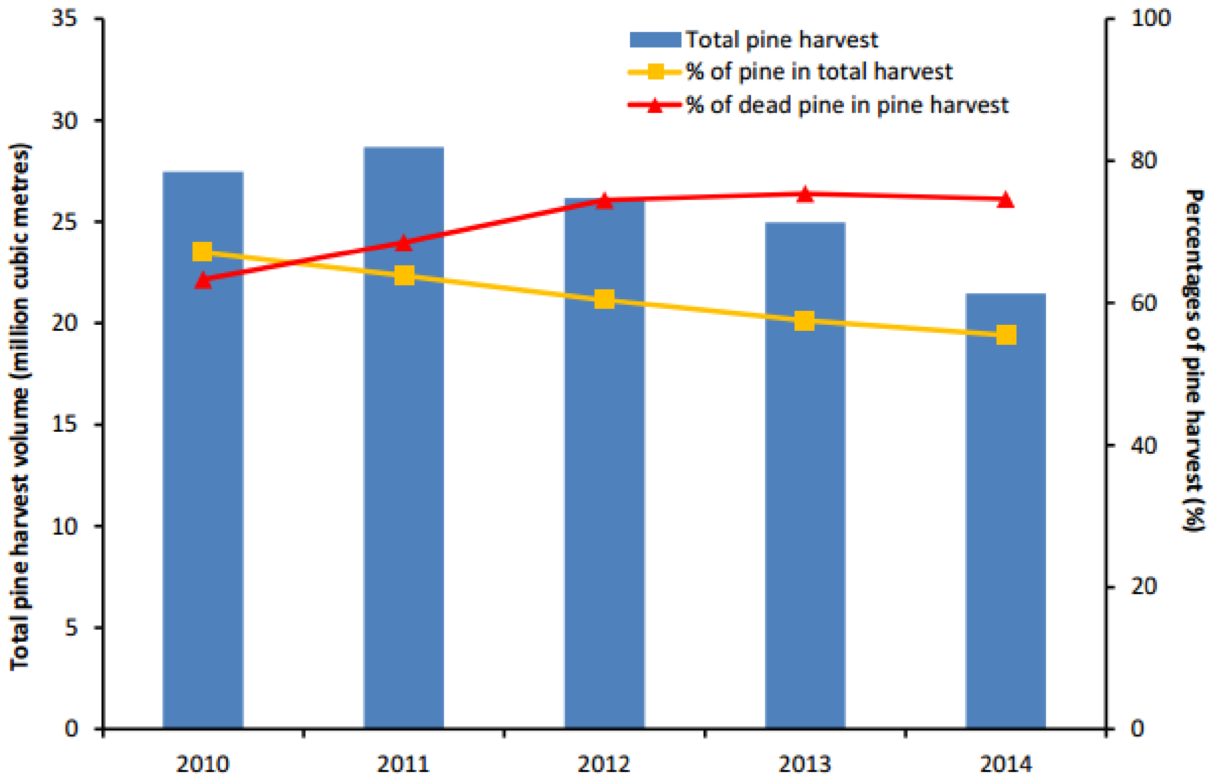

FIGURE 4. PINE HARVEST IN THE MANAGEMENT UNITS (CHEN & WALTON 2015)

The harvest levels in the beetle affected units are showing sign of decrease just recently. On March 30th, 2016, the AAC for Merritt TSA dropped from the 2010 level of 2.4 million cubic meters per year to 1.5 million with a subsequent decrease to 1.2 million cubic meters per year in effect starting March 30th, 2021 (Nicholls 2016). This decrease of almost 40 percent in 5 years was due to the chief forester of British Columbia's concern over to what extent will the licensees keep logging mountain pine beetle-infested wood. The mountain pine beetle epidemic in the Merritt TSA peaked around 2007, which means most killed pine trees are dead almost ten years now. Considering that there is almost no economic value of pine wood died over 15 years, this reduction in AAC is partly in order prevent any over-exploitation of growing standing volumes, and to ensure sufficient long run sustainability (Nicholls 2016; Lewis & Hartley 2005).

Mountain pine beetle wood products and market

The harvest of mountain pine beetle-affected wood is limited by the shelf-life of dead pines. Wood deterioration after death from biotic agents like secondary beetles or fungi as well as abiotic agents such as moisture, oxygen, temperature, the wind, and fire would result in the loss of recoverable volume (Lowery 1982; Sinclair et al. 1977; Giles 1985). And in general, this recoverable volume is negatively correlated with the time after death. It is believed that although the shelf-life for different wood products varies. The general idea is that within 1 to 3 years of death, there is little loss in wood as long as trees remain standing (Lewis & Hartley 2005). Publications around the rate of decay with time-since-death is limited to British Columbia but according to interviews conducted by Lewis and Hartley (2005), decay poses little effect on standing dead wood regarding utilization. It is when the trees fell over ground that decay starts to progress rapidly. These results from the interviews were supported by Harvey's study of mountain pine beetle killed trees in Oregon, United States (1986). The rate of tree fall subjects to several variables, among which the soil moisture content is one of the most important variables (Lewis & Hartley 2005). Trees fall rate appears to be higher in wetter areas. 90% fall rate is projected by year 15 in wetter sites and about 25% to 50% trees will fall within a decade after mortality in drier sites (Lewis & Hartley 2005).

Standing dead pine has a shelf-life between 2 to 15 years depending on product type, current market, current technology, and tree characteristics (Lewis et al. 2006; Orbay & Goudie 2006; Trent et al. 2006). And beetle-killed pines has lower economic value due to the loss from decay and handling (Byrne et al. 2006). Dry, brittle trees are more susceptible to breakage (Work 1978). The solid wood products with blue patterns from blue stain fungi infection may appeal to some artists, but they are not preferable to general consumers (Stickney & Doucet 2007). These properties posed some significant challenges in all phase of wood product manufacture and market chain (Byrne et al. 2006).

The wood industry of BC has been focusing on producing lumber and panels, which is rational and efficient considering the market condition and the characteristics of salvaged pines (Bogdanski et al. 2011). However, more attentions should be shifted towards more innovative ways of utilizing the remainder wood as the quality of salvaged pines keep declining and the practice of salvage logging will come to an end shortly. Bogdanski et al. (2011) listed five groups of wood products as potential opportunity: lumber and lumber-derived products; structural panel products and engineered products; non-structural panels and other wood products; pulp and paper; and energy.

Lumber and lumber-based products are the conventional products of wood industry, and its viability is declining over time due to the loss of decay (Lewis & Hartley 2005). The deterioration of sheer volume to be harvest, as well as the degradation in aesthetic value from blue stain fungi, would result in less efficient usage of logs hence reduction in product value. Two of the possible strategies are using the lumber to glue pieces of lumbers together into beams, and to treat the lumbers with preservation and stains to address the appearance issue

(Bogdanski et al. 2011). However, these strategies match very limited markets and do not address the low lumber recovery issue.

Structural panel and engineered products are possible to use for mountain pine beetle-affected wood. These beetle-killed logs could be made into veneer and plywood, which could be further manufactured into laminated veneer lumber, beams, flooring, concrete forms and more (Wang et al. 2007). Oriented strand board could be another good option for utilizing beetle-affected wood (Bogdanski et al. 2011). Nonetheless, due to the high permeability of beetle-killed wood, the cost for resin (act as glue to hold layers of strands together) would be substantial (Byrne et al. 2006).

Other panel products include medium density fibreboard, particle boards other than oriented strand board, and other boards made directly from salvaged pine or sawmill residues (Bogdanski et al. 2011). However, an investment in such a plant to produce particle boards are very energy intensive (Haygreen & Bowyer 1996).The uncertainty of fibre availability poses a great risk upon these projects considering how much investment is involved (INRS 2001; Bogdanski et al. 2011). Hydrate material products such as cement-wood or plastic-wood products (Hartley & Pasca 2006); Log home, treated and untreated fence posts and utility poles (Byrne et al. 2006); making furniture and kitchen tiles could consume some dead pine fibre, but the markets are limited (Bogdanski et al. 2011). One potential successful usage of beetle logs in this category is log homes. This sector in Montana had been profitable using the standing dead lodgepole pine trees (Braden et al. 1998). In the rural areas of BC, the log home sector also performs well with a high level of employment and revenues per unit wood usage (Stennes & Wilson 2008). Similar to other products listed above, log home sector will not consume large amounts of timber, it only contribute to 14% of round logs used in 2006 in BC (Bogdanski et al. 2011).

Beetle-killed lodgepole pine could be used to make pulp. However, depending on how long the tree has been dead, costs may increase significantly due to an increased level of resin or a decreased level of moisture content (Watson 2006). Research suggest that the property of wood has minor changes within several years after been killed (Kadla et al. 2008), so the impact on manufacturing should be small as well (Bicho et al. 2008; Dalpke et al. 2008). With a large amount of dead standing beetle-affected wood, pine might be an alternative source of fibre in BC for many years. But the decreasing trend in the pulp and paper industry and the uncertainty of long-term fibre supply poses risks on capacity building (Bogdanski et al. 2011).

There are several incentives in the bioenergy sectors on top of the opportunities in the mountain pine beetle-affected areas. Drivers include government policies to use renewable energy and bioenergy being carbon neutral (Bogdanski et al. 2011). BC has been successful generating bioenergy as a by-product from sawmills and even using roadside residuals, but to commit to a fully dedicated energy plant for mountain pine beetle-killed wood is not viable under the current energy price (McBeath 2006).

Fortunately for Canadian forest industry, its current largest oversea market, China, imports lumber from Canada primarily for concrete forming purpose in building construction. BC contributes to near half of China's wood import volume currently, and 90% of them are the lowest grade with a very competitive price (Wahl et al. 2012). It is reported that in 2009, China purchased 1.63 billion board feet of lumber, which doubled the amount of the previous record of 784 million board feet in 2008. Putting into monetary perspective, China spent $327 million on wood products from British Columbia in 2009, which was a threefold increase comparing the $113 million in 2007 (Mann 2010). Figure 5 shows the BC origin exports of wood products and pulp (excluding bioenergy) to the United States comparing to Mainland China from 2006 to 2015 derived from Statistic Canada, 2015. As shown in the graph, export to the US suffered a 55% decline during 2006 and 2009, presumably due to the US housing crisis during the same time. Meanwhile, there is a twofold increase in Mainland China for the same products exported from BC. The growth in the Chinese market plateaued around 2011 when the US market started to bounce back. Due to this dynamic of the Chinese market and the US market, the lowered quality of beetle-killed-wood lumber has been making sales. However, this 16 million cubic meters softwood lumber market of China is very price sensitive, once the low-grade beetle kill wood is completely consumed, Canada may lose its share.

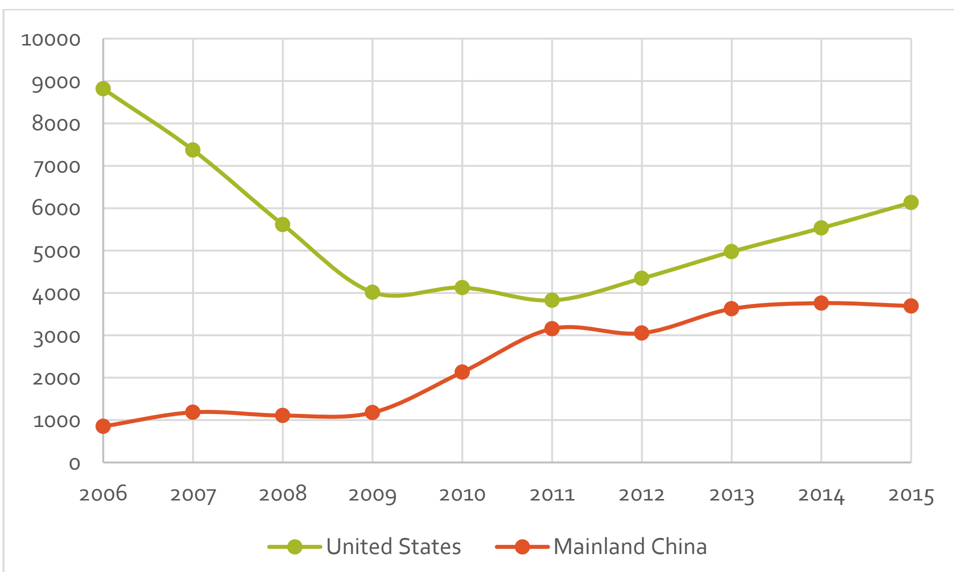

FIGURE 5. BC ORIGIN EXPORTS TO THE US AND MAINLAND CHINA IN $MILLION (EXCLUDING BIOENERGY; DATA FROM STATISTIC CANADA)

4. Summary

The pine lost during this ongoing mountain pine beetle outbreak caused unprecedented damage. However, it is not as bad as what scientists had predicted (Bell 2010). The epidemic was dramatically slowed down by the complex terrain and forest structure in central and northern British Columbia (Bell 2010).

The mountain pine beetle is a native species that, as a disturbance to forests, is naturally occurring and has co-evolved with native pine species for millennia despite recent invasive expansion into non-historical territories (Lousier 2006). It is an integral part of this forest ecosystem, so what we as foresters need to manage should be aiming at how to manage the pine forest in a healthier and more resilient fashion rather than trying to eliminate beetle attacks from happening. The mountain pine beetle epidemic is nature's way of self-regulation – As the mature forest keeps gaining thermal energy by storing carbon from photosynthesis, it increasingly attract heterotrophs to come and renew the structure, dissipating the over stored solar energy. Infested stands may switch from carbon sink to carbon source, but will typically recover in 5-20 years.

Lodgepole pine is disturbance-adapted species recolonize after stand-replacing events. Three factors contributing to the likely return to lodgepole pine dominant forests post-outbreak are: residual overstory survived pines, understory advanced regeneration and a pine-favorable fire regime. There are usually sufficient stocking of natural regeneration from serotinous seed for self-recovery. In the rare occasion of not sufficient restocked forest lands, the government does have an ongoing project of replanting and rehabilitating with suitable plantations (Bell 2010).

The forests after infestation won't necessarily lose their viability as a vigorous ecosystem because most of the pine forests have a rich understory and seed stock so if left alone, would eventually recover on its own (Hansen 2014). But certainly, if higher value timber stands or rich wildlife habitats are desired in a short to midterm, some manipulations are needed.

There are several things we could tend to use silviculture methods, some issues to be noticed even out of control and some may sound daunting at first but need not to worry after all. Some proactive measures such as high thin for density management and maintaining stand hygiene are proved to be effective as proactive strategies (Taylor et al. 2006). More investments in improving tree health and growth rate would also help to reduce the effect of mid-term timber supply deduction on the forest industry both on a community level and provincial level.

MFLNRO increased the AAC to address the potential issue of the built-up fuels and to salvage timber as much timber as possible before they lose economic value. On a flip side, the temporary uplifted AAC would cause a sharp drop in harvestable volume after all salvage harvest completed, which would pose a significant challenge to forestry based communities economically (Byrne et al. 2006).

Many potential utilizations of beetle-affected wood had been proposed, but most have high risk due to a low recovery rate from wood and high cost in investments (Bogdanski et al., 2011). The uncertainty of future fibre supply also prevents producers to utilize the current fibre capacity fully (Bogdanski et al., 2011).

More researches need to be done to observe this particular outbreak and to compare it with other historical events to better understand impacts of active management on the forest ecosystem. More innovative approaches for using mountain pine beetle- affected wood should also be encouraged to maintain BC's competitiveness in the global wood market.

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